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Territorial Energy Assessment

Final Report

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PREFACE

The Caribbean and Pacific insular areas of the United States are dependent on imported petroleum products to supply their energy needs. This dependence, coupled with the increasing cost and the uncertain availability and supply of sources of energy, places an increasingly severe financial burden on the local governments, leading to rising balance of payment deficits. Without a secure power and water supply there can be no real economic development on the islands. Until the energy problem in the territories is satisfactorily addressed, the cost to the Federal Government of maintaining their economic viability will continue to rise and contribute to overall inflation.

Since 1973, the economic impact of rapidly rising world oil prices has been particularly severe on the U.S. territories, the Trust Territory of the Pacific Islands and the Commonwealth of Puerto Rico. Though these localities vary greatly in the size and complexity of their economies, their political status, and their social and cultural backgrounds, they all share certain traits: they are geographically isolated island groups with an almost total dependence on imported products as an energy source. Dramatically rising oil prices, coupled with the uncertainty of supply over the near as well as long-term, are resulting in severe strains on local economies and capital that is badly needed for economic development.

In order to address the critical needs of these insular areas, Congress included Section 604 in P.L. 96-597, the Omnibus Territories Act (December 1980) which requires the development of comprehensive energy plans with the goal of reducing the reliance on imported oil through making maximum use of indigenous energy resources:

MANDATED OBJECTIVES (Highlights of Section 604 of P.L. 96-597)

"(c) The Secretary of Energy...shall prepare a comprehensive energy plan with emphasis on indigenous renewable sources of energy for Puerto Rico, the Virgin Islands, Guam, American Samoa, the Northern Mariana Islands, the Federated States of Micronesia, the Marshall Islands and Palau. The plan shall be prepared with the approval of the Secretary of the Interior and in cooperation with the chief executive officer of each insular area by:

(1) surveying existing sources and uses of energy;

(2) estimating future energy needs to the year 2020, giving due consideration to a range of economic development possibilities;

(3) assessing, in depth, the availability and potential for development of indigenous energy sources;

(4) assessing the mix of energy sources (including fossil fuels) and identifying those technologies that are needed to meet the projected demands for energy; and

(5) drafting long-term energy plans for such insular areas with the objective of minimizing their reliance on energy imports and making maximum use of their indigenous energy resources.

(d) The Secretary of Energy...with the approval of the Secretary of the Interior, as part of the comprehensive energy planning may demonstrate those indigenous renewable energy technologies which are determined to be most cost effective through the use of existing programs.

(e) Within two years from the date of enactment of this Act, the Secretary of Energy...shall submit the comprehensive energy plan for each insular area to the Congress.

(f) There are hereby authorized to be appropriated such sums as may be necessary to carry out the purposes of this section."

This section of P.L. 96-597 was authorized but no funds were appropriated. Recognizing the serious nature of the situation, however, the Acting Under Secretary of DOE directed, in April 1981, that a three-phased approach to meeting the intent of the legislation be defined. The first step was to characterize the current energy situation in each territorial entity and to provide an estimate of the cost connected with developing comprehensive territorial energy plans. The Savannah River Operations Office (SR) was assigned responsibility for the Caribbean region (Puerto Rico, Virgin Islands), and the San Francisco Operations Office (SAN) for the Pacific entities (Guam, American Samoa, Northern Marianas, Palau, Federated States of Micronesia, Marshall Islands). The Office of Intergovernmental Affairs, Territorial Affairs Branch (HQ/IR), was assigned DOE Headquarters responsibility for overall coordination.

Consistent with the Acting Under Secretary's direction, a strategy for the conduct of this effort was written and approved in May 1981 which defined a three-phase approach:

Phase I was intended to provide a current perspective on territorial energy problems; to identify existing energy supply and demand data; and to identify energy resources that might be developed and appropriate technology options. Based on these findings, Phase I defined and estimated the cost of the technical assessment and economic analysis activities required to support the development of specific energy plans.

Phase II would have involved the conduct of the technical assessments defined under Phase I. Successful completion of these tasks would have provided the information necessary to understand and compare alternate energy development options in each territorial entity.

Phase III would have completed the process with the preparation of energy plans for each territorial entity. This would have involved an integrated analysis comparing alternative energy options, the coordinated selection of proposed energy projects, the subsequent drafting of energy plans, and territorial/DOE/DOI coordination and concurrence before the plans are submitted to Congress.

The Phase II and III efforts were combined into one final effort focusing on the objectives outlined in the legislation. Emphasis was given to near-term commercially feasible technologies for the Pacific and Caribbean entities. This report will consist of two distinct sections, each having its own executive summary.

A key factor in the DOE approach is the recognition that success in this effort depends heavily on developing a close, continuing working relationship with the DOI and the territorial energy offices. This point is clearly reflected in the initial strategy paper and in the conduct of the project activities and reflected in the Phase I and Final Reports.

The purpose of the Phase I Report was to serve as a preliminary assessment of technical and economic analysis activities required to allow DOE to meet the intent of Congress under P.L. 96-597. In January 1982, DOE's Under Secretary directed that $300,000 be located from within the Department's appropriation to complete the Project.

These funds were divided between the Pacific and Caribbean regions to address the diverse socio-economic and geographic factors. These factors were then balanced against renewable technology alternatives to imported petroleum primarily for generating electricity. Both the Energy Offices of the Commonwealth of Puerto Rico and the U.S. Virgin Islands participated directly in the formulation of their respective sections of the project. The Savannah River Operations Office awarded grants to both these offices to produce energy planning documents that reflected their governments' needs and policies. Supplemental information to those reports was provided by the Savannah River Operations Office. The Energy Offices of the Pacific entities participated extensively, as a part of the SAN team.

The legislation called for the energy plans to be submitted to the Congress within two years of its enactment. Some energy data collection will continue as a by-product of this report and will be made available to the territorial Energy Offices to enhance the information provided in this report.

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PACIFIC TERRITORIES ENERGY ASSESSMENT

EXECUTIVE SUMMARY

This assessment is concerned with energy planning for the governments of the American territories of Guam and American Samoa, and of the four nations that are now emerging from the United Nations Trust Territory of the Pacific Islands: the Commonwealth of the Northern Mariana Islands, the Republic of the Marshall Islands, the Republic of Palau, and the Federated States of Micronesia. This study was directed by the United States Congress under Public Law 96-597, and carried out by the United States Department of Energy in cooperation with the respective island governments. This report addresses the current and future energy needs of the island governments and considers the feasibility of employing alternate sources of energy, especially indigenous renewable energy resources, to reduce dependence on petroleum-based fuels.

The past decade of rising oil prices has had a severe economic effect on the Pacific territories, which depend almost totally on imported petroleum products for energy. In the mainland United States, a diversified energy supply mix has mitigated the full impact of escalating oil prices. The territories, however, have no indigenous fossil fuels, and their near-complete reliance on a single, increasingly expensive energy source has created fiscal burdens that have hampered economic development.

Generating costs on the mainland range from two cents per kilowatt-hours (kWh) to fifteen cents per KWh, with a national average of 7.2 cents per kWh in late 1982. The island governments are responsible for electricity generation and bear the entire cost burden for fuels used to generate electricity, often at the expense of other public services. It is not unusual for local governments to pay as much as $2.00/gal for diesel fuel used in power plants, which results in electricity cost as high as 40-50c/kWh when equipment amortization costs are included. These costs are usually not recovered when the power is sold.

In virtually all cases, consumers are subsidized by their governments and pay less than the full cost of service. In some instances, users are not metered or pay a flat rate. In most cases, consumers are charged well below even the cost of fuel alone.

Politically, Guam and American Samoa have been territories of the United States since the end of the 19th century and are referred to as United States flag territories. The Trust Territory of the Pacific Islands was assigned to the United States under a United Nations Security Council Trusteeship in 1947 for the purpose of promoting the Islands' economic, social, educational and political advancement. Negotiations between the United States and each of the four emerging governments have now been completed for the installation of elected constitutional governments and the termination of trusteeship status. When these agreements are approved by plebiscite and are ratified by the United States Congress and the United Nations Security Council, the Trust Territories stand to receive substantial amounts of financial assistance from the United States over periods ranging from 15 to 50 years. These funds are expected to be used to facilitate economic development. The United States commitment to Guam and American Samoa is ongoing.

Since World War II, all of the islands have made noteworthy progress in health care, education, and political development. Economic growth, however, has been slow, particularly since energy costs soared in the 1970s. None of the islands has developed a self-sustaining local economy, and all depend heavily on appropriations from the United States Congress and, in some cases, on the presence of the United States military for the strength of their economies. Federal assistance to the islands in 1980 accounted for 46% to 95% of total island government revenues.

All of the territories have a very narrow, fragile economic base. Characteristically, island imports, including food, far exceed exports, and there are few industries other than tourism and fishing. Economic growth is severely constrained by limited land, capital, water, skilled labor, and the lack of an adequate and reliable power supply. The island governments are the single most important economic sector in almost every case. They employ the largest percentage of the labor force, they are often the largest energy user, and they receive and disburse the United States transfer payments which make up the bulk of the cash economy.

Guam is exceptional because it has the largest population and highest level of development among the territories. American Samoa and the four trust territories must plan in the context of a sharp urban-rural dichotomy, populations dispersed across large expanses of ocean, widely varying energy demand requirements, and a number of cultural factors, including land use patterns, which will affect energy decisions. Islanders who live in the urban centers participate in the cash economy, but a large percentage of people live in rural areas and survive largely by subsistence farming and fishing. Social services, including electrical service and public water supply, are generally confined to the urbanized areas. Many rural areas have extremely poor services or none at all. These conditions, combined with growing populations, have resulted in heavy migration to urban centers, exacerbating social conditions and making unmet energy demand a matter of growing concern to the affected governments.

Hopes for future economic growth in the territories rest largely on the development of the tourist and fishing industries. Agriculture and United States military activities are added possibilities in selected areas. Energy consumption by the commercial sector will certainly increase as the Pacific Islands move toward their goal of economic self-sufficiency. This goal, however, is unlikely to be reached in the absence of an adequate supply of energy.

Electricity is produced and distributed as a function of local governments. Frequent breakdowns of generating equipment, caused primarily by inadequate operation and maintenance, have resulted in recurrent blackouts and unreliable service throughout the territories outside of Guam. As a result, major private commercial operations must often provide their own power, and sometimes, water. This is one reason that new commercial enterprises have been reluctant to locate in the islands. Without some relief from high petroleum costs, the Pacific Islands cannot hope to maintain, much less improve, their economic status. Rising fuel prices not only act as a barrier to expanding the economic base, they threaten the industries that are already established.

Factors other than energy supply problems have limited United States private sector interests in investing in the Pacific territories. These include a general unfamiliarity with the region, its people and culture, and a lack of recognition of the investment potential. Japanese enterprises have more knowledge of the area and have shown more initiative, but all potential private sector investors have been checked by the small size of the market, the remote location, and difficulties in communications.

Geographically, the Pacific Island territories are spread out over a region far larger than the continental United States, but the land area, population, and energy demand associated with each government are relatively small, even in comparison with the State of Hawaii.

Territory	Area	Population	Peak Demand	Consumption	Per Capita
Guam	590(KM^2)	105,000	155.0(MW)	9,178(Mbbls)	1.47
Amer Samoa	215	32,400	13.3	1,276	.41
CNMI	510	16,900	15.4	330	.91
Marshall Is.	182	31,000	5.0	157	.16
Palau	487	12,000	3.1	148	.26
FSM, total	874	74,000	7.0	229	
Truk State	328	38,000	3.1	97	.08
Ponape	310	23,000	2.3	86	.10
Yap	119	8,200	1.2	36	.15
Kosrae	5,500	0.4	0.4	10	.07
Hawaii	16,641	974,000	1,500	43,000	1.50

Imported petroleum products constitute virtually all of the commercial fuels now consumed in the islands. The only other source worth noting is family-gathered firewood which is used for domestic cooking. Major uses of petroleum are for air, marine and land transportation, electricity production, and construction equipment. Technologies to convert biomass to liquid fuels are unlikely to displace petroleum products used for transportation in this century. Additionally, all of the island territories possess indigenous renewable resources that can be used to generate electricity. Thus, the energy problems that can be addressed in the Pacific at present involve local government expenditures for fuels used to generate electricity.

A transition to alternate energy systems will require some years to complete. The critical problem, however, is immediate, and steps must be taken to improve the efficiency and reliability of current energy systems while the transition to longer range solutions is in progress. It is unfortunate that the energy price crisis occurred before renewable resource technologies were mature enough for application in the Pacific. Many technologies are available to convert renewable resources into electrical energy, but only a few are good candidates for success in the conditions prevalent in the islands. The Pacific is not a good location for technological experimentation. Basic infrastructure taken for granted on the mainland United States is absent. High storm winds and humid, salt-laden air are extremely hard on equipment of all kinds. Skilled labor is often unavailable, and the islands are far from sources of parts and repair personnel.

Island governments will make energy development decisions in the context of spending and investment priorities. The approach to solving the energy problem the territories face involves: (1) reducing or controlling demand through effective energy management programs that include conservation and electric rate reform, and (2) addressing the supply side of the equation by displacing current fuels with less costly ones, and if possible, preventing new petroleum dependencies.

Residual fuel oil (RFO) is used to generate electricity on Guam and Saipan. Elsewhere, at lower demand centers, diesel oil is employed. These two petroleum products represent the largest fuel use by island governments. The Marshall Islands, Palau, and American Samoa are considering switching from diesel to the much less expensive RFO or coal. Such a decision could bring immediate relief from punishing fuel costs, whereas attempting the transition directly to renewable energy sources might involve an inordinate period of waiting for the new technologies to become established technically and economically.

On the other hand, both coal and RFO are feasible only in large demand centers, and unless existing generators can be converted, the decision to use RFO would involve large capital expenditures for new generating, fuel handling and storage facilities.

Funds would then be unlikely to be available for early investment in renewable resource technologies, locking the territories into a long-term commitment to imported fuel.

Because the cost of coal-generated power can be as low as one-third to one-half of the cost of diesel on a caloric basis, it is another attractive energy source to consider either as a transition fuel or as a permanent displacement for oil. The principal problems with coal use in the territories are inadequate port facilities, limited land, and the high initial capital costs associated with conversion. As with RFO, coal use is subject to economies of scale which limit its application to the largest demand centers, if at all. In addition, the island governments generally view coal unfavorably because it would be an imported fuel and as liable to supply interruptions as petroleum fuels.

Energy management, which includes, technical institutional and behavioral measures that can contribute to more efficient energy use is an effective means of reducing overall present demand as well as moderating future growth in demand. It is especially appropriate in the territories because consumers are charged less for electricity than the full cost of generating it.

All of the Pacific Island governments strongly aspire to energy self-sufficiency, which they believe is possible and, therefore, highly favor use of the indigenous, renewable energy resources. Three principal direct uses of solar energy are considered in this report; low-temperature solar thermal for heating; high-temperature solar thermal for process heat; and electrical generation and photovoltaics. Other technologies with the potential to contribute to island energy supplies include wind energy conversion, geothermal, hydroelectric, ocean thermal energy conversion (OTEC), ocean currents and tides, solar ponds, municipal solid waste (MSW) combustion and biomass conversion into electricity, biogas and liquid fuels.

All of the above technologies differ markedly in their present state of technical readiness and economic feasibility, and in their suitability for satisfying local requirements. Cost estimates for each technology are provided mainly to illustrate the wide range of costs, which may be encountered when considering such factors as system size, storage and characteristic patterns of local energy demand. An important added factor contributing to the wide range in costs is in the uncertainty resulting from the fact that most of these technologies are still in various stages of development and not established commercially in the market place.

While renewable energy technologies have many favorable as well as unfavorable attributes, one in particular deserves mention. Many renewable energy technologies are not affected greatly by economy of scale and are effective in small-scale systems without incurring significant economic penalty. Thus, they can be effective in providing a solution to the problem of highly dispersed and remote energy requirements where the cost of transporting energy to the point of consumption is prohibitive. An important social advantage of this characteristic is their potential for promoting development in previously ignored rural areas, thereby decelerating migration to the urban centers.

Any decision will be determined largely by local conditions. Such factors as resource availability, economics, demand characteristics, atmospheric conditions, cultural and political compatibility, and support infrastructure to provide skilled manpower and supplies are all site-specific. The approach taken by one island government can differ markedly from that chosen by another. The following are the recommendations for each of the Pacific territories made by the DOE team of consultants working in collaboration with the territorial energy representatives.

GUAM

A. Improved Energy Management.

- The actual costs of generating electricity should be established.
- Consumers should be billed for electricity in accord with their use and the actual costs of generation. The comprehensive billing and collection program should be continued.
- Energy efficiency standards should be established and enforced for all new buildings in Guam.
- Energy education should be extended and encouraged in the community.

B. Investigate Alternate Energy Technologies Where Appropriate.

- A comprehensive engineering study of the use of coal at the Cabras electrical generating plant should be conducted. Both a retrofit and new plant case should be examined and the costs of each determined.
- An analysis of the use of municipal solid waste should be carried out, complete with estimates of capital, and operating and maintenance costs.
- A detailed engineering feasibility study should be done on a biomass tree farm electrical generating system for Guam.
- Monitoring should continue on the development of salt-gradient solar pond technology. As the technology matures and costs decline, the possibility of salt-gradient solar ponds for Guam should be evaluated.
- Developments in photovoltaic technology should continue to be followed. Photovoltaics should be applied where and when it is appropriate, particularly in remote, stand-alone applications. As the technology and battery storage develops, re-examine its applicability to baseload power for Guam.
- Ocean thermal energy conversion technology developments should continue to be tracked. As the technology matures, its applicability to Guam should be again evaluated.
- Wind resource data should be taken at specific sites with potential for multi-megawatt installations. If the resource can be confirmed, then manufacturers and investors should be contacted to develop systems which can survive on Guam.

REPUBLIC OF PALAU

A. Koror and Surrounding Urban Areas.

- Rate structure reform should be undertaken to more accurately reflect the costs of production.
- Electricity meters should be installed on all government facilities and then on all points of connection to the system.
- Energy efficiency standards should be developed for all new buildings, beginning with the government sector.
- Implementation of energy conservation measures should be undertaken, again beginning first in the government sector, including replacing light fixtures and components with more efficient units, energy efficient appliance and end-use device substitutions, passive cooling retrofits on existing structures, and the use of daylighting where possible.
- An energy data system should be developed to monitor and audit energy use in all sectors.
- A personnel training program should be established in renewable energy system concepts, including installation, troubleshooting, and repair, and in the conduct of building energy audits and energy data management.

- A renewable energy curriculum element should be developed at the Micronesian Occupational Center for long-term manpower training.

- There should be a solar hot water retrofit at the Koror hospital.

B. Remote Villages ana outer Islands.

- There should be performance testing of a small-scale hydroelectric system at a favorable site on Babeldaob.

- An engineering design should be conducted of a photovoltaic-diesel hybrid system for an outer island application.

- An analysis should be conducted of the infrastructure requirements needed to support hydroelectric development on Babeldaob.

- A wind energy resource assessment should be conducted for selected sites on the east coast of Babeldaob.

COMMONWEALTH OF THE NORTHERN MARIANA ISLANDS

A. Improved Energy Management.

- Electrical rate structure reform should be designed and implemented.

- All electricity users should be metered and billed.

- Energy efficiency standards should be developed and enforced for all new buildings in the Commonwealth.

- The efficient use of energy should be encouraged through the demonstration of energy conserving techniques wherever possible.

- Energy education should be enhanced within the community, the government, and the school systems.

B. Application of Renewable Energy Technologies Where Applicable.

- A detailed engineering feasibility study should be conducted on a biomass tree farm to be located on Tinian or Rota. If found feasible, such a system should be implemented. The applicability of such a system should then be considered for Saipan. The power level to be studied for Tinian and Rota should be on the order of 1 MW, with a 5 MW system evaluated for Saipan.

- The salt-gradient solar pond technology should be followed for potential application in the Commonwealth.

- A preliminary survey of geothermal possibilities should be conducted for both Saipan and Tinian.

- Solar hot water and biogas systems should be exploited as much as possible.

- Photovoltaic modules should be employed at remote sites in the Commonwealth, particularly those which are able to accommodate low power and intermittent use. Prime candidates are the islands of Alamagan and Agrihan.

- Technology developments should be followed in ocean thermal energy conversion, solar thermal energy conversion, and battery storage for potential application in the Commonwealth.

THE FEDERATED STATES OF MICRONESIA

A. Lelu, Kilonia and Surrounding Area, Moen and the Lagoon Islands, and Colonia and Surrounding Area.

- Install electric meters for all users, including all government departments and housing.
- Bill all users, including government agencies.
- Consider reforming the rate structure to allow revenues to cover operating costs.
- Consider establishing a local power authority.
- Continue performing energy audits and developing a data base for energy planning.
- Continue collecting solar insolation data, and start collecting wind data at the appropriate height for a wind generator in a few selected locations.
- Develop training in renewable energy system concepts, including installation, maintenance, trouble shooting and servicing.
- Install a producer gas or palm oil system for performance testing. Test effects of palm oil used as a substitute for diesel fuel (Kosrae, Yap).
- Continue to assess the potential of using biomass for direct combustion in generators (Ponape, Truk).
- Study the feasibility of using solar ponds for baseload power (Yap, Truk, Ponape).
- Monitor the new hydroelectric facility being built on the Malem River to see if such systems can contribute to baseload production (Kosrae).
- Assess data from the newly installed pyranometer to determine whether solar photovoltaics might eventually help meet baseload, or rural, power demands (Kosrae).
- Continue to develop hydropower resources, particularly the Nanpil River (Ponape).
- Investigate the feasibility of using cables to provide electricity generated on Moen to the other Lagoon Islands (Truk).
- Assess performance data from the Xavier wind electric system and the Faichuk photovoltaic system to assist in planning for such systems elsewhere in Truk State.

B. Rural Villages and Outer Islands.

- Perform audits to determine rural energy needs and develop a plan to fulfill those needs.
- Continue to encourage the use of smokeless wood cooking stoves for domestic and school cooking.
- Develop small-scale, community-based energy projects involving hydropower, photovoltaics, palm oil or producer gas.
- Encourage rural training and education in renewable energy system concepts.
- Collect solar insolation and wind data at selected sites to determine whether small, stand-alone wind and photovoltaic systems will be useful (Ponape, Truk, Yap).
- Continue to develop sail-assisted fishing vessels and investigate retrofit of field ships with some form of sail assist.
- Based on newly acquired solar insolation data, begin engineering design for a photovoltaic system for Utwe (Kosrae).
- Monitor the Palikir Power hydroelectric project to determine whether similar projects would be useful in other rural areas (Ponape).

REPUBLIC OF THE MARSHALL ISLANDS

A. Majuro Atoll.

- Efforts at rate structure reform should be strengthened.
- All electrical connections should be metered and billed.

- Energy efficiency standards should be developed and enforced for all new buildings.

- Energy conservation measures should continue to be implemented, particularly in the government sector, and should include passive cooling building retrofits, insulation, daylighting, replacement of inefficient light fixtures and components, and adoption of more energy efficient appliances and end-use devices.

- An energy data system should be established to monitor and audit energy use in all buildings.

- Personnel training should be established in photovoltaic and wind energy system installation, troubleshooting, and repair, as well as in the conduct of building energy audits.

- Efforts should be taken in education curriculum development and teacher training in basic energy use concepts, as part of an overall effort to enhance public awareness about energy production and consumption.

- A solar hot water retrofit should be considered for the Majuro hospital.

B. Outer Islands.

- An analysis should be conducted of infrastructure requirements needed to support specific levels of wind energy use in the northern atolls.

- A wind energy resource assessment effort should be mounted, including data collection, statistical analyses, and technology performance projections based on these data, for selected outer islands in the northern atolls.

- An engineering design should be performed for a photovoltaic-diesel hybrid system for a selected atoll application.

- Specifications should be developed for design and materials modifications and cost determinations for effective corrosion protection of commercial wind and photovoltaic energy systems.

- Diagnostic equipment should be installed to measure the performance of planned and existing photovoltaic energy systems in the outer islands.

- Design, performance, and cost assessment of a photovoltaic powered ice making and ice storage system should be considered for remote island use.

AMERICAN SAMOA

A. Tutuila.

- A plan should be developed to begin preliminary investigations of the geothermal resource of the island.

- Efforts should be taken to verify existing municipal solid waste data, develop additional data, and evaluate various MSW conversion technologies.

- The installation of domestic solar hot water systems should continue, and evaluations made as to the engineering feasibility of solar thermal systems for process heat.

- Energy management activities, including conservation, data collection, energy audit work, and rate structure reform should be continued.

- The concept of a strategic petroleum reserve system should be developed in more detail.

- There should be an investigation of multi-purpose reservoirs for reservoir hydrolectric systems on the island.

- The use of palm oils or producer gas for electricity production should be investigated, and a small pilot plant constructed.

- Additional site-specific data to support ocean thermal energy conversion should be collected.

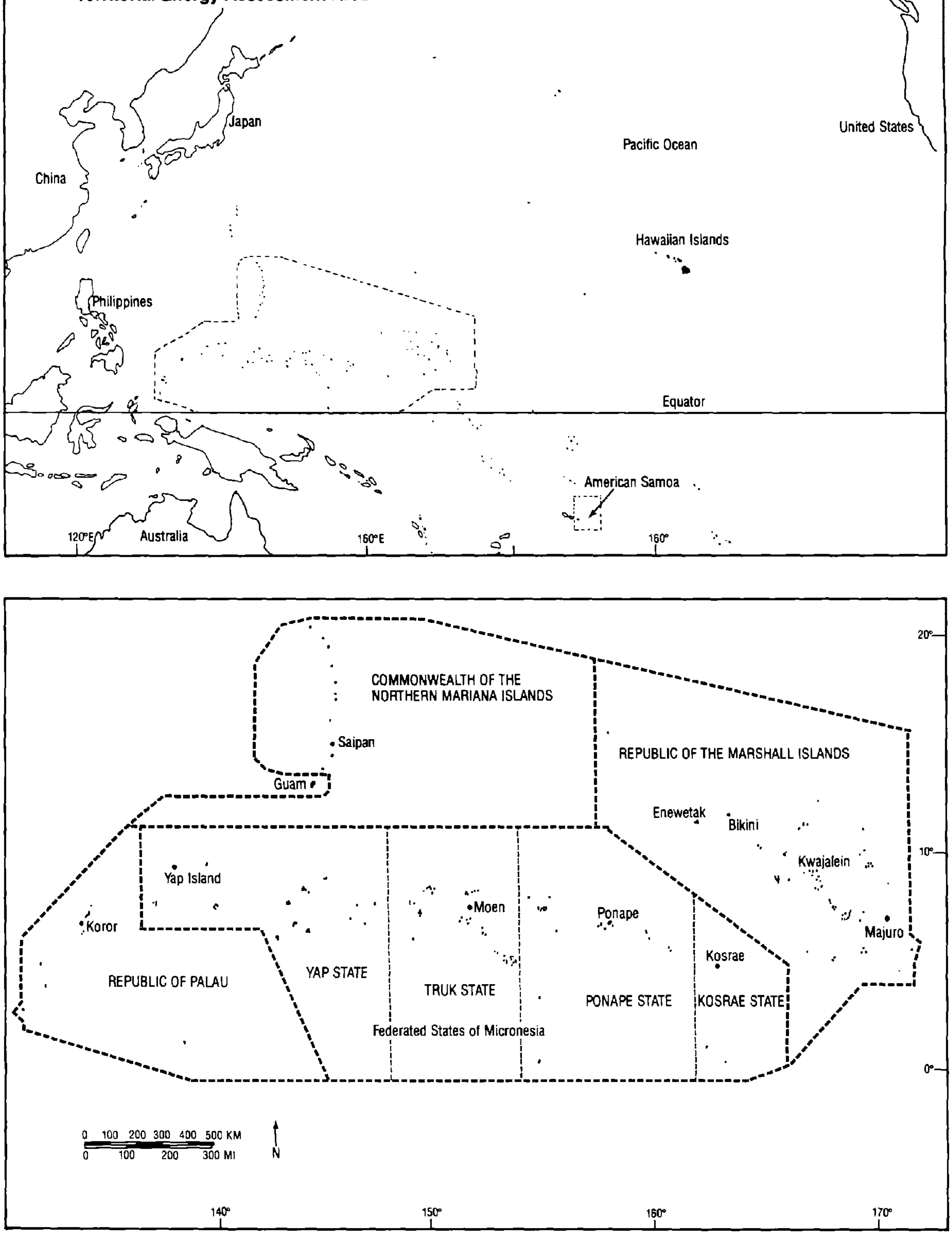
B. Remote Villages and Outer Islands.

- A small prototype plant should be constructed to provide electricity via palm oil or producer gas conversion at a site in the Manu'a islands.

- Small photovoltaic systems should continue to be installed where low power demands need to be met.

- The village and building energy audit efforts in the Manu'a islands should be continued.

Figure 1-1
Territorial Energy Assessment Area



CHAPTER 1: OVERVIEW OF PACIFIC ISLAND ENERGY ISSUES

In the last decade, the economic impacts of rising world oil prices have been felt with special severity by the inhabitants of the Pacific Island nations and territories. The Pacific Islands depend on imported petroleum products for almost 100% of their energy needs. Their small, developing economies are extremely vulnerable to ever-increasing energy prices. However, oil prices are the product of international forces, and the Pacific Island governments cannot affect them. In addition, the islands have no known indigenous fossil fuel resources. They do, however, possess a number of renewable resources that can be used to generate electricity. As a result, the island governments have indicated a strong desire to develop indigenous, renewable energy resources as part of their drive toward economic independence.

This assessment is concerned with energy planning for the governments of the American territories of Guam and American Samoa, and of the four nations that are now emerging from the United Nations Trust Territory of the Pacific Islands (TTPI), which the United States has administered since 1947. The four emerging nations are the Commonwealth of the Northern Mariana Islands, the Republic of the Marshall Islands, the Republic of Palau, and the Federated States of Micronesia (see Figure 1-1). All six governments express an adamant desire for energy self sufficiency coupled with economic independence. There is a common need for comprehensive energy planning and the development of alternate energy resources.

THE ECONOMIC IMPACT OF RISING FUEL COSTS

Rising fuel costs affect the Pacific Islands directly and indirectly. Shipping by both air and sea are of paramount importance because the islands are geographically remote and have extremely limited industrial and manufacturing bases. Shipping costs rise with fuel costs, driving up the prices of any goods that are imported or produced with energy. Food and fuel, which all of the islands import, are such goods.

The narrowness of the economic base in the islands heightens vulnerability to the effects of increased energy prices and uncertainties of supply. If fuel costs rose so high that tuna canneries in American Samoa, for example, could not make enough profit to survive, or if supplies became so uncertain that normal operations were impossible, the local economy would be severely affected because there are not enough other industries to compensate for the jobs and revenue that would be lost.

This report concentrates on ways of displacing petroleum fuels used to generate electricity, because it appears that the energy problems that can be addressed most productively in the Pacific at present involve government expenditures for energy. The island governments now bear a heavy burden of costs for fuels used to generate electricity. However, all of the locales under consideration possess various renewable energy resources which, when proven and developed, could substantially relieve the current dependence on imported petroleum for electric generation.

Liquid fuels are critical to the health of local industries such as tourism or fishing and to the delivery of the wide range of goods upon which the Pacific Island nations depend. However, methods of producing fuel alcohol from biomass feedstocks available in the Pacific and other alternate transportation technologies will have to develop further before they can be regarded as economically and technically feasible for the Pacific. Thus, unless unexpected technical breakthroughs occur, resources indigenous to the area are unlikely to meet a significant portion of liquid fuel demand for aviation, marine transportation, or construction within the forty-year time frame of this assessment.

The island governments, unlike the various levels of government on the United States mainland, are responsible for electricity generation. Historically, generating equipment has been purchased for the islands by annual appropriations of the United States Congress. These appropriations have in some cases been supplemented by loans. The local governments pay for fuel, operations and maintenance costs, and they sell the electricity generated at artificially low rates that heavily subsidize the consumer. The costs of generating and supplying electricity usually come out of the general operations budget and represent a significant portion of government expenditures. In fiscal 1980, for example, the costs of fuel alone for electrical generation represented 30% of the Northern Marianas operations budget.

Economic development in all of the islands has been slow since World War II, but particularly since energy costs soared in the 1970s. The fuel price rises of the last decade have pushed island governments into a self-defeating cycle. As substantial price increases occurred, the governments needed supplemental funds just to continue operating existing equipment. Extensions and improvements in electrical service needed to foster economic development were foregone. Delivery of other public services has also been slowed. Even when supplemental funds were available, the island governments were sometimes forced to meet monthly fuel bills by borrowing from other budget categories such as health services or road building.

THE PACIFIC--A SPECIAL CASE

Economic development plans in the Pacific have generally not given in-depth consideration to future energy requirements. Federal assistance programs have not been geared to indigenous energy resource assessment and development, and the data needed to evaluate specific technology applications and define projects for specific sites have not been gathered. In fact, many federal energy programs, designed to address conditions on the mainland, are concerned with conservation. In the Pacific, developing new sources of supply is more important. Mainland conservation programs are largely irrelevant when many households outside of urban centers do not have electrical service, 24-hour a day service may not be routine even in the population centers, and potential industries, such as fishing, falter for lack of a power source for refrigeration or other essential operations. The Pacific is a special area, and it poses some special planning problems.

Infrastructure

The Pacific Island nations and territories are a mixture of cultures and societies that have undergone repeated buffeting since the first European contact. In Micronesia, four major powers--Spain, Germany, Japan and the United States--and a major war have done much in the last hundred years to submerge fragile traditional societies. Now, the emerging nations of Micronesia are in the midst of significant political changes that are leading to a degree of independence unknown for centuries. Samoa, caught among the conflicting interests of Germany, Great Britain, and the United States, was divided into Western Samoa and American Samoa and also experienced great changes as a result of World War II.

None of the islands has developed a self-sustaining local economy, and all depend heavily on federal support. Few island workers receive the education and training needed in developing modern economies, and in any case, private sector jobs are not available. Local governments are by far the largest employers in the islands. In some areas it is possible to thrive outside the cash economy by subsistence fishing and farming, but by any measure, unemployment rates are high.

Many technologies are available to convert renewable resources into electrical energy, but only a few are good candidates for success in the conditions prevalent in the islands. The Pacific is not a good location for technological experimentation. Infrastructure taken for granted on the mainland United States is absent. Paved roads are few, most population centers have "water hours" despite heavy rainfall, and power outages are frequent. The climate is extremely hard on equipment of all kinds. In the typhoon belt, for example, wind generators may be blown down, and all kinds of generators are subject to damage by wind-driven debris. Throughout the islands the corrosive effects of humid, salt-laden air shorten equipment life and exacerbate maintenance problems. Islanders are anxious to acquire modern technologies, yet they generally lack the technical background necessary to select, install, and maintain such systems. The islands are far from sources of parts and repair personnel, and manufacturers of alternate energy generating equipment have not always compensated with increased field support.

Planners must struggle with these and a number of other problems peculiar to the Pacific. Often, the solutions that are most cost-effective or technically appropriate in the Pacific Islands are very different from those that would work best in other areas.

Geography

The Federated States of Micronesia (FSM), the Republic of Palau, the Commonwealth of the Northern Mariana Islands (CNMI), and the Republic of the Marshall Islands are emerging from the Trust Territory of the Pacific Islands, which covers some 7.8 million square kilometers (3 million square miles) of the western Pacific Ocean just above the equator. The entire area, including Guam, is part of Micronesia. It embraces some 2140 small islands and islets, fewer than 100 of which are inhabited. The population totals just over 270,000. Some remote islands are only sporadically inhabited, and others have permanent populations of less than 25 people. The islands lie in the three major archipelagoes of the Carolines, the Marshalls and the Marianas. They range from large volcanic upthrusts to tiny coral islets. Elevations can be as low as two meters (6 feet) on a coral atoll to 965 meters (3166 feet) on Agrihan Island, Marianas. Guam, where almost half of the people in the area live, is located in the Marianas, but it was never part of the Trust Territory; it is an unincorporated, organized territory of the United States (see Table 1-1).

Table 1-1--TERRITORIAL DEFINITIONS AND STATUS

Territory/Posession	Status
Guam	Unincorporated, organized territory
American Samoa	Unincorporated, unorganized territory
Trust Territory of the Pacific Islands	United Nations "strategic" Trusteeship
Commonwealth of the Northern Mariana Islands	Commonwealth in Political Union with the United States
Federated States of Micronesia	Proposed Compact of Free Association with United States
Republic of the Marshall Islands	Proposed Compact of Free Association with United States
Republic of Palau	Proposed Compact of Free Association with United States

Key to Table 1-1:

Territory refers to any area over which the United States exercises sovereignty, and includes insular possessions such as Wake and Midway Islands.

An organized territory is one for which the Congress has provided an organic act, or statute, which establishes the machinery and powers of government.

An unorganized territory is one for which Congress has not provided an organic act but for which the basic machinery of government may be provided by a locally framed constitution (i.e., Samoan Consititution of 1960).

Incorporated territory is an area to which the United States Congress has fully extended the provisions of the United States Constitution and is clearly on the road to statehood, territorial incorporation being part of that process. The obverse would be true for an unincorporated territory.

Trust territory refers to an area that has been placed under the international trusteeship of the United Nations and entrusted to an "Administering Authority" which does not exercise or claim sovereignty. A "strategic" trusteeship places United Nations responsibility with the Security Council rather than General Assembly.

Commonwealth is a term of elusive meaning that can be illuminated only by a subjective examination of the relationship between the entity and the United States. Consider, for example, the British Commonwealth of Nations, the Commonwealth of Pennsylvania, the Commonwealth of the Northern Mariana Islands, and the Commonwealth of Puerto Rico, which in Spanish is rendered "Estado Libre Asociado".

Free Association is an internationally defined term which refers to formerly dependent territories that have achieved self-government in association with another state, on the basis of the inhabitants' free will and of relative equality.

Source: Ruth Van Cleve, The Office of Ierritorial Affairs, New York, Praeger, 1974.

The unincorporated, unorganized territory of American Samoa is also part of the United States Pacific territories. American Samoa is the only United States territory south of the equator. It is about 3200 kilometers (2000 miles) from the closest Trust Territory Islands. It consists of seven rugged, mountainous islands of volcanic origin some 3700 kilometers (2300 miles) southwest of Hawaii. The population is just over 32,000 people, 93% of whom live on the main island of Tutuila.

Urban and Rural Differences

Clearly, even if energy costs were not a factor, the central system, grid-connected power systems found on the United States mainland are not possible in many of the Pacific Island groups. Only Guam, being a single island, is in a position to address its energy planning from such a perspective. The four island nations and American Samoa must deal with a sharp urban-rural dichotomy, populations dispersed across large expanses of ocean, widely varying load requirements, and a host of ıltural, institutional and economic factors which affect planning.

In some areas where the channels between islands are shallow enough to permit the use of cables, grid extension from a central generating facility may be possible. Such a project is now underway between Koror and Babeldaob in Palau, and may at some time be feasible among the islands of Truk Lagoon in the FSM. In other areas, planners must devise two types of systems to meet tw(very different needs. Urban centers, where population and economic development are concentrated, demand baseload generating capacity in the megawatt range. The diesel generators now used to meet these demands, with varying success, will be difficult to replace entirely with renewable resource technologies. Renewable resource generating capacity is therefore most likely to be used in a fuel-saver capacity and to prevent new petroleum dependencies in rural areas.

The Pacific Island governments are attempting to slow migration to the population centers by providing services and encouraging economic development in the rural areas. At present, not all of the island inhabitants have the same quality of life, as measured by income and access to energy sources. This has led to a migration of people seeking the services and jobs available in the urban centers, and this, coupled with a birth rate as high as 3.5% in some areas, is overloading social services and funneling people out of the subsistence economy and into the cash economy faster than they can be absorbed. The efforts of governments to stop or even reverse this population flow will affect energy planning.

Small villages have needs and lifestyles very different from those in the urban centers and may require only a few kilowatts of intermittent capacity to power communications or a refrigerator. A number of small-scale generating technologies are technically mature and commercially available to meet such small, dispersed demands. The Pacific Islands are in the forefront as users of these technologies, especially photovoltaics.

Because the demands to be met in the urban and rural areas are so different, electrical generating systems in the Pacific must be planned with great attention to matching power source end use. Other factors to be considered include the availability of workers with the technical skills to maintain and operate generating equipment and any potential cultural barriers to the use of the technology.

POLITICAL HISTORY AND STATUS

The United States has a long history of involvement and responsibility in the Pacific Islands. Despite their slightly differing political status, both Guam and American Samoa are frequently referred to by the term United States flag territories since the end of the 19th century and as such have undergone a slightly different political evolution from the four nations emerging from the Trust Territory.

Except for two and one-half years of Japanese occupation during World War II, Guam has been a United States territory since Spain ceded it to the United States in 1898 at the end of the Spanish American War. Elections for governor and lieutenant governor have been held since 1970. Guam elects its legislature and a delegate to the United States Congress, who serves as a non-voting member. Guamanians are United States citizens, and when they reside in the mainland United States, they may register and vote in national elections without restriction. They do not vote in national elections while living on Guam.

The United States annexed Eastern Samoa under the Deeds of Cession agreed to with the ruling chiefs in 1900, but the act was not completely ratified by the United States Congress until 1929. American Samoa, as the islands became known, has had an elected legislature, the Fono, since 1949. Its constitution became effective in 1964. The first governor and lieutenant governor were elected in 1977. In 1981, American Samoa's elected delegate to the United States Congress was made a non-voting member. American Samoans are United States nationals who vote only in their own elections, not in national elections.

At the end of World War II, the United States, under the aegis of the United Nations, took administrative responsibility for a group of widely scattered islands in the western Pacific: the Marianas, the Marshall Islands, Palau, Ponape, Truk, Yap and Kosrae. These islands, most of which had been taken from the Japanese during World War II, became known as the Trust Territory of the Pacific Islands.

In accepting the United Nations Security Council's Trusteeship Agreement in 1947, the United States took responsibility to promote the economic, social, educational and political advancement of the islands with the goal of helping them become self-determining, self-governing states.

The Commonwealth of the Northern Mariana Islands was administratively separated from the Trust Territory government in 1976. Negotiations regarding termination of the Trusteeship Agreement and definition of the post-Trusteeship political status of Palau, the Marshall Islands and the Federated States of Micronesia have continued for more than a dozen years. All three governments now have constitutions and elected governments. The Compact of Free Association, which sets forth for the post-Trusteeship period the international political status of each government and its relationship with the United States, has been initialed by the United States and the three other governments. Under the Compact agreement, the Republic of Palau will receive $1 billion from the United States over the next 50 years. These monies are intended to underwrite government operations, public works, and health and education programs. The Marshall Islands will receive $800 million over the next 15 years, and the FSM $1.4 billion over 15 years.

The steps required to formalize the Compact agreements are 1) approval by the island groups through popular vote, 2) United States Congressional approval, and 3) United Nations approval. Congressional and United Nations action regarding the Commonwealth of the Northern Marianas has been delayed pending completion of negotiations with the other three governments. Congress and the United Nations are expected to vote on the Compact agreements of all four governments at the same time. Table 1-1 summarizes the political territorial definitions and status for the Pacific Island governments included in this analysis.

FUEL COSTS AND ISLAND GOVERNMENTS

The Pacific Island governments are the single most important economic sector in almost every case. They employ the largest percentage of the labor force, they are often the largest energy user as well as the sole electricity supplier, and they channel the federal funds which make up the bulk of the cash economy.

All of the island governments depend heavily on appropriations from the United States Congress and, in some cases, on the presence of the United States military for the strength of their economies. Federal assistance to the islands in 1980 accounted for 46% to 95% of total island government revenues (see Table 1-2).

Guam is the only island government which funds even its operating budget from self-generated income, and it is far from self-supporting. Except for its scenic beauty and excellent harbor, Guam has limited commercial resources. Large United States Navy and Air Force installations and tourism provide its economic underpinning. There is very little agriculture on Guam. American Samoa, on the other hand, has traditionally been an agrarian culture, with family owned and worked subsistence plantations growing mainly bananas and taro. The principal commercial activities in American Samoa are tuna fishing and canning.

The four nations emerging from the TTPI have depended even more than the unincorporated territories on United States transfer payments for services and capital improvements. The area's gross product is otherwise derived from tourism, copra, subsistence farming, small scale and mid-size commercial fishing, and from sales of handicrafts. While the semi-urbanized residents of the

Table 1-2.--Total Pacific Island Government Revenues
(in millions of dollars)

	Total Govt. Revenues	U.S. Federal Assistance	Federal Assistance as a % of Total Revenues
Guam[a]	$184.9	$85.2	46%
American Samoa[a]	54.2	34.2	63%
Republic of Palau[b]	10.3	9.1	88%
CNMI[a]	49.0	39.8	81%
FSM[b]	35.2	33.4	95%
Republic of the Marshall Islands[b]	8.6	7.7	90%

a) Fiscal year 1980
b) Fiscal year 1981

administrative centers participate in the wage economy, those who live on the outer islands engage largely in subsistence agriculture and fishing, augmented by small amounts of cash from the sale of copra and handicrafts.

Because the Pacific Island economies are so small, the cost of fuel used to generate electricity makes up a major portion of the government budgets. In fiscal year 1980, the cost of fuel for electricity generation represented 17% of the TTPI operations budget and 30% of the CNMI operations budget. Fuel costs for generating electricity as a percentage of total revenues ran from 5% for the TTPI to 29% for Guam (see Table 1-3). The importance of fuel costs to the TTPI budget was masked by the temporary presence of monies intended for large construction projects. Without them, fuel costs as a fraction of total government revenues would increase to 10%.

Table 1-3.--Revenue Spent on Energy, FY 80
(in millions of dollars)

	Guam	American Samoa	CNMI	TTPI
Fuel Costs to Govt. for Electricity[a]	53.4%	4.6	4.7	7.8
Fuel Costs of Electricity as % of Total Government Revenues	29%[b]	9%	10%	5%

(a) Costs based on DOI FY 82 projections deflated to FY 80 using an annual deflator of 20% (assumed 10% inflation plus 10% price increase).

(b) The civilian and military share the electric power system; the military consumes slightly less than half of the power generated.

In an effort to help the Pacific Island governments develop ways of meeting the fuel price crisis, the Department of Energy has earmarked $8.6 million for energy projects in the Pacific in the last five years. American Samoa received $3.8 million, Guam $2.3 million, CNMI $1.3 million and the Trust Territory $1.2 million. These funds enabled each government to establish a territorial energy office and to initiate conservation and data collection programs, install some renewable resource generating systems, and begin to develop energy plans.

Despite the DOE funds and the proportion of government revenues spent to generate electricity, there are still frequent blackouts on many islands and unmet demand throughout the Pacific. Oil price rises have slowed in the recent past, giving island governments some much needed economic relief and allowing time for energy planning. The urgency of the energy problem remains. It is probable that petroleum fuel costs will continue to increase more rapidly than revenues from the United States or local sources. Even if electrical consumption remains approximately constant, fuel costs for electrical generation can be expected to continue to consume an unacceptably high fraction of government operating funds unless there is a shift away from imported fuels to indigenous renewables.

Without some relief from high energy costs, the Pacific Islands cannot hope to maintain, much less improve their economic status. Reductions in general industrial maintenance, including maintenance of conventional electrical generating equipment, have already occurred as a result of operating funds being diverted to pay fuel bills. This threatens the economic development plans of all of the island governments, which have hoped to expand their economic bases in order to generate more local revenue. New commercial enterprises that could provide wages to workers and taxes to the governments need assurance of ample, reliable electric power. Such assurance would require not only sufficient operating funds for existing generating equipment, but also additional capital investment on the part of island governments.

Rising fuel prices not only act as a barrier to expanding the economic base in the Pacific, they threaten the industries that are already established. Fuel price increases raise business expenses and lower profit margins. If the margin becomes slim or nonexistent, businesses will leave the area. The fishing fleet in American Samoa is now facing just this sort of fuel price pressure on profits.

CONVENTIONAL ENERGY SOURCES

Diesel fuel and residual fuel oil (RFO) used to generate electricity represent the largest fuel use for the Pacific Island governments (see Table 1-4). Electricity is used by residences, commercial enterprises, and the governments themselves. Gasoline, aviation fuel and diesel oil are used extensively for aviation, fishing, and sea and land transportation; their substitution with other energy forms is not anticipated to any significant extent in the foreseeable future. These fuels are shipped to the islands from refiners elsewhere and stored for use in tank farms that are often provided by the supplier.

Table 1-4--Fuels for Electrical Generation (1980)

	Thousand barrels			Fuel for electrical generation as a percentage of total fuel use*
	Diesel	RFO-6	Total	
Guam	42	1818	1860	38%
American Samoa	126		126	12
CNMI	35	145	180	55
Marshall Islands	36		36	29
Palau	44		44	34
FSM - Truk	20		20	23
- Ponape	22		22	34
- Yap	17		17	56
- Kosrae	4.5		4.5	41

* Exclusive of commercial and military jet fuel; computation done on volume basis.

In the past, the use of residual oil for power generation has been limited to Guam and Saipan. Elsewhere, diesel oil has been the fuel of choice for electricity production. The large difference in cost between diesel and residual oils has encouraged consideration of the latter at other locations.

In the Marshall Islands, for example, construction of a new power plant and an expanded fuel tank farm to accommodate use of residual fuel is nearly completed. The Republic of Palau now has a similar plan under consideration. While these developments will reduce overall fuel costs in the near term, they indicate a long-term commitment to the use of imported petroleum for electricity generation, and they may tie up large enough amounts of capital to preclude investment in renewable energy resources for some time.

The governments provide fuel for the field ships which deliver foodstuffs and other essential supplies to the outer islands of the Marshall Islands, the Northern Marianas, FSM, Palau, and American Samoa. In many areas, the level of service the ships supply is close to the level required for survival. Even though these ships consume a fraction of the diesel fuel used to generate electricity, further fuel price rises could force the island governments to cut back further on field ship trips.

Major commercial operations often provide their own electric power and, sometimes water, because the local governments are unable to meet their needs or the central system is unreliable. This has been cited as one reason that new commercial enterprises have been reluctant to locate in the islands. Even though the fuel is not provided by the government in such cases, private commercial and military energy use is extremely important to the overall energy picture of the Pacific Islands. The presence of these military facilities and major commercial enterprises generally represents the critical underpinning of the host economy.

Residential consumers use electricity principally for lighting. Amenities such as refrigeration, water heating, television, labor saving appliances, and other devices that have come to be considered necessities on the mainland are present, but not in large quantities.

The principal use of electricity in the commercial sector is probably for refrigeration. It is used for food storage and in the fish trans-shipment or processing industries. Air conditioning in hotels and other commercial buildings is another major use. In the government sector, electricity is used for lighting, office equipment and air conditioning. Local government services consume electricity to pump water, operate sewage treatment plants, light streets, operate hospitals and so on. The data available suggest that the Pacific Island governments commonly use about half the power generated (see Table 1-5). Local governments have initiated conservation measures, but their absolute consumption will probably remain near current levels. This means that they will use a smaller percentage of the total power available, if electricity is extended to nonelectrified areas and outer islands in the future.

Table 1-5.--Electric Power Use
(million kWh/y)

	End-Use			
	Government	Pvt.	Military	Total
Guam	89	441	401	1051[a]
Am. Samoa	21	45		66
CNMI	n.a.	n.a.		101
Marshall Islands	9[b]	8[b]		17
Palau	8	15		23
FSM - Truk	6.6	4.8		11.4
- Ponape	9.4	5.4		14.8
- Yap	3.9	4.1		8.0
- Kosrae	1.3	0.8		2.1

(a) Includes line losses of 120 million kWh/y

(b) Based on Majuro data

n.a. - data not available

Electric Generation

In all instances, operating and maintaining generating equipment, as well as distributing power, are the responsibilities of the Pacific Island governments. In a few instances governments are dealing with the political dimensions of setting rates by forming public utility commissions made up of representatives of industry and the general public. The hope is that the commissions will be able to make recommendations and set policy without necessarily reflecting upon elected government officials.

There are no privately owned utilities, but in some areas, government officials have begun to express some willingness to explore the possibility of privately held utilities. However, at present, the basic responsibility for providing electricity remains with the governments, and they are uniformly determined to find a source of electricity that is not associated with unpredictable cost escalations and precarious fuel supplies.

Generating costs per kWh are made up of the costs of fuel, personnel, maintenance, and other operations. The total cost of generating electricity in the Pacific Islands is not known, but estimates place it between 17¢/kWh and 25¢/kWh. If capital costs are included, the range is 50¢/kWh to $1.00/kWh. These high costs are a product of the tropical climate, which results in a high equipment derating factor; often inadequate operation and maintenance practices; the complete absence of power sources that are not fueled by oil; and the high cost of fuel, particularly diesel, in the Pacific. Some indication of the current costs of fuel alone are given in Table 1-6. For the calculation, unifying assumptions were made concerning costs (see footnote a, Table 1-6). In fact, the costs of fuel varied somewhat depending on the supplier.

Table 1-6.--Relation Between Fuel Costs and Electric Rates

	Electric Power generated 1980 (kWh/y)	Cost for fuel[(a)] (thousands $)	Fuel cost/ kWh[(b)] (cents/kWh)	Residential Utility Rate[(c)] (cents/kWh)
Guam	1051	64,080	6.1	14
Am. Samoa	66	6,804	10.3	10-14[(d)]
CNMI	101	6,798	6.7	6[(e)]
Marshall Isl.	17	1,944	11.4	8
Palau	22	2,376	10.8	6
FSM - Truk	11.4	1,101	9.7	6
- Ponape	15	1,193	8.0	3
- Yap	8	907	11.3	5
- Kosrae	2.1	243	11.6	3

(a) Diesel at $54/bbl and RFO-6 at $34/bbl as of Spring 1981. Guam prices were somewhat lower due to location of refinery on island. Consumption data are for 1980.

(b) Cost of lubricating oils, maintenance, parts and capital not included.

(c) Use less than 1000 kWh/month.

(d) Range reflects tiered rate structure.

(e) Rate in 1982.

Table 1-6 also shows the electricity rates the Pacific Island governments charge. In most cases, they are well below even the cost of fuel alone. There is an even greater discrepancy between the amount of power distributed and the amount of electricity billed to customers. Many users are not metered, especially within the government sector, and many are charged flat rates. In addition, revenues collected from billings have been as low as 20% of the total amount billed. Customers who do not pay their bills rarely lose service. Under these circumstances, raising rates in order to raise revenues is not generally effective.

The decisions involved in setting rates that reflect the full cost of electricity generation versus continuing to subsidize consumers raise a cloud of complex economic issues, and because the governments are the suppliers, political issues as well. When fuel price increases are reflected in electric rates, the residential sector is directly affected, and decreased usage usually results. Most residents of the islands, with the possible exception of Guamanians, have incomes significantly lower than the U.S average. Many people practice subsistence fishing or farming and participate in the cash economy only partially. The ability to pay for even modest amounts of power irrespective of cost is not widespread. On the other hand, if the governments absorb the increased costs, fuel costs take up a larger percentage of the budget and the public is affected by reductions in other public services.

Programs to attract industry are also caught in the rate structure dilemma. Rates which cover the true costs of generation are less attractive to new commercial enterprises, especially because commercial consumers have been and still are subsidized. On the other hand, the governments need the increased revenue in order to meet the needs of commercial users by expanding generating capacity and making it more reliable.

The governments of Guam and American Samoa subsidizes electrical rates to a lesser degree than any other Pacific Island government. Electric rates are almost high enough to cover the cost of electricity generation. The standard of living, as measured by income and access to electricity, is closer to United States standards than it is in the other islands. Ironically, as fuel prices have pushed rates up, economically driven conservation in Guam is eroding the financial base of the Guam Power Administration. Meanwhile, the other Micronesian islands, which subsidize electric rates heavily, are also financially pressed and face difficulties in extending service to the significant portion of the population that does not have electricity.

Electrical demand on the various islands is modest. Except for Guam, with its large military bases, peak demand is less than 15 MW. Total operating capacity exceeds peak demand, but in some places, such as American Samoa and Ponape, peak demand is too close to operating capacity to be considered prudent operating practice. In most of the islands there is standby capacity at hospitals, airports, communications centers and water pumping stations; however, the amount of fuel consumed for these standby uses is small. Table 1-7 shows electrical generating capacity owned by the governments. There is additional privately owned generating capacity in most of the islands.

Table 1-7.--Electrical Generating Capacity

Territory	Base Load (MW)	Peak Load (MW)	Electric Operating Capacity (MW)	Population	Operating Capacity[a] per person (kWh/person)
Guam	120	155	173	105,800	1.64
Am. Samoa[b]	12.6	13.3	13.3	32,395	0.41
CNMI[c]	10.5	14.5	21.6	16,862	1.28
Marshall Isl.[d]	3.1	4.3	4.9[e]	31,045	0.16
Palau	2.2	3.1	6.75	12,173	0.55
FSM - Truk	1.1	3.1	6.0	37,383	0.16
- Ponape	1.8	2.3	2.5	22,367	0.11
- Yap	1.0	1.2	3.3	8,172	0.40
- Kosrae	0.2	0.3	0.52	5,522	0.094

(a) Typical figures for California (March 1981) were on the order of 1 kW/person, cf Energy Watch, Calif. Energy Commission, June 1981.

(b) Includes Tutuila, Ofa and Tau

(c) Saipan only; Tinian and Rota, etc., are less than 1 MW.

(d) Majuro, Ebeye, Jaluit

(e) A new 3 MW unit will be on line soon. Three more 3 MW units are under construction.

In general, rated capacity is larger than the operating capacity shown in Table 1-7. This reflects deratings caused by extreme climatic conditions; limitations set by sub-stations (Palau); deadlined units that are under repair; voluntary cutbacks to minimize fuel consumption (FSM); and other island-specific circumstances. Maintenance problems are common throughout the Pacific Islands, and equipment failures were resulting in under-use of generating facilities even before fuel prices rose enough to be an inducement to reduce electrical power output.

At the same time, generating equipment is not always put to optimum use in the Pacific. For example, breakdowns of equipment designed to handle base load have forced the use of low efficiency, high-speed generators designed for peaking loads. These problems, combined with generally small total power requirements, suggest numerous opportunities for introducing new electrical generating equipment. Even if all existing equipment that could be repaired were operational, distribution problems in the scattered islands make it unlikely that the population could be served adequately without the use of dispersed generating facilities powered by renewables.

The last column in Table 1-7 contains a measure of the electrification within the various island nations and territories. As of 1982, 1.6 kW per person was a crude estimate of the electrification in California. This figure includes power for commerce, government and industry as well as residential use. By comparison, only Guam and the CNMI are close to 1.6 kW per person. To a certain extent, a lower capacity per person reflects the dispersed and isolated nature of populations in the FSM, Palau and the Marshalls that are not served by a central, gridded generating facility. However, populations in outlying areas tend to be small and are growing smaller as people migrate to the population centers. Thus, the very small kW/person numbers in Table 1-7 are not badly distorted by a lack of electrical service in isolated areas. If all rated capacity were on line in the islands, the kW/person figure would be larger, but not by a factor of two. Even if all units were repaired and operating at their maximum efficiency, one would have to conclude that even by the standards of developing economies, the present population was not adequately served by the existing generating system.

FUTURE ECONOMIC DEVELOPMENT AND ENERGY DEMAND

Energy consumption is a consequence of the social and economic development of a society. All indications are that energy demand in the Pacific Islands will increase rapidly in the near future as a result of high birth rates, and the desire for an improved standard of living and a wider industrial base. The overall population of the islands is expected to grow at a rate of 3% to 4% a year, quadrupling by 2020. In addition, there is a high, but unquantified, unmet demand in the Pacific now, and this will add to rising demand as new generating facilities come on line.

PL 96-597 specifies that one of the activities to be undertaken in this assessment be "estimating future energy needs to the year 2020, giving due consideration to the range of economic possibilities." It should be noted that the range of economic possibilities must be considered within the relatively strict limits on available land, water, skilled labor, and various natural resources that obtain in the Pacific Islands. It must also be recognized that the longer the time frame a project attempts to encompass, the more speculative it becomes. The actions of known factors become harder to predict with increasing length of time, and the potential for the introduction of unforeseen factors increases.

Little of the information available bears on estimating energy needs in the Pacific through the year 2020. Indeed, at the opening project meeting held in Guam May 18, 1981, representatives of the island energy offices strongly asserted that they were concerned with immediate energy problems, and requested that the primary emphasis of this report be directed to these areas. This document attempts to respond to that setting of priorities.

Energy consumption by the commercial sector will certainly increase if the Pacific Islands move toward their goal of economic self-sufficiency. The growth of private enterprise will depend to a large extent upon an adequate supply of electricity. Projections of future electricity consumption should take into account future economic growth scenarios that the individual island nations and territories consider likely. The energy plans in Chapters 3 through 8 attempt to factor in the economic development plans of the governments in question.

Energy consumption by the public sector will, of course, be determined by the extent of government services and activities. However, because fuel costs will probably continue to rise, and the time horizon for the introduction of renewables is not known, the effects of rising fuel prices on future government energy consumption should be examined with a number of possible development scenarios in mind.

There are reasons to believe that petroleum use will accelerate in the years to come. Extensions of electrical services to areas not presently served, increased per capita ownership of automobiles, increased travel as a result of improved roads, and rapid development of economies as a result of financially rewarding compact settlements, will all add pressures for increased energy consumption.

Island governments will necessarily make energy development decisions in the context of many spending and investment priorities. If other island governments are to follow the lead of the Marshall Islands and make near-term decisions to meet their generating needs with new oil-fired power plants, it will affect the time required to make a transition to different energy sources. Funds are very limited, and the one-time costs of alternate generating equipment can be high. Planners may decide to buy the less expensive conventional equipment and accept perpetual fuel costs. It is not yet clear that all of the governments support reduced electricity use from new or planned oil-fired power plants, although all do support the use of renewables for dispersed use and remote locations. The success of renewables in the islands will depend partly on the success of life cycle economic concepts under which the economic merit of alternate energy systems becomes more apparent.

It must be recognized that a transition to alternate energy systems will require some years to complete. The critical problem, however, is immediate, and steps must be taken to improve the efficiency and reliability of current energy systems while this transition to longer range solutions is in progress. In the cases of Guam and American Samoa, coal might serve as a transition fuel for baseload generation. Like oil, coal would be an imported fossil fuel, but world supplies are plentiful and its price is more stable.

With or without coal, federal or private investment in alternate energy sources must be made as soon as possible. Existing electricity supply systems are now inadequate, and the United States has an ongoing commitment to Guam and American Samoa and 15 to 50-year commitments to the four nations emerging from the Trust Territory. This is a critical and opportune time to invest in energy supply systems that will strengthen the economies of the Pacific Islands and lead to their self-sufficiency. Such an investment would eventually lower costs to the United States government as well as to the island governments.

The Pacific Islands are fortunate in that they possess valuable solar, wind, biomass and other alternate energy sources that can be used to reduce dependence on oil. The next chapter discusses a number of these technologies and the technical, cultural, environmental, institutional, and economic aspects that must be considered in choosing among them to make the best energy system for each island group.

CHAPTER 2: POTENTIAL ENERGY SOURCES FOR THE PACIFIC

The selection of appropriate alternate energy systems must first proceed from an identification of the energy needs of the end-user as well as a realistic understanding of the state of readiness of the respective energy technologies under consideration. A third set of factors are those locational characteristics such as land availability that, depending on their magnitude, can either favor or preclude certain technologies from further consideration in a given area. Lastly, it must be possible to assign some measure of cost-effectiveness to candidate energy technologies at the locations for which needs have been established.

Within the Pacific Islands, a wide mix of locational factors influence technology acceptability and appropriateness. Resource availability, geography, climate, infrastructure, culture, and local energy demand all vary to some extent in the region. Technology readiness will not be widely divergent among the island groups, if at all. Cost-effectiveness in one location may mean cost-effectiveness for a technology at other sites, since most island energy economies are characterized by similarly high priced liquid fuels. However, a technology such as hydropower conversion may have widely divergent cost characteristics at two locations due to factors such as differences in resource quantity and site attractiveness. Or, a known solar resource and a proven solar pond technology acceptable on one island may be unsuitable on a second island with a smaller population and more limited electricity demand because of the relatively large amount of power (20 kW) produced by even a small solar pond system.

In considering various technological means of reducing the Pacific Islands' present dependence on imported oil, the application of energy management as an approach to reducing consumption and increasing efficiency of energy use must be considered. A variety of energy management measures discussed later in this chapter could be used to allow the islands to enjoy a larger measure of energy independence. Furthermore, this approach is perhaps the only available option which can be readily undertaken in the immediate future to reduce the consumption of liquid petroleum fuels used for transportation and construction equipment.

For the purpose of general energy technology comparison, it is helpful to list selection criteria in a matrix format. Table 2-1 presents such a matrix. Final selection of an energy technology for a given location is likely to require a site-specific engineering feasibility study incorporating current economic and technology performance data. Before such decisions can be made, however, the wide variety of potentially available technology options should be narrowed. The results of a screening format are generally qualitative in nature, although some measure of hard data may underlie several of the conclusions that can be drawn. This will be the case in Chapters 3 through 8, where the selection criteria listed in Table 2-1 are applied to the range of alternate technologies for each government being evaluated.

The range of alternate energy technologies examined for Pacific Island locations was drawn from both legislative requirements (P.L. 96-597) and from the professional judgment of Department of Energy and island government energy planning staffs about the likelihood of technology success in the insular environment. Three principal direct uses of solar energy are considered: low-temperature solar thermal for water heating, high-temperature solar thermal for process heat and electricity, and photovoltaics. Other technologies include wind energy conversion, geothermal, hydroelectric, ocean thermal energy conversion (OTEC), ocean currents and tides, salt-gradient solar ponds, and municipal solid waste (MSW) combustion. Three biomass fuel options -- tree farm harvesting and combustion to produce electricity, biogas, and liquid fuels -- are also examined.

Perhaps the most fundamental criterion necessary for technology success is the availability of the natural resource used in the energy conversion process. The absence of fossil fuel resources throughout these islands has long necessitated the importation of liquid, petroleum-based fuels. In the search for alternatives to this costly and continuing dependence, attention has focused on those renewable energy resources found in many areas of the Pacific for which energy conversion processes have been or are being developed. It should be noted that renewable energy resource assessment efforts have not been conducted uniformly across the island groups. A promising, though uneven, picture of the region's indigenous energy potential is all that is now possible.

Table 2-1
Technology Selection Criteria

	SOLAR						BIOMASS					OCEAN CURRENTS AND WAVES			ENERGY MANAGE-MENT
	Solar Hot Water	Photo-voltaics	Solar Therm-al	WIND ENERGY	GEO-THERMAL	HYDRO-ELECTRIC	Tree Farms	Biogas	Liquid Fuels	MSW	OTEC		SOLAR PONDS	COAL	
RESOURCE															
proven															
suspected															
unknown															
none															
TECHNOLOGY READINESS IN PACIFIC															
high															
medium															
low															
RELIABILITY PROBLEMS IN PACIFIC															
high															
medium															
low															
DURABILITY PROBLEMS IN PACIFIC															
high															
medium															
low															
APPLICATION															
centralized															
decentralized															
POTENTIAL CONSTRAINTS															
cultural impact															
land availability															
environmental impact															
human resources															
infrastructure															
CAPITAL COSTS															
high (over $10,000/kW)															
intermediate ($3,000 - $10,000/kW)															
low (up to $3,000/kW)															
O&M COSTS															
high															
intermediate															
low															
COST EFFECTIVENESS															
near term (0-5 yrs)															
mid term (6-15 yrs)															
long term (16-40 yrs)															
EXPECTED OIL SAVINGS OR AVOIDANCE															
high															
intermediate															
low															

For example, the availability of the direct solar resource seems readily apparent, but quantification has only recently begun. Technologies are available to convert both direct and diffuse sunlight into either electricity or thermal energy, but continued instrumentation will be needed to define future solar technology design and performance limits for the Pacific.

Several other renewable energy resources are suspected in the Pacific region, though the precise, site-specific resource assessments needed for technology investment have generally not been done. For other technologies, no resource is known to be present, but little or no resource characterization has been performed to prove or deny such a finding conclusively. For such resources, additional "prospecting" may be required before a technology implementation can proceed. Lastly, there are resources which are clearly not present in some areas, such as hydropower on atolls. While this analysis focuses on renewable energy, consideration has also been given to coal as a possible replacement for oil in central electric generating systems on some of the larger islands. There is no known coal resource anywhere in the region, but the potential to import it is strong enough in some island groups to merit discussion.

A second, and equally important, selection criterion is the readiness of a technology for the assured production of energy. Medium to high levels of readiness reflect the successful operation of the technology at several different locations, in a variety of size configurations, and for a time period sufficient to prove performance over a range of operating conditions (climate, use patterns, environmental degradation, etc.) Judgments between medium and high levels of technology readiness are less likely to be quantitative than to reflect analytical confidence built up over defined periods of time. One other possible measure between the two levels might be the size of the popular commercial market developed to serve the technology, particularly in settings similar to those under consideration in the Pacific Islands.

Systems for which only isolated demonstrations have been conducted must be considered to be at a low level of technology readiness. In this category might be those technologies for which government demonstrations or pilot plants exist, but around which only a small commercial industry has evolved. Low-readiness systems also include those which have been tested and proven elsewhere but which have not yet been successfully implemented in a remote Pacific Island environment. Finally some technologies have been developed conceptually, and perhaps even tried experimentally, but have not been made operational, either in whole or in part, due to as yet unsolved or even undefined technical problems.

Even when a technology has reached an acceptable level of readiness, the interplay of technology and location may create performance issues of reliability and durability where none previously existed or were considered negligible. For example, the corrosive effects of salt spray on metals routinely used in mainland United States applications of several energy technologies must be acknowledged and addressed. Otherwise, the loss of durability could easily negate the investments in, and intended benefits of, many renewable energy systems.

The interaction between location and technology is also critical in selecting the appropriate system size to meet a defined energy requirement. In most Pacific Island locations, limited energy demand centers can be served most efficiently by energy technologies capable of small and intermediate scale applications. Technologies selected for application in the Pacific should feature a close match with likely levels of demand on the islands so that the economic penalties of overinvestment and underutilization of capacity are not incurred. Many renewable energy technologies are inherently modular, with relatively fixed conversion efficiencies per unit, so that increments of capacity can be added as they are needed rather than overbuilding capacity to meet some predetermined economy of scale that may never be used fully.

Some renewable resource energy technologies, such as biomass combustion, can provide continuous baseload power without storage and are suitable for meeting electricity demand in urban centers. Other technologies, including those that depend directly on sunlight or wind, provide intermittent power and are best used in central generating systems in a fuel-saver capacity. The intermittent nature of some power sources is not a serious drawback in some rural areas. Current battery storage technology can often meet small, remote village demand, and in many cases, 24-hour service is not absolutely necessary.

Other categories of more directly locational criteria include environmental, land use, and cultural factors unique to particular island or villages. Soil depletion from too-rapid biomass harvesting could limit the acceptability of that technology, while the already constrained availability of land on small atolls precludes most land-intensive energy conversion technologies. Remote island areas may also feature cultural patterns of communal decision-making and life style which rule out technologies village inhabitants judge to be intrusive. The presence and staying power of such potential constraints to technology adoption will not be fully understood until site-specific system siting proposals are put forward. Nevertheless, some of the field work performed to date under alternate energy grant programs in the islands has identified a few of the more apparent environmental and cultural limitations. These are reflected later in the assessment of technology options for each island government.

Additional criteria that must be met for certain technologies to succeed include an adequate base of trained experts in energy system installation, operation, and most important, maintenance. Without a local support capability, interest in and commitment to a technology will be insufficient. Similarly, there must be a physical infrastructure in place, or capable of being easily developed, to insure that the trained workers can carry out their support responsibilities. Wind generator maintenance, for example, requires both a capable work crew and the necessary spare parts, repair equipment, and service facilities. Some technologies will have clearly more elaborate and expensive requirements than other. However, the basic infrastructure and human resource criteria will need to be satisfied for any energy system.

One further set of criteria which cannot be neglected in the selection of alternate energy systems for the Pacific Islands are the economic parameters which govern the purchase, operation, and long-term productive value of competing technology options. Three commonly used criteria include: system capital cost, system operating and maintenance cost, and overall system cost-effectiveness as measured against the next most likely energy technology choices. Table 2-2 presents some characteristics of the technologies included in this report, including rough estimates of some of the costs associated with each.

Capital and operation and maintenance costs will vary according to both technology and site. For example, because Guam experiences higher insolation levels, fewer solar photovoltaic modules would be needed to meet an identical electrical demand than in, say, Kosrae. Because the system cost of photovoltaics is sensitive to even a small change in module cost, insolation (location) will be a major determinant in the capital cost of this technology throughout the Pacific. Technology complexity, durability, remoteness, and infrastructure support will determine the nature of continuing operation and maintenance costs for most energy systems. For nonrenewable resource energy systems, the greatest component in this category is the constant escalation of fuel charges over time.

High capital cost, per se, need not be an explicit negative in energy technology selection. Analyses have shown that when they are evaluated on a life-cycle basis, many systems with high-first-costs have a lower cost of delivered energy than systems with lower-first-costs. This type of analysis should be identified and explained by island decisionmakers so that financial planning can better accommodate the impact of high-first-cost technologies on local budgets.

Given the constraints now posed by insufficiently developed infrastructure and human resources throughout the islands, there is likely to be a high premium placed on energy technologies with limited operational costs. Those systems chosen for remote areas which do not further strain the existing skill and physical support gaps already apparent on many islands are also likely to be highly valued.

The common denominator in determining the cost-competitiveness of alternate energy systems will be the uniformly high price of imported petroleum now used throughout the region. Conventional energy system costs are relatively well understood; thus, it will be the characteristics of alternate energy systems (technology readiness, resource attractiveness, load match, etc. that will determine the cost-effectiveness of various options. For general planning purposes, costs-effectiveness can be described in terms of the time periods in which each technology is expected to be used in each island group. Technical and economic analyses support some of these determinations; others are more judgmental, based on developments outside the Pacific region.

In examining renewable energy system potential for given island groups, it is important to note that the full implementation of any technology--no matter how favorable the resource base--will not occur as rapidly as the resource opportunity may suggest. The remoteness of the islands, the limitations on the rate at which existing generating equipment can be replaced, the limits posed by an undeveloped physical infrastructure, and general institutional inertia, will all temper the pace of transition to even the most vividly cost-effective technology options. Yet it is important that early experience be gained in using the most promising technologies so that as anticipated cost-effectiveness targets are reached, fullest use of the technologies can occur.

The following sections of this chapter present brief discussions on the state-of-the art of a range of alternative energy technologies. Included are general observations as to the appropriateness or inappropriateness of the technologies to the Pacific region as a whole. These are based on resource similarities, generic technology readiness, cultural factors, and other influencing criteria.

PHOTOVOLTAICS

Photovoltaic technology, first developed for space satellite power systems in the late 1950s, has experienced a rapid growth in terrestrial applications over the past ten years. The technology is based on the conversion of sunlight to electricity by photovoltaic cells. The cells are discs or

Table 2-2. Characteristics of Technologies for Production of Electricity Under Consideration for Pacific Territories

Technology	Size/Description of System	Current[a] Capital Cost Estimate K$/kW	Current[a] Cost/kWh	Capacity Factor[b] Range (%)	Area Required	Temporal Characteristics
Wind	Few to tens of kW, not grid connected	3-6	$ .50-1.00	10-30	Little	Intermittent, needs storage
Wind	Few to tens of MW, grid connected fuel-saver mode	1-2.5	$ .25-.50	10-30	20 ha/MW	Intermittent, fuel storage mode with no storage
Photovoltaic energy	Several kW range, not grid connected	10-15	$1.00-2.00	15-25	$20m^2$/kWp	Intermittent, needs storage
Photovoltaic energy	Few to tens of MW, grid connected fuel-saver mode	10-20	$1.00-2.00	15-25	2 ha/MWp	Daily cycle, intermittent, fuel-saver, no storage
Solar Thermal energy conv.	Several kW to tens of MW, stand alone or grid connected	5-20	$ .50-2.00	15-25	3 ha/MWp 15 ha/MW	Intermittent, needs storage; or fuel-saver, no storage
Hydropower	Few MW, grid connected	0.8-1.3	$ .10-.50	50-70	Little	Water availability dictates limitations
Geothermal energy	Tens of MW, grid connected	1.5-2	$ .10-.50	70-90	As required	Baseload power
Ocean tidal/ current	Harness ocean currents or tidal flow	Unknown	Unknown			
OTEC- shore based	5 MW 40 MW	8-10 5	$ .20-.40 $ .50-.40	70-90	Little	Baseload power
Solar pond	5 MW salt gradient excavating/diking	2-20	$ .25-.50	70-90	20 ha/MW	Baseload power with peaking possibilities
Wood	Few MW and up, boiler, gasifier	1-2	$ .12-.15	70-90	800 ha/MW	Baseload power
Coal	Few MW and up	1.3	$ .10-.15	70-90	1 ha/MW	Baseload power
Diesel	Fractional to several MW engine generator	1[c]	$ .40-.50	70-90	Little	Baseload power
Residual oil	Several of tens of MW boiler	1[c]	$ .15-.20	70-90	Little	Baseload power

(a) "Hawaii Integrated Energy Assessment," LBL 12061, January 1981; "Cost of Energy from Some Renewable and Conventional Technologies," SERI/SP-741-1022, April 1981; other sources.
(b) Fraction of time source can produce energy, averaged over a year of operation.
(c) Environmental protection equipment will increase cost.

squares of specially-treated material (such as silicon) that generate a voltage when exposed to light. The conversion process requires no mechanical or thermal energy conversion steps. The process is silent, non-polluting, without fuel costs and except for large, complex applications, relatively free of maintenance expense.

Photovoltaic cells are the building blocks of a photovoltaic power system. The cells are commonly placed in larger supporting structures called modules. Depending on system size, modules can then be mounted in photovoltaic arrays and combined with other sub-system components, to form a photovoltaic power system. A complete system generally includes power monitoring, control and regulation equipment and storage batteries if necessary. The electrical current generated by a photovoltaic system is dependent on the amount of light striking the solar cells and on the total area of sunlight intercepted. At noon on a clear day, the maximum solar insolation available is about 1 kW/m^2. With a 15% efficient photovoltaic system under this condition, about 150 W/m^2 or 15 W/ft^2 is available. In the Pacific Islands, an average monthly insolation range of 2.9 kWh/m^2-day (Ponape) to 5.8 kWh/m^2-day (American Samoa) has been derived. Those island groups with an insolation resource at the higher end of this range will be ideal locations for photovoltaic applications. Data collection is now underway to characterize the insolation resources of the islands so that optimal system designs can be achieved.

The market maturity of photovoltaics is reflected in the range of power uses now being met with the technology. These uses include; street and highway lighting; communications systems; cathodic protection; water pumping; and in remote areas, village power and medical refrigerators. Depending on system size and configuration, virtually all stand-alone electrical power needs can be met with photovoltaic energy.

In the Pacific Islands, photovoltaics systems have already been employed in radio communication, lighting and the powering of small medical refrigerators. An engineering design for an 8 kW village power system is presently underway for a remote atoll in the Marshall Islands. The low power needs of most outer islands match well with the one to 10 kW size range and output of photovoltaic systems. A growing number of small appliances, light tools and other electrical end-use devices of potential application in remote areas have been designed to operate directly off photovoltaic systems. More end-use appliances are expected to become available for integration with photovoltaic systems as the technology achieves greater worldwide use.

Photovoltaic systems costs are based on a combination of sub-system costs (i.e. module support, power conditioning, batteries), not all of which may be present in each system design. In mid-1982, the price of photovoltaic modules ranged from $7 to $20 per peak watt, depending on manufacturer, specifications and quantity. Complete system costs may be double the module cost per peak watt depending on complexity of design and storage requirements. Engineering design and overall photovoltaic system costs are expected to rise as the size of system installations increases. Conversely, small photovoltaic applications (in the several hundred watt range) require little in the way of systems or engineering costs. In such instances, module costs alone comprise the bulk of total system expense. Total system costs in the $10 to $25 per peak watt range translates roughly to a delivered electricity cost of $1/kWh for intermittent power. A baseload photovoltaic system which would generate the same total energy as a 10 MW diesel or oil-fired generator would be a 40 MW (peak) photovoltaic system and at 15% efficiency, would occupy about 80 hectares (almost a square kilometer or 198 acres). The storage capacity required to use photovoltaics for 24-hour baseload operation would add to the land area required and put to total system costs per kilowatt hour at least double the figure for an intermittent system.

The relative cost-effectiveness of photovoltaics will depend on site-specific-design complexities and on the economics of competing energy sources. Even at the low end of the above cost estimates, photovoltaics are not yet cost-competitive with grid-supplied electricity in the United States. However, the costs <u>are</u> favorable when compared to conventional electric alternatives in remote, non-electrified areas of the world, such as the Pacific Islands. An analysis of photovoltaic applications for remote Pacific Islands was performed for DOE during Phase II of this project. Several village level uses of photovoltaics for intermittent power were found to be cost competitive with diesel generation at current prices.

Estimates of annual photovoltaic cell production in the United States vary; however, 1981 sales are believed to have been in the 4 to 5 MWp range. Industry production capacity is thought to be about 10 MWp annually, with several new blocks of capacity additions announced but not yet operational. Over one-half of United States photovoltaic sales were in the export market in 1980. Market projections suggest that this trend will continue through the early 1980s.

Owing to site-specific economics, as well as to the variability of the solar resource, it is difficult to generalize about the variability of the solar resource, and it is difficult to generalize about the size range of application currently open to photovoltaics. Still, it is generally believed that photovoltaic systems now compete favorably with diesel or gasoline generator costs in sizes up to about 10 kW, taking into account, the world price of petroleum, remote system-servicing and fuel delivery costs.

The modularity of photovoltaics makes it an attractive technology for consideration in the Pacific. It allows the initial installation of small systems throughout the many dispersed, low energy demand centers while permitting new increments of capacity to be added easily as the power needs of the users grow. Modularity also preserves the initial investment in system hardware since new increments can simply build upon existing modules. Many land-intensive energy technologies are inappropriate for the land-constrained islands. Photovoltaic systems can be roof-mounted, often directly on the buildings they are intended to serve. Seventy-two square meters can yield 4 kWp. Most remote Pacific Islands have municipal or other government buildings sturdy enough for such applications. Finally, the low maintenance requirements of photovoltaics, adds value to the technology as technical expertise and energy system support infrastructure are in short supply throughout much of the Pacific region.

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SOLAR HOT WATER

Solar water heating is a principle application of low temperature solar thermal energy systems. Flat plate collectors absorb the sun's rays, convert them into thermal (heat) energy, and keep the energy from being re-radiated, or lost, back to the environment. Captured heat energy is transported away from the collector plant by means of a heat transfer fluid (liquid or air) for either immediate or later use. In many cases, no moving parts are required in this transport, as natural convection and conduction forces may be used. These systems are considered "passive," while systems using motors and pumps to move the transfer fluid are classified as "active."

Passive thermosiphon systems operate entirely by natural convection and gravity. Income water heats in the collector, warms, and rises to a storage tank where it displaces cooler water at the bottom of the tank. This cooler water returns to the collector, heats and convects back to the storage tank, getting progressively warmer in each pass through the collector. Passive systems are ideal for water heating in environments such as the Pacific Islands where there is no danger of freezing temperatures.

Active systems feature collector panels on the exterior of buildings or mounted on the ground. Their transfer fluid is moved from the collector to storage via pumps, valves and temperature control systems. Because freeze protection is not a design concern in the Pacific, potable water may be used as the transfer fluid.

The design of low-temperature systems depends most strongly on the quantity of isolation received on the collector. Other important variables affecting the design are humidity, wind, hourly, daily and seasonal temperature differences; and the performance of a system. Insolation ranges in the Pacific are more than adequate for the operation of solar hot water systems.

Low-temperature solar thermal systems for heating water, are a market-ready technology. More than 200 United States companies now manufacture low-temperture active solar systems for heating water and space. Some 7000 companies are involved in the installation of these systems nationwide. Over $45 million in solar hot water system sales were recorded in 1980. Annual sales growth has averaged more than 40% over the past five years.

Within the United States, manufacture and sales of passive solar hot water systems is more difficult to gauge. Many systems have been user-built and installed, thus falling outside the sales accounting system established for active system manufacture and distribution.

The performance required of a solar water heating system is a function of the number of systems users, the amount of hot water required on a daily basis, the time of use, and the temperature of water needed. Where there is little need for hot water, the attractiveness of solar or any other water heating option may be limited. In the tropics, bathing with cool water may actually be preferred. There are other less discretionary uses in hospitals or in food handling, for example, where solar hot water systems could be easily applied.

In most Pacific Islands villages, there will be neither the demand nor the infrastructure to support solar water heating technology. Insufficient roof supports and the absence of distributed or pressurized water systems, combine to limit opportunities for solar hot water production. In urban areas, many consumers have significantly reduced their hot water use or even eliminated it as conventional energy costs have risen. It is expected, therefore, that solar water heating will find its principal use as a fuel-saver in urbanized areas where the use of electricity energy, in lieu of less-valuable thermal energy, can be avoided. Urban areas in the Pacific will also have the necessary water distribution systems and a more structurally sound housing stock available to support roof-mounted systems.

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TREE FARMING FOR ENERGY

Burning biomass in the form of wood is the oldest form of energy conversion. Over sixty countries rely on wood for more than 25% of their total energy needs. Extensive studies of plantation tree farming for gasifiers and dendrothermal power plants are underway in Southeast Asia.

Ninety percent of the tree harvest in the tropics is for fuel. Natural tropical forests can be highly productive under management, although they commonly stabilize at much lower levels in the absence of regular harvest. Annual yields of 35 to 55 tonnes of fresh wood per hectare (15 to 25 tons per acre) are achieved where moisture is not limiting. These yields are equivalent in heating value to 60 to 90 barrels of oil. Large area management on marginal soils, however, can be expected to yield about half these amounts.

Tree farms are an attractive option for Pacific Islands, but many issues must be considered. Once established, tree farms carry a minimal maintenance cost, stabilize soil, and protect the environment. Nitrogen-fixing species can be chosen, leading to soil enrichment. High protein, leafy co-products of the wood from the trees can be marketed as animal feed.

Pacific Basin geography includes two types of islands. The "high islands" are tree covered and often irregular, with steep slopes. The low coralline atolls are flat and support little tree vegetation, often restricted to coconuts whose husks and shells constitute a major energy source.

Ecologically, the United States Pacific Islands are of two major types. Those generally north of 10 N latitude are dryer (less than 250 centimeters or 100 inches of rain annually), more prone to typhoon damage and more susceptible to weedy grass cover and fire damage. The more equatorial islands are much wetter (300-450 cm or 120-180 inches annually); not so subject to typhoons and more commonly covered with rich tropical forest. The choice of fuelwood species would be quite different for these two ecological systems.

Ecological effects associated with tree farming in the western Pacific are complex. Planting and harvesting of tree farms must be carefully managed to assure continued productivity. Single species stands of energy crops present unique problems since they tend to be ecologically fragile, that is they may be subject to massive damage caused by stress, pests or diseases. Monocultural stands of trees may be sensitive to fire and will probably also be sensitive to the high winds accompanying tropical storms and typhoons. A stand of giant leucaena (koa haole) on Saipan was damaged recently by a typhoon. The trees are continuing to grow normally.

The issues of land use, nutrient provision, water availability, pest and disease control and soil quality maintenance all must be addressed. Land availability is a major issue for many Pacific Islands. Some islands are divided into small family-owned tracts, allowing only the option of cooperative tree farming. Other islands are largely in public ownership.

The whole photosynthetic process is of low efficiency; typically much less than 1% of the solar energy falling on a plot is converted into usable product. For equivalent electrical energy production, the area required to be dedicated for a tree plantation (8000 ha for 10 MW) would have to be forty times as much as might be required for a salt-gradient solar pond. Large scale farming has not been a cultural tradition of the Pacific Islanders. Relatively small numbers of people have the motivation or experience to develop and manage large farm enterprises. Those that have existed have been based almost entirely on expatriat labor.

While the use of tree farms to generate electricity has not been studied in detail for the Pacific Islands, it has been for several sites in the State of Hawaii. As early as 1979, C. Brewer and Company were leading a study of eucalyptus trees, involving planting of 325 ha (800 acres) of test plots on the island of Hawaii. The Hawaii Natural Energy Institute led another study on the use of the giant leucaena as a cultivated energy source for the island of Molokai. Under tropical conditions, this fast-growing tree can be harvested every three to four years to yield about 30 dry tonnes of wood chips per hectare. The HNEI study came to the conclusion that a tree farm on Molokai might be able to provide wood chips as a fuel for an electrical generation plant at a capital cost of about $1,200/kW. If the cost of boilers and generating equipment (about $1,300/kW on Guam) is added to this, a total capital cost of about $2,500/kW might be a reasonable estimate. Alternatively, the wood could be gasified and the resultant low BTU gas used to fuel internal combustion engines. Use of existing engines and generators would lower the initial capital cost.

Biomass yield per hectare per year is ultimately the single most important factor governing the suitability of tree farming. Yield values are not available for pertinent tree species in the United States territories and such data must be obtained before reaching conclusions on possible use as a means of generating electricity.

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WIND ENERGY CONVERSION

Wind energy is the kinetic energy associated with the movement of large masses of air resulting from uneven heating for the atmosphere by the sun. Wind energy conversion systems transfer this kinetic energy into both mechanical and electrical energy. Wind energy systems have been used in mechanical water pumping applications for centuries. Since 1900 they have been used to generate electric power.

There are two principal wind machine designs; horizontal-axis systems with blades mounted on towers and yawed to face into the wind; and vertical-axis systems with vertical rotors that operate with the wind coming from any direction. The vertical-axis wind turbine design has the potential to save on construction and maintenance costs because the expense and upkeep of a tower could be avoided. Both horizontal and vertical-axis wind generators are being sold commercially in the United States; however, horizontal-axis systems dominate the market. Modern wind turbine systems have been designed to convert as much as 40 to 50% of the kinetic energy flowing through the swept-area of the rotor blades into rotary power.

Wind turbines are rated according to their electrical output at a specified wind speed. For example, a hypothetical 2 kW wind turbine will not attain its 2 kW output (per unit of time) unless it is operating at or above its rated wind speed (e.g. 9 meters per second). The economic value of the technology cannot be forecast for a given site, then, without a good understanding of the wind characteristics at the site. Preferably, wind speed data should be recorded and statistically analyzed over hourly, daily and seasonal increments for periods of one or more years. At a minimum, data should include both wind speed and direction, and should be recorded at or very near, sites intended for machine installation.

Most small, commercially available wind machines require wind speeds of from 2.7 to 5 meters per second (5.6 to 11 mph) for system start-up and speeds of 10 to 15 m/s (22 to 33 mph) before full rated output is achieved. According to this criteria, data for many recording stations in the Pacific are not sufficient for system start-up, much less operation at rated capacity. It must be emphasized however, that some electricity will still be produced at speeds below rated machine velocity. The exact amount and value of this increment of maximum achievable power can not be known for any site in the Pacific without more thorough data collection.

Siting is a critical consideration in planning a wind generator application. Performance and economics of the system are closely related to the wind speed at an intended site. An average annual wind speed of 6.6 meters per second compared to 5.3 meters per second would reduce power costs of similarly rated machines at different sites by about one-half. Because the wind resource varies from one site to another, resource assessment data are usually not valid beyond the immediate area in which they are collected. Furthermore, the extractable power in the wind varies as the cube of the wind speed. A small change in wind speed can therefore result in a large change in the amount of power available to the user. Gusting, prolonged calms, and other variances in wind flow can significantly affect the economics of wind energy conversion at a given site.

Wind turbines do not operate at full capacity all the time. At extremely windy sites, they may reach 40-50% of rated capacity. At more typical sites, an operating capacity of 25-35% is more common. Capital cost is by far the greatest determinant of the cost of energy obtained from a wind turbine. As a result, the greater the longevity of a system, the more favorable its cost of energy will be on a life-cycle basis. Information about wind system reliability and lifetime is scarce, particularly, for the newer generation of turbines. Additional operating experience from these machines will be needed to establish and verify the true economics of system operation. At favorable United States mainland sites, wind systems have cost about $600 per installed kilowatt, and have been projected to produce energy at 3¢ to 4¢ per kilowatt-hour by the mid-1980s. In the Pacific, costs will be higher.

Wind energy is being developed and commercialized in both the public and private sectors. Wind energy is already cost-competitive in many specialized applications where the wind resource is known to be favorable. Mass production, technology advances, and larger machines will help drive down capital costs and contribute to greater system reliability.

In the United States, about thirty-five companies are engaged in the manufacture and sale of small-scale wind generators. Four other companies are producing mechanical wind energy machines, largely for water pumping. Sales remain small, although they are growing rapidly. In 1980 there were about $10-15 million in sales of large and small machines totaling about 5 MW of capacity.

Water pumping and other mechanical applications are practical uses of wind power, though electric power generation is probably the principal application of the technology in the United States today. Small electrical systems (1-100 kW) are being employed on-site for residential and farm uses; intermediate scale systems (100 kW-1 MW) are being considered for large farms, irrigation systems and small utilities; systems larger than 1 MW are expected to be used in electric utility and industrial applications. Simple mechanical wind systems, used to pump fresh water from shallow lens wells, may be one of the most likely applications on many Pacific atolls.

Wind energy is intermittent. If continous power is required, some provision must be made for energy storage and back-up for wind energy systems. One option is to combine wind systems with pumped water storage or with solar, or conventional, electrical generating capacity in a hybrid system that would provide continuous electric power. At present, there are only a few years of information available on the performance of wind systems interconnected to conventional electric grids. As the wind turbine industry matures, this unknown is expected to be more completely understood.

In areas where intermittent power sources are acceptable, wind generators can provide a good match with small end uses. Wind systems are modular and can be expanded incrementally as demand grows with no loss of the capital investment in the original machines. While wind machines must be situated where the resource is available, wind systems have minimal land requirements. At some sites, land use, or cultural or environmental constraints might arise.

Concerns about wind energy conversion also include the reliability of generators installed and left to operate in remote areas. Regular maintenance i.e., oiling, is necessary to insure continued reliable operation of wind turbines. Servicing and repair of generators in the field will require both expertise in labor and repair equipment such as cranes and shop facilities. In remote, rural environments, such needed equipment may be either non-existent or in extremely limited supply. Likewise, trained personnel may also be unavailable for more than the most elementary of servicing needs. These constraints strongly suggest that a minimum level of industrial infrastructure should be in place before widespread introduction of wind energy conversion technology in remote areas can be expected to be successful.

Within the Pacific, concern remains that the continual operation and maintenance of the technology will prove unachievable given the limited infrastructure and lack of skilled labor throughout the region, particularly on outer islands. In addition, the frequency of tropical storms throughout the entire equatorial Pacific will require special system designs (site hardening, tilting towers, etc.) which may still leave the machines vulnerable to damage or destruction in the event of worst-case storms. Most wind turbines will suffer damage at wind speeds twice their rated capacity. For this reason, turbines have a cut-off mechanism to disengage the rotors at a certain velocity. With or without a cut-off mechanism, most machines will be damaged by typhoon winds above 25 m/s (50 mph) and there is always the danger of damage from wind-driven debris. Even in mild weather, corrosion will affect the metal components of wind machines and towers on the islands, and known metal protection methods and isolation of parts may be insufficient to prevent structural decay.

More fundamentally, the wind resource of all the island groups is poorly understood. Data have been recorded only at airfields on many islands, often in poorly designed locations. Observations have been for climatic rather than energy conversion analyses, and are therefore of limited use. Also, some upward adjustment of wind speed at existing data collection stations should be done to account for greater wind speeds above the near-ground-surface (i.e. 25-foot evaluation towers now in place). Given the sensitivity of wind system economics to fluctuations in wind speed over time, not enough information has been gathered to support even theoretical forecasts of the potential of the resource at any given site.

Wind machines already installed in selected Pacific locations have suffered a variety of start-up problems due principally to their not being designed for remote island use. The installation and repair of systems on even the most industrialized islands has been hindered due to the absence of available cranes. Some corrosion and structural flaws were found on one machine; another was taken out of service due to uncertainty over its ability to survive a passing typhoon Finally one machine was destroyed when a crew lost control of the tower pole during machine tilt-up. The systems were designed for mainland application and initial problems should perhaps have been expected. However, the experience to date illustrates the range of technical and human barriers to be overcome before wind energy conversion in the Pacific can succeed.

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MUNICIPAL SOLID WASTE

Municipal solid waste (MSW) refers to garbage, trash and other types of urban waste which traditionally has been buried in sanitary landfills or incinerated. Because MSW contains organic, combustible materials in concentrated form, it can also be used as a source of energy for the production of electricity or methane gas.

Several basic technologies are used to recover energy from urban wastes. The first and simplest of these is direct incineration, which involves burning the matter in waterwall combustors to produce steam. The second approach involves mechanical processing in which the waste is separated and shredded to produce a refuse-derived solid fuel (RDF) suitable for combustion. A third method, called pyrolysis, consists of heating the garabage in the absence of air to convert it into liquid, gaseous, or solid fuels. Another process, bioconversion, uses biological means to decompose the wastes into methane-rich gases.

Burning MSW to produce steam is a proven and commercially available technology which has been in use throughout the world for over twenty years. A waterwall combustor is a furnace with water tubes in which the heat generated by combustion converts water to steam. It is equipped with special grates to burn the waste just as it is received or after it has been mechanically separated. The steam is then used to generate electricity for industrial processes or for heating and cooling buildings. Metal and glass may be recovered from the ashes following combustion.

Mechanical recovery processes generally involve separation of the waste into combustible and noncombustible components either at the source or by mixed-waste processing at a central site. In the latter method, the material is shredded to near uniform particle size (a maximum of 10 to 15 em) which then goes through a separation process to segregate the combustible organic fraction from the inorganic part which will not burn. The fuel derived (RDF) can then either be burned by itself or used as a supplemental fuel.

RDF has several clear advantages. It is in a form which can be conveniently stored and transported. It can be produced to a constant, specified standard to meet the handling and burning requirements of a boiler. Its disavantage is that significant costs are entailed in the processing stage.

Pyrolysis is a process that causes chemical change by heat. It can produce or recover gas with low to medium energy content, oil-like liquids or solid residue with a high heating value. Pyrolysis systems are not generally available, are classified as advanced technology, and must be considered very long-range or unsuitable options for the Pacific.

Bioconversion uses living organisms to convert organic matter into useful energy forms. Anerobic digestion breaks down the waste in a digester to produce methane-rich gas under controlled conditions. Only about 50% of the original volume of organic solids is changed to gas, leaving a significant amount of material which must be disposed of. This technology is still in the development stage and is not commercially available.

Another bioconversion process which appears promising is the recovery of methane from old or active landfills. In this method, wells are drilled into the landfills to extract bacterially generated gas.

An important factor in determining the technical and econimic feasibility of an MSW-to-energy conversion system is an adequate description of the quantity and composition of the waste material produced. As part of the assessment activities undertaken in this project, a study has been commissioned to assess the quantity and quality of wastes produced on Guam and Tutuila and to evaluate the technical and economic viability of an MSW conversion system at those two locations.

The energy content of the wastes is quite variable, depending on the composition and moisture content of the material collected. The heating value of the waste on Oahu received in dry weather has been estimated at 2500 cal/gm (4500 Btu/lb) while the rainy weather value can be as low as 1600 cal/gm (2900 Btu/lb) with a moisture content of 55%. For separated, dried and shredded refuse, the heating value expected is 3770 cal/gm (6800 Btu/lb) and for moisture and inert-free material (e.g., RDF) the figure is given as 4500 cal/gm (8100 Btu/lb). A barrel of oil in comparison, yields about 1.46 K cal (5.8 million Btu).

The feasibility of MSW use in producing power is highly site-specific and depends on a number of factors such as the availability of an adequate supply of MSW within a reasonable distance of a generating plant; methods used for collection, processing and conversion; and the relative difficulty and expense of alternative disposal methods with respect to the latter. Conversion of wastes to energy also has the benefit of relieving land requirements needed for landfill operations. It is applicable primarily to urban centers of relatively high population density. On most inhabited islands in the Pacific, with the possible exception of Guam and the island of Tutuila in American Samoa, the population density is probably too low to support the use of this technology in the foreseeable future. Where it is applicable, the maximum contribution of MSW for power generation will be limited by the availability of the resource of 5% or less of total electricity requirements.

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GEOTHERMAL

Geothermal energy is obtained from heat within the earth. The technology for producing electricity from geothermal resources is at a high state of readiness for the Pacific Islands. Commercial exploitation of geothermal energy has led to its use in electric power generation, space heating and cooling and industrial processing. About one-third of geothermal applications around the world are for power production; the worldwide installed geothermal electric generating capacity is about 2500 MW. About 30% of this use is in the United States. Approximately 8300 MW (thermal) of geothermal energy is used for space conditioning, water heating and agricultural and industrial applications. Geothermal energy is used for producing electricity in California, Hawaii, New Zealand, Japan, and Italy.

Resevoirs of geothermal energy are regions within the drillable portion of the earth's crust (about 3 kilometers) that contain potentially recoverable thermal energy. The three principle types of geothermal systems are hydrothermal, geopressured and hot, dry rock. The hydrothermal system is the only system of commercial interest now and consists of either a water or vapor-dominated resevoir. The water-dominated system is the most common and consists of a reservoir of hot water capped by low-permeability rock or layer of cooler groundwater. Wells drilled into this reservoir produce a combination of water and steam, depending on the temperature of the reservoir. Vapor-dominated systems, characterized by high heat flow and low groundwater permeability, occur in only a few places and consist of nearly 100% steam. Geopressured systems are hot water aquifers containing dissolved methane trapped under high pressure in deep sedimentary formations. Hot, dry rock systems are accessible geologic formations with low groundwater permeability. No water is present and energy is extracted by circulating water through wells connected by manmade fractures in the rock.

Several methods are used to identify geothermal resources. Drilling is the only certain method, but it is extremely expensive and is usually done after a number of other less expensive and less certain techniques have been used. These other techniques include geologic mapping of surface characteristics, geophysical and geochemical methods which rely on measuring unique physical and chemical characteristics of geothermal systems. Because of difficulties in interpreting data and because of interferences masking important characteristics, a number of these techniques are used together. Exploration costs on the United States Pacific Islands would be particularly high because of the need to bring in equipment and technical help.

Hydrothermal systems are the only systems being used for energy production now and are the only ones which should be considered for now for exploitation in the Pacific. Electric power can be produced reliably at competitive costs from hydrothermal reservoirs hotter than about 150°C. Geopressured energy is not at that high state of readiness and is best viewed as a mid-term option. Hot, dry rock is at a lower state of development and systems using this resource will not be on-line until the 1990s.

The general environment in which geothermal resources occur is found throughout the Pacific. Areas of geologically recent volcanic activity are leading candidates. The presence of hot springs, geysers, fumaroles and even abnormal geothermal gradients point to a potential resource. Resources on most small islands in the Pacific are largely unassessed; and because of the costs of exploration and the absence of clear-cut signs of thermal water, this potential indigenous energy source has been largely unexplored and unassessed. American Samoa and the Commonwealth of the Northern Mariana Islands have characteristics that suggest that there may be a substantial untapped geothermal resource.

The most likely application of geothermal energy on the Pacific is for electricity production at a central facility to meet baseload demand. There does not appear to be surface springs or near-surface reservoirs that could be easily tapped for small decentralized systems to supply electricity or process heat. Drilling deep wells for such systems would be prohibitively expensive. Because steam or hot water cannot be tansported long distances economically, electricity generation must be done at the site of the well.

There are a number of possible barriers to geothermal energy conversion on the United States Pacific Islands. Land use and ownership patterns are often an integral part of cultural tradition. Exploration and development of the resource do not require massive facilities nor extensive land disruptions, but they can have certain indirect effects, such as land subsidence or small earthquakes, after withdrawing toxic fluids. Toxic fluids and toxic or offensive gases, such as hydrogen sulfide, can be emitted, solid wastes may accumulate and contamination of surface water is possible. As with other energy technologies on United States Pacific Islands, lack of properly trained personnel is a large constraint. For geothermal systems, there is the added constraint of a need for highly trained personnel and expensive equipment to assess the resource.

Generating power for high-quality hydrothermal steam is economical and electric power from existing geothermal plants is cost-competitive with power from fossil-fueled facilities. However, developing geothermal resources usually involves large initial investments for exploration, well drilling and wellhead equipment. Each installation is unique, requiring specially designed generating equipment. On the other hand, operating costs for energy conversion are low despite low-conversion efficiencies. Current geothermal production costs are between 1.5¢ and 6¢ per kWh, with the costs split about equally between field development and construction, and operation of the plant. Costs in the Pacific would be higher. There is an additional problem concerning uncertainty of how long the reservoir will last. Once the resource has been identified and the power facility developed, geothermal systems have the potential to provide significant amounts of Pacific Island baseload electricity production.

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HYDROPOWER

Hydropower used to produce mechanical power or to generate electricity is one of the world's oldest and most widespread renewable energy technologies. Where the resource is present, hydropower can be readily developed as an economical, environmentally acceptable and renewable source of energy. In the Pacific, terrain conditions will probably limit the use of this technology to meeting localized electricity needs with small-scale systems on a few islands. Since hydropower can be considered for producing mechanical power in only a few rural areas, this section discusses hydropower for generating electricity only.

By convention, hydroelectric systems are defined by capacity and placed into three categories: large; capacity greater than 30 MW, small; capacity from 0.1 to 30 MW, and micro; capacity less than 0.1 MW. Pacific Island aplication include small and micro facilities.

The Physical resources required for developing hydropower are differences in head (elevation) between the point of water capture and electrical generation, the rate of discharge (water flow), and the stability of flow over a period of time (reflecting storage capacity and/or high perennial flows). Essentially, power is directly proportional to head and discharge. The energy produced is proportional to the power developed over a period of time. When energy is produced over long periods of time, utilizing the fully-rated capacity, the hydropower facility has a high plant factor (exceeds 50%). If energy is produced intermittently or at less than the rated capacity for long periods, the facility has a low plant factor (less than 50%).

Man-made resources for developing hydropower include a dam and/or reservoir in the river to capture the water, a penstock to transport the water, and turbines and generators to convert the flow of falling water to electricity. The two main types of hydroelectric systems are storage or reservoir systems and run-of-the-river systems. The storage systems includes a high dam and reservoir to provide sufficient head combined with water storage to stabilize discharges. The run-of-the river system includes a small river control structure and has limited or no storage capacity. To develop equivalent amounts of power for either storage or run-of-the-river types, there are trade-offs between capturing the potential head and potential discharge. Capturing large flows requires relatively short penstocks. Developing an equivalent amount of power for low-discharge streams requires a large elevation difference involving long penstocks and/or large reservoir capacity. Run-of-the-rivee systems are usually less expensive than reservoir systems because they do not require constructing large dams and reservoirs.

Special types of reservoir systems include pumped storage facilities and multiple-use reservoirs. In a pumped storage facility, water is pumped to a reservoir by electrical pumps to take advantage of excess electrical production. This water is used later to generate electricity. In a multiple-use reservoir, water from the reservoir can be used for other purposes such as municipal and industrial water supply, transportation, flood control, and waste disposal. Multiple-use reservoirs may make hydroelectric facilities more cost-effective in the Pacific.

The efficiency of the generating equipment also affects the amount of power produced. Selecting the proper system includes matching the types of turbine with the available head. Categories of head and types of turbines include:

Term	Range	Turbine Type
High head	Greater than 60 m (197 ft)	Impulse, crossflow, Francis
Normal head	20 - 60 m (66 - 197 ft)	Francis, propeller, crossflow
Low head	5 - 20 m (16 - 66 ft)	Francis, propeller, crossflow bulb, tubular
Ultra-low head	Less than 5 m (16 ft)	Propeller, open flame, tubular

Small hydroelectric systems use either synchronous or induction generators to convert the power to AC electricity. Micro systems are often stand-alone systems generating DC electricity and storing this electricity with a battery system. Because hydropower output can be adjusted to meet changing demands, most systems connected to the central grid can be used to meet peak electrical demands. Where hydropower is plentiful and where stream flow is high, hydropower can also supply baseload electricity.

The relatively small and masses of the Pacific Islands limit the types of hydropower development possible. The drainage areas are small, mostly less than 28 square kilometers (10 square miles). Hence, despite the relatively abundant rainfall, natural streamflows are small and the resulting hydropower plant application must almost always be small or micro in size. In addition, run-of-the-river facilities tend to be extremely limited in capacity unless sites with relatively steep elevation differences are considered. Therefore, economics of scale are normally not possible for small facilities. Long and costly penstocks may be needed in order to use potential elevation differences and to achieve significant plant capacities on low-discharge streams. On Pacific Islands, the best hydro resources are often in undeveloped areas without roads, power lines, or cleared land. This adds to the expense of developing the resource.

Hydropower is at a high state of readiness for the Pacific Islands. With proper maintenance, reliability and durability should not be a problem and small plants can run for long periods for low operating costs. Hydropower could be a catalyst for economic development in remote areas where installations would be small and relatively simple. Such plants could be built and operated with local labor because aside from the initial engineering, minimal training is required, and local materials could be used for most of the construction. Depending on the size and complexity of such a system, construction time would be on the order of one to two years.

Constraints to development include land availability; access to land; competition for use of the water with irrigation, municipal and industrial needs; and environmental considerations. As with other renewable energy technologies the most critical constraints are the lack of technically trained personnel on the islands and the lack of a reliable parts supply infrastructure.

The costs of developing hydropower systems on the Pacific Islands will vary widely depending on whether or not a reservoir system is needed, the size of the dam, the length of the penstock, the remoteness and accessibility of the land, and the type of generating system. The initial capital cost of the system and the cost of borrowing money are the chief expenses. Once the system is built, operating costs are low. The installed cost of small-scale hydropower plants ranges from about $800 to $1300/kW and the cost of electricity produced ranges from about .10¢ to .50¢/kWh.

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SOLAR THERMAL

Solar thermal energy systems concentrate and collect solar energy. They can be built in various sizes and configurations depending on the temperature demanded by an application. Only direct isolation can be utilized by concentrating solar thermal systems. Diffuse sunlight cannot be focused on collector absorbers to achieve the high temperatures required for steam and electricity production.

At least five different techniques exist for concentrating and collecting solar thermal energy: 1) heliostat-fixed receiver; 2) parabolic dish (point-focus); 3) parabolic trough (line focus); 4) hemispheric bowl-moving receivers; and 5) Fresnel lens. In the first four techniques, the reflector is most commonly a silver-placte glass mirror. Thr Fresnel lens is molded in plastic and can focus to either a point or a line. Oil, steam, water, air and other tansfer agents are used to collect thermal energy in the receiver and carry the heat away for use either in electrical generation or process heat applications. In each technique, either the receiver or reflector must track the sun at a pace approximating the earth's rotation (15° per hour). Accurate tracking requires sun sensors, motors and some type of timing system.

Solar thermal systems can meet a number of energy needs ranging from process heat and electricity generation to space heating and cooling and water heating. Process heat (steam) up to about 300°C is readily produced from parabolic trough systems for a variety of industrial uses. Parabolic dishes and heliostat systems can yield temperatures above 1000°/C for large-scale electricity generation. Heat engine generators (Stirling, Rankine, Brayton) may be used with point focus systems, while a variety of internal and external heat exchangers and fluids are being considered in advanced heliostat-fixed receiver systems.

High temperature solar thermal systems have yet to be widely produced. As such, the economics of their operation remain hypothetical. Early estimates indicate that a cost of $1400/kW_e$ installed capacity (1979 dollars) may be expected for a large, 100 MW_e, system. Few high-temperature solar thermal systems using tracking collectors have been sold commercially, primarily because of high costs. Most systems in place nationwide have been constructed in field tests with Federal support. There are about ten commercial manufacturers of tracking trough concentrator systems. In 1980, sales reached a value of about $20 million. Nearly half of these systems were sold in the private sector without government funding. A smaller quantity of point-focus systems have been sold commercially.

Large configurations of high temperature solar thermal systems require significant expanses of land. A system which is 30% efficient will require approximately 0.7 hectares (1.7 acres) will be needed to capture 1 MW_p of thermal energy. Solar tracking is relatively complex compared to fixed flat plate systems, and systems may be subject of occasional mechanical or electrical problems. Skilled labor will likely be required to attend to start-up as well as normal operations. Both process heat and electricity production applications will require at least some on-site thermal storage (perhaps with pressurized water or steam) with accompanying costs and land requirements.

Several factors augur against the utility of high temperature solar thermal systems in the Pacific. Parabolic dish and trough arrays as well as heliostat fields are vulnerable to high winds. The longevity of such systems could not be assured within typhoon-prone areas of the equatorial Pacific. The land required for these systems may be unavailable on all but the largest islands. Even the smallest of systems (1-5 MW), while appropriate for demand levels on Guam and Saipan, may be too large in capacity by an order of magnitude for most of the small energy demand centers of the Pacific.

Given the early state of technology readiness, the demand for on-site technical expertise to support a system's operation and maintenance needs will be great. Such expertise is not now found in the region and would have to be imported for the near to mid-term throughout the Pacific Islands.

The most fundamental obstacle to the future use of solar thermal technology is the lack of a defined direct solar insolation resouce. Climatic data recorded at weather stations across the equatorial region for the 1979-81 period indicate a significant percentage of cloud-cover over the observation stations. Little daily or monthly variance in this cloud intensity is apparent. If analysis of long term cloud cover and percent sunshine data substantiate these tentative findings, most of the region will be precluded from using concentrating solar thermal energy systems no matter what other implementation criteria can be met.

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SALT-GRADIENT SOLAR PONDS

Many western Pacific Islands have solar insolation levels high enough to support the use of salt-gradient solar ponds, but high capital costs and other constraints may limit the application of the technology. Salt-gradient solar ponds are bodies of saline water, three to five meters (10 to 16 ft) deep, capable of delivering thermal energy on a continuous, 24-hour-a-day basis. In electrical applications, solar pond power plants can deliver baseload power from 80% to 90% of the time.

The term "solar pond" is commonly used to describe energy conversion systems which use a direct absorber of solar energy and as a storage medium for the thermal energy collected. The salt gradient solar pond is usually a pond in which the lower, absorbing depth is stabilized against convective motion by a salt gradient. The deeper portion has a higher salt concentration and hence a higher density, while the upper portion of relatively fresh water serves as the insulating layer. Energy is extracted from the deeper portion either by an in-pool heat exchanger or by circulating the hot brine through an external heat exchanger. The energy so obtained can be used for space heating, process hot water or hot air, desalination, crop drying, power generation or the production of liquid fuels such as ethanol.

Salt-gradient solar ponds have three distinct zones. The upper convective zone of primarily fresh or brackish water (sea water can even be used) is from 0.15 to 0.3 meters (.5 to 1 feet) thick. The middle non-convective zone of increasingly salty water is from 1 to 1.2 meters (3 to 4 feet) in depth. The bottom or storage zone, which is usually saturated in salt and is convective, is typically 1 to 4 meters (3 to 13 feet) in depth.

The upper zone is not a designed component of the solar pond but forms naturally as a result of rain, runoff and other natural occurrences. It can be a detriment to pond efficiency because much of the thermal energy which is absorbed by the layer is lost due to convection and evaporation. It is also subject to wave action which can stir up the lower layers and destroy the thermal storage capability of the pond. The middle or non-convective zone is the key energy absorbing component in the solar pond. This zone performs similar to the glass or plastic cover on a solar flat plate collector because it is relatively transparent to the short-wavelength incident solar energy but is opaque to infrared, long-wavelength re-radiation from the warmed water below. This makes the non-convective layer a good thermal insulator against heat loss from the lower storage layer. The bottom storage layer has a high density created by the high salt concentration. While it is a convective layer, it is insulated from the outside world by the non-convective zone and hence it can and does accumulate solar energy in the form of heat. It is this hot saltwater in the storage zone that provides the thermal energy needed to produce the electricity.

In a high insolation area the solar pond will collect and deliver thermal energy at an efficiency of 15 to 20%. In lower insolation areas, the efficiency may drop to 12%. Conversion of low-temperature thermal energy similar to that obtained from a solar pond has been accomplished at an efficiency of 8%. Combining these two efficiencies, the overall efficiency of conversion of solar energy to electricity by a solar pond is expected to range between 1% and 1.5%. The implication of this low efficiency is that in order to be cost effective, the solar ponds and the conversion equipment must be relatively inexpensive. In practice, this means that the berming required to form the pond itself must be easily done. The berm and pond bottom must be made of clay or some other material impervious to the brine solution. Many of the existing experimental solar ponds have used liners of plastic or some other membrane, but this has added significantly to the capital costs.

Site location also has a strong influence on the practicality of solar ponds. Ideally the site should be flat, should consist of impervious soils, no water should flow beneath or near the site and potential salt brine leakage form the solar pond should present no danger to nearby water supplies.

In both the United States and Israel, solar ponds have been built and research is being conducted. The United States focus has been on solar ponds for thermal use with the bulk of the work being done in Ohio and New Mexico. Israel, on the other hand, has concentrated on generating electricity. Research in Israel has been led by a private company, Ormat Turbines Ltd. Ormat has had extensive experience culminating in a 7500 square meter pond located at Ein Bokek on the Dead Sea. The solar pond has a steady state capability of 15 kWe, however the power conversion unit it capable of higher output and the pond has yielded 150 kWe for short periods, thus proving that a solar pond can be used as a battery. The first quarter section of a one square kilometor pond has just been built and is expected to give a steady state power of 1.25 MW. When completed, the one square kilometer pond is expected to have a capacity of 5 MW.

Capital costs for such a pond are projected by Ormat at about $1000/kWe at the 20 MW size and $700/kwE at the 40 MW size. However, recent data fram a SETS, INC. of Honolulu, Hawaii study of the applicability of salt-gradient solar ponds to the Western Pacific Islands indicate that the first shore-based pond there might have a capital cost in the neighborhood of $20,000/kWe installed. Further development might lead to capital costs in the range of $2000/kWe installed.

To summarize, most of the western Pacific Islands have sufficient solar insolation to support a salt-gradient solar pond development. Projected land dedication requirements are relatively modest with 10 MWe, perhaps, needing two square kilometers of pond. However, not all of the islands have suitable land that can be dedicated for this purpose. While some study has been devoted to siting a solar pond in a lagoon or on a reef the additional costs and the uncertainty of the heat flows place this technology much further into the future. In addition, since many islands obtain their fresh water from the Herzberg lens underlying a portion of the island, brine leakage from a salt pond could have serious consequences. The best current estimates available for island installations in the western Pacific, center about $20,000/kWe output, dropping to $2000/kW as experience accumulates.

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OCEAN THERMAL ELECTRIC CONVERSION

By far the greatest reservoir of renewable ocean energy exists in the tropical areas in the form of the temperature difference (DT) between solar-heated surface waters and the cold water available from the depths. This DT of 20-25 degrees Celsius, which varies with site and season can be used to drive a heat engine and produce electricity through application of a process known as ocean thermal energy conversion (OTEC).

Recent milestones of note in demonstrating this technology are the fielding of the Mini-OTEC barge mounted system off Keahole Point in Hawaii and the shore-based Japanese designed and installed OTEC plant on the Republic of Nauru in the western Pacific. The Mini-OTEC was placed in service on August 2, 1979, becoming the world's first at-sea, closed-cycle OTEC plant to generate net energy. It operated for three and a half months, generating a gross output of 60 kW with a net output of 15 kW. The Nauru plant, which began operating on October 14, 1981, achieved a gross output of 120 kW with a net of 31 kW. Both plants were of unoptimized design and built to operate for a short period of time.

Two basic power cycles have been suggested for the conversion of ocean thermal energy into electricity. The closed-cycle system pumps warm ocean surface water into a heat exchanger (evaporator) where a second fluid (such as ammonia or freon) with a low boiling point is vaporized and allowed to expand through a turbine, which in turn drives an electric generator. Upon leaving the turbine, the vapor is condensed in a second heat exchanger (condenser) with cold water drawn up from deep in the ocean through the cold water pipe. The condensed fluid is pumped back into the first heat exchanger and the cycle begins again. The process is similar to that employed by an ordinary steam power plant.

In an open-cycle system, a portion of the warm surface water is flashed into vapor by drawing a vacuum over it. This vapor flows through a turbine, generating electricity as in the closed cycle, and this is condensed back into water by the cold water drawn from the depths. By virtue of its vaporization and recondensation, this water is now fresh, and can be reclaimed and used as a source of fresh water. It has been estimated that more than 2.8 million liters (750,000 gallons) per day of fresh water per megawatt of power capacity can be generated in an open-cycle system.

OTEC plants can be constructed on-shore, offshore on tower mounted platforms, in deep water on moored platforms, or in the open water as grazing plantships. A number of alternative applications may also be ultimately possible with OTEC. In addition to the possibility of producing fresh water using the open-cycle system, the cold water brought to the surface by all OTEC plants is nutrient-rich and suitable for mareculture. Hydrogen and oxygen can be produced through electrolysis, ammonia can be synthesized in combining the hydrogen with nitrogen obtained from the air, and synthetic fuels such as methane and methanol can be produced where carbon resources are available.

The available global resources of ocean thermal energy far exceeds known requirements, and are of the highest quality in the region between 20°N and 20°S latitudes, where most United States Pacific Islands are located. An important point to note is that this energy source is virtually inexhaustible and available day and night, and is capable of producing baseload quality electricity. For most of the Pacific Islands, which are characterized by steep offshore profiles, access to the cold water is relatively close to shore, making possible consideration of land-based or near shore plant sites.

An inherent difficulty in using this resource arises, however, because of its relatively low thermal quality, especially when compared to conventional forms of energy. With a DT of 22°C, the maximum theoretical efficiency achievable in a heat engine is only about 7%, with practical efficiencies attainable on the order of about 2%. In comparison, a fossil-fired plant can reach efficiencies of 35% or higher. But low efficiency in the case of OTEC is acceptable because the fuel is limitless and free. The low efficiency simply means that enormous quantities of water, both warm and cold, must be processed, involving very large pipes, pumps and heat exchangers on a scale which extends beyond current practice. For instance, for a 20 degree DT, each kWe of generating capacity requires about 80 square meters, (800 square feet) of heat exchanger surface; and for a 40 MWe OTEC plant, the total flow of water required is on the order of the annual flow of the Potomac River. If this flow were to be accommodated by a single pipe, it would require a pipe of more than 10 meters in diameter extending a thousand meters below the surface of the ocean.

Although the technical problems encountered in the design and construction of an OTEC plant are formidable, this technology does not require any major scientific breakthroughs to be achieved. However, no commercially sized application has been made to date, and considerable questions remain regarding the cost of the technology. A review of nine available studies of OTEC costs showed a range of capital costs in 1980 dollars of $1600 to $4300 per kilowatt capacity, and a range of electricity costs of 31 to 96 mills per kWh for island applications. These estimates were generally based on plant sizes on the order of 300-400 MW capacity, far too large for Pacific Island use. The economic size of OTEC plants tends to restrict their applicability. The larger load centers in the Pacific, Guam, Saipan and American Samoa, could accommodate small OTEC plants, and cost estimates for plants of a size suitable for such locations increase significantly. A major factor in reducing cost will be the use of aluminum heat exchangers to replace the titanium heat exchangers now used.

The environmental effects of OTEC plants are expected to be confined to the shore area where transmission lines cross the surf line from offshore plants or to the immediate plant area for onshore plants. If large volumes of cold bottom water were discharged near the surface some localized environmental effects could occur. No cultural barriers to OTEC are anticipated.

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BIOGAS

Biogas is a generic term used for gaseous fuel products which can be obtained from biomass material by means of several conversion processes.

One such process uses anaerobic bacteria in a digester containing animal wastes, high-moisture terrestial materials such as cane trash and sweet sorghum, or acquatic crops such as kelp and algae. The anaerobic digestion process begins with bacterial action to hydrolyze complex materials such as cellulose and proteins into sugars. These sugars are then fermented by acid-forming bacteria to produce simple organic acids, and finally, methane-forming bacteria reduce the acids to methane and byproduct carbon dioxide. The resulting product, an approximate 50-50 mixture of the two gases, has an energy value of about 44 kCal/liter (500 Btu/cubic foot). It can either be burned directly or transported via pipeline after scrubbing to remove the carbon dioxide. A minor but offensive byproduct, hydrogen sulfide, is usually present, but can be removed in the scrubbing process.

Liquid effluent from the digester is nutrient-rich, and can be used to grow algae for animal feed. The residue, or sludge, which collects at the bottom of the digester tank is also a useful byproduct as high quality fertilizer.

Biogas digesters are ideally suited for integrated farming operations in which animal wastes are converted into fuel, feed and fertilizer. It requires simple construction skills, can be reliably operated, and is economical in cost. In Saipan, a digester of about 570 liters (200 cubic feet) has been constructed of reinforced concrete at a contract cost of $4000. Digesters also can be constructed with plastic, or with clay bricks at a lesser cost.

Biogas digesters are especially suited for rural farms and villages common in the territories of the Pacific, where the products of the digester can meet a variety of needs. However, farm animal are often unpenned, so wastes are not collected, and many islanders have a strong cultural aversion to handling wastes.

Thermochemical conversion is another means of obtaining a gaseous fuel from biomass. In its simplest method, a product commonly known as producer gas is generated by heating wood chips in a kiln in the presence of a limited quantity of air. Such air gasifiers are simple to construct, reliable in operation, and can be designed to process a wide variety of feedstock such as forestry products, agricultural residues, acquatic crops and municipal solid wastes.

The fuel gas can be used directly to fire stationary combustors such as a boiler, kiln, or process furnace, or it can be cleaned and used as a substitute fuel to operate engines for power generation and for transportation. The use of producer gas to fuel an engine dates back to 1881, and portable gas producers were in common use throughout Europe by the 1920s to fuel trucks and tractors.

The chief drawback of producer gas is its relatively low energy content which makes it uneconomical to transport it for any distance.

The most obvious application of this technology would be in small, rural areas of the territories that are not presently grid connected. The gas could be used to displace diesel oil in generating electricity, in powering transportation vehicles, and in energizing other equipment. It is estimated that one ton of dry wood can displace approximately 65 gallons of diesel fuel.

LIQUID FUELS

Displacing petroleum-based liqued fuels used for marine and terrestrial transportation with fuels obtained from renewable resources represents a difficult problem which will not be solved to any appreciable extent during this century. However, liquid fuels produced on a small scale, using farm crops as feedstock, may become important in meeting a variety of local fuel needs in the near future.

Biomass is the only renewable resource potentially available in the territories that can be used as feedstock in liquid fuels conversion technologies.

Conversion processes available or expected to become available include biological conversion involving fermentation to produce ethanol, and direct extraction of oils through pyrolysis. Of these, only fermentation merits serious consideration at this time.

Ethanol is an alcohol product which can be used for lighting, heating and cooking, cooling and for transportation purposes. It can also be burned to provide peaking power. The forms in which it can be used as a liquid fuel are as hydrated ethanol, as anhydrous ethanol, and as an additive to gasoline and diesel oil. The heating value of anhydrous ethanol is 5600 KCal/liter (84,600 Btu/gal) compared to 8250 KCal/liter (124,000 Btu/gal) for gasoline.

The technology to produce ethanol through fermentation has existed for centuries. The alcohol can be readily produced from such crops as corn, wheat, sugar cane, potatoes, cassava, beets and Jerusalem artichokes; from agricultural byproducts and wastes; and from cellulose. Hydrated ethanol in concentration of up to 12% can be produced in about 30 hours at 76°C (100°F) through direct fermentation. Filtration and distillation are then required to raise the concentration up to 95% (190 proof), suitable for use as a fuel. Anhydrous ethanol is used as an additive to gasoline. The entire process is energy-intensive, and at best, the net gain in the energy balance is small. To maintain the net gain, the heat energy input to the process should be provided from other nonpetroleum, renewable sources as much as possible. This process also requires significant amounts of water, on the order of 16 liters for each liter of ethanol produced. The major potential hazard posed by the manufacture of ethanol results from stillage discharge. The stillage contains very high biological oxygen demand and can be harmful if it is directly released into waterways. One solution to this problem involves extracting the solid contents of the stillage for use as fertilizer or cattle feed.

While the economics of scale for most industrial processes favor large plant capacities, certain economies of scale are also present for small scale ethanol production, which make dispersed on-farm alcohol production a viable alternative. Some of the benefits small scale operation, especially in the outer rural regions, include lower transportation and capital costs; the availability of local, field-dried feedstocks; and economies of integration with other farm operations such as the use of stillage to enrich feed, and the use of methane generated from animal wastes in digestors to furnish energy for the alcohol plant.

The largest uncertainty concerning the production of ethanol in the territories is the availability of the feedstock required. Suitable crops for this use must be identified, and techniques for growing and harvesting them need to be established. Expected yields in terms of energy output are highly site-specific, requiring detailed information for candidate sites. Land is a precious commodity throughout the islands, and particular care is needed to utilize it for its greatest benefit.

Some of the answers to these and other questions will be provided by the results of a comprehensive soil classification survey being conducted by the United States Department of Agriculture, and a biomass feasibility study now in progress at the University of Hawaii College of Tropical Agriculture.

OCEAN TIDAL AND CURRENTS

Energy production from the ocean's tidal resource has potential in those near-shore areas with a great daily tidal range. Tides are longer period waves generated by the gravitational interaction between the earth and its moon. A mean tidal range of more than five meters (16 feet) is considered necessary for an economically feasible electric power generation system. Impoundment of ocean water in a river estuary or bay with narrow inlet is the only method that has been practically employed or that is being substantially developed.

Design and emplacement of a tidal energy system are complicated because tidal fluctuations may, in part, be a resonant phenomenon. If so, these fluctuations, and hence the available extractable energy, may be lessened as portions of the tidal energy are converted. Nevertheless, tidal power systems have already produced useful energy on a limited scale.

Existing tidal power installations include the 240 MW Rance River project in France (mean tides of 8.5 meters, 28 feet) and the Kislaya Bay project in the Soviet Union. Net electrical output of the French facility has reached 500 GWh/y, with the total cost of operation comparing favorably with peaking power obtained from conventional hydroelectric plants. South Korea, Canada, and France are pursuing additional tidal energy development projects. The successful operation of the Rance River project suggests that where the tidal resource is favorable, a viable future exists for the extraction of tidal-based energy.

Ocean current conversion uses large, submerged hydroturbines anchored in the path of a strong current and connected to an electric generator. In one approach, an axial flow turbine configurtion can be used to convert the ocean currents' kinetic energy into mechanical (and then electrical) energy. Such systems are in the early stage of development, and convincing projections as to their costs of operation cannot yet be made. A major factor in the cost of energy from ocean current systems is likely to be the expense involved in mooring the hydroturbines. Due to the low power density represented in even the swiftest of ocean currents, turbines used to capture and convert this resource must be large. The energy output of such systems is likely to exceed the amount of power that could be used or afforded in most present demand centers in the Pacific.

All properly placed ocean current devices rely on a steadier source of energy than do wave or wind devices. In general, the swiftest ocean currents are in the equatorial regions, however, detailed information on the worldwide distribution of ocean current energy is not extensive. There has been no characterization of either ocean tidal or currents resources for energy conversion purposes in the Pacific Islands. Only limited tide data are collected near some harbors and anchorages. Application if and when possible,will need to be close to demand centers (or an electrical grid) to reduce the cost and energy losses inherent in long distance cables or transmission lines.

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ENERGY MANAGEMENT

Energy mangement includes all those technical, institutional, and behavioral measures which can contribute to the more efficient use of existing energy supply capacity. When they are successfully applied, these measures free increments of existing capacity for use elsewhere, perhaps in expanding economic activity that was previously energy-constrained. Energy mangement is thus an energy "supply" option and has been included in the list of technology choices available to Pacific Island governments.

Among the several measures applicable to Pacific Island energy management are the following:

- Installation and effective monitoring of electricity meters
- Reform of electric rate structure to reflect more accurately the true costs of production
- Passive cooling retrofit of existing buildings to reduce the heat load and air conditioning requirements
- Design and implementation of energy efficiency standards for all new building construction
- Substitution of energy efficient end-use devices and removal of unneeded energy consuming devices wherever possible
- Development of energy data base capabilities to support all energy management decisions

Each of these measures has the potential to assist energy demand management significantly on islands now served by a centralized grid. The measures are ready to be applied throughout the Pacific, and have been successfully employed elsewhere to a great extent. Perhaps the key factor in achieving success in energy management in the Pacific will be the individual performance of those responsible for specific design, monitoring, and data analysis tasks. Compliance with a multitude of decentralized energy conservation measures could initially tax the human resource capabilities of some island governments. Training and public awareness efforts should be instituted, therefore, to help insure the success of energy management in the islands.

All of the above measures have very low or no capital costs associated with them. Implementation and compliance activities result in "operational" costs that will vary in magnitude with the complexity of measures attempted and the efficiency with which they are conducted. Barring the complete inability to institute and sustatin conservation efforts, the above measures should easily pay for themselves in oil savings to each of the respective island governments.

SMALL-SCALE OR APPROPRIATE TECHNOLOGIES

For Pacific applications, the terms small-scale and appropriate are interchangeable and are defined in the traditional fashion. Small-scale and appropriate energy technologies are decentralized and built mostly from local materials. They can be built, maintained, and repaired with local labor and expertise and are labor rather than capital intensive. They should be village or community owned, compatible with the environment and culture, and improve local well-being. Social, cultural, and employment considerations are important elements of such technologies. The terms small-scale and appropriate are relative and refer to the application, not a generic technology.

Small-scale energy technologies for Pacific Islands are used mostly in rural villages away from population centers and on outer islands. Despite harsh environments and remoteness, local people are able to build and service these systems. These technologies will help communities avoid importing fuel for essential end uses; in a few cases they will reduce the amount of fuel being used. As such, they will not make a significant impact on the total amount of petroleum products being imported, but they can offer a significant improvement to rural well-being, particularly in areas that do not now have electricity.

Examples of small-scale technologies and applications appropriate for Pacific Islands include efficient wood stoves for domestic or school cooking, mechanical wind machines for pumping water from shallow lens wells, solar dryers for drying food or copra, solar devices for cooking or desalinating water, and simple sail systems for fishing boats. Small wind electric machines, solar photovoltaic systems, and producer gas/palm oil systems are also appropriate for rural energy needs, but such systems are capital-intensive and usually require parts and technical expertise from elsewhere. They have been discussed separately in this chapter.

Efficient wood stoves have made a large impact during the last decade in countries that rely on wood or biomass wastes for domestic cooking. On Pacific Islands, cooking in rural areas and on the outskirts of urban areas is usually done over open fires on the ground, often in small cooking shacks. Fuels are usually coconut wastes of wood. Cooks are quite skillful at building efficient fires, but these fires still require large amounts of fuel, and these fuels are becoming scarce, particularly around urban areas. Cooking on such fires is time-consuming, hard work, and unhealthy if the shacks are not well-ventilated.

Cooking stoves that can burn wood or biomass wastes efficiently have some type of firebox which takes the fire off the ground; an efficient method for combusting the fuel, controlling the air, and channeling the heat throughout the stove; openings on the top of the stove in which the cooking utensils fit snugly; and a chimney to ventilate the smoke. Such stoves are built from local materials such as clay and sand. The most popular stoves worldwide are of the Lorena type.

Building these stoves with local materials on Pacific Islands is often not successful because of the high salt and coral content of the sand and the lack of fresh water to wash the sand. In such cases some cement is used, and the stove is cast, sometimes in layers, within a mold. Costs for a family stove, including cement, molds, and labor are under $50. Most of these stoves are variations of the smokeless wood stove developed at the University of the South Pacific, Fiji.

Efforts to change something as fundamental to local cultures as cooking encounter a variety of cultural barriers, including the reluctance to vary daily living patterns. These barriers are the controlling element for widespread use of these stoves. However, users are pleased with the results of the stoves, and their use is slowly spreading.

Pumping water by mechanical wind machines is one of the oldest and widespread energy technologies. Wind-powered water pumps are available commercially, or they can be built from local materials. Commercial machines are mostly of the standard horizontal design with multiple blades connected to a hub and rotary power shaft. This shaft is connected to a gear box which converts the rotary motion to a linear, reciprocating motion of the sucker rod, which in turn is connected to a piston pump. The hub and blades have a diameter from 1.8 meters (6 feet) to 4.9 meters (16 feet). The amount of water pumped is a function of wind speed, blade diameter, length of stroke, and depth of well. Commercial machines usually start operating at wind speeds of over 3.6 m/sec (8 mph). In a 6.7 m/sec (15 mph) wind, a 2.4 meters (8 feet) diameter mill can pump about 1900 liters (500 gal) per minute from an 18 meters (60 feet) well. A 2.4 meters diameter (8 feet) machine without tower and sucker rod costs from $1200 to $1500.

There are a variety of designs for home-built machines such as the Cretan sail-wing, the Dutch type, and vertical axis machines such as the Savonius Rotor.

A good application of wind machines for Pacific Islands is to pump water from the shallow, freshwater lenses that underlie many of the islands. Pumping rates must be controlled so that the freshwater layer is not depleted, allowing brackish water to intrude and contaminate the well. These machines, which have rugged construction and may be specially treated to prevent corrosion, are susceptible to storm damage. Because of their relatively simple construction, easily understood mechanical operation, and the manufacturers' familiarity with shipping systems to remote areas, water pumping machines are free of many of the problems that plague wind electric machines.

Drying copra on United States Pacific Islands is traditionally done either by spreading the copra out in the sun or by using small drying shacks with fires fueled by coconut wastes. The former is difficult because of the high rainfall on many of the islands, and the latter is often unsatisfactory because the smoke may contaminate the copra and affect its quality. Fuel may also be scarce. There is a similar problem with preserving or drying food in villages without refrigeration. Simple solar dryers are used successfully throughout the world to dry such commodities. There are a variety of designs for these dryers, and they are almost always built locally with local materials, except for glazing. Costs vary from $5 to $250, depending on size and proportion of materials obtained elsewhere. Design considerations include durability, type of glazing, means of controlling the temperature and ventilation, and protection of the commodity being dried from the elements and insects. Experience has shown few cultural barriers with these dryers other than a reluctance to substitute a new idea for a traditional one.

Solar devices for cooking, desalinating brackish water, or water heating can also be built mostly with local materials. There are a variety of simple designs, and cost and design considerations are the same as with solar dryers. Operational problems include storm damage and scaling of pipes from brackish water. Sometimes simple pipefittings may be hard to find. Cultural barriers to solar cooking are often more severe than those that affect wood cooking stoves because cooking using the sun is an entirely different concept. There do not appear to be cultural barriers for the other devices, but there is not a great demand for hot water except for health dispensaries.

Most boats for family transportation and fishing are home-built. The typical boat is built from plywood for about $700 including labor, is about 6 meters (20 feet) long with narrow beam and shallow draft, and is powered by a 40 hp outboard motor. Because of poor maintenance and the rough environment, the average life of a boat is about three years. As the price of fuel increases, the boats are becoming prohibitively expensive to operate.

A return to sail-assisted fishing vessels could partially solve this problem. A few people are experimenting with prototype vessels on the islands and are collecting performance data. These boats are canoe type with outriggers and no center board. Sails and some fiberglass parts of the hulls are imported. Secondary power is provided by small (10 hp) outboard motors. The main cultural barrier is convincing people to give up their high speed motorboats for the slower, less glamorous sail boats.

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COAL-BURNING TECHNOLOGIES FOR POWER PRODUCTION

Currently, conventional combustion of coal usually refers to direct combustion of pulverized coal in high pressure boilers. Alternately, the combustion mode can be moving-grate-fired coal systems. The product usually measured is steam. For a 25 MW unit, approximately 250,000 pounds of steam per hour must be raised to 950°F and, depending on the system, up to 1300 psig. Without emission control, the typical emissions will be about 0.83 lb SO_2, 0.5 lb NO_x, and 4.18 lb particulates per 10^6 Btu. Scrubbers can remove more than 76% of the SO_2, and electrostatic precipitators can reduce particulates to very low levels. The final waste consists of bottom and fly ash and scrubber sludge. These are produced at rates of about 1000 lb (ash) and 1100 lb (sludge with 50% moisture) per hour, again depending on the system and on the character of the coal. Costs in the continental United States for a complete coal-fired electrical generating plant are on the order of $1000-1500 (1981 dollars) per installed kilowatt.

Costs for coal as a fuel are approximately half those for oil, for the same amount of energy. In addition, even though coal would still be an imported fuel in the Pacific, there are many suppliers. Japan is increasingly turning to steam-coal to diversify its energy mix and to insulate itself from undue dependence on any one supplier. In 1981, Japan procured the majority of its steam coal from six suppliers. Table 2-3 shows the amounts and the prices they paid.

Table 2-3. Japanese Sources and Costs of Steam Coal, 1981

THOUSANDS OF

Country	Import Quantity (1000s of tons)	Import Price (U.S. $)
U.S.A.	2331	73.8
Australia	5398	67.8
Canada	1108	64.4
USSR	271	66.7
China	1305	67.1
South Africa	1853	58.4

The pattern of purchases has changed recently. In March, 1982, Canada and South Africa each supplied almost one third of Japan's coal. The United States, Australia, USSR, and China supplied another one third. Several of the Pacific Islands included in this report are conveniently close to shipping routes between Japan and its coal suppliers.

The use of coal for electrical power generation in the Pacific Islands will depend strongly on the suitability of docks, harbors and channels for use by the ocean-going dry-bulk carriers. In contrast to liquid fuels, diesel and residual oil, which can be delivered by pipeline from moorings at a distance from the docks, coal loading and off-loading must be done at the dockside. Coral reefs near the shores of many Pacific Islands restrict the access of large bulk-carrier vessels to all but a few locations. In general, existing facilities can rarely accommodate vessels whose drafts are greater than 40 feet (50,000 dwt). The common Panamax-size (60,000 dwt) dry-bulk-carrier can be brought dockside only in a few places such as Guam or Kwajalein in the Marshall Islands.

Coal-fired boilers for a 25 MW power station use 12 to 14 tons per hour of 10,000 Btu/lb coal. In the United States, it is customary to store 60- to 90-day supply of fuel in case of shortfalls from suppliers. This amounts to about 15-25% of the annual fuel use. For a 25 MW plant which uses about 12,000 tons of coal per year, the amount in this storage would be 17,000 to 30,000 tons. Dead storage of this sort would occupy about one hectare (2.5 acres) of land, assuming that the coal pile is built up to 25 feet, compacted and covered or sodded and seeded. Additional "live" storage is also needed to accommodate surges in storage requirements brought about by intermittent ship deliveries.

Ash disposal and transport is another area of concern. Four to seven percent is typical of the ash content of bituminous coals. Thus, a 25 MW plant might generate 5000 to 8000 tons of ash per year. Local use might be made of the ash, or it might be dumped at sea. Dumping permits must be approved by the United States Environmental Protection Agency if done from a territory or commonwealth of the United States.

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CHAPTER 3: ENERGY PLANNING FOR GUAM

Guam, the westernmost territory of the United States, is the largest island in the Mariana archipelago (see Figure 3-1). It lies 6200 kilometers (3700 miles) west-southwest of Honolulu, and only 2500 kilometers (1500 miles) south-southeast of Tokyo. The island's strategic location at the edge of the Asian rim gives it a role of importance for American activities in the Pacific basin.

From an energy planning perspective, Guam is almost unique among the Pacific Islands included in this assessment. The Government of Guam must plan for only a single island. The population is quite large for a Pacific Island--105,000 people on one island compared, for example, to some 17,000 on seven islands in the nearby Commonwealth of the Northern Mariana Islands--and there is a large United States military presence. All electricity users, including both military bases, are on the grid, and because Guam is more prosperous than the other Pacific Islands, a larger proportion of the population has electrical service. In recent years Guam's electricity demand has been declining as a result of conservation efforts, and generating capacity is now generally adequate. Peak demand has not changed significantly in six years, and the Guam Power Administration is more likely to need to replace old generating units than to expand capacity. Financing current operations and any replacements may pose problems.

Even though Guam's energy picture may be more similar to that of, say, Maui, Hawaii than that of Kosrae, FSM, certain Pacific Island constants apply. Guam is almost entirely dependent on petroleum fuels for both transportation and for electricity generation. Given the state of technology development, however, it is more likely to relieve its reliance on oil for electricity generation than for liquid fuels used for transportation. This is because Guam possesses several renewable energy resources that can be used to generate electricity, and the island is well located for coal use if planners decide to pursue that option. The relatively remote location still poses problems of obtaining repair parts and servicing for any type of generating system. Land and water are limited; skilled labor, though more available than it is in some island locations, is also limited. The climate subjects all types of facilities to corrosive salt air and damaging high winds.

Guam was formed through an uplift of undersea volcanoes and is surrounded by coral reefs near the shore. The island is relatively large, 50 kilometers (30 miles) long and from 6.7 to 14.2 kilometers wide (4 to 8.5 miles wide), with a total area of about 590 square kilometers (214 square miles). The northern part, which contains the main fresh water lens, is a high coraline limestone plateau rising up to 260 meters (850 feet) above sea level. The southern part is mountainous, of volcanic origin, with peaks to 400 m (1300 feet). Apra Harbor, one of the largest protected harbors on earth, is located on the western side of the island.

Guam's climate is tropical, with a mean average temperature of 27°C (81°F). Rainfall, three-quarters of which falls between June and December, averages about 215 centimeters (85 inches) a year on the lowland coast around Apra Harbor and 280 centimeters (110 inches) in the highest mountain locations of the southern half of the island. Like many Pacific Islands, Guam lies within the typhoon belt and is periodically struck by tropical storms and typhoons. Each year, a few minor typhoons with winds up to 150 km/h (100 mph) hit the islands while every five to six years a "super typhoon," with winds in excess of 250 km/h (150 mph), strikes. For example, typhoon Pamela struck Guam in 1976, causing $250 million damage. The constant need to prepare for such severe winds affects everything on Guam.

The civilian population is concentrated in the central part of the island. As is the case in much of the world, considerable population redistribution has taken place since the end of World War II, predominantly from rural to urban areas. In Guam, this means from the south to the central portion of the island. Guam's population density is approximately 180 people per square kilometer (490/square mile) of land area, about eight times the United States average of 22/square kilometers (62/square miles). Guam has a higher population density than all of the states except Massachusetts, Rhode Island, Connecticut and New Jersey.

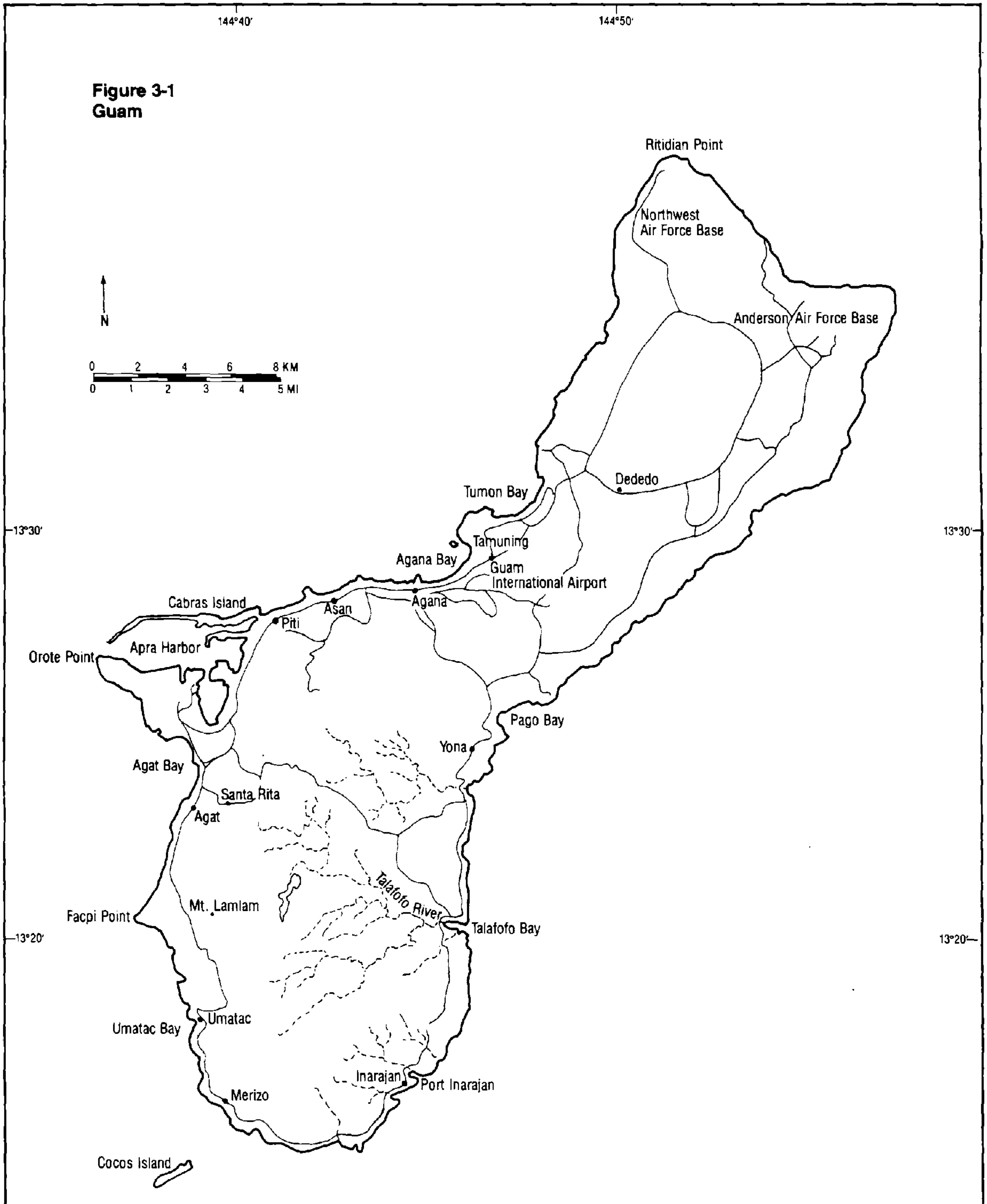


Figure 3-1
Guam

HISTORY AND POLITICAL DEVELOPMENT

The modern history of Guam began in 1521, when Ferdinand Magellan landed on the island and found it inhabited by Chamorros, a Malaysian people believed to have come originally from Southeast Asia. For many years Guam was dominated by Spanish governors in the Philippines and was a port of call for Spanish ships sailing from Acapulco to Manila. Colonization and active Spanish rule began in 1668, but little economic development occurred during this time.

Following defeat of Spain in the Spanish-American War, Guam was ceded to the United States in the treaty of Paris in 1899. Administration by the United States Navy began the next year.

United States naval administration was interrupted when the Japanese captured the island in December, 1941. Japan occupied it for 2 1/2 years. Guam was recaptured by the United States Marines and Army in July, 1944. The island had suffered much destruction, but after the war it entered a period of reconstruction and rehabilitation which changed it from a quiet agricultural island to a center of United States military operations and growing commercial activity.

In 1950, President Truman signed the Organic Act of Guam, giving the island the status of an unincorporated territory, extending American citizenship to its people, and providing local legislative autonomy. The Act also transferred administration of Guam's civil affairs to the United States Department of the Interior and placed the executive, legislative, and judicial branches of local government in civilian hands. The Organic Act was subsequently amended several times and is now the island's basic constitutional instrument.

Guamanians enjoy most of the privileges of American citizenship, but they cannot vote in United States presidential elections unless resident in one of the states. They have an elected representative in Washington, who serves for a two-year term and who exercises the rights and privileges of a United States Congressman except for the right to vote on the floor.

Since 1970, the executive branch has been headed by an elected Governor and Lieutenant Governor. Guam's 21-member unicameral legislature is elected every two years and has full power in territorial matters, including limited taxation and appropriation authority.

In September, 1982, a referendum was held in Guam on the future status of Guam. The results indicated that the people want to move toward a commonwealth status.

POPULATION, EMPLOYMENT AND WAGES

The present population, based on 1980 census figures, is 105,800 of which 21,500 are military personnel and their dependents. About 48% of the population is ethnic Chamorro, 24% is Caucasian (mostly from the United States), 20% is Filipino, 3% is Korean, 2.7% is Micronesian, and the balance consists of Japanese, Chinese and other ethnic groups. Between 1920 and 1940, Caucasians and Filipinos accounted for only 4% and 3% respectively. The growth in the Caucasian fraction is mainly due to increased military strength on the island while the increase in Filipinos comes largely from immigration.

If the present rate of growth in population is maintained, Guam's population will double by the year 2010. Because of the high birth rate, Guam's population is substantially younger than that of the United States, with 40% of the population being under 15 years of age, compared to the national average of 23%. The need to provide jobs for the new workers is expected to exert strong pressures on the government for economic development and growth. The increased population will also need services and products of all kinds, thus providing much of their own stimulus for economic development.

Government constitutes the largest economic sector on Guam, with federal and local government expenditures playing a dominant role in sustaining the economy. The Department of Defense (DOD) has 5623 civilian employees. All public employees account for about one-half of the workforce (about 17,000 out of the total of 34,000).

Guam's job market has shown substantial improvement during the recent past. Increased tourism is providing many new jobs with estimates for 1981 being 4000 direct jobs and 1600 indirect jobs in this industry. Manufacturing accounts for about 1200 workers. According to the latest available figures, the jobless rate declined from 7.6% in September 1978 to 7% in September 1979. According to the same figures, Guam's total personal income for 1978 was $366 million, an increase of 24% from the $295 million in 1977. The annual per capita income gained 20% during the same period, from $3511 to $4198. A survey of households showed the 1978 average income of approximately 19,000 households to be $19,309, the same 20% over the previous year noted above. Excluded from this study were active duty military personnel, their dependents living on posts and non-immigrant aliens.

PRESENT ECONOMY AND INFRASTRUCTURE

Since the Spanish era, Guam has gone through a succession of administrations, each with an increasing degree of self-government. The people of Guam now have almost full responsibility for their own economic development.

The economy of Guam has shown rapid development over the past 10 years, spurred by the growth in the tourist industry and the reconstruction following the effects of typhoon Pamela in 1976. Gross business income has increased from $786.4 million in 1978 to $977.8 million in 1979. Corrected for inflation, this amounted to a 12% growth rate.

The federal government, primarily the military, has played a dominant role in the island's economy, both as a source of employment and income, and as a major landowner. The economic impact of the military can be measured by its total expenditures of $671 million in 1981, consisting of military and civilian pay, military construction, and federal income taxes which are reverted to the Government; the number of civilians employed by the DOD, 5623; and the land area under its ownership, some 16,000 ha (40,000 acres). Military exchanges and commissaries account for about 20% of all local retail sales.

Military ownership of 35% of the land has become a major issue which affects economic development, especially in the area of Apra Harbor, center of Guam's commercial maritime activities. Recently, the Navy agreed to release 4.5 ha (11 acres) at Cabras Island to the Port Authority for commercial development, and additional land transfers in this area are now under consideration.

A multitude of federal agencies and the local government are involved in improving the existing infrastructure. Projects involving transportation, port, telephone, power, water and sewer facilities which are in various stages of completion. Notable among current and future capital improvement projects are the new air terminal complex, the commercial port expansion, public utilities improvement and expansion, renovation of University of Guam and public school facilities and expansion and establishment of an agricultural and industrial park. Improvements to these public facilities are crucial to future economic development. A major impetus has been the reconstruction program initiated in response to the massive damage inflicted by typhoon Pamela in 1976.

A Comprehensive Transportation Development Plan was prepared in 1975 and is being implemented in the following areas: 1) the reconstruction of the existing roadway system; 2) new highway recommendations; and 3) the implementation of a bus system. Funds for highway construction come from the Territorial Highway Fund, supported by the local fuel tax and vehicle registration fee revenues and grants from the Federal Highway Administration.

The Guam Telephone Authority (GTA) became an autonomous agency in 1974, inheriting a telephone system that was under capitalized, inefficient and known for its inadequate service. Current GTA construction is primarily involved in completing the first phase of a program to extend and improve the telephone system. The first phase of reconstruction and all subsequent reconstruction plans will be funded by loans from the Rural Electrification Administration (REA) or by GTA using in-house funds. The GTA has already received more than $20 million of an REA loan, and has begun repaying the principal ($126,000 to date).

The Guam Power Authority (GPA) became an autonomous agency in 1969 when it was separated from the Guam Public Utility Agency. This was done to facilitate the financing and implementation of an expansion program to meet the then rapid growth of power demand.

The Public Utility Agency of Guam is responsible for providing adequate water supply and sewer services throughout the island. In January, 1980, a water Facility Master Plan was completed for Guam. This included a comprehensive inventory of existing water distribution facilities and a recommendation for capital improvements to meet the island's needs through the year 2000. Also begun in 1980 was a study of the fresh water lens underlying Guam. Six additional wells have been constructed and have increased the average production of water by 5.7 million liters per day (1.5 million gallons per day). The Inarajan-Merizo water line has been completed. It provides a link between the southern Guam water users and the main water source in the northern and central deep well system.

The federal government is supporting a major effort to improve the island's wastewater treatment systems. The next five years will see expenditures of $44 million with one project for $4.5 million already underway and a total of $5.2 million approved for design and construction for two more projects. Both of these projects are expected to be funded completely by the Environmental Protection Agency.

The Guam Airport Authority was created in 1975 as a public corporation and autonomous instrumentality of the Government of Guam. The new Guam International Air Terminal (GIAT) is essentially complete. It is the cornerstone of the multimillion dollar tourism industry, and it affects almost every other segment of the island's economy. In a typical year, the direct dollar impact from the airlines operating through GIAT is more than $25 million. Of this amount, almost $6 million goes for wages, employee benefits and goods and services purchased locally.

Apra Harbor is the center of Guam's commercial maritime activities. Cabras Island and the Glass Breakwater form the harbor's protective northern border, while Orote Penninsula constitutes the southern boundary. The Port Authority's terminal facilities are located on 13.5 ha (33 acres) of reclaimed land on Cabras Island. The Commercial Port of Guam is largely restricted to servicing Guam's imports and exports. Some trans-shipment does take place, and there is minor civilian port-related industry in the form of ship repair and warehousing.

Port development at Apra Harbor has been constrained because of military land ownership. However, a recent Department of Defense review resulted in approximately 150 ha (375 acres) of land bordering the Harbor being declared excess and available for release to the Government of Guam. A comprehensive plan for development of this area in support of port operations has been completed, and implementation of port development facilities responsive to the needs of the growing economy is expected to proceed.

In the private sector, tourism grew rapidly during the 1970s to become second only to the federal government in expenditures, and as an employer third only to the Government of Guam and the federal government. Tourism has grown from 6,600 visitors in 1967 to 320,000 in 1981, with approximately 80% of the visitors arriving from Japan. Overall, it is estimated that tourists spend $190 million a year on Guam, creating an estimated 4000 direct jobs, 1600 indirect jobs, and generating over $10 million per year in tax revenues to the local government.

The sustained increase in the number of visitors to Guam has resulted in high occupancy rates at the 14 major hotels on the island. This sector of the economy is expected to grow. The Guam Hilton Hotel, currently with 370 rooms, and the Guam Okura Hotel, with 223 rooms, each plan to add 100 rooms to their inventories; and the government of Nauru has announced plans to build a 400-room hotel on Tumon Bay. The first phase of a 600-room hotel development by City Hill Development Co. and a $7 million resort on Cocos Island by Cocos Lagoon Development Corp are both already under construction.

In recent years, the construction industry has not fared as well as the tourist sector. As a result of federal assistance provided for reconstruction in the wake of typhoon Pamela, this industry experienced a boom until about 1979 when most typhoon related projects were completed. Since then, the industry has fallen on hard times, aggravated by rising interest rates and the effects of the "adverse wage rate" imposed by the federal government. Intended to encourage employment of local United States citizens and to discourage contractors from importing low paid temporary alien workers, the adverse wage rate doubled construction wages on the island between 1977 and 1979, seriously undermining the industry. Recently, the Reagan administration abolished the wage rate provision in favor of a lower "Guam prevailing wage rate" administered locally by the Guam Department of Labor. This development, along with decreasing interest rates, an upsurge in new government housing and capital improvement projects, and increasing tourist trade, has markedly improved the outlook for the industry. Total construction dollar amount for 1983 is expected to reach an estimated $183 million, compared to $111.2 million five years earlier.

The manufacturing and external trade sector of the private economy on Guam has become the second major contributor to the island's gross receipts, accounting for over $200 million in 1980. However, approximately 90% of the receipts are accounted for by Guam's single petroleum refinery, Guam Oil Refining Company (GORCO), which employs only about 10% of the manufacturing labor force. GORCO was sold to new owners October 1, 1982, but will continue to operate in Guam under the same name. Manufacturing accounts for approximately 1200 workers, or 3.5% of total employment. Principal types of manufacturing industries include rock and concrete products, printing and publishing, food processing, and garments and watches.

The impact of agriculture and fisheries on the economy is minimal. Guam has abundant, well-watered land and good fishing grounds. Traditionally, subsistence agriculture and fishing were major economic activities on Guam, but they are now the smallest industries on the island, hindered in development by a number of technical and institutional obstacles. It is estimated that less than one-third of the fresh fruits and vegetables consumed on the island are locally produced. The best estimate for island-wide catch of fish represents less than 10% of the five million pounds consumed annually.

PROSPECTS FOR ECONOMIC DEVELOPMENT

Guam has enjoyed considerable economic growth over the past decade, and the essential elements are present for continued expansion. However, Guam's present economic base is limited, and substantial assistance from the United States government will continue to be needed to sustain economic growth. Government and tourism are the largest sectors, and the economy will remain vulnerable to outside influences such as changes in military deployments and economic conditions elsewhere. This is especially true with respect to Japan, as it is a major contributor to Guam's tourist industry.

Fortunately for its economy, Guam is strategically located to assume a role of growing importance in United States affairs in the western Pacific region. Given this fact, and the declining United States military presence in the Far East, the military establishment can be expected to remain on the island in force. Military spending fluctuates with changes in world political and strategic conditions, and with changes of policy in Washington. Thus, there is no guarantee that the large military establishment on Guam will remain forever. However, with the current federal defense budget rising, it can be anticipated that some of the increased spending will be on Guam. Future growth is anticipated in increased homeporting of Navy ships in Guam as well as expanded ship maintenance and support activities.

The future for the tourist industry looks bright, provided the supporting infrastructure can keep pace with the expansion. Included in this expansion will be all utilities, the number of hotel rooms, and development of beaches, parks, and other tourist-oriented facilities.

An analysis of tourist arrivals made in 1979 showed that 75% of all arrivals came from Japan, 12% from other Asian countries and 14% from North America. Most of the visitors were in the 18-30 age group. Guam's popularity as an inexpensive vacation or honeymoon destination continues to grow in Japan, and the potential for growth in the North American vacation market has hardly been touched. Planned expansion of air service to Guam and additional routes being opened to the South Pacific will also serve to stimulate the industry.

The Government of Guam recognizes the need for an enlarged and diversified manufacturing base to balance the present emphasis on tourism. Government policy calls for encouraging the establishment of new industries in light manufacturing and for initiating an incentive program to accelerate the expansion of existing manufacturing firms. The Guam Economic Development Authority (GEDA) was formed in 1965 to encourage and participate in the growth of this sector. GEDA hopes to develop new industries in light manufacturing, trans-shipment, and regional and professional services such as education, health care, banking, research and development.

Even though the Government of Guam has established a major goal to make the island less dependent on agricultural imports, it is not clear that it can be accomplished soon. The main avenue of approach is to organize better the marketing and support infrastructure. In addition, a detailed soil survey--consisting of chemical and physical analyses of the soils, classification of soil type, and a detailed soil map--has been completed.

The economic development plans for Guam call for building on present fisheries capabilities to develop large scale harvesting, trans-shipment and processing industries. This should help reduce present dependence on fish imports and increase the number of jobs available to the people of Guam.

PRESENT ENERGY STATUS

Guam's energy situation is significantly affected by the two large military facilities on the island (Commander Naval Forces, Marianas, and Anderson Air Force Base, 43rd Strategic Wing). The specific military fuel requirements and the energy used by 21,500 military personnel and dependents on the island affect the domestic market. Table 3-1 shows that the military accounts directly for almost half of the electrical energy use and consumes 55% of the petroleum.

The largest single civilian use of conventional fuels (20% of the total) is for electrical power production. A power pooling agreement was negotiated in 1972 between the Guam Power Authority further expansion of the Navy's power generating capability. At that time the United States Navy owned the Piti Power Plant (approximately 79 MW) and one steam turbine (26.5 MW) at the the Tanguisson plant. The Navy presently operates the Piti plant (now rated at 67 MW) as well as other backup generators. The GPA operates Tanguisson (two 26.5 MW units), and the New Cabras (two 66 MW units), Dededo (four 2 MW diesel units) and Tamuning (four 2 MW diesel units) plants. It also operates the leased power barge Inductance (28 MW steam unit), which is owned by the Navy.

TABLE 3-1 -- ELECTRIC POWER GENERATION, GUAM 1980

FUEL			OUTPUT (million kWh/yr)	END USE (million kWh/yr)			CAPACITY[c] (MW)			LOAD (MW)	
Type	Amount Purchased (1000's of bbl)	Price (a) ($/bbl)		Res (b)	Comm'l/Gov't Milit	Indust	Rated	Operat	Stby	Base	Peak
Diesel	42	37	1051[d]	---441---	89	401	314	173	141	120	155
RFO-6	1818	32	Total 1051[d]	---441---	89	401	314	173	141	120	155

(a) Retail Prices at Guam Oil Refinery Co., December 1980, exclusive of taxes and local transportation

(b) Includes 20,919 residential customers

(c) Nameplate capacity

(d) Includes line losses of 11%, or approximately 120 million kWh/y

The largest generating units are at the Cabras plant and are considered to be very efficient (9800 Btu/kWh). These units, together with the additional operating capacity on the island, are less than 10 years old. The United States Navy's generators are older (1951, 1964) and are less efficient. Nevertheless, in view of the relation of capacity and demand (Table 3-1), Guam will probably not need additional generating capacity in the near future. Peak demand has not changed significantly in six years. Acute problems in the near term will center around financial issues.

The United States Navy now operates the load dispatching center of the Island-Wide Power System pool. The Navy shares power generating costs with GPA, but GPA buys fuel for all the plants within the pool. The principal fuel GPA uses for power production is residual oil purchased under contract from Coastal Petroleum Company. The Navy currently supplies 12% to 20% and consumes 40% of the total power generated (Table 3-1). In an effort to assist in the payment of GPA's debt obligation, the original power pool agreement has been amended to require the Navy's current contribution.

High oil prices, accelerating inflation and a net revenue loss have made rate increases necessary in order to maintain GPA's financial viability. The first portion of this rate increase (10.7%) was placed in effect Sept. 1, 1979 and the second portion (2.1%) in July, 1980. In recent years GPA has had difficulty meeting its fuel bills, despite several rate increases. Basic residential rates as of March, 1981, were 6.6 cents per kWh plus a fuel adjustment charge of 6.73 cents per kWh. Since 1981, the Government of Guam has rejected two attempts by GPA to increase electricity rates. In June, 1981, GPA submitted a request for a rate increase. However, Guam's governor and the legislature opposed the increase at that time and GPA withdrew the request. The legislature subsequently provided GPA with a $4.3 million subsidy to cover its budgeted shortfall for the first half of 1982. In January, 1982, GPA again filed for a rate increase. On March 19, 1982, the Guam legislature passed a law blocking the increase and requiring that GPA "charge customers for electric service at rates which do not exceed those set in rate schedules and rules which were in effect on January 26, 1982." The law does not say how long the rate freeze will remain in effect.

Reducing demand by conservation (either forced or voluntary) is not a simple matter. Many residential consumers have stopped heating their water, reducing consumption and hence GPA revenues. This has raised the non-fuel costs per kWh, and such increases are not automatically reflected in a new rate structure. Fuel costs account for an estimated 73% of the per kWh cost. The GPA fuel bill for electricity for one week is about $1.2 million. There is no provision in the current rate structure to create a sinking fund to retire the Department of Interior's $36 million ten-year loan due December 31, 1990. GPA is not well situated financially, and may have difficulty raising the capital for improvements of any kind.

In an effort to seek compliance with the Clean Air Act and its amendments and the Clean Water Act, GPA has tested the effectiveness of a sea-water scrubber. Some of the operating power plants cannot be adapted to that type of pollution equipment, posing potential additional financial burdens for GPA if compliance to existing United States regulations is enforced. Estimated costs for retrofitting the plants are projected to be about 20% of the costs of a new plant.

Gasoline is a major import to Guam and is important to the tourist industry. Guam Oil Refining Company (GORCO) does not produce gasoline but does supply fuel to the United States military in the far East, residual fuel oil to the Saipan Power Plant and bunkering fuels to the fishing fleets of many nations. Table 3-2 shows Guam's importance as a refueling port.

TABLE 3-2 -- END USES OF ENERGY FUELS, GUAM, 1980
(in 1000's of bbl)

Fuel	Amount Purchased	Price ($/bbl)	Gov't	Private	Comm'l/ Indust/ Construction	Marine Transportation	Electric Generation	Military	Export
Propane/ Butane[a]	33	37		15	18				
Motor Gasoline	661	64	40	582[c]	26			13	
Aviation Gasoline	1	137	1						
Jet Fuel-K	1444	67			1300			144	
Jet Fuel-N	2797	40						2797	
Kerosene	0								
Diesel	1527	37	1	3[c]	38[c]	114[c]	42	1329	
RFO-4	2								2
RFO-6/ Bunker C	1931	32				57	1818	12	44
Navy Spl Oil	781							781	

(a) Ratio of .4/.6

(b) Retail prices at Guam Oil Refinery Co., December 1980, exclusive of taxes and local transportation; gasoline is pump price

(c) Includes fuel for 38,000 automobiles; 12,200 trucks and heavy cargo vehicles; 652 registered boats and an unspecified number of outboard motors

Population: 105,816 (Sept. 1980)
Households: 28,212 (Sept. 1980)

ENERGY DEVELOPMENT PLANNING

Renewable energy fuel sources are abundant in Guam. Unfortunately, the present island power system and back-up are both based on oil imported from distant countries. The Government of Guam recognizes the problems this situation poses and is seeking to diversify the mix through exploitation of alternate sources of energy, including indigenous renewable ones. The potential new energy sources include coal, ocean thermal energy conversion, salt-gradient solar ponds, energy management and conservation, wind, bio-mass, municipal solid waste, parabolic mirrors and other small scale solar focusing devices, solar water heating, bio-gas and photovoltaics.

While the general infrastructure in Guam for support of the various alternate energy sources is not well-developed as yet, remedial steps are being taken in both the public and private sectors to remedy this. To date, there seems to be little private interest in the renewable sources of energy.

However, as the technologies become more mature and as the oil option becomes less tenable, this may change. Table 3-3 presents estimates for the ranges of various parameters which affect each of the possible technologies. Special note should be taken of the impact of the climatic conditions existing on Guam--the high winds associated with typhoons and tropical storms and the corrosive salt air. Both will strongly affect the success or failure of alternate energies there.

Energy Management

While emphasis on energy conservation is not new to Guam, it may be that additional efforts will further reduce demands. In addition, energy management techniques and better bookkeeping may help consumers to manage their own use more effectively. Such techniques do not contribute any additional energy, but when they help reduce electrical demand, they can make additional energy available to support Guam's economic development goals. Some of the most important energy management possibilities are listed below:

- Establish the true costs of electrical generation, including operation, maintenance and both capital amortization and set-aside funds for future expansion.

- Determine how much of the cost will be borne by the consumer and how much subsidized by the Government of Guam. Decide the form of the subsidy.

- Continue to enforce collections.

- Encourage efficient energy use by establishing and enforcing energy efficiency standards for all new buildings.

- Set up demonstration projects as a part of an ongoing education process in efficient use of energy. Such projects could include passive techniques of cooling, use of reject heat from air conditioners to preheat water, co-generation where appropriate, and other specialized techniques.

- Establish and extend existing energy education and training courses in the community, government and commercial sectors.

The above list is not complete, but it indicates the kinds of activities that have proven successful and effective elsewhere. For Guam, probably the most important points involve learning what energy costs really are and supporting a comprehensive energy education and training program.

Coal

Although coal would have to be imported, there are a number of reasons why there is good potential for coal-fired baseload electricity production on Guam. Coal is cheaper and much more abundant than oil. Guam is one of the few Pacific Islands with the port facilities to handle coal freighters, and the island is located along trade routes that are now used for shipping coal. Coal-fired boiler technologies are well established and commercial. The technologies for coal moving and preparation are also mature. Finally, the reliability and durability of coal systems in the Pacific have been well established over the years, both for fixed, shore-based as well as shipboard plants. Coal systems are commercially available in sizes from a few through several hundred megawatts, thus making a good match between the size of the technology and the needs on Guam.

Some of the oil-fired boilers owned by Guam Power Authority (GPA) and the United States Navy are approaching retirement age and replacements will be needed. In an effort to mitigate the increases in fuel costs brought on by increasing oil costs, GPA is considering replacing some oil-fired boilers with coal-fired replacements. The existing steam turbines which are still in workable condition would be retained. The main GPA power plants, located on Cabras Island, are only 2.5 kilometers (1.5 miles) from the Commercial Port, the anticipated off-loading port for coal, thus, they would be good candidates for conversion. The Tanguisson plant is located about 28 kilometers (17 miles) from the port and is not considered a prime candidate for coal conversion.

Since the coal replacement is envisioned as taking place at the site of an already existing power plant, few constraints related to siting are expected. There seems to be sufficient land available at the Cabras site for coal handling and processing. The GPA is already exploring pollution control at the oil-fired plants to comply with EPA regulations; a change to coal would merely shift the emphasis. Existing qualifications of the labor force are expected to be adequate for operating and maintaining the coal-fired plants.

Table 3-3
Technology Selection Criteria

	SOLAR						BIOMASS								
	Solar Hot Water	Photo-voltaics	Solar Therm-al	WIND ENERGY	GEO-THERMAL	HYDRO-ELECTRIC	Tree Farms	Biogas	Liquid Fuels	MSW	OTEC	OCEAN CURRENTS AND WAVES	SOLAR PONDS	COAL	ENERGY MANAGE-MENT
RESOURCE															
proven	●	●				●					●		●		●
suspected				●			●	●	●	●					
unknown			●		●							●			
none														●	
TECHNOLOGY READINESS IN PACIFIC															
high	●	●			●	●	●							●	●
medium				●				●	●	●			●		
low			●								●	●			
RELIABILITY PROBLEMS IN PACIFIC															
high											●	●			
medium				●				●	●	●			●		
low	●	●	●		●	●	●							●	●
DURABILITY PROBLEMS IN PACIFIC															
high			●	●							●	●			
medium	●	●					●	●	●	●					
low					●	●							●	●	●
APPLICATION															
centralized				●	●	●	●		●	●	●	●	●	●	●
decentralized	●	●	●	●	●	●		●					●		●
POTENTIAL CONSTRAINTS															
cultural impact					●		●	●	●	●			●	●	●
land availability		●	●	●	●	●	●	●	●				●	●	
environmental impact					●	●	●	●	●	●	●	●	●	●	
human resources	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
infrastructure	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
CAPITAL COSTS															
high (over $10,000/kW)		●	●								●	●			
intermediate ($3,000 - $10,000/kW)				●	●	●	●		●	●			●		
low (up to $3,000/kW)	●							●						●	●
O&M COSTS															
high			●	●							●	●		●	
intermediate					●	●	●		●	●			●		●
low	●	●						●							
COST EFFECTIVENESS															
near term (0-5 yrs)	●						●	●							
mid term (6-15 yrs)		●		●	●	●			●	●			●	●	●
long term (16-40 yrs)			●								●	●			
EXPECTED OIL SAVINGS OR AVOIDANCE															
high														●	●
intermediate	●						●						●		
low		●	●	●	●	●		●	●	●	●	●			

The capital costs for converting the Cabras plants to coal are estimated by GPA to be about \$1100/kW. This would be the case for purchasing a coal boiler and re-using the existing turbine for each of the generators. Since the boilers at the Piti plant are old and will need to be replaced, it may be that the existing oil-fired boilers at Cabras could be used there, thus helping offset the costs of new coal-fired boilers for Cabras. Capital costs for a complete coal-fired plant on Guam have been estimated, also by GPA, at about \$1300/kW. This cost includes handling, a storage facility and a conveyer system from the Commercial Port to the plant.

Fuel costs for the new plant are estimated to be about half those for the present oil-fired plant. Utilizing the fuel savings to pay off the conversion costs and interest would result in an investment payback of 11 years.

Tree Farms

Bio-mass, including agricultural waste and bio-mass specifically grown as an energy crop, has been used throughout the world as a fuel for boilers to drive steam turbine electrical generation equipment. It is possible for a bio-mass generating system to be fueled by agricultural waste, wood chips, municipal solid waste or coal. Bio-mass-fueled generating technology is mature, and the hardware is readily available. In fact, direct use of sugar cane residue, bagasse, provides more than half of the electrical energy used on the island of Hawaii.

Guam, according to a 1977 study, has 6400 hectares (15,000 acres) which could be classified as very suitable for agriculture, but only 80 to 280 ha (200 to 700 acres) are now seasonally cropped. Total reclaimable land for agriculture is estimated at over 42,000 ha (96,000 acres). It is estimated that the fuel from one hectare of giant leucaena (koa haole) can provide 5 kW for a year. If we assume that a planting of giant leucaena can be harvested every four years, it would take only 8000 ha (9 km on a side) to furnish fuel for a 10 MW plant (see Chapter 2).

If desired, the harvesting and chipping (or cutting into firebox sized logs) could be labor-intensive on Guam, creating new job opportunities. On the other hand, if the labor were not available, the process could also be highly automated as it is in many other parts of the world. This would lead to higher initial capital costs. Existing boiler systems in Hawaii which use bagasse have been able to operate adequately in a tropical climate, and there is no reason to think that conditions on Guam would be so different as to cause undue problems.

Feasibility of a bio-mass electrical generating capability on Guam is not yet established. Consumptive use of water for the steam and cooling cycles may present problems in view of a limited supply of water. Preemption of agricultural land for a tree farm could be a problem since it is a goal of the govenment to become more self-sufficient in agricultural production. However, the United States military has expressed a willingness to discuss co-use of some of its extensive holdings on Guam for purposes such as bio-mass plantations.

Municipal Solid Waste

The Guam Environmental Protection Agency (GEPA) released a comprehensive report in July, 1978 which concluded that 235 tonnes (258 tons) of municipal solid waste (MSW) were being generated daily on Guam. The GEPA strongly endorsed MSW conversion as a result of its study: "Economic analysis indicates that material and energy recovery is the cost-effective solution to disposal of Guam's municipal solid waste from the year 1980 to the year 2000, and is recommended." In the same study, they projected that solid waste would grow to 330 tonnes (367 tons) per day by 1985. Since the study, MSW generated on Guam seems to have stabilized at about the 220-240 tonne level. Even so, reclaiming the energy from this amount will supply a significant portion of the energy needs on Guam as well as alleviating much of the solid waste disposal problem.

MSW is currently collected island-wide. For use as a fuel, it would be processed on site or at a nearby collection point to attain fuel uniformity. The reduced waste is an attractive fuel substitute for electricity generation. If the Piti plant were converted to burn MSW, depending on how much was collected and processed it could produce from 50,000 to 100,000 kWh per day. This uses the best current estimates of 2 to 4 MW as the power available from MSW. Resource recovery of metals and glass would be an important element of MSW as would effective use of waste disposal sites. The technology for use of MSW for generating electricity is mature and there are a number of manufacturers who market modular units adaptable to a wide variety of MSW resources. The one unknown variable is whether the military on Guam would participate in MSW utilization. Without them, perhaps 2 MW could be generated while with their participation the power might reach 4 MW.

Solar Hot Water

Solar insolation measurements for Guam indicate that the resource in 1979 averaged 5 kWh/m^2-day, more than adequate for a variety of solar collection applications. The use of solar energy for domestic and commercial water heating is particularly appropriate for Guam. One of the major residential uses (about 40%) of electrical energy on Guam in the past was for just this purpose. Since about 30% of the electrical energy use on Guam is residential, this means that about 15% of the total energy use on Guam was for residential water heating. More recently, customers have turned off their electric water heaters except for a few hours a day when they need hot water. If aggressive solar water heating retrofitting and new construction efforts led to general adoption of solar water heaters instead of electric water heaters, it could significantly reduce electricity demand on Guam. Investing in a solar water heating system also sets the costs to the consumer for water heating for the lifetime of the solar system.

Commercial solar water heaters are readily available from sources in Japan, Australia and throughout the United States The various kinds on the market range from sophisticated, pumped systems with separate collectors and storage tanks to simple solar water heaters which combine the solar collector with the tank storage, the bread-box collectors. In addition, there are a number of designs for simple thermosiphon systems which can be built by the homeowner for a small fraction of the cost of a commercial one.

Some solar water heaters are already installed on Guam. There seems to be no problem with acceptability, and, for installation on the roof of a residence or on the property, there is no land availability question. Protection against high winds and wind-driven debris is required. No significant environmental problems have arisen.

Existing mechanical and electrical capability on Guam should be adequate for routine maintenance of the solar collector systems. The repair and servicing of solar water heaters is similar to the repair and servicing of any plumbed system or small electrical appliance. Scaling and corrosion from the sometimes hard water may present special problems on Guam.

Photovoltaics

Photovoltaics could also capitalize on the solar energy resource available on Guam. A number of concepts have already been commercialized, ranging from single-crystal silicon photovoltaic cells to thin-film amorphous cells. The single-crystal cells, after an initial period of development, have demonstrated good reliability and durability in a wide variety of service. Photovoltaic arrays are widely used throughout the Pacific in off-grid, low power applications, and such applications would be the most appropriate use of the technology on Guam. Photovoltaics is not yet suitable for baseload power production in the Pacific.

Photovoltaics operated without batteries can provide electricity during the sunlight hours, saving oil or diesel. If the hours of operation of the electrical load can be restricted to the sunlight hours, then PV can supply all the energy needed without the necessity of storage. Operating and maintenance costs with no storage are small. PV is competitive today with high-speed diesel generators in off-grid locations. Costs need to drop another factor of ten before PV can be seriously considered as a baseload energy source for larger electrical requirements (e.g. kW to MW).

No adverse impacts are anticipated in the areas of cultural or environmental effects, or land availability. Land required for a 10 MW peak system might amount to 20 ha. Since photovoltaics is a relatively new technology, an educational program would be necessary to train personnel to perform routine O&M. It would also be necessary to develop sources for parts and servicing.

Sunshine on Guam averages about 5 kWh/m^2-day. This means that a PV system used in a fuel-saver mode to yield energy equivalent to a 10 MW oil-fired electrical generation system would occupy about 80 ha, almost a square kilometer. The storage system to allow continuous 24 hour operation would add to the cost and land area.

Salt Gradient Solar Ponds

There are a number of experimental solar ponds throughout the world in a wide variety of climates. While solar ponds have not reached the point of commercialization, indications are that needed developments consist principally of efforts to make the components less expensive and to reduce installed system costs. Solar ponds are especially attractive because they provide baseload, not intermittent power. The wind and salt air conditions on Guam may pose special problems in adapting the technology for the Pacific.

The scale of proposed solar ponds is fully compatible with the needs on Guam. A baseload 10 MW pond might require 2 square kilometers of pond and could either replace present expensive, fossil-fueled diesel generators or accommodate electrical growth for the next few years. This same 10 MW pond could provide peaking power of up to 100 MW for short periods. Alternatively, a pond of about one hectare could be used to supply about 50 kW baseload and up to 500 kW peaking power to a remote location.

A solar pond would be a low-profile installation which would require land dedication but little else. It has little or no effluent and the raw materials needed for the pond consist of sunshine and, from time to time, some additional salt. While salt is not presently reclaimed on Guam, salt evaporation ponds could be constructed. The salt could also be purchased from Taiwan. The land most suitable for salt gradient solar ponds is in the northern part of the island. Unfortunately, this is also where the major fresh water lens is. Leakage of the salt brine from the pond could contaminate this sources of fresh water if it were not suitably contained.

Skills needed for construction and operation of a solar salt gradient pond consist of general construction plus machinery operation and maintenance. The heat exchangers are similar to many of those in widespread use for low-grade heat recovery. An educational program should be carried out to upgrade and improve existing capabilities. While Guam is more developed than many of the Pacific territories, it still is remote from a complete support system. This could make maintenance more difficult. Nonetheless, because of its potential to provide baseload power, energy planners on Guam should follow the development of this technology closely.

Wind

Wind power may be able to contribute small amounts of energy to remote locations on Guam; however, large installations may be incompatible with the fact that Guam is subject to typhoons. In addition, current information on winds prevalent on the island seems to indicate that they vary around 7 m/s (15 mph). Most wind generators do not begin to generate energy until the wind reaches 4.5 m/s (10 mph) and are rated for winds in excess of 9.5 m/s (20 mph). Dropping the average wind from 9.5 to 7 m/s drops the generated energy by about a factor of two and a half, thus de-rating the windmill to less than half its design power and increasing the capital cost by a factor of two and a half.

Existing measurements of winds on Guam carried out by NOAA fall in the range of 3 to 5 m/s. If locations with consistent winds in excess of 10 m/s can be identified, it may become worthwhile to attempt to design special wind generators which can survive typhoons. The United States DOE, in conjunction with the Guam Territorial Energy Office, recently placed a small wind driven electrical generator on Guam. This generator is presently out of commission due to defective equipment design and inexperience of the operators. There is also a small 500 W water pumper windmill on an aquaculture farm in the interior of Guam.

Bio-Gas

Anaerobic fermentation of biological waste generates significant quantities of methane (natural gas). Where this occurs in a community sewage treatment plant, the gas is often used for process heat in the plant; any excess can be purified to remove corrosive gasses and sold to a local utility. Guam does not have an existing gas pipeline system, and installation of such a system would be expensive. In any case, the total amount of energy supplied by such a system would be small.

Anaerobic digestion can also be done on a small scale, appropriate for a single family or a small group of families. Adoption of this technology could replace the energy used by individual families for cooking and thus reduce residential energy use. Small scale bio-gas generation and use may also be appropriate for small farms where there is both a ready supply of waste and the need for the gas. Cultural and environmental conditions on Guam make widespread adoption of this technology unlikely. If it were adopted, the total amount of energy supplied by such a system is likely to be small in comparison to present use on the island.

Solar Thermal Energy Conversion

Solar thermal energy conversion (STEC), the converting of solar energy into thermal energy and then into electricity via the steam cycle, has received a great deal of attention recently. While several experimental STEC systems have been fielded, much development work remains to be done. At the size of the present configurations appropriate for a small village, the first experimental distributed collector systems are just beginning to accumulate operating experience. As yet, little information is available on reliability or durability, especially under the relatively hostile wind and corrosion environment existing on Guam.

Sizes presently being worked on are probably too small for what Guam seems to need for its urban centers. However, there may be applications for a single "dish" (10 meters, 30 feet in diameter) which can supply about 15 kW peak power at a remote site.

The land availability question remains. It is anticipated that about 30 ha would be needed to generate 10 MW at peak solar incidence. Because the solar resource is about 5 kWh/m^2-day, in order to provide the same energy that a baseload oil or diesel system provides, the size would have to be more than quadrupled. Land requirements might amount to 150 ha (1.2 kilometers square) for a STEC system which would generate the same total energy as a 10 MW diesel driven or oil-fired electrical generation system.

Little in the way of adverse environmental effects are anticipated. Since the technology is new, an educational program would be necessary to involve local people in installing, operating and maintaining the STEC system.

STEC, like wind and photovoltaics provides an intermittent power source. In order to provide baseload power, an energy storage system is needed. Such storage costs would be over and above the costs associated with installation of the basic system. Mid- to long-term baseload applications might become more competitive as costs for storage and for STEC fall.

Ocean Thermal Energy Conversion (OTEC)

A temperature difference of at least 24°C (43°F) is found between the surface and waters at depth throughout the ocean surrounding Guam. In particular, such a temperature difference is found just off Cabras Island, the proposed site of Guam's OTEC plant. Based on this, and on experimental results for OTEC worldwide, the Government of Guam has entered into an exclusive agreement with International Energy Enterprises to design and construct a shore-based OTEC plant on Guam. Present plans involve attempting to obtain private financing to build one 5 MW OTEC module with a double sized cold water pipe (CWP), thus allowing expansion to 10 MW later. The site on Cabras Island is thought to provide close-in access to thermal resources which could eventually allow a total of up to 50 MW capacity at the plant. As with coal, bio-mass, and solar ponds, OTEC also promises to be a baseload power source.

While information and operational experience is now being accumulated on the performance of cold water pipes in ocean environments, pipes to date have been much smaller in diameter than those needed for megawatt sized OTEC plants. The 100 kW OTEC system the Japanese built in the Republic of Nauru used a 70 centimeters (28 inches) cold water pipe, while those needed for MW sized plants must be 5 to 10 meters (16 to 33 feet) in diameter. The heat exchangers used to date have been titanium, and seem to have performed well. A scale-up by a factor of 10 to 100, however, may introduce problems unforseen at the present time. Recent work by the Trane Corporation on aluminum heat exchangers has been promising. If it is successful, significant cost reductions can be achieved. The pumps and associated massive flows of both cool and warm water are also on a scale unprecedented in such applications. In short, while development of the technology is proceeding well, it is not yet commercial at any size. The ever- present danger from typhoons and the associated high winds will certainly be among the controlling engineering design factors for such an installation on Guam.

The Guam proposed 5 MW OTEC plant would be of such a size that it could make a significant contribution to the accumulation of operational data for commercial sized OTEC plants. It would also contribute to total baseload capacity needs on Guam.

The Government of Guam is strongly committed to the concept of an OTEC plant on Guam, thus, there already is an official acceptance of it. Since the Guam agreement envisions a shore-based plant on Cabras Island, and there appears to be adequate land there, land availablity should not be a problem.

Negative environmental impacts are expected to be small. The University of Guam has an outstanding biological oceanography department which could certainly do the detailed studies necessary to determine the validity of this expectation. On the positive side, it is possible that the cold water effluent could be used for mariculture, thus combining energy production with food production.

The people of Guam are perhaps better prepared than most of the Pacific inhabitants to play a role in installing and performing routine O&M on an OTEC plant. However, the sheer magnitude of the component parts and the nature of the technology will require a major training program and a continuing need for people well educated in modern technology. These programs should extend into the existing school systems. Because the technology is so new, an adequate support infrastructure must be established for repair and replacement parts and/or servicing either on-island or off.

Liquid Fuels Conversion

In addition to the use of bio-mass for generating electricity, sugar cane, cassava and other crops have been grown and fermented to synthesize alcohol in many parts of the world. However, the technology for liquid fuels conversion is not yet commercial. In addition, currently realized yields of alcohol per hectare are relatively low, and the amount of land available for this purpose on Guam may not be sufficient to have much of an impact on fuel use. The technology might prove useful for a single farm where sufficient land could be devoted to "energy crops" to make the farm self-sufficient in fuel for tractors and other farm vehicles. This would also make the by-products like stillage available locally for use as animal feed without the necessity of drying or transporting. Liquid fuels conversion also makes sense where there is a waste stream, such as spoiled corn, which can be used in this way instead of being thrown away. Before this proceedure can be evaluated for use on Guam, more data on specific crops and procedures need to be gathered.

Ocean Tidal and Currents

Tidal energy conversion is in commercial use in some parts of the world. However, the tidal range at Guam is small. Few ocean current measurements have been taken near Guam. Unfortunately, ocean currents have such a low energy content and the mechanisms for harnessing the energy are so massive that utilization of flows likely to be found near Guam would probably have to be on such a large scale and so expensive as to be impractical.

Hydropower

A number of hydropower resource studies have been conducted on Guam. One of the most recent was by the Army Corps of Engineers. The general conclusion of these studies is that the resource is not large enough to have a significant impact on the electricity supply problem for Guam.

FINDINGS AND RECOMMENDATIONS

With the baseload and peak electricity demands on Guam running 120 MW and 155 MW, there is good opportunity to replace a significant fraction of the oil-fired generating capacity with alternate fuels. Table 3-4 summarizes the most promising technologies which can make a major contribution to the baseload power requirements:

TABLE 3-4

PROMISING BASELOAD ALTERNATE ENERGY TECHNOLOGIES

TECHNOLOGY	READINESS	LAND FOR 10 MW PLANT
CONS/ENER MGMT	Now	Little or none
COAL (RETROFIT)	Now	Existing plant
COAL	Now	Existing plant
MSW	Now	Existing plant
BIOMASS (TREES)	Near Term	8000 ha (5000 acres)
SOLAR PONDS	Mid Term	200 ha (500 acres)
PHOTOVOLTAICS	Long Term	80 ha (200 acres)
STEC	Long Term	150 ha (370 acres)
OTEC	Long Term	Existing area on Cabras

In addition to these baseload technologies, solar water heating and bio-gas production have the potential to reduce energy demands on the central power system. Energy thus released could then be used for industrial expansion, providing more jobs.

Conservation of energy is not new to Guam, but it may be that additional efforts will still be effective. Energy management techniques and better record keeping may also help consumers in their efforts to minimize energy costs while accommodating needed expansion of business.

Generating electricity with coal-fired boilers is one of the most promising technologies for Guam. There are a number of sources worldwide for coal, and coal costs are likely to remain well below those of oil. Costs for converting the Cabras oil-fired plant to coal are projected to be recovered in about 11 years through lower fuel costs.

Municipal solid waste is presently routinely collected on Guam. Processing it and using the combustible portion to generate electricity makes very good sense. Projected power available from the waste amounts to about 2 MW without military participation and about 4 MW with their waste. In addition, problems of solid waste disposal are mitigated.

Bio-mass is also a very promising electrical generation technology for Guam. There is sufficient land suitable for agriculture which could be dedicated to a tree farm. It may be that the expressed desire of the Government of Guam to become self-sufficient in agricultural production will lead it to dedicate this land for food purposes rather than for tree farms. It is possible, however, that some land might be made available by the United States military.

Salt-gradient solar ponds present an attractive option for Guam if the environmental problems of brine leakage can be overcome. Land use requirements for a solar pond are only about 1/40th of those required for a tree farm to fuel an equivalent sized plant, and solar ponds have the possibility of functioning not only as baseload plants, but also as peaking plants.

Photovoltaics currently finds its best uses in remote, low power applications where the intermittency of the energy source is not a drawback. However, the fact that it is among the most efficient technologies in use of land, makes it very attractive for Guam where land is at a premium.

Solar thermal energy conversion is just now beginning to accumulate operational experience. It too is an intermittent source and would have to have a storage mechanism in order to function as a baseload system. The components of a solar thermal system, as they are presently designed, are not likely to survive the wind and weather conditions on Guam. A single "dish" might find application at a remote site.

The winds on Guam are apparently not strong enough to make a significant contribution to energy needs. If enhanced wind locations can be located, this source may merit another look.

Ocean thermal energy conversion is being developed principally by the United States and Japan. While good progress is being made, the technology is not commercial at the present time.

Use of bio-mass for synthesis of alcohol is not yet economical. It may prove useful for farm self-sufficiency. Harnessing of ocean currents requires large equipment and is not economical for Guam. Hydropower on Guam, while it could be harnessed for small, isolated applications, is not abundant enough to have a significant impact on energy needs.

Table 3-5 lists the energy planning recommendations for Guam.

TABLE 3-5

ENERGY PLANNING RECOMMENDATIONS -- GUAM

- o Improved energy management
  - Establish the actual costs of generating electricity
  - Bill the consumers in accord with use and actual costs of generation. Continue the comprehensive billing and collection program.
  - Establish and enforce energy efficiency standards for all new buildings in Guam
  - Extend and encourage energy education in the community
  - Implement solar water heating on government buildings where feasible as a demonstration project
- o Investigate alternate energy technologies where appropriate.

- Conduct a comprehensive engineering study of the use of coal at the Cabras electrical generating plant. Both the retrofit case and the new plant case should be studied and the costs determined.

- Carry out an analysis of use of MSW for generation of electricity, complete with estimates of capital, and operation and maintenance costs

- Do a detailed engineering feasibility study on a bio-mass tree farm electrical generation system for Guam

- Continue to monitor the development of salt-gradient solar pond technology. As the technology matures and the costs decline, evaluate the suitability of salt-gradient solar ponds for Guam.

- Stay abreast of developments in photovoltaic technology. Apply photovoltaics where and when it is appropriate (remote, stand-alone systems at present). As the technology, especially the storage technology, develops, restudy its applicability to baseload power for Guam.

- Continue to follow ocean thermal energy conversion. As the technology matures, evaluate its applicability to Guam.

- Take wind data at specific sites with potential for multi-megawatt installations. If the resource can be confirmed, then manufacturers and investors should be contacted to develop systems which can survive on Guam.

CHAPTER 4: ENERGY PLANNING FOR THE REPUBLIC OF PALAU

The Republic of Palau presently relies entirely on petroleum fuels for energy. It is unusual among the island nations in that there is a significant amount of generating capacity in the private sector, but only the government produces power for resale. The Republic is an archipelago of 350 tropical islands and islets located in the westernmost part of the Caroline Islands about 960 kilometers (600 miles) from the Philippines and some 1280 kilometers (800 miles) southwest of Guam (see Figure 4-1). The main group of Palau Islands is dominated by the 390 square kilometer (150 square miles) island of Babeldaob, Micronesia's largest land mass. A chain of smaller high and low islands running 200 kilometers (125 miles) in length, and four small coral atolls some 400 kilometers (250 miles) to the southwest make up the rest of the Republic. The combined total land area of the islands is about 490 square kilometers (190 square miles).

Just over 12,000 people live in the Republic of Palau. Adjacent to Babeldaob and connected to it by a single-span bridge is the smaller island of Koror, where about 8000 people live and which has been the administrative center of the archipelago since the era of Japanese control. Koror and the southern part of Babeldaob are served by a central power system. Even though there is theoretically sufficient generating capacity to meet existing needs, the distribution system has been too small and unreliable to deliver the power generated. That system is now being improved. Peleliu also has a small system which provides service only intermittently. Major commercial users, such as Van Camp fish processing and the Continental Hotel have, in the past, found it necessary to supply their own energy needs to avoid unscheduled shutdowns. The unreliability of the electrical power system has discouraged commercial development.

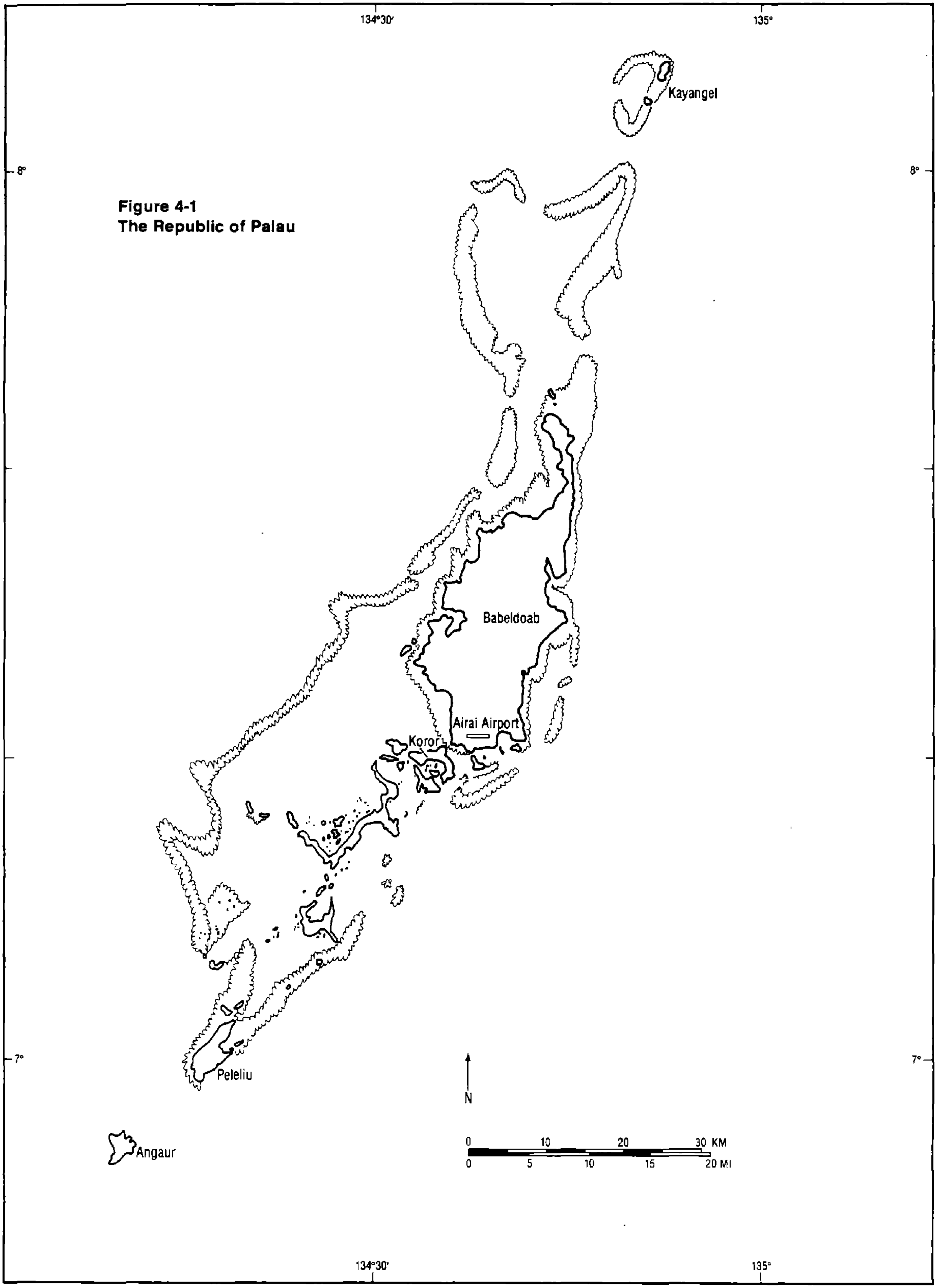
The Palauan government is nearing completion of financing arrangements to build new oil-fired generating capacity. If this is done, the urbanized area will have excess capacity available for economic development and the Republic will be committed to petroleum fuels for the near to mid term for a major portion of its electrical generating needs.

The Republic of Palau is one of the governments which has recently emerged from the Trust Territory of the Pacific Islands. Thirteen years of negotiations ended in August 1982 when Palau and the United States signed a Compact of Free Association. The Compact, which sets forth agreements governing relations between the two countries for the next 50 years, must now be ratified by the United States Congress and approved by the electorate of the Republic. It is likely that economic planning based on development of Palau's natural resources, including its great natural beauty and its renewable energy resources, will now be able to proceed with a greater proportion of specifically identified projects and a better understanding of energy needs than has heretofore been possible.

Palau's waters contain some of the most spectacular and diverse reef systems in the world. It is a virtual paradise of reefs, lagoons, miniature limestone islands, saltwater lakes, and mangrove swamps. The ecosystem of these waters is complex and delicate. It harbors the rare marine crocodile and the even rarer dugong (sea cow). Between Koror and the southern Palau islands of Peleliu and Anguar are the world-famous Rock Islands, a series of tiny, mushroom-shaped limestone outcroppings.

The Palau Group land mass is volcanic in origin with basaltic structure and limestone formations predominating. The main islands are reasonably well-watered and thickly vegetated. Babeldaob's rolling hills reach an elevation of about 210 meters (700 feet) in places. Its forested interior contains many small streams. Much of the upland area supports only coarse grasses; hardwood trees and other useful plants occur in certain areas of the interior. Wildlife is scanty and of little economic value. Most of the other islands are composed of coral limestone, and some are too dry and barren to invite habitation. Coral reefs fringe the islands and enclose quiet, shallow lagoons. On the seaward side of these reefs, the banks drop off sharply to the ocean depths.

The climate is hot and humid most of the year with little variation in daily temperature, which ranges between 24°C and 29°C (75°F to 85°F). Northeast trade winds blow steadily from December through


134°30′
135°
Kayangel
8°
8°
Figure 4-1
The Republic of Palau
Babeldoab
Airai Airport
Koror
Peleliu
7°
7°
N
Angaur
0 10 20 30 KM
0 5 10 15 20 MI
134°30′
135°

April. Winds are light from June through November. Typhoons, though infrequent, are likely to occur between July and September throughout the western Carolines. Rainfall is heavy throughout the year, though heaviest from July through September. The average annual rainfall is approximately 380 centimeters (150 inches).

HISTORY AND POLITICAL DEVELOPMENT

The early history of Palau is shrouded in legend and myth. Although Palauan legend presents its world as a relatively closed and complete universe, the archipelago was probably settled by an Indo-Malay people around 1500 B.C. For thousands of years Palauan culture and matrilineal clan systems flourished. The world of Palau was divided into two competing, embryonic semi-states: Babeldaob, centered on Melekiok Village, and Youldaob, roughly present-day Koror. These states were chronically at war and even today preserve an intense socio-political rivalry. The archaelogical evidence suggests that Palau once had 30,000 inhabitants.

After western contact began in the sixteenth century, the islands were nominally a Spanish possession, but that country made little effort to exercise control until 1885. Following the Spanish American war, Spain sold her interests in the Pacific to Germany. German sovereignty lasted only until 1914, when the Japanese seized Germany's holdings in Micronesia and retained them until their surrender to the United States at the end of World War II.

Japan had an economic as well as military stake in its Pacific possessions and encouraged their colonization by Japanese nationals. At one time approximately 24,000 Japanese lived in Palau, far outnumbering the indigenous population. From 1945 to 1951, the islands were under the jurisdiction of the United States Navy, at first under military control and later under a civilian government. Until the establishment of the Republic of Palau in 1981, the islands were administered by the Interior Department under a trusteeship agreement with the United Nations.

POPULATION AND EMPLOYMENT

In 1980, Palau's resident population was 12,172. This figure was down slightly from that of 1973 (12,673) because more Palauans went abroad to seek education and jobs. Some 1800 Palauans lived abroad in 1980. With a population growth rate of 2.1% in 1979, down from 3.3% in 1973, Palau's population is growing more slowly than that of the rest of Micronesia. In 1973, 59% of the population was under 19 years of age. Current projections for resident population are:

1985	14,050
1990	16,050
1995	18,400
2020	26,000

About 8100 people or 65% of Palau's resident population, live in Koror where 70% of jobs in the wage sector are located. A major development goal now that the K-B bridge links Koror to Babeldaob and a road system is being extended along the big island's shores, is to reverse the drift of population into overcrowded Koror and to foster commercial agricultural growth in the rich lands of Babeldaob. There are some encouraging signs that as amenities and roads are extended to the big island, families are returning to live in their home villages within commuting distance of the capital. It is expected, however, that Koror's resident population will reach 13,000 in 1995, despite major efforts to open up economic opportunity elsewhere in the Republic.

At present there are about 3200 jobs in the wage sector; 46% of these are in government. Unemployment is a high 28% of the labor force. As of June 1981, Palau had 622 alien workers; 388 were nonresident fishermen, and the rest worked in trades and administration. The level of income in Palau is substantially in excess of the international poverty level and higher than that of any other Micronesian Island group. There is no significant malnutrition or poverty. If economic development does not keep pace with population growth, however, this situation could change.

The plan target is to reduce unemployment to 22% in 1985, 18% in 1990, and 14% by 1995, taking some subsistence agricultural and fishing activities into account. This means the present number of jobs must double by 1995, primarily through additions in the private sector. The government has plans for an educational system which offers children an opportunity to prepare realistically for the future and which diminishes the attractiveness of bureaucratic careers in comparison to other endeavors that are important for Palau's economic development.

The economy is heavily dependent on United States payments to finance the cost of government. Government, in turn, is the principal employer in Palau with 46% of the total work force on its payroll. Under the pending Compact of Free Association, United States Government support payments and economic assistance will continue at substantial levels over the next 50 years.

ECONOMY AND INFRASTRUCTURE

Palau's Gross Domestic Product rose from $14 million in 1975 to about $20 million through 1979. Of this 1979 amount, the United States contributed about $9 million in public sector support payments. Locally-generated tax and other revenues produced about $3.3 million.

One key economic indicator is the dollar value of the total amount of goods and services generated in Palau, the Gross Domestic Product, and its present value compared with those of recent years. The 1977 Indicative Development Plan for Palau drew upon FY 1975 data to develop estimates of GDP. The most recent data available from Trust Territory sources cover FY 1977. These data are presented in Table 4-1.

Table 4-1. Preliminary estimates of the Gross National Product of Palau

FY 1975 (July 1974 - June 1975), FY 1977 (October 1976 - September 1977) and FY 1979

(Millions of 1981 $)

	YEAR		
	1975	1977	1979
Compensation of Employees			
Taxable wages & salaries	7.5	9.2	10.3
public	5.1	5.8	6.5
private	2.4	3.4	3.8
Imputed rental value of free employer-furnished accommodation	0.2	0.1	0.1
Personnel benefits and other income	0.2	0.5	0.6
Subtotal	7.9	9.8	11.0
Operating Surplus			
Private business enterprises	3.1	3.4	4.3
Copra production	-	-	-
Value of nonmarketed production	2.0	2.2	2.5
Imputed rental value of owner-occupied housing	0.4	0.5	0.6
Imputed rental of free government accommodations	0.1	-	0.1
Subtotal	5.6	6.1	7.5
Consumption of fixed capital	0.5	0.5	0.5
Indirect taxes less subsidies	0.6	1.0	1.0
GROSS DOMESTIC PRODUCT	14.6	17.4	20.0

Sources: Data for FY 1975 and FY 1977 taken from 30th Annual Report by the United States to the United Nations on administration of Trust Territory, FY 1977. Data for 1979 are extrapolations prepared by Rivkin Associates.

Palau's principal economic sectors--fisheries, agriculture and tourism--are producing well below their potential as a result of a multiplicity of constraints. The infrastructure of the main islands impedes all development because it is either insufficient or in generally poor condition. Roads, water, sewers and electric power systems are unreliable and poorly maintained. All electric power is generated with costly, imported diesel fuel, and this total dependence requires heavy United States subsidies. The private sector lacks a means of credit to finance new enterprise and is prevented from expansion by the infrastructure deficiencies.

POTENTIAL FOR ECONOMIC DEVELOPMENT

The basic economic development goals of the government of the Republic are to increase economic self-sufficiency, to reduce or eliminate financial dependence on the United States, and to improve the overall standard of living in the urbanized area and throughout the sixteen states.

Palau, along with the other Pacific Island nations, must pursue its economic development under constraints of limited land, water and skilled labor. However, Palau is in a particularly favorable situation now that the final details of the 50-year Compact agreement are being worked out. Both the present Capital Improvement Project (CIP) and the program to be implemented under Section 212 of the Compact address the need to improve infrastructure and provide a support base for economic development. Air and sea traffic facilities that could enable Palauan products to reach other East Asian markets have a high priority under these programs.

Past concerns about imbalances in the economy, particularly with respect to consumption and savings and to the balance of international trade seem to have lost their relevance in the light of this capital works commitment. The trade gap is not a pressing problem at this time, and it is expected to resolve itself as the CIP programs are completed, allowing exportable surpluses to be produced.

Palau imports food, and the copra mill depends on imported copra. Local agricultural production in both food and coconut is well below its potential. Small-scale subsistence agriculture is practiced in the outer islands and around Koror. However, much of the available agricultural land is not now cultivated, reflecting inadequate incentives for villagers to increase production above subsistence needs.

Government policy is to improve small-scale agriculture by giving villagers incentives to plant crops for the Koror market and to stimulate large-scale production of coconut and other crops for which Palau has processing and export potential. However, the rural populations are characterized by elderly individuals and couples living alone with small grandchildren. Those who are old enough to join the labor force have migrated to Koror seeking jobs. Any labor-intensive economic scheme proposed for the outlying areas must take these sociological factors into account.

It is anticipated that once the land use needs of the United States Government under the Compact are identified and the recently undertaken soil survey by the United States Soil Conservation Service is complete, Palau will be in a position to prepare a land use plan as the basis for fostering increased agricultural production.

While fishing now provides amply for local needs, there is every indication that the Republic could earn significant amounts from seafood exports. The tuna and reef fishing industries could be greatly expanded, and the potential of other varieties of seafood (clams, trochus, shrimp, lobster) remains to be exploited. Infrastructure improvements, especially for refrigeration and storage, would be needed. The present fishing service industry is run down and needs to be repaired and expanded. All ship repair facilities at Malakal and Peleliu are presently idle but could be revived.

Sustained, reliable sources of water and electric power will be needed for an expanded fishery and processing operation. Van Camp, under the terms of the Compact, will receive considerable United States tax and customs duties incentives. Its operations could be expanded considerably depending on the scale of the catch and the services available. The company now provides its own power for the tuna processing facility. Much of the needed improvement in power facilities and port expansion is planned under the United States support commitments. The Republic will, however, need to supplement this with direct investments in preservation facilities and refrigeration vessels to transfer catches from outlying areas to Koror.

It is expected that tourism could become a major contributor to the economy by the mid 1990s. At present there are four hotels with a total of 91 rooms. Expanded hotel capacity is needed, as are diving, boating, rental car and other support facilities. The government concern is to develop tourism without threatening the environment or damaging the Palauan culture.

Minerals represent another potential resource that may have economic significance for Palau. Residents of Angaur have recently signed a 10-year agreement with a Japanese group for the extraction of over 900,000 tonnes (one million short tons) of phosphate. No other extraction activity is in progress, but the remaining bauxite deposits on Babeldaob merit re-examination, as do studies to identify potential seabed mineral resources beyond the reefs.

Present Capital Improvement Program

Project commitments under the Trust Territory Capital Improvement Program are expected to be completed within the next two years. The estimated total value of the present CIP is approximately $36 million (1980 $). The basic thrust of the CIP is to provide the urbanized area of Koror and its satellites of Arakebesan, Malakal and Airai with improved services and facilities to sustain population growth and economic development. Projects are also scheduled for the secondary centers of Peleliu and Angaur.

Under the CIP program, some 17 kilometers (10.7 miles) of primary and secondary roads are being upgraded to all weather standards in Koror, Arakebesan, Airai and Malakal. This is in addition to Navy road building on Babeldaob. The container storage area at Malakal dock is being upgraded and expanded, and several projects are being undertaken in the urbanized area to provide sustained, reliable water sources and distribution systems which meet United States clean water standards. At Peleliu, the present CIP includes building water catchment facilities, storage pumps and a distribution system. At Angaur, storage pumps and a distribution system are planned.

Sewer systems are being completed in Koror under the CIP (23 satellite pumping stations). A major extension and upgrading of the main Airai airport near Koror is nearing completion. Lighting, generators and electrical connection to the main Koror power system will be provided.

Generator improvements (with a projected 20-25 year life) have recently been installed to upgrade the Koror power plant. Upgrading of power lines in Koror is also intended. The existing lines to the water treatment plant will be replaced. All of this work is predicated on continued reliance on petroleum based power generation.

Compact Capital Commitments

The provisions of Section 212 of the Compact of Free Association commit the United States to construct major physical facilities necessary to support economic growth in Palau. Details are spelled out in a supplementary agreement to the Compact. While some of the Compact activities will be in the urbanized area, the major significance of this program will be to open up Babeldaob for economic growth and to provide basic infrastructure necessary to growth in other remote areas. The United States will have the first fifteen years under the Compact to complete construction projects identified for the post-trusteeship CIP. A timetable for the CIP projects has not yet been decided, although it is expected to be completed before the plebescite is held on the overall Compact. The present array of projects anticipated under this program are as follows:

1. Roads: Perhaps the most significant Compact project will be building a 85 kilometers (53 miles), all-weather road network on Babeldaob.

Spurs will be completed to several villages, providing farm-to-market opportunities in support of agricultural development.

In addition, 13.6 kilometers (8.5 miles) of secondary roads in the urbanized area and 16.2 kilometers (10 miles) of roads on Peleliu will be improved.

2. Ports, Docks and Channels: Ports, dock and channel facilities will be upgraded in the urbanized area, and certain outlying communities will be provided with adequate docks and channels to support fishing and inter-island transportation. At Malakal, 137 meters (450 feet) of the existing wharf area will be improved. Dock and channel improvements will be undertaken at Peleliu, Anguar, six villages on Babeldaob, and Kayangel. New docks will be installed at the outer islands of Tobi and Sonsoral.
3. Airfield: The Peleliu airfield will be upgraded.
4. Water Systems: Water systems will be installed for six villages on Babeldaob and four outer islands. A 2745 meter (9000 foot) long, 15 centimeter (6-inch) water pipeline will be installed to Airai village.
5. Wastewater Disposal: The existing Koror waste water disposal system will be extended to Arakebesan.
6. Intervillage Communication: Transceivers are to be established for 30 remote locations, although all or part of this effort may be subsumed under present Trust Territory communications improvement programs and the Comsat operation.

7. Educational Facilities: A total of 72 classrooms are planned for various locations, and a gymnasium will be provided for the Koror High School.

8. Health Facilities: Two new dispensaries will be built outside the urbanized area and two existing dispensaries will be upgraded.

9. Administration: The existing public works facility at M-Dock will be razed and relocated to a 52 square meter (6000 square foot) covered space on Malakal. This will free a key location near the center of Koror for new development.

Other high priority capital requirements are being considered for funding under the Compact capital improvement provisions. These are:

1. An all-weather airport terminal at Airai to provide services for passengers and cargo to handle an expected major increase in air service.

2. A public transportation system for Koror, to reduce automobile use and to improve public safety.

3. Some form of regular boat service for passengers and goods between Babeldaob and Koror.

4. Improved solid waste disposal practices for the urbanized area, involving major upgrading or relocation of the Koror dump.

5. An improved and expanded administrative-legislative-judicial center in Koror.

6. Improved communications systems throughout the Republic. Palau has signed a contract with Comsat for a United States-financed ground station and related facilities. Comsat will institute services permitting long-range telephone, satellite television, radio, and other communications. Operation of the Comsat station is scheduled to begin by December 1982.

Finally two provisions of the Compact have direct implications for future energy development activity in Palau. The first is found in Section 214, where the United States has agreed to provide, on a grant basis, for fifteen years commencing on the first anniversary date of the effective date of the Compact, the sum of $2 million annually as a contribution "to efforts aimed at increased self-sufficiency in energy production...." In addition, Section 221(c) pledges the United States to make available to Palau (as well as to the Marshall Islands and the Federated States of Micronesia) such alternate energy development projects, studies and conservation measures as are applicable to the Trust Territory of the Pacific Islands, for the purposes and duration provided in the United States laws. Each of these commitments indicates the importance of self-sufficiency to the economic development prospects of the Republic and provides United States financial assistance in achieving this goal.

PRESENT ENERGY SYSTEM STATUS

Palau currently has 4.95 MW of diesel-fired electrical generating capacity at the Malakal (Koror) Power Plant available to serve the urban center of Koror and its immediate surroundings. There is another 2.9 MW of nameplate generating capacity at the plant, but it is currently out of service for repairs. In a practical sense, however, only a little more than 3 MW of this total 7.85 MW installed diesel generator capacity can be made available at any given time. Substation limitations prevent full utilization of the system's diesel capacity. Substation improvements have been considered in Palau for some time, however the agreement about and timing for construction of a new main station plus line and substation upgrading have not been made final.

To help meet electrical demand in the Republic, a 3.2 MW gas turbine generator was installed in Koror in 1982. The generator is on loan from a British firm pending completion of an agreement with the Palau government for a new residual oil-fired power plant to be supplied by the firm. Electrical output from the gas turbine is delivered directly to the grid, bypassing the substation and its limitations, thus allowing a peak demand of around 6 MW to be met occasionally. Generator performance problems, both at the main station and with the gas turbine, prevent a steady 6 MW load from being served at all times. A total of 20.2 million kWh of output was produced at the Malakal Power Plant in 1980 (see Table 4-2).

A listing of the installed diesel generating units in Koror, including rated capacity and status of each, follows:

750 kW White Superior	-	Can only generate 400 kW due to radiator, and engine problems
750 kW White Superior	-	Down; awaiting parts on order
1000 kW White Superior	-	Down; awaiting parts on order
800 kW Caterpillar	-	Down, switchgear/electrical problems
800 kW Caterpillar	-	Operational
1250 kW ALCO	-	Operational
1250 kW ALCO	-	Operational
1250 kW ALCO	-	Operational (Because of radiator cooling problems, only two of the three ALCO units can be operated at this time.)

A combined total of approximately 1 MW of other electric generating capacity exists in small diesel units serving outer islands and villages. The high cost of fuel restricts the operating time of most of these units to four to six hours per day. About 2.2 million kWh/year were generated at these sites in 1980, with a total peak load of .1 MW being served.

Table 4-2

GOVERNMENT ELECTRIC POWER GENERATION, PALAU 1980

FUEL			LOCALITY	OUTPUT (million kWh/y)	END USE (million kWh/y)			CAPACITY (MW)		LOAD (MW)	
Type	Amount Purchased (1000's of bbls)	Price(a) ($/bbl)			Res	Comm'l/ Gov't Indust	Milit	Rated	Operating Standby	Base	Peak
Diesel	44.0	53.76	Koror	20.2					3.0(b)		3.0
			Other islands	2.2	---14.8---		7.6	7.75(c)	1.0(b)		0.1
			TOTAL	22.4	---14.8---		7.6	7.75(c)	4.0(b)		3.1

(a) Diesel price at the Mobil Bulk Plant, February 1981, exclusive of taxes and local transportation

(b) Reflects derating due to climatic conditions

(c) Nameplate capacity including deadlined units

As of 1980, there were almost 1500 connection to the main Palau electric distribution system, 455 of which are unmetered. The policy in Palau has been to honor new requests for hook-ups, provided system reliability will not be impaired. However, the outdated distribution system has effectively limited the peak demand which can be met, and therefore the number of end-users that can be served.

Electricity users throughout Palau are currently charged only 6¢ of an estimated 21¢/kWh cost of production; that estimated cost is based on fuel cost only and does not include operation and maintenance. Generation costs for each of the four newest units (three ALCO and one gas turbine) are roughly identical. The current rate structure necessarily results in government budget deficits that will continue to grow as power demand increases. The bulk of unmetered users are government agencies, consuming some 35% of all power generated in Palau.

Due to reliability problems with the Koror system, many large industrial users have been obliged to install their own generators. The large fish processing plant in Palau has generators with 500 kW total operating capacity, the United States Army has a 350 kW plant for communication services, and the largest hotel on the island of Koror has a 350 kW unit. At least 2 MW of generating capacity is now privately owned.

In the residential/commercial end-use sector, the principal uses of electric power are cooking, refrigerating and lighting. There are few electric hot water heaters, and air conditioning tends to be in government rather than private buildings. Typical electrical consumption in the residential sector (expatriate-occupied dwelling units excluded) is estimated at about 70 kWh/month.

About 30% of the 148,000 barrels of petroleum products consumed in 1980 were used to generate electricity. The principal users of oil products, however, are the fishing and fish processing industries. Transportation fuels represent the third major category of petroleum use in Palau. Over 1300 automobiles (private and government), 100 registered and many more unregistered boats, plus commercial aviation, comprise the specific uses of fuel within the transportation sector. The government of the Republic operates a very limited field ship system, so fuel used for interisland transportation of people and goods is included in the marine transportation sector.

Economic development goals in Palau center on enhancing three major activities: tourism, fisheries, and agriculture. Sufficient and reliable public power will be required to attract potential investors, otherwise the government of the Republic will have to offer tax compensations to industries that have to develop their own power sources. The government of Palau prefers the first option and is now in the planning stages of an effort to increase its central electric generating capacity significantly.

In 1982, the Republic reached a preliminary agreement with the IPSECO company of Great Britain that will, when concluded, result in construction of a 16 MW residual oil-fired generator and transmission system for Palau. The proposed $27 million system would replace existing capacity now in place in Koror and supply power to Babeldaob Island. Plans are being considered to bring the electical grid to all of Babeldaob's coastal villages, although the cost is expected to be extremely high. One estimate cites a cost of $5 million for such a grid extension.

As a result of the preliminary agreement with IPSECO, Palau has been provided with the portable 3 MW generating turbine now in use at the Malakal station. It is being used to augment power, as needed, at that facility. The proposed 16 MW plant to be provided Palau would be privately financed by a British bank. Negotiations for financing and site of the new power plant are still pending. A major concern of the Palau government has been to structure the project so that it can eventually be self-financing. The proposed generators would burn Bunker C grade fuel, available through Singapore at much less expense than the diesel fuel now used at the existing plant. A proposed quasi-governmental Public Utilities Agency would sell fuel from a proposed tank farm that would be built in conjunction with the power plant. Revenue from sales to local consumers and fishing vessels would provide additional funds with which to pay back the loan.

This large project is being planned with the objective of providing electrical power to supply economic development in Palau for the forseeable future. Only with the guarantee that adequate capacity and reliable distribution systems exist, will outside investment be attracted to Palau. Revenue from power sales to these potential investors can then contribute to the retirement of the debt incurred to build and operate the new plant.

PLANNING FOR THE FUTURE

Outside the urban area of Koror and the areas of Babeldaob that are to be electrified, energy options other than petroleum fuel based power plants must be considered. Should the 16 MW plant be constructed on Koror, the present generators on that island (the three ALCO units) may be dispersed to the outer islands (i.e. Peleliu). Villages in the interior of Babeldaob and elsewhere in Palau where electric grid extension will not soon be available are potential sites for the application of one or more renewable energy resources. Investigation has gone forward as to the most feasible candidates for early adoption in such areas. These technologies will be addressed in more detail below.

Those alternate energy systems of most potential significance in Palau can be identified by applying to all candidate technologies the selection criteria presented in Chapter 2. An examination of the technical, economic, and social factors represented in these criteria, when based on circumstances unique to Palau, can indicate the relative appropriateness of each option. These alternate technologies and their possible role in meeting Palau's current and future energy needs are outlined in Table 4-3 and discussed below.

Table 4-3
Technology Selection Criteria

	SOLAR: Solar Hot Water	SOLAR: Photo-voltaics	SOLAR: Solar Therm-al	WIND ENERGY	GEO-THERMAL	HYDRO-ELECTRIC	BIOMASS: Tree Farms	BIOMASS: Biogas	BIOMASS: Liquid Fuels	MSW	OTEC	OCEAN CURRENTS AND WAVES	SOLAR PONDS	COAL	ENERGY MANAGE-MENT
RESOURCE															
proven	•	•											•		•
suspected						•	•	•	•		•				
unknown			•	•	•							•			
none										•				•	
TECHNOLOGY READINESS IN PACIFIC															
high	•	•			•	•								•	•
medium				•			•	•	•				•		
low			•							•	•	•			
RELIABILITY PROBLEMS IN PACIFIC															
high			•	•	•		•	•	•	•	•	•			
medium						•							•		
low	•	•												•	•
DURABILITY PROBLEMS IN PACIFIC															
high			•	•						•	•	•			
medium	•						•	•	•				•		•
low		•			•	•								•	
APPLICATION															
centralized		•	•	•	•	•	•			•	•	•	•	•	•
decentralized	•	•	•	•		•		•	•				•		•
POTENTIAL CONSTRAINTS															
cultural impact				•		•	•	•	•	•		•	•	•	•
land availability		•	•	•	•	•	•				•		•	•	
environmental impact				•	•	•	•	•	•	•	•	•	•	•	
human resources	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
infrastructure	•	•	•	•	•	•	•	•	•	•	•	•	•	•	
CAPITAL COSTS															
high (over $10,000/kW)		•	•								•	•	•		
intermediate ($3,000 - $10,000/kW)				•	•	•	•		•	•					
low (up to $3,000/kW)	•							•						•	•
O&M COSTS															
high			•	•							•	•		•	
intermediate					•	•	•		•	•			•		•
low	•	•						•							
COST EFFECTIVENESS															
near term (0-5 yrs)	•	•				•		•					•	•	•
mid term (6-15 yrs)		•		•	•		•		•						
long term (16-40 yrs)			•							•	•	•			
EXPECTED OIL SAVINGS OR AVOIDANCE															
high															•
intermediate	•	•				•							•		
low			•	•	•		•	•	•	•	•	•		•	

Energy Management

Energy management practices offer potential savings in oil costs in the grid-served areas of Palau. The opportunities for savings through conservation are the greatest in the government sector, where little electricity use is metered. Rate structure reform, gradually imposed, could increase government revenue and help in the financing of planned capacity additions. Once the Koror generation and distribution network is improved, more reliable service should be available, thus, encouraging new investment in Palau. For there to be a maximum amount of power available to support this expected growth, efficiencies of energy use should be instituted.

A range of simple energy management actions, from elimination of unneeded end-users to an energy audit and monitoring capability in the government should be pursued. Building energy performance standards, passive cooling retrofit (particularly of government buildings), metering, rate structure adjustment, and installation of more energy efficient appliances and lights all promise immediate oil savings potential.

For areas now outside the Palau grid, energy use and needs surveys could be conducted so that a better match between demand and energy supply can be made once these areas are developed. The appropriateness of many renewable energy technologies can be understood only after accurate measures of energy load in candidate areas have been identified.

The cost of most energy management activities is small relative to the oil savings return that is received. Focusing on the government sector first would provide an example to commercial and residential users and illustrate that there is a social benefit tied to the efficient use of energy. Training and public awareness programs should accompany all energy management activities.

Hydroelectric

Small scale hydroelectric power production looks promising for Palau. The technology is fully mature and plant components are readily available. The potential for hydroelectric power production in Palau is centered on the island of Babeldaob. An analysis of the major drainage basins on Babeldaob concludes that small scale applications of hydroelectric power appear promising for many of the island's river basins. In general terms, the five major streams of Babeldaob for which long-term flow data have been obtained by the United States Geological Survey are characterized by low heads and large seasonal flow variations. The prime locations for further investigation appear to be the Kumer/Gaden Basin, the Tabecheding Basin, and in the Ngertebechel Basin at the confluence of the right and left branches of the Ngertebechel River.

Each of these sites has physical characteristics which would minimize site development costs, while their locations in relationship to existing infrastructure and demand centers are favorable. According to the 1981 technical analysis conducted for Palau, the Kumer/Gaden site shows a drop of more than 18 meters (60 feet) within 90 to 120 meters (300 to 400 feet) of run, with an excellent impoundment site above. Located within 1600 meters (one mile) of the existing highway past the Airai Airfield, it could provide peaking power to the Koror grid. The Tabecheding sites, near Aimelik, were found potentially feasible. Their location near areas of potential agricultural growth could provide a ready use of both power and water. Overall, a potential of over 1.2 MW of hydroelectric power exists on Babeldaob, according to this most recent hydrographic analysis. Additional investigation and site-specific feasibility studies will be required before any site can be developed.

Given the size and location of potential hydroelectric resources in Palau, the applications of the technology are expected to match well with the small demand centers in the remote areas of Babeldaob. However, as the grid is eventually extended across Babeldaob, the hydroelectric plants could be integrated into the network to contribute peaking power to all of Koror-Babeldaob area. The only major performance issue related to the technology is whether the annual flows of candidate rivers will be sufficient to provide reliable power, either in a base or peaking capacity. Impoundment design will have to account for the intermittency of stream flows wherever they occur.

There are a number of potential constraints on hydroelectric development in Palau. Sufficient land may not be available, and the environmental impacts often associated with hydroelectric proposals will need to be addressed. The more remote the development site, the more capital intensive will be the construction and installation effort. Though some potential sites are close to the Koror urban area, many require access by boat at this time, pending further extension of the coastal road around Babeldaob.

Despite the absence of detailed feasibility studies, and the potential land and environmental constraints, it is possible to say that there is a limited near-term potential and possibly more significant mid-term potential for hydroelectric power in Palau. Once the designation of competing land uses in Babeldaob is better understood, the most favorable hydroelectric sites should be given a more detailed examination. In the interim, additional site characterization and economic feasibility analyses should be conducted.

Solar

Characterization of the solar insolation resource of Palau has begun only recently. Monthly average daily insolation values from 4.2 to 5.3 kWh/m^2-day have been derived from the available sunshine data for Koror. This is a sufficient, though imprecise, initial indication of the attractiveness of the solar resource in Palau. A pyranometer installed on Koror in 1982 is expected to yield hourly increments of total sky (direct and diffuse) radiation on a daily basis.

Photovoltaics and Solar Water Heating

Despite the lack of firm solar resource data, photovoltaic energy systems have been installed and are used at some remote sites in Palau for lighting, radio communication, and medical refrigerators. These and other low-power end uses appear best suited for photovoltaics, particularly in the remote, off-grid areas of Palau. Some of the small, photovoltaic-powered refrigerators have worked poorly in Palau and in the Marshall Islands and Truk State of the FSM. The problem appears to lie not with the energy technology but with the design of the appliance expected to operate from the photovoltaic power source. There is a need to make better matches between end use devices and photovoltaic arrays.

There are no solar hot water or other solar thermal applications in Palau at present. However, there is a demand for hot water at major commercial installations and government facilities, such as the Koror hospital where a solar hot water system will be added during pending renovations. The derived insolation values and general climate of Koror favor the operation of efficient thermosiphon hot water systems throughout Palau.

Solar hot water and photovoltaic systems are modular in design and lend themselves well to any number of load sizes. The lack of adequately trained personnel, long a problem in energy system operation and maintenance (O&M) in the Pacific Islands, will not hamper solar utilization to any great extent in Palau. Thermosiphon and photovoltaic conversion processes have no moving parts, and the simplicity of their operation makes each an important energy alternative for the Republic.

As in most other island Pacific Island groups, solar system reliability and durability remain unknowns in Palau. Long (15-20 year) lifetimes are forecast for solar hot water and photovoltaic systems in more temperate, nonmarine climates. However, expected lifetimes of the same systems, and indeed of any energy systems, in the Pacific, may be abbreviated by corrosion, high winds, and other environmental stresses.

Capital costs for photovoltaics remain high, though cost reductions by a factor of two to three are possible by the middle of the decade. Low O&M costs over the lifetime of both solar hot water and photovoltaic technologies help make small to intermediate sized systems attractive now and in the near term in comparison to conventional diesel generators with their high fuel and O&M costs. Developing the necessary human resources and infrastructure support (warehousing of spare parts, repair facilities) would be rewarded even though current capital costs for the technology are high.

Solar Ponds

The insolation resource of Palau, while not quantified in terms relative to solar pond design and performance, does appear favorable for the technology. The second critical resource required for development of the technology is sufficient land (or perhaps lagoon) area for construction of a pond. An examination of the feasibility of salt-gradient solar ponds in Palau has suggested the technology is ready where acceptable sites are available.

The smallest practical size for a salt-gradient pond has been identified as one hectare (about 2.5 acres). For many land-constrained areas of Palau, this requirement might preclude development of the technology, but sufficient undedicated flat land may be available for pond construction in some places. Given the low efficiency of energy conversion associated with the process, ponds larger than one hectare may be required for economical system design. The generating capacity of a one hectare pond ranges from 15 to 25 kW, depending on factors such as conversion efficiencies, system losses, and peak versus baseload use.

The attractiveness of the solar salt pond concept is in its ability to produce base and peaking power as needed. The technology is also modular, in that new ponds could be built to accommodate increments of growth with little lead time. At some point, however, even in the largest of the Pacific Islands, land constraints due to competing uses will limit the use of the technology. Solar pond durability in the Pacific environment is not well understood. If a system were unable to operate over the long term (15-20 years) its cost effectiveness would be seriously affected.

Physical infrastructure and support services would be required for construction and operation of salt-gradient solar pond power plants introduced to a location such as Palau. Until local skills could be developed, outside labor would be needed to oversee the construction and O&M needs of the plants. The uncertainty of actual system performance in a remote area would add to the O&M costs and thus affect the economic competitiveness of the technology.

Solar ponds sited on reef shelf areas would be likely to pose environmental impacts of some magnitude. Dredging and impoundment would adversely affect the biological productivity of the offshore areas. A major breach of pond lining, on-land or offshore, could present water pollution problems of unacceptable dimension. The proper design of pond lining might at least be able to rule out catastrophic on-land contamination potential. Slight leaking will be inevitable.

The capital costs of initial solar pond construction in Palau, as outlined in a recent analysis of the technology, are estimated to be about $20,000 per installed kilowatt. Subsequent plants would experience cost reductions on the order of 30% to 50%. If such plants could be constructed within this cost range, and if land use and environmental constraints can be mitigated, the life cycle power cost would be attractive compared to the alternative of diesel-generated power.

Biomass

The significant land mass and heavy vegetative cover of Babeldaob Island suggest the potential for certain biomass energy applications in Palau. Forest resource and agricultural census studies have been completed for Palau, though analysis of findings has not been performed from an energy perspective. The soils classification survey for Palau completed at the end of 1982 will contribute to a better understanding of the biomass production potential of the Republic.

Apart from these basic resource assessment efforts, there has been no examination of the potential for existing or introduced plant, tree, or crop species to provide energy via applicable conversion processes. Comparisons can be made between Palau and other islands in the Pacific where tree species favorable to plantation farming and combustion exist. A preliminary conclusion is that there is sufficient land mass and favorable climatic conditions in Palau, particularly on Babeldaob, to support tree farming biomass conversion.

The agricultural crop base in Palau is presently limited to subsistence production, with only a small commercial agricultural sector. Food self-sufficiency is a stated goal of the government and would appear to preclude redirection of food crops to biomass liquid fuels conversion. Biogas feedstocks, however, may be recoverable from copra and fisheries industries and could represent an energy resource for Palau. No assessment of this potential has yet been conducted.

While land may be available in a theoretical sense for intensive tree farming or other biomass crop production, constraints may be imposed by local land tenure practices, terrain configuration, and competing agricultural uses. Too-rapid harvesting of any biomass crop can damage soil productivity, particularly where heavy tropical rains such as those Palau often receives can cause erosion. In addition, local labor cannot be presumed to be available for biomass plantation establishment and upkeep. Where labor cannot be assured, the alternative to biomass harvesting is often more energy-intensive mechanical weeding and collecting practices. The costs added by this approach would clearly affect the economic competitiveness of biomass energy conversion in Palau negatively.

Perhaps the most limiting constraint to biomass energy development is the lack of infrastructure on Babeldaob to support resource harvesting, transport and combustion. Until a road network and link to the urban areas of Palau is is in place, the exploitation of Palau's apparent biomass resource will not readily proceed. The biomass conversion technologies with some potential in Palau--tree farms and biogas conversion--are therefore considered mid-term options at the earliest.

Wind Energy

The wind resources of Palau have not been characterized with regard to their potential in wind energy conversion systems. Data exist for only one primary observation station in the Republic, that of the Palau weather station in Koror. Average wind speeds recorded at this station in 1980 ranged from 2.4 m/s (5.5 mph) in November to 4.1 m/s (9.3 mph) in February. Peak wind speeds recorded each month in 1980 were between 8 m/s (18 mph) and 14.3 m/s (32 mph).

A wind energy assessment for the western Pacific has been conducted by the University of Hawaii, based on ship reports of open ocean wind speed. Data were analyzed over a thirty year period (1950-1979). Based on these data, average annual open ocean wind speed for the area surrounding Palau was registered as 5.7 m/s (13 mph). Average annual power represented by this wind resource is 250 Watts/m^2. Seasonal averages of both measures are presented below.

LOCATION	SEASON	WIND SPEED (m/s)	POWER (W/m^2)
Palau;	Winter	6.2	300
	Spring	5.5	240
7°N, 134°E	Summer	4.6	175
	Autumn	4.9	190

These data are of course representative averages. Highly site-specific wind resource data are required to justify investment decisions in wind energy systems. Nevertheless, the open ocean wind speed data from the area around Palau strongly suggest that the wind energy resource available on land in Palau will be highly variable with respect to seasonal power output of wind energy conversion systems. Moreover, the trade wind inversion which often enhances the wind resource over high islands weakens to the west and south of the north Pacific anti-cyclone. As a consequence, high island enhancement of open ocean wind speeds in Palau is expected to be less significant than it is in Hawaii, for example.

It is also expected that atolls in Palau will likely experience a slight reduction in open ocean wind speed due to friction from both land and vegetation. Despite the absence of valid on-land wind resource data applicable to wind energy system performance in Palau, open ocean wind speed data provide a valuable indicator of both the promise and limitations of the resource in the area.

The value of site-specific accurate wind speed data cannot be overstated, because the cost effectiveness of any system depends on its performance in a highly variable resource regime. The extractable energy could vary so much with changes in wind speed at a given site that, unless this were known prior to system purchase and installation, system economics could never be adequately anticipated.

Small wind energy conversion systems are presently at a fairly well established state of technology readiness, however their potential application in Palau has yet to be verified by even a single machine. The end uses which might be served by small wind energy systems would depend much on the location of the resource. A favorable wind regime near a small village would open up many more opportunities for the technology than a resource located at some distant or inaccessible site. Generally, though, wind machines combined with some electrical storage capacity can be used to provide for a number of low power electrical applications such as a village energy system and battery charging. Should a wind resource be confirmed at sites near existing electrical transmission lines, there may be the potential for grid-connected fuel saver uses for wind energy conversion systems.

Water pumping applications are also possible with wind systems, because no energy storage is usually necessary.

The routine maintenance and repair of wind energy conversion systems will be difficult to guarantee in the near term because parts and repair personnel are not now available in Palau. Without trained personnel to facilitate O&M as it is necessary, costly imported labor and periods of wind machine inoperation reduce the economic benefits that might otherwise flow from the technology. Perhaps the Micronesian Occupational Center in Koror could develop a training program that would begin preparing Palauans and other Pacific Islanders for wind and renewable energy conversion system O&M.

Depending on the location of the wind resources most favorable to energy conversion, land availability may be an issue if a large number of machines are considered at a single location. The identification and mitigation of technical, environmental, or cultural impacts cannot be done without first knowing where the resource sites are located.

The capital costs of wind systems will be high in Palau, given the long distance transport required from the mainland United States (assuming United States turbines are the ones eventually purchased). Until adequate service and repair facilities are available in Palau, the O&M costs of the first wind energy systems will be higher than those in more developed areas of the world.

Given the tremendous uncertainty over the value of Palau's wind resource for energy conversion, data collection must preceed any widespread commitment to wind energy conversion technology. For this reason, assuming the resource is present, the technology is no closer than a mid-term option for Palau .

Solar Thermal Systems

Diffuse solar insolation can be used in photovoltaic and low temperature solar thermal systems, but only direct insolation can be focused or concentrated to achieve the high temperatures needed for steam and electricity production. No measure of direct insolation has yet been taken in the Republic of Palau, and such a measure is needed before concentrating solar thermal systems could be designed or their potential performance evaluated. Solar thermal systems, however, are expected to be most cost-effective in capacities of several hundred kW and up and would not be appropriate for meeting the many small electric power demands in remote areas throughout Palau. Connection to a central grid would offer the most likely future application for high temperature thermal-electric systems, while process heat systems could serve small to intermediate size industrial uses such as fish processing.

Depending on the size of the proposed systems, and the constraints imposed by other siting requirements, land availability could be a drawback to large solar systems. Performance might be hampered by the Palauan environment. Solar thermal systems are particularly vulnerable to high winds and other hazards where glass breakage may occur. In addition, the technology of high temperature solar thermal energy conversion has not reached as high a state of maturity as photovoltaics or solar hot water systems have reached. Given the special design considerations and complex maintenance procedures which may be needed for high temperature systems on remote islands, solar thermal applications may not be a potential near-term option for Palau.

MSW

There are no data on actual tonnages of MSW generated in Palau, and only the population center of Koror has the population density that would suggest even a minimal MSW resource in the Republic. On the assumption that .7 kg (1.6 lb.) of MSW is produced per person and that Koror's current population is approximately 8000, some 2.04 million kg/year would be available for combustion and energy conversion. This relatively small amount of MSW, even if verified by empirical data as being perhaps 50% greater and of the proper energy content (i.e. Btu/ton), may not be able to fuel even the smallest practical MSW facility. In addition, the conversion of MSW may be further limited by the inability to actually get all of the available MSW from Koror into one central spot for combustion. Collection services may not be sufficient to guarantee a reliable supply of MSW at a cost that would make the technology competitive with other energy generation options.

In sum, the expected addition of new oil-fired generating capacity in Koror and the relatively unknown quantity of the resource combine to limit the near to mid-term potential of MSW conversion in Palau.

Coal

The near to mid-term electricity requirements of the Republic are expected to be met by the planned addition of residual oil-fired generating capacity. Aside from the fact that the coal resource is nonexistent in Palau and coal would have to be imported from foreign sources, there are no remote demand centers of sufficient size to justify economically even the smallest coal-fired generator. There is no interest in the Republic of Palau at this time for any proposals to import coal for electric power production.

OTEC

General oceanographic maps of the north and west Pacific indicate a favorable ocean thermal energy resource in the waters surrounding Palau. However, no temperature gradient or other physical or chemical analyses of offshore waters have been conducted to verify that the conditions necessary for OTEC development are present in Palau. Worldwide operational experience with OTEC is so limited, even on a test basis, that the state of technology readiness is insufficiently established for either near or mid-term application in Palau.

Ocean Tidal and Currents

No resource assessments have been performed to date to characterize either the tidal or ocean current resources of Palau. Observations suggest that there may be some channel locations surrounding Koror where ocean currents are routinely quite strong. However, given the low energy density represented in ocean currents, it is not known whether the quantity and velocity of these currents are sufficient for energy conversion. Due to the absence of major estuaries in Palau, the tidal resources are not expected to be of a magnitude to support tidal energy conversion. The technology for exploiting this resource is not well developed, and would represent a long-term option, at best, for application in Palau even if there were a proven resource.

Geothermal

There are no known geothermal resources in Palau. Though the use of geothermal energy is well established worldwide, there is nothing to suggest that the resource is present in Palau or that an extensive geothermal prospecting effort should be mounted in the near term.

FINDINGS AND RECOMMENDATIONS

Energy planning in Palau is being conducted at two levels: urban and rural. The urgency attached to achieving reliable electric power in the urban area has led to a major effort to upgrade the existing oil-fired generating facilities and distribution network. When fully implemented, these projects will provide Palau with reliable generating capacity for the near to mid term, as long as good maintenance practices are followed. With firm power assured, the next objective will be to foster economic growth to make use of the expanded generating capacity and to provide revenue to help finance the new system.

Though the Republic of Palau has apparently chosen its main energy technology for the near to mid term, interest in using the several renewable energy resources which the area posesses remains. The first locations where these resources will be applied are the more remote villages on Babeldaob, where grid extension from Koror may not reach for some time, or at all. Then there are the few outer islands (Kayangel, Peleliu, Angaur, Sonsorol and Tobi) where grid extension will never reach. Renewable energy resources are likely to be exploited to meet the relatively small demands which now exist in those places. Until the more promising renewable energy systems can be developed, diesel units now in use on Koror, but surplus once the proposed 16 MW addition is installed, may be used.

With this as the general strategy governing energy planning in Palau, several near-term steps could be taken to reduce the costs and improve the efficiency of energy use over the next five to ten years. These activities can again be distinguished on a urban/rural basis, and the near-term benefits are different in each setting. The benefits to be achieved in the Koror area will be the saving of fuels used in electricity production, freeing more capacity for the support of economic development activities in the Republic. The benefits of near-term actions in the remote villages and islands will be to avoid new dependencies on oil in these areas by introducing cost-effective renewable energy options as rapidly as possible. A secondary benefit of this activity will be to gain valuable experience in the use of renewable energy technologies that may offer a long-term benefit to all of Palau as their costs decrease over time.

In more specific terms, the actions of greatest potential benefit in the Koror area include: the institution of sound energy management practices, in particular rate structure reform; metering of government buildings; energy audit and data management capability; energy performance standards for new buildings; and end-use energy conservation practices such as replacement and/or removal of inefficient appliances, lights, etc. Also in the Koror area, currently cost-effective technologies such as solar water heating should be used at government facilities.

For the more remote areas, attention should be focused on the two or three technology options for which Palau's resources appear most favorable. These include small scale hydroelectric power on Babeldaob, photovoltaic powered village energy systems, and a more extensive characterization of the Palau wind regime where observation now suggests a possible resource. Concurrent with these activities, village energy use and needs surveys should be conducted so that potential loads to be met with renewable energy systems can be defined as accurately as possible.

The above findings have been reached as a result of the technology reviews conducted earlier in this chapter and summarized in Table 4-3. Each of these recommendations is detailed in Table 4-4 which follows.

Table 4-4

Energy Planning Recommendations

Republic of Palau

Koror and Surrounding Area

- o Improved energy management
  - rate structure reform
  - installation of electric meters on all government facilities
  - development of energy efficiency standards for all new buildings, beginning with the government sector
  - implementation of energy conservation measures, again first in the government sector, including passive cooling retrofits on existing structures, replacing light fixtures and other energy efficient appliance substitutions
  - development of an energy data system to monitor and audit energy use in all sector
- o Infrastructure development to support remote village renewable energy technology O&M and Koror energy management activities
  - personnel training in renewable energy system concepts, including installation, troubleshooting, and repair, plus the conduct of building energy audits and energy data management
  - renewable energy curriculum development for long-term manpower training at the Micronesian Occupational Center
- o Implementation of renewable energy technologies to help reduce government sector energy use

Remote Villages and Outer Islands

- o Performance testing of a small-scale hydroelectric system at a favorable site on Babeldaob
- o Wind energy resource assessment, including data collection, statistical analyses, and technology performance projections based on such data, for selected sites on the east coast of Babeldaob
- o Extension of village energy needs surveys and energy use audits to all remote villages of Palau for use in subsequent technology selections
- o Addition of performance diagnostics to existing photovoltaic systems now in use in Palau
- o Engineering design of a photovoltaic-diesel hybrid system for an outer island application
- o Analysis of infrastructure requirements needed to support hydroelectric development on Babeldaob

CHAPTER 5: ENERGY PLANNING FOR THE COMMONWEALTH OF NORTHERN MARIANA ISLANDS

The Commonwealth of the Northern Mariana Islands (CNMI) is composed of 16 islands which have a combined total land area of 510 square kilometers (184 square miles). The chain extends 730 kilometers (440 mi) from Farallon de Pajaros (Uracas) in the north to Rota in the south (see Figure 5-1). The United States Territory of Guam is only 205 kilometers to the south of Saipan. Only six of the islands in CNMI--Saipan, Tinian, Rota, Alamagan, Anatahan, and Agrihan--are regularly inhabited. Saipan, Tinian and Rota account for 65% of the land area of the Commonwealth, 99% of the population and almost all of the economic activity and energy supply and demand.

The three major islands presently enjoy electrical generating capacity adequate to meet current demand and to support economic development. However, the electrical distribution system on Saipan is unreliable and needs to be improved. The Commonwealth depends totally upon imported petroleum for both transportation and electrical power generation. World oil prices and supplies have been relatively stable in recent years, but the CNMI government recognizes that if market perturbations similar to those occurring in the mid-1970s were to occur again, the resultant uncertainty of supply and difficulties in meeting oil prices could cause severe economic stresses. As a result, the CNMI is concerned with developing indigenous energy resources both to reduce oil demand in the population centers and to provide new, non-petroleum energy sources for the outer islands.

Geologically, the Northern Mariana Islands are mountainous "high islands" of volcanic origin. The Marianas are part of the Palau-Yap-Mariana-Japan trench system which forms the boundary between the Asiatic structural blocks and the true Pacific Basin. The island chain is aligned along the crest of the gulf that is associated with the great Mariana trough that reaches a depth of nearly 10 kilometers (6 miles). In the southern islands, coraline limestone caps the volcanic formation. Saipan is the only island with a sizable lagoon. It extends almost the entire length of the western side of the island.

The climate of the CNMI is tropical, uniformly warm and humid. This climate, coupled with the salt-laden air, severely limits the lifetime of mechanical equipment. Saipan is reputed to have one of the world's most equable climates with an average year-round temperature of 27°C (81°F). Wind and rainfall are the most variable elements. There are distinct dry and rainy seasons in the Marianas, which would affect efforts to exploit hydroelectric resources. Average yearly rainfall is 130 cm (50 in); over half of it between July and November.

From July through November, typhoons with winds in excess of 300 km/h (180 mph) periodically sweep through the islands. Flooding and wind damaged vegetation are a common result of storms with winds above 100 km/h. Storms of this sort are very destructive, and are particularly hard on structures of all kinds. The effects of these high winds and the associated wind-driven debris on alternate energy systems must be considered when reaching decisions on which types of alternate energy are most appropriate for the CNMI.

HISTORY AND POLITICAL DEVELOPMENT

Present day inhabitants of the Northern Marianas are the decendants of the original Chamorro settlers of the islands, Carolinians, and a growing number of Asian settlers, including many Filipinos who are engaged in the construction and service industries. The Chamorros who settled the islands, probably in the third or fourth century A.D., were reputed to be tall, warlike and fearsome. The first European visitor to what is now the CNMI may have been Ferdinand Magellan, who landed in Guam in 1521. Subsequent to Magellan's departure, the islands in the CNMI were virtually ignored until the arrival of

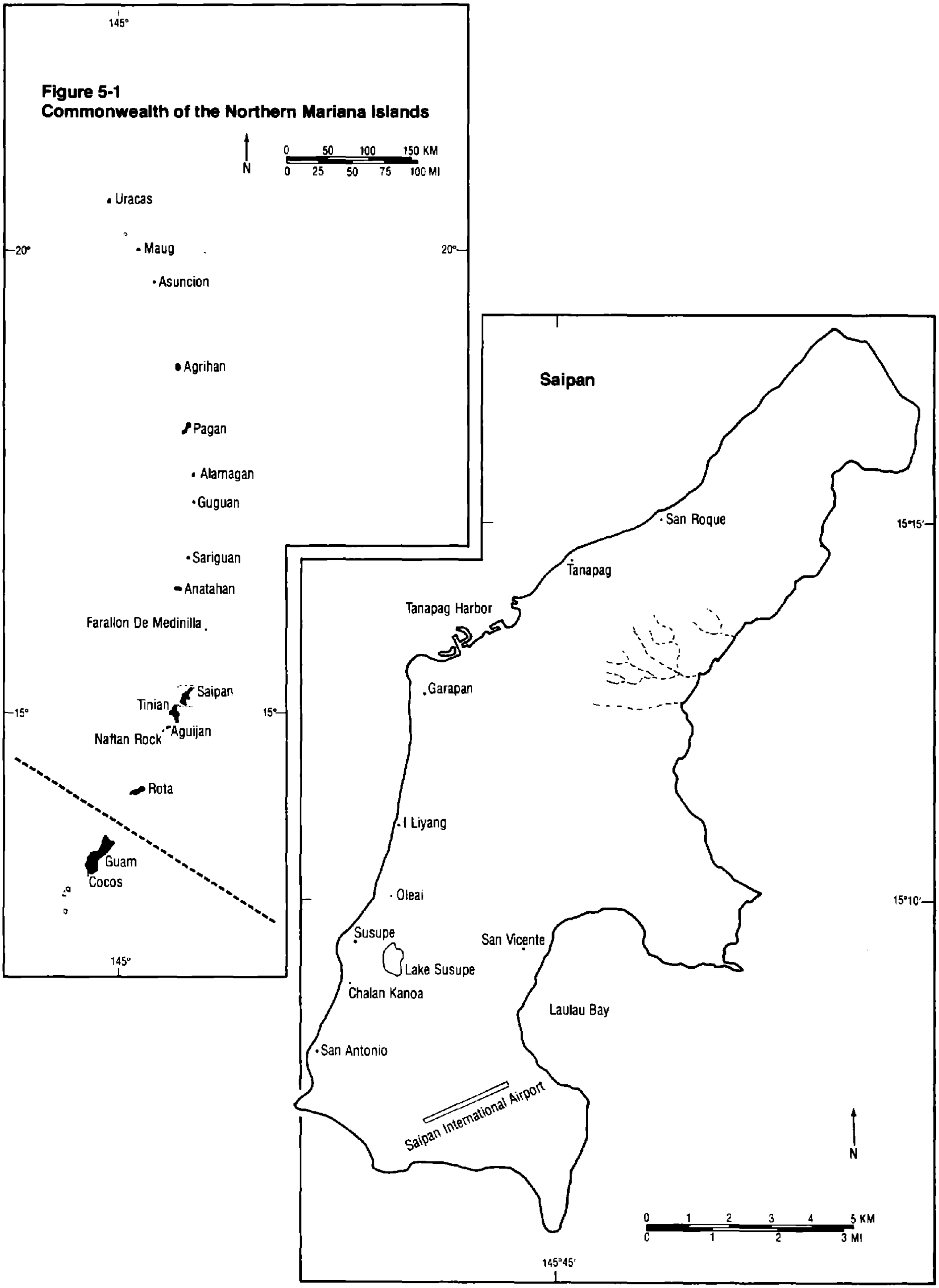


Figure 5-1
Commonwealth of the Northern Mariana Islands
N
0 50 100 150 KM
0 25 50 75 100 MI
145°
20°
15°
Uracas
Maug
Asuncion
Agrihan
Pagan
Alamagan
Guguan
Sariguan
Anatahan
Farallon De Medinilla
Saipan
Tinian
Aguijan
Naftan Rock
Rota
Guam
Cocos
Saipan
San Roque
15°15′
Tanapag
Tanapag Harbor
Garapan
I Liyang
Oleai
15°10′
Susupe
San Vicente
Lake Susupe
Chalan Kanoa
Laulau Bay
San Antonio
Saipan International Airport
0 1 2 3 4 5 KM
0 1 2 3 MI
145°45′

Spanish Jesuits in 1668. The priests christened the archipelago "Marianas" in honor of Queen Maria Anna, widow of Philip of Spain and patroness of the first missionaries. In 1565 a Spaniard, Don Legazpi, formally proclaimed the Mariana Islands to be Spanish territory. However, for a century after Don Legazpi's visit, Spain made no effort to colonize the islands, using them mainly as a watering and provisioning stop on the sailing route from Acapulco to Manila. During this time, persecution, famine and disease so depopulated the islands that, by 1698, all of the remaining inhabitants had been removed to Guam. By 1780 the number of Chamorros even on Guam had fallen to only 1639.

Saipan was repopulated in the nineteenth century, initially by Carolinian sailors from the Eastern Caroline islands who received permission from the Spanish Governor on Guam to settle there in 1815. Later, it also became home to people of partial Chamorro decent whose parents had been forcibly evacuated from the Northern Marianas by the Spaniards earlier. They were also attracted by the possibility of engaging in copra production and of having greater freedom from Spanish control than they had on Guam.

In 1899, after its defeat in the Spanish-American War, Spain ceded Guam to the United States and sold the Northern Marianas, along with the rest of Micronesia, to Germany for $4.5 million.

The Marianas proved to be an economic liability to Germany. Because of scarce resources and distance from Europe, commerce never took off as expected. At the beginning of World War I, the islands were taken by Japan without struggle. In 1920, the League of Nations formalized this wartime seizure by placing the Northern Marianas, as well as the Carolines and the Marshalls under a League of Nations Mandate to Japan.

During the Japanese period (1914-1944), the islands acquired new significance. They lay along routes of Japanese economic expansion and were considered strategically vital to Japan. Japanese commercial enterprises and colonization brought development to the Marianas. Much of the still existing and utilized infrastructure such as roads, docks and water system are from this era. Sugar and starch (sugar cane, taro and cassava) production dominated economic life. Fishing also contributed to the economy. By 1937, there were 47,000 residents in the Marianas, most of whom were Japanese citizens or nationals, Okinawans and Koreans. "Natives" numbered only 4,000. Garapan, in Saipan, became a thriving commercial town of 15,000 by 1941.

World War II, however, radically transformed the Marianas. Ninety percent of the local population survived but agriculture lay in ruins. Withdrawal of troops left a landscape cluttered with airstrips, abandoned installations, piles of waste, live ammunition of all kinds (artillery shells, mortar shells, hand grenades) and a completely altered indigenous society. At first, the islands were placed under naval administration. Then, on July 18, 1947 the Security Council of the United Nations and the United States entered into a Trusteeship Agreement, covering all of the former Japanese mandated islands, including the Northern Marianas, the Eastern and Western Carolines and the Marshall Islands.

In March, 1976, both the people of the Northern Marianas and the United States Congress approved a Covenant to establish a Commonwealth of the Northern Mariana Islands. Then, on April 1, 1976, the Northern Marianas separated from the rest of the Trust Territory and became "separately administered," moving toward an eventual Commonwealth status. By popular referendum, the people of the Northern Marianas adopted the Northern Marianas Constitution, subsequently approved by the United States Government. The Constitution of the Northern Marianas became effective on January 9, 1978 and the people witnessed the inauguration of their first elected governor, legislators and other elected officials. Establishment of the CNMI government meant that Saipan was now the site of the headquarters for both the Trust Territory of the Pacific Islands (TTPI) government and the new CNMI government. This marked the first time in more than 400 years that the people of the Northern Marianas had had a part in choosing their own government.

POPULATION, EMPLOYMENT AND WAGES

According to the 1980 census, 16,862 people live in the CNMI. Saipan (125 square kilometers, 45 square miles) is home for 14,585 people, Rota (90 square kilometers, 32 square miles) 1300 and Tinian (110 square kilometers, 40 square miles) 899. The population of Alamagan (12 square kilometers, 4 square miles) is only 57 people, Agrihan (50 square kilometers, 18 square miles) an estimated 25, and Anatahan (35 square kilometers, 13 square miles) is only sporadically populated. The same is true of Pagan which has not been populated since it erupted in 1981-1982.

The Micronesian population of the CNMI is relatively young. In 1980, over 45% of all Micronesians in the CNMI were under the age of 15 years. This age structure results from a high birth rate, a relatively low infant mortality rate, and a low death rate. Table 5-1 presents population projections through the year 2000.

TABLE 5-1 -- NORTHERN MARIANAS POPULATION PROJECTION

Sex	Age Group	1980	1981	1982	1983	1984	1985	1990	2000
Both	Total	16,758	17,596	18,575	19,598	20,576	22,165	23,320	32,630
	0-14	7,613	7,991	8,456	8,884	9,339	10,111	10,890	15,210
	15-64	8,622	9,052	9,513	10,082	10,483	11,335	11,673	17,060
	65-over	523	553	606	632	671	721	757	860
Male	Total	8,457	8,886	9,378	9,875	10,362	11,161	11,780	16,260
	0-14	3,885	4,080	4,320	4,534	4,774	5,130	5,566	7,770
	15-64	4,326	4,547	4,778	5,047	5,269	5,687	5,853	8,580
	65-over	246	259	280	294	319	344	361	410
Female	Total	8,301	8,710	9,197	9,723	10,205	11,006	11,540	16,370
	0-14	3,728	3,911	4,136	4,350	4,565	4,981	5,324	7,440
	15-64	4,296	4,505	4,735	5,035	5,214	5,648	5,820	8,480
	65-over	277	294	326	338	352	377	396	450

Estimates are based on the 1980 Population Census Preliminary Data. The cohort-component method of population projection is used to obtain the estimates.

The present Micronesian labor force in CNMI probably numbers about 5000, or about 64% of the total Micronesian population over the age of 15 years. Measured in terms of employment and wage and salary payments, it appears that the private sector has undergone real expansion since the advent of Commonwealth status. Tax returns indicate that between 1977 and 1980, total wage and salary payments doubled in the private sector and the number of persons employed rose by 25%. In contrast, the government sector expanded only 32% in wage and salary payments and actually declined in the total number of employees. Overall, money wage and salary income appears to be steadily increasing. In 1975, the total was $21.5 million while in 1980 it was $41.9 million ($29.5 million in 1975 dollars). Per person, the annual wage went from $3491 to $5494 ($3869 in 1975 dollars), an 11% increase.

Although the growth has been extraordinary for a Pacific Island nation, the CNMI does not enjoy the standard of living and the benefits of a typical mainland community or the closest neighboring United States Government possession, Guam.

PRESENT ECONOMY AND INFRASTRUCTURE

In the years prior to World War I, the economy of the Marianas was mainly a subsistence economy based on fishing and gathering. In the Japanese years, those between World Wars I and II, agriculture became the mainstay of the Northern Marianas' economy. Since World War II, this agricultural pattern has changed dramatically with only 240 ha (600 acres) now under cultivation and 9100 ha (22,500 acres) in grazing. There are probably fewer than 75 full-time commercial farmers or ranchers throughout the CNMI. Fishing in the Commonwealth consists largely of subsistence activity supplemented by three to four small-scale commercial operations. Most families in the CNMI engage in casual or subsistence fishing from time to time, but persons engaged in serious full-time fishing probably number no more than 25 to 35.

Growth of the visitor industry has been dramatic since the direct air service to and from Japan was established in 1977. Total visitors to the Commonwealth numbered 119,370 in 1980, an increase of 134% over the 51,110 visitors to the CNMI during 1976. Tourism is now the leading private sector activity in the Commonwealth.

Construction, retailing and a range of service enterprises account for most private sector activities. As of mid-1980, 598 different businesses were active in the CNMI. General merchandising, retailing, wholesaling and importing make up about 26%, while miscellaneous services (for example, car rentals, auto and appliance repair, tailoring, tour services and printing) account for 35% of the businesses. Construction and construction supply are 11%, while hotels, bars and restaurants also make up about 11%.

Facilities and infrastructure throughout the CNMI are in need of substantial expansion and rebuilding if economic development is to continue. Until very recently, the Saipan water system could not meet the demands of consumers and was turned off during the evening hours to permit recharging of the storage tanks. Apparently, much of the productive water capacity was being lost to leaks in the systems. Recently, Covenant Capital Improvement Project (CIP) funds have been used to build new water mains and distribution lines in four areas of Saipan, and a new 760 kiloliter (200,000 gallons) reservoir and booster pump. As a result, most areas now have 24-hour water service.

Electric power service is provided by the Public Works Department. The power supply and distribution system on Saipan have grown less and less reliable over the years as a result of increases in demand coupled with inadequate maintenance of the equipment. Although the power source for Saipan has been upgraded recently with a new oil-fired plant of 21 MW capacity, additional investment will be required to improve the power distribution system which has deteriorated and causes power failures.

Only a small percentage of the island residences have solid waste pick-up service. The waste that is collected is disposed of in land fill. Suitable solid waste disposal sites are limited.

The Commonwealth Government maintains and operates a short wave radio for communications with the northern islands and ships within the territorial waters of the Marianas. A commercial cable TV station with 6 to 8 channels operates on Saipan. The islands of Saipan and Tinian are served by Micronesian Telecommunications Inc. (MTC), a subsidiary of Hawaiian Telephone. The telephone service is limited and will require major improvements to meet the demands of the future.

Health care services in the Commonwealth are provided by the Department of Public Health and Environmental Services, which is publicly funded. No private physicians practice in the CNMI. Dr. Torres Hospital, an 84-bed former United States Army field hospital constructed in 1962, is the major health care facility in the Commonwealth. Both its in-patient and out-patient facilities are heavily used. The hospital has been unable to meet the requirements for the accreditation required to obtain reimbursement under Medicaid. Other health care facilities include a Public Health Center in Chalan Kanoa, and a dispensary on Agrihan. Sub-hospital facilities with full-time physicians and nursing staff are operated on Tinian and Rota.

PROSPECTS FOR ECONOMIC DEVELOPMENT

The Commonwealth, along with the other Pacific island governments, must plan for economic development under constraints of limited land, water, natural resources and capital. Three promising areas for further development are tourism, agriculture and fisheries. Attainment of long-range development objectives depends both on planning and on available resources and infrastructure. One of the most important resources is the human resource. The population projections in Table 5-1 show a population of almost 33,000 by the year 2000, and, as it is now 45% of that population will be under the age of 15. Providing the jobs and education that will prepare residents of the CNMI to take those jobs that will contribute to the growth of the economy is a major task now facing the government.

The present policies respecting importation of alien labor attempt to strike a balance between strictness and responsiveness to the needs of the labor market. The regulations allow alien labor to be imported to meet demonstrated needs, but only after it has been determined that qualified local labor is not available.

According to recent estimates, about 8600 ha (21,140 acres), or 18% of the total Commonwealth land area, are in private hands. All other lands in the CNMI, roughly 39,000 ha (96,300 acres), are public lands and belong collectively to the people of the Commonwealth who are of Northern Marianas descent. Much of the island of Tinian has been set aside for possible use for United States Military use. However, if this option is not exercised soon, the land will revert back to the government of the CNMI. The relatively large proportion of public land results from the Japanese and German administrative policy to take lands not enclosed and cultivated, thus preventing the accumulation of large private land holdings such as one sees, for example, in Hawaii. The magnitude of public land holdings gives the government of the CNMI an unusually broad latitude in developing land use plans.

One special institutional factor related to the use of land resources may influence development of the Commonwealth. Ownership of land is limited constitutionally and in the Covenant to persons of Northern Marianas descent. Persons of Northern Marianas descent are defined as either individuals of at least one-quarter Northern Marianas Chamorro or Carolinian blood, or corporations whose directorships and voting are held 51% by such individuals. It is important to note, however, that the restrictions do not appear to have discouraged investment in the visitor industry, the Commonwealth's leading private sector economic activity.

Relative to its population size and economic base, the Commonwealth possesses impressive public sector financial resources for development. These resources derive primarily from the financial relationships established between the Commonwealth and the United States under the Covenant. However, the Commonwealth does not have sufficient financial resources to implement all the long range infrastructural projects necessary to meet the federal water and health standards and local socio-economic development needs. The CNMI government is attempting to make the most effective use of local funds, including Covenant funds, to maximize the impact upon the economy and to encourage private sector growth.

To assist the CNMI in becoming more self supporting and to achieve progressively higher standards of living for its people, the Covenant commits the United States Government to provide direct budgetary support payments to the CNMI. These payments are earmarked for government operations, capital improvements, and economic development loans. Table 5-2 gives a general listing of anticipated expenditures for the period FY 1981 through FY 1987.

TABLE 5-2 -- GOVERNMENT OF CNMI: PROJECTED CIP PLAN BY ACTIVITIES
FY 1981 - FY 1987

SECTOR	AMOUNT (millions of 1980 $)
Health	1.0
Education	6.2
Natural Resources	3.2
Public Safety	0.5
Community Affairs	0.8
Housing	1.0
Public Works (Power)	9.4
Public Works (Water)	12.1
Public Works (Sewer & San)	1.7
Public Works (Roads)	6.0
Ports and Harbors	3.9
Public Buildings	3.0
Administration	2.7
Total	$51.5 million

Covenant grants are set at $14 million annually in FY 1975 dollars and adjusted to compensate for inflation. Covenant direct grants represented approximately 62% of the resources available to CNMI in FY 1981, excluding unobligated prior year balances.

The Covenant stipulates that the direct grants to the CNMI will be provided for a period of seven full fiscal years from the establishment of the Commonwealth. This means that the direct grants will continue through FY 1985. After FY 1985, the CNMI will continue to receive the grants at the same annual level plus inflation adjustments until Congress appropriates different amounts.

The Commonwealth also raises revenues from internal sources. Total CNMI internal revenues were estimated at about $9.7 million for fiscal year 1980. Major sources of internal revenue are excise taxes levied on petroleum and other products imported into the Commonwealth for sale, lease, or rental ($2.4 million in FY 1980), graduated taxes on individual wage and salary earnings ($994,000 in FY 1980) and gross receipts of businesses ($1.8 million in FY 1980).

The Commonwealth's principal advantages are those of location and site. A tropical climate and great natural beauty, hardly further from Japan than Miami is from New York, make the CNMI an ideal tourist destination for the populous and affluent Japanese market. The growing demand for new tourism experiences in the United States may also enhance the tourist industry in the CNMI.

In a remarkably short time, the "visitor" industry has become the leading source of export earnings and the source of about one-fourth of CNMI private employment. The strategic issues for the next few years are, first, how to keep the flow of tourists increasing in the face of increased competition, and second, how to increase the net domestic income per tourist-day. It is expected that the visitor industry will continue to be the leading private industrial sector in the Commonwealth.

The major flow of tourists has been created by the air service between Saipan and Japan and will, in the future, depend on the number of seats in that service as well as on the availability of hotel rooms on Saipan. Personnel in the Marianas Visitor Bureau (MVB) think that the world petroleum situation, and the resulting increases in air fares may combine to enhance the competitive position of tourism in the CNMI.

The location has other advantages. The strategic importance of the Northern Marianas in the Western Pacific is recognized in the Covenant between the United States and the CNMI. The United States has an option to use much of Tinian for a military base, and, while this seems unlikely at present, either the exercise of the option or the surrendering of it will have a significant economic impact. The proximity to marine resources presents the possibilities of increased fishing, fish processing and the development of other marine related activities. In addition, its location, so close to the East Asia markets, may prove attractive to United States firms desiring a forward office based in a Commonwealth with United States ties.

PRESENT ENERGY STATUS

The principal energy sources in the Commonwealth of the Northern Mariana Islands are various petroleum products. About 20% of the imported fuel is gasoline, used primarily for transportation, while more than half is diesel or RFO-6 used for electrical generation. As Table 5-3 shows, there is 21.6 MW operating capacity (in addition to 3 MW of standby equipment) in Saipan, 1.4 MW on Tinian and 2.3 MW on Rota (all as of fall 1982). A 25 kW unit was ordered for Pagan. Its future use, however, is now in question because of the recent volcanic eruption on Pagan. These new units replaced some 12.7 MW of old units, which are in stand-by state, and the power barge "Impedance" (33 MW), which was returned to the United States Army Corps of Engineers. The new units are considered to be more fuel efficient and reliable than the replaced units which had been acquired from 1968 to 1971. The large system on Saipan operates on residual oil but uses diesel for start-up. Other island generators in use burn diesel, except for two 35 kW gasoline generators on Agrihan and Alamagan which are used to power communications systems.

Although it is expensive to fuel, the electrical generating equipment in the Commonwealth of the Northern Mariana Islands is new, and, with standby capacity, can meet current demands (Table 5-3). Maximum peak and baseload demands for 1981 were 15.4 MW and 11.6 MW (Saipan), 480 kW and 400 kW (Tinian), and 740 kW and 630 kW (Rota). In anticipation of growth, Saipan Permanent Power Plant has procured a fourth 7.2 MW unit, which will be on line by September 1983.

An electrical rate of $.03/kWh prevailed for eight years prior to September 1, 1976. Since then, electrical rates have increased to $.06/kWh for 0-2000 kWh/month, $.07/kWh for 2001-25,000 kWh/month and $.08/kWh for more than 25,000 kWh/month. In 1982, costs to produce electricity, including fuel, maintenance and personnel expenses, were estimated by the management of the Saipan Permanent Power plant at more than $.12/kWh. Thus, consumers are still receiving a substantial subsidy.

The largest individual electricity users are the large tourist hotels on Saipan, followed by commercial enterprises. There are no large industrial electricity users on Saipan, and there is no military demand. The greatest electricity demands are, in decreasing order, for air conditioning, water heating, cooking, lighting, refrigeration, and TV and radio. There are 2900 customers, including 800 unmetered users who pay a flat $35/mo rate. The latter tend to use small amounts of electricity. CNMI government facilities on Saipan do not pay for utilities and the Trust Territory of the Pacific pays a flat $400,000 per year. The net result of all this is that the total income from electricity use divided by the amount generated gives an effective income of about $.025/kWh.

Hotels are among the largest energy users on Tinian and Rota. In addition, Micronesian Development Company, a dairy farm on Tinian, uses about 29,000 kWh/mo and 160 kiloliters (1000 barrels) of diesel fuel per year. It is serviced by the power plant but has auxiliary and back-up generating capacity on the order of 125 kW. There are 160 electrical customers on Tinian of which 111 are metered. The others pay a flat rate of about $20/mo. Average residential use is 250-300 kWh/family-month. Appliances (stoves, TV and refrigerators) are the main electricity users.

Commercial airlines represent a large liquid fuel demand on Saipan. The airlines' activities do have a direct effect on tourism, but their purchases are made directly from the supplier, Mobil Saipan,

TABLE 5-3 -- ELECTRIC POWER GENERATION, CNMI, 1981

FUEL			LOCALITY	OUTPUT (million kWh/yr)	END USE (million kWh/yr)			CAPACITY[c] (MW)			LOAD (MW)	
Type	Amount Purchased (1000's of bbl)	Price[a] ($/bbl)			Res	Comm'l/Gov't Indust	Milit	Rated	Operating[b]	Standby	Base	Peak
RFO-6	136	35.00	Saipan	95.4				24.0	21.6	11.3	10.5	15.4
Diesel	29	54.81	Tinian	3.1		------104.8--------		0.67	0.6	0.6		
			Rota	5.5				0.67	0.6	0.8		
			Pagan	0.8[d]					0.1[c,d]			
			Total	104.8		---------104.8--------		25.3	22.9	12.7		

(a) Diesel price at the Mobil Bulk Plant, August 1982, exclusive of taxes and local transportation; RFO-6 (residual fuel oil #6) from Guam Oil Refining Plant, August 1982.

(b) Reflects deratings due to local conditions.

(c) Includes 0.05 MW on order.

(d) Assumes reoccupation of Pagan.

and do not affect the local economy directly. Gasoline comprises an appreciable portion of the fuels used on the island, as does diesel oil. Both are bought by the private sector for miscellaneous uses (see Table 5-4). These uses include fuel for the construction industry and auxiliary fuel purchased by the large hotels, primarily for generating stand-by power. Note that electrical generation consumes almost half of the imported petroleum products.

ENERGY DEVELOPMENT PLANNING

Renewable energy fuel sources are abundant in the Northern Mariana Islands. Unfortunately, at present the entire electrical power system and back-up of the Commonwealth are based on oil imported from countries thousands of miles away. The government of the CNMI is seeking to reverse this trend through the implementation of programs to develop alternate sources of energy, including the renewable ones. A number of indigenous energy resources have been identified. In a memo from the Chief Physical Planner of the CNMI to the Special Assistant for Planning and Budget dated 10/13/82, a revised energy program was presented. The memo listed the following five emphases: 1. Energy Audits and Conservation Education; 2. Solar Water Heater Kits; 3. Photovoltaic Power; 4. Biogas Digesters and 5. Biomass Plantations. Among other technologies which might also find use in the CNMI are solar thermal, wind, geothermal, municipal solid waste, ocean thermal energy conversion, ocean currents and salt gradient solar ponds.

Table 5-5 presents estimates of the range of some of the parameters which are important in selecting the technologies. While all these efforts to utilize alternate energy sources may help ease the CNMI's dependence on imported oil, it should be recognized that the climatic conditions are both different and more severe than where many of the sources are being developed. In addition, due to the remote location and the lack of the infrastructure necessary for timely maintenance, it is often very difficult to keep systems functioning effectively.

Energy Management

Within the CNMI, a number of energy management and conservation options have been identified. While the options will not contribute any new sources of energy, they will help to reduce the demand on existing generation facilities and make them available to help support the CNMI's economic development goals. It will take time both to implement many of the possibilities and to see their results. This

TABLE 5-4 -- END USES OF FUELS, CNMI, 1981
(in 1000's of bbl)

Fuel	Amount Purchased	Price[a,b] ($/bbl)	Gov't	Private	Comm'l/Indust/ Construction	Marine Transportation Field Ship	Other	Electric Generation
Motor Gasoline	67	52	8[c]	59[d]				
Aviation Gasoline	0.4	175		0.4				
Jet Fuel-K	84	73			84			
Kerosene	1	62		------1.0------				
Diesel	42	55			21[e]			21
RFO-6	136	32						136

(a) At Mobile Bulk Plant, February 1981, exclusive of taxes and local transportation.

(b) Guam Oil Refining Company supplied 182,000 bbl in 1980; difference is believed to be related to storage requirements and losses. RFO-6 price is as of August 1980.

(c) 1500 autos.

(d) 5500 autos, 192 boats.

(e) Private communication George Chan: Comm'l/Indust-16%, Construction-84%.

Population: 16,862 (Sept. 1980)
Households: 3,440 (Sept. 1980)

means that building understanding and consensus among the people will be the first priority action to be taken. Some of the most important options are listed below:

- Establish the true cost of electrical generation including operating and maintenance costs, loan repayment and set-aside funds for future equipment procurement.
- Having established this, decide how much of it the Government of the CNMI wants to subsidize and the means of subsidy.
- Find out where the electrical energy is being used. Installation of meters for all users will be a first step.
- Bill all users, including the TTPI and the CNMI government units for the electricity they consume.
- Encourage efficient use of energy by developing and enforcing energy efficiency standards for all new buildings in the CNMI.
- Encourage efficient use of energy by demonstrating energy conserving techniques such as passive cooling, utilization of reject heat from air conditioners to preheat water, co-generation where appropriate and the like.
- Efficiency of cooking is also a prime candidate for reducing the demands for more energy. There has been significant improvement where the "smokeless stoves" have been introduced in the Pacific. Their adoption in the CNMI might release electrical generation capacity for more income producing uses.
- Continue energy education and training within the community, government and educational systems.

These steps are not to be taken as an exhaustive list of the possibilities, but only as indicative of the types of actions that have proven successful elsewhere. Probably the most important ones are

Table 5-5
Technology Selection Criteria

	SOLAR						BIOMASS					OCEAN			
	Solar Hot Water	Photo-voltaics	Solar Therm-al	WIND ENERGY	GEO-THERMAL	HYDRO-ELECTRIC	Tree Farms	Biogas	Liquid Fuels	MSW	OTEC	CURRENTS AND WAVES	SOLAR PONDS	COAL	ENERGY MANAGE-MENT
RESOURCE															
proven	•	•									•		•		•
suspected				•	•		•	•	•	•					
unknown			•									•			
none						•								•	
TECHNOLOGY READINESS IN PACIFIC															
high	•	•			•	•	•							•	•
medium				•				•	•	•			•		
low			•								•	•			
RELIABILITY PROBLEMS IN PACIFIC															
high											•	•			
medium				•					•	•			•		
low	•	•	•		•	•	•	•						•	•
DURABILITY PROBLEMS IN PACIFIC															
high			•	•							•	•			
medium	•	•					•	•	•	•					
low					•	•							•	•	•
APPLICATION															
centralized					•		•		•	•	•	•	•	•	•
decentralized	•	•	•	•	•	•		•					•		•
POTENTIAL CONSTRAINTS															
cultural impact					•		•	•	•	•			•	•	•
land availability		•	•	•	•	•	•	•	•				•	•	
environmental impact					•	•	•	•	•	•	•	•	•	•	
human resources	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
infrastructure	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
CAPITAL COSTS															
high (over $10,000/kW)		•	•								•	•			
intermediate ($3,000 - $10,000/kW)				•	•	•	•		•	•			•		
low (up to $3,000/kW)	•							•						•	•
O&M COSTS															
high			•	•					•		•	•			
intermediate		•			•	•	•	•		•			•		
low	•													•	•
COST EFFECTIVENESS															
near term (0-5 yrs)	•						•	•		•					•
mid term (6-15 yrs)		•		•	•				•				•		
long term (16-40 yrs)			•								•	•		•	
EXPECTED OIL SAVINGS OR AVOIDANCE															
high							•								•
intermediate	•				•								•		
low		•	•	•		•		•	•	•	•	•		•	

understanding what energy costs really are, pricing the energy realistically, and carrying out a comprehensive energy education and training program in the CNMI.

Tree Farms

Biomass, including agricultural waste and biomass specifically grown as an energy crop, has been used throughout the world as a fuel for boilers to drive steam turbine electrical generation equipment. It is possible to fire any of these fuels alone or in combination with each other or with municipal solid waste or with coal. Thus, a biomass electrical generation system need not depend on any one fuel. Biomass fired generating technology is mature, and plant components are readily available. Direct combustion of a sugar cane residue called bagasse provides more than half of the electrical power used on the island of Hawaii. While a specific system has not yet been designed to operate in the CNMI, this experience in a similar climate is encouraging.

Saipan, prior to World War II, had up to 8100 hectares (20,000 acres) under cultivation, most of it in sugar cane. At present, only 250 ha (600 acres) is under regular cultivation for crops in all of the CNMI. The ground cover planted after World War II to prevent erosion, the tangantangan, has done well on Saipan. Another variety of this, the giant leucaena, has been planted on Saipan in an experimental plot and it too seems to thrive under the conditions. It is estimated that about 5 kW baseload power can be generated for a year from one ha of giant leucaena (koa haole) when harvested and chipped (30 tonnes/ha). If we assume, as mentioned in Chapter 2, that a planting of giant leucaena can be harvested every four years, it would take only 800 ha to support a 1 MW power plant (see Chapter 2 for a more detailed discussion). This is a plot of land less than 3 kM on a side. Such a plant could support all the energy requirements of Tinian or Rota. A 10 MW biomass plant, 8000 ha (9 kilometers on a side), could furnish more than 50% of Saipan's electrical energy needs. Pre-emption of agricultural land for a tree farm is not expected to be a problem because so much of the land is both fallow and under the control of the government. An additional possibility is that private farmers might be encouraged to plant trees for use by the power plant, or even as a cash crop for export as pulpwood. If the wood were valued at $100/tonne, four hectares, one harvested each year, could yield $3000 to the landowner each year.

Establishment of biomass electrical generating capability in CNMI is expected to cause few social and cultural impacts of a negative nature. One environmental problem might be the occasional typhoon and the accompanying high winds. The first planting of giant leucaena in Saipan was slightly damaged by a typhoon. Regrowth is taking place normally. Some of the electrical generating systems presently in use in Guam and elsewhere in the Pacific are residual oil-fired steam generators and, while the sizing of the water tubes would be different for a wood-fired boiler, the concept is very similar and should lead to similar maintenance experience in the CNMI. In short, the operation and maintenance of a biomass electrical generating system is expected to be both familiar to the local labor force and to be readily accomplished by them.

Wood can also be gasified and the resulting producer gas, that gas which comes from the incomplete combustion of woody materials, can also be made and used in the CNMI. Wood or coconut husks can be used for raw material as can any other similar material. The gas itself can be used to power a conventional oil-fired generator system or even to power a vehicle if it has been converted to burn the fuel. Sources of possible fuel and the steps needed in order to utilize it must be investigated before the applicability of this technology can be determined.

A number of manufacturers world-wide are marketing systems which can be sized anywhere from a few kW to several MW. For sites such as Tinian or Rota this technology may be very appropriate.

If the CNMI is subject to the Clean Air Act, measures to clean-up the stack gas from the biomass boiler or gasifier are readily available and can be used. Consumptive use of water for the steam and cooling cycles may present problems, particularly on Saipan where the existing water distribution system is just now being upgraded and there is an apparent water shortage. If a labor-intensive technology of biomass cultivation for energy is chosen, it could provide many new jobs. Full time agricultural jobs are new to many of the residents but there is a tradition of part-time farming. If the transition can be made to full-time husbandry, this energy option could lead to increased employment in the CNMI.

Municipal Solid Waste

As estimated by Barrett, Harris & Associates in 1980, solid waste generated on Saipan might amount to between 6605 and 9137 tonnes/yr. Presently, little of this is collected. If we assume that it could be collected and that half of this might be suitable for combustion in the biomass plant, it could be used as a supplement for wood from the tree farm. Used in this way, it would contribute as much energy as the tree crop from an additional 110 to 150 ha while at the same time reducing the solid waste disposal problem.

Biogas

Anaerobic fermentation of biological waste generates significant quantities of methane (natural gas). Where this takes place in a community sewage treatment plant, this biogas is often used for process heat for the plant, any excess can be purified in order to remove corrosive gases and the remaining gas sold to a local utility. Unfortunately, there are no secondary or tertiary sewage treatment plants in the CNMI where this could be done.

It is the intent of the CNMI to encourage dairies, piggeries and other similar industries to become energy self-sufficient. To this end, they have established demonstration biodigesters at several of the piggeries and intend to assist the dairy on Tinian by demonstrating biodigestion of the cattle waste to provide gas for process heat and to use the excess for electricity generation. The effluent from the digester can be used to grow algae and aquatic plants for feed and fertilizer.

There are now between 20 and 30 piggeries on Saipan and the wastes from these could be processed to generate biogas for use at the piggery; excess could be sold to local users or used to generate electricity. The dairy farm on Tinian could also process its wastes in this manner. While these sources may not contribute much to generation of electricity for general energy needs in the CNMI, full use of available sources would reduce demand to some extent and hence the load on conventional electrical generation facilities. Because there is no gas pipeline distribution system in the CNMI, a decision to use biogas as a utility fuel would entail a significant expense for installation.

Anaerobic digestion can also be done on a small scale more appropriate for a single family or a small group of families. Adoption of this technology could replace the energy used by individual families for their cooking and thus contribute toward reducing energy demand. There is increasing acceptance of this concept on Saipan and Tinian, however, widespread adoption will entail significant changes in traditional practices.

Solar Hot Water

While historical data on solar insolation are not available for the CNMI, partial data (beginning in 1982) and general impressions indicate that the resource is more than adequate for a variety of solar applications. It is estimated that about five to six kWh per sq meter are available per day on Saipan. The use of solar energy for heating water for domestic and commercial use is a particularly appropriate application for the CNMI. In the past, about 40% of the residential electrical energy was consumed for this purpose. With the general adoption of solar water heating, this component of energy use could be significantly reduced.

Commercial solar water heaters are readily available. The options on the market range from sophisticated, pumped systems with separate collectors and storage tanks to simple solar water heaters which combine the solar collector with the tank storage, the so-called bread-box collector. In addition, there are a number of designs for simple thermosiphon systems which can be built by the homeowner for a small fraction of the cost of a commercial one. It is the aim of the Energy Office to continue to conduct workshops for people who want to make their own solar water heater. Solar water heaters are marketed through outlets in Japan, Australia and throughout the United States. Five year guarantees are commonplace.

There are already some solar water heaters installed in CNMI. There seems to be no problem with acceptability, and, for installation on the roof of a residence or on the property, there is no land availability question. As is the case with the other technologies, typhoon resistant installations are necessary, and protection against wind-driven missiles is required. No significant environmental problems have arisen.

Existing mechanical and electrical capability in CNMI should be adequate to keep the systems functional. The repair and servicing of solar water heaters is similar to the repair and servicing of any plumbed system or small electrical appliance. One potential problem may be that the pipes may scale more severely or corrode faster due to the high mineral content of the water. This can be mitigated through use of high temperature PVC. Probably the most attractive feature of investing in a solar water heater is that, by doing so, the consumer is setting his costs for water heating for the life of the solar system, independent of inflation.

Photovoltaics

Photovoltaic systems also capitalize on the solar energy resource available in the CNMI. A number of photovoltaic concepts exist and have been commercialized, ranging from single crystal silicon photovoltaic cells to thin film amorphous photovoltaic cells. The single crystal cells, after an initial period of development, have demonstrated good reliability and durability.

No adverse impacts are anticipated in the areas of cultural, land availability or environmental effects. The total land required for a 10 MW peak system might amount to about 20 ha. Since photovoltaics is a relatively new technology, an educational program will be necessary to train personnel who perform routine O&M. It will also be necessary to develop sources for parts and servicing.

Sunshine in the CNMI has a daily energy content of about 5-6 kWh/m^2. Thus, a PV system which could supply energy equivalent to a conventional oil or diesel-fired system would be more than four times as large as the peak rating size. This means that a photovoltaic system which would generate the same total energy as a 10 MW diesel or oil-fired generator would occupy about 80 ha, almost a square kilometer. The storage system to allow reliable, continuous 24-hour operation would add to the cost and land area. However, photovoltaics can also be operated without storage, providing electricity during the sunlight hours and saving oil or diesel. In addition, if the hours of operation of the electrical load can be restricted to the sunlight hours, then PV can supply all the energy needed without the necessity of batteries.

The CNMI intends to use photovoltaics for light and radio for each household in Alamagan and Agrihan, and for refrigerator/freezers for the dispensaries. They will also be used to power lights and fans for Rota and Tinian airports.

Operating and maintenance costs are expected to be small. Photovoltaic generation of electricity is competitive today with intermittent use of high speed diesel generators in off-grid locations. Costs need to drop another factor of ten before PV can be seriously considered as a baseload energy source for larger electrical requirements (eg kW to MW).

Salt Gradient Solar Ponds

There are a number of solar ponds in use throughout the world in climates ranging from arid desert areas to more northern areas where the pond itself freezes over in the winter. Experience is accumulating. While solar ponds have not reached the point of commercialization, indications are that developments needed will consist mainly of efforts to make the components less expensive and to integrate the installation to reduce the overall system cost. Solar ponds are especially attractive because they provide baseload, not intermittent power. Experience to date has indicated that the concepts are sound and that a fully commercial system should operate reliably and without undue attention to either operation or maintenance. The wind and salt air conditions in the Pacific may present special problems.

The scale of proposed solar ponds is fully compatible with the needs in the CNMI. A baseload 10 MW pond might require about 2 square kilometers of pond, and, as the case with the tree farm concept, could either replace present expensive fossil-fueled diesel generators or accommodate electrical growth for the next decade or two.

A 10 MW salt gradient solar pond system is a 10 MW baseload system which is not only able to continuously put out 10 MW but, if it is equipped with the heat exchangers and generators to do so, it can also handle peaking loads of up to 100 MW for short periods.

A solar pond would be a low-profile installation which would require land dedication but little else. Leakage of the concentrated brine from the pond could contaminate the fresh water lens underlying the islands unless it were contained. A salt-gradient solar pond has little or no effluent and the raw materials needed for the pond consist of sunshine and from time to time some additional salt. The salt would have to either be imported or obtained locally by use of evaporation ponds. If evaporation ponds were made and used, there is the possibility that salt could become an export commodity. Skills needed consist of general construction skills plus machinery operating and maintenance. The heat exchangers required are similar to many of those in common use for low grade heat recovery and should present no particular operating or maintenance problems. A comprehensive educational program should be carried out to upgrade and improve existing capabilities. The remoteness of the installations may make maintenance more difficult.

Wind

Wind power may be able to contribute small amounts of energy to remote locations, however, large installations seem to be incompatable with the fact that the CNMI is subject to heavy typhoon winds. In addition, current information on winds in the vicinity of the islands seems to indicate that they vary around 7 m/s (15 mph). Most wind generators do not begin to generate energy until the wind reaches 4.5 m/s (10 mph) and are rated for winds in excess of 9.5 m/s (20 mph). Dropping the average wind from 9.5 to 7 m/s drops the generated energy by about two and a half, thus de-rating a four kW windmill to about one and a half kW and increasing the capital cost per kW by the same factor. If locations with consistent winds in excess of 10 m/s can be identified, it may become worthwhile to attempt to design special wind generators which can survive typhoons. For special cases in remote areas, particularly for small farms, small wind generators or water pumpers may prove very effective.

Geothermal Energy

The technology needed to convert geothermal energy to electricitiy is well developed for use in other places. It may be that it could also be applied to the CNMI. The islands of the CNMI have characteristics which suggest that there may be substantial geothermal resources. The recent history of volcanic activity on Pagan (May 15-23, 1981 and January 4-6, 1982) emphasizes this. Recently, there has also been a "sulfur boil" off the coast of Tinian. Other eruptions in the past have been on some of the other islands. Geothermal resources may exist on the islands of Saipan and Tinian, but geologic reconaissance is needed to locate geothermal indicators and to assess the likelihood of locating an exploitable geothermal resource there, or on other habitable islands of the chain. Geothermal power could either be used for major generation facilities or, where the resource is less, to provide energy for village needs.

Solar Thermal

Solar thermal energy conversion (STEC), the converting of solar energy into thermal energy and then into electricity via the usual steam cycle, has received a great deal of attention recently. While several experimental STEC systems have been fielded, much development work yet needs to be done. At the size most appropriate for the CNMI, the small village configuration, the first developmental distributed collector systems are just beginning to accumulate operating experience. As yet, little information is available on reliability or durability, especially under the relatively hostile wind and corrosion environment of the CNMI. Sizes envisioned for CNMI seem to be compatible with sizes now being developed, both commercially and with government funding.

The land availability question remains. About 30 ha would be needed to generate 10 MW at peak solar incidence. A single "dish" of about 10 meters (30 feet) diameter can supply about 15 kW peak (see Chapter 2 for more details). This might be appropriate for a remote village. Little in the way of environmental effects are anticipated. Since the technology is new, a comprehensive educational program will probably be necessary so that local people can participate in installing, operating and maintaining the STEC system.

Like photovoltaics, this technology also needs extensive storage capacity before it can be relied on for baseload electricity generation. Such storage costs would be over and above the costs associated with installation of the basic system. In addition, because the solar resource is about 5-6 kWh/m^2-day, the size would have to be quadrupled in order to provide the same energy that a baseload conventional system provides. Land requirements might amount to 150 ha (1.2 kilometers square) for a STEC system which could generate the same total energy as a 10 MW diesel driven or oil-fired electrical generation system. Costs and land dedication for storage would be in addition to this. This places it in the same category as photovoltaics and restricts its applicability to situations where intermittent power is acceptable or to remote locations. Baseload applications might become more competitive as costs for energy storage and for STEC fall.

Ocean Thermal Energy Conversion

Some of the most favorable ocean thermal resources in the world are found in the CNMI. Near both Saipan and Tinian a temperature difference of 21°C (38°F) exists between the surface waters and waters at 550 meters (1800 feet). This increases to 23°C (41°F) at 900 meters (3000 feet). Based in part on this, and on the appropriateness of the projected size of a pilot Ocean Thermal Energy Conversion (OTEC) plant (10 MW), the government of the CNMI proposed to the United States Department of Energy (DOE) that one of the sites for a first plant be on Saipan. The plan submitted to DOE was for a plant to be located near Puntan Kagman, on the southeast coast of Saipan. The DOE site selection committee reported, "The major weakness is centered around the site selection. The site is located in a typhoon prone area and the survivability of the plant and cold water pipe (CWP) is questionable. The plant design is also susceptable to a multitude of less critical problems as a result of near shore location such as trapped currents which would reduce the available sea water temperature differential and possible build-up of trapped debris." It is not clear whether the site selection committee considered that no site in CNMI would be acceptable or just that this special site was in particular jeopardy.

There is as yet little relevant data on either the reliability or durability of an OTEC electrical generating plant. While information and operational experience are being accumulated on the performance of cold water pipes in ocean environments, pipes to date have been much smaller (70 centimeters or 28 in diameter in the facility the Japanese built in Nauru) than those needed for megawatt-sized OTEC plants (5 to 10 meters in diameter or 16 to 33 feet). Not only will such structures be much more difficult to fabricate and to protect from the ocean environment, no one has ever emplaced a pipe 5 to 10 meters (16 to 33 feet) diameter by 1000 meters (3300 feet) long in the ocean. The heat exchangers used to date have been titanium, and seem to have performed as designed. A scale-up by a factor of 10 to 100, however, may introduce problems unforseen at the present time. Recent developmental work by the Trane Corporation on aluminum heat exchangers has shown promise. If the initial encouraging results are substantiated, costs could fall. The pumps and associated massive flows of both cool and warm water are on a scale that is unprecedented in such applications. In short, while development of the technology is proceeding well, it is not yet commercial at any size.

Technically, the CNMI proposed 10 MW OTEC plant would be of such a size that it could make a significant contribution to replacing some of the present fossil fuel intensive plants or it could fill expansion needs for the next decade or two. There seems to be little applicability of OTEC to smaller installations.

The CNMI government has been and is strongly committed to the concept of an OTEC plant on Saipan or Tinian, thus, there already is an official acceptance of such a plan. Since the CNMI proposal invisioned a near offshore plant, there would likely be little land requirement except for passage of the power lines to a central load dispatching point.

Negative environmental impacts are expected to be small. On the positive side, it is possible that the cold water effluent could be used for mariculture, thus combining energy production with food production.

The CNMI does not have a labor pool with the skills needed to operate and maintain an OTEC plant. Concurrent with planning and building such a plant therefore, a determined effort should be made to train local people. This should also extend into the existing school systems. In addition, an adequate support infrastructure must be established for repair and replacement parts and/or servicing either on-island or off.

Liquid Fuels Conversion

In addition to the use of biomass for generating electricity, sugar cane, cassava and corn have been grown and fermented to synthesize alcohol in various parts of the world. While crops certainly could be grown in the CNMI for conversion in this way, the efficiency of conversion to alcohol is so low that land available for this purpose in CNMI may not be sufficient to make a significant impact on present use of transportation fuels. In addition, liquid fuels conversion technology is not yet commercial. Where it might make sense eventually is in use in single farm situations where sufficient land can be planted in the appropriate crops to make the farm self-sufficient in fuel for tractors and other vehicles. This would also make the by-products, such as animal feeds available for consumption locally without the necessity of drying and transporting. It makes particularly good sense where there is a waste stream, such as spoiled corn, which can be utilized in this way instead of being thrown away. More must be done to determine the appropriate crops and the site-specific yield expectations before this technique can be evaluated for the CNMI.

Ocean Tidal and Currents

Ocean currents have not been sufficiently characterized in the CNMI to determine the potential feasibility of ocean current energy conversion. However, the apparent energy content, the scale of the machinery necessary to utilize it and the presently undeveloped state of technology make it unlikely that this technology holds much promise for the CNMI.

Coal

While coal as a fuel has many attractive features, the use levels in the CNMI may not be high enough to justify conversion from oil to coal. Such conversion would require significant land dedication for the plant and the coal handling facility as well as improvements in cargo handling capability at the port. The quantities of coal needed may well be so small as to make them prohibitivly expensive, and thus the generated electricity also expensive.

Hydropower

There is little in the way of hydropower resources on any of the islands in the CNMI.

FINDINGS AND RECOMMENDATIONS

With the maximum baseload and peak electricity demands on Saipan running 11.7 and 15.4 MW, on Tinian 400 kW and 480 kW and on Rota 630 kW and 740 kW, there is good opportunity to replace a significant fraction of the oil-fired generating capacity with that powered by alternate fuels. Table 5-6 summarizes the most promising technologies which can make a major contribution to the baseload power requirements:

TABLE 5-6 -- PROMISING BASELOAD ALTERNATE ENERGY TECHNOLOGIES

TECHNOLOGY	READINESS	LAND FOR 10 MW PLANT
CONS/ENER MGMT	Near Term	Little or none
BIOMASS (TREES)	Near Term	8000 ha (20,000 acres)
SOLAR PONDS	Mid Term	200 ha (500 acres)
GEOTHERMAL	Long Term	Little Required
PHOTOVOLTAICS	Long Term	80 ha (200 acres)
STEC	Long Term	150 ha (370 acres)
OTEC	Long Term	Little Required

In addition to these baseload technologies, solar water heating and biogas technologies have great potential to reduce the demands on the central power system and make it available for more productive use.

Conservation and energy management are listed as a baseload electrical energy sources because energy conserved and efficiently used reduces the requirement for additional generation equipment and it releases present capacity for more productive uses. It can provide immediate additional energy at a minimum cost.

A biomass tree farm is probably the most promising of the baseload energy generation techniques for the CNMI. It uses readily available resources and has the potential for both short-term and long-term contributions to solution of the energy supply problems of the CNMI. A detailed engineering study on a biomass tree farm at a reasonable power level (1 MW) will be necessary in order to assess the viability of the concept. Note should also be taken that municipal solid waste and coal can be used as supplementary fuels in a properly designed biomass system.

The solar ponds technology is going through a rapid growth stage and costs may drop markedly in the near future. This technology is very attractive because it can function both as a baseload and as a peaking electrical energy source.

There are significant prospects for geothermal energy on Saipan and Tinian. The presence of the "sulfur boil" off Tinian recently indicates that the resource may be present there. The technology is mature.

Photovoltaics is presently best used for remote area, low power needs. If some of the projections for cost reductions for photovoltaic systems come to pass, it should be examined for applicability to baseload power production in the CNMI since it is probably the minimum land use option of all the alternative energy systems.

STEC, with its present vulnerability to high winds, does not appear appropriate for CNMI. As the technology matures, and as the storage technology also develops, this may change.

OTEC technology, while not commercial at present, has such promise as a baseload electrical generation source that it should be followed closely. It has the potential to provide a ready and abundant source of electrical energy for the CNMI.

The other alternate energy sources should be utilized for energy wherever appropriate. Applications in isolated areas may be particularly useful. However, until further development brings the costs down, other alternate energy sources are not considered to be capable of significant impact on major electrical generation needs.

Table 5-7 lists energy planning recommendations for the CNMI.

TABLE 5-7 -- ENERGY PLANNING RECOMMENDATIONS - CNMI

- o Improved energy management
  - Carry out electrical rate structure reform
  - Meter all electricity users
  - Bill all electricity users
  - Develop and enforce energy efficiency standards for all new buildings in the CNMI
  - Encourage efficient use of energy by demonstrating energy conserving techniques
  - Enhance energy education within the community, the government and the educational systems
- o Application of renewable energy technologies where applicable
  - Exploit solar water heating and biogas use to the maximum extent possible.
  - Conduct a detailed engineering feasibility study on a biomass tree farm to be located on Tinian and/or Rota. If found feasible there, proceed with implementation and study the applicability to Saipan. The power level to be studied for Tinian and Rota should be of the order of 1 MW and 5 MW for Saipan.
  - Follow the technology development of salt gradient solar ponds.
  - Conduct a preliminary survey of Saipan and Tinian to investigate geothermal possibilities.
  - Use photovoltaic modules for remote sites, particularly those which are able to accommodate to low power and intermittent use. Prime candidates are on Alamagan and Agrihan. Follow the technology development of photovoltaics and energy storage.
  - Follow the development of STEC technology, especially the "dish" approach.
  - Follow the development of OTEC technology.

CHAPTER 6: ENERGY PLANNING FOR THE FEDERATED STATES OF MICRONESIA

The Federated States of Micronesia (FSM) includes, from east to west, the states of Kosrae, Ponape, Truk, and Yap, and their outlying islands and atolls. All are former districts of the Trust Territory of the Pacific Islands (TTPI). The FSM is almost 100% dependent on imported petroleum for both electricity generation and transportation fuels. The electrical generation facilities, which depend entirely on imported petroleum products from Mobil Oil Micronesia, Ltd., include the relatively new and well-maintained Tofol power plant at Lelu, Kosrae and the plant at Colonia Yap. The plants in Kolonia, Ponape, and Moen, Truk are older and not so well-maintained. The total capacity of each plant is under 6 megawatts, power outages occur frequently, and future economic expansion is expected to overburden some of the plants. Much of the generating equipment is composed of medium or high-speed diesel units that are not designed for baseload electricity production, thereby presenting an additional maintenance problem.

Energy planners for the FSM would like to provide adequate electricity generating facilities for the population centers, reduce vulnerability to fuel supply interruptions and price increases, and to provide small, reliable electricity generating systems for outlyilng villages and remote islands. These goals must be pursued in the context of small areas of land spread out over large expanses of ocean, a very narrow economic base, and a burgeoning population. Steady migration from the outer islands and a birth rate of about 3.5% is swelling the size of the urbanized areas. Populations in the district centers range from about 2000 at Lelu, Kosrae to 10,000 at Moen, Truk. The FSM covers almost 1.6 million square kilometers (1 million square miles) of the Central and Western Pacific Ocean, from about 1° to 12° north latitude and from 135° to 172° east longitude (see Figure 1-1). The area includes over 600 islands and atolls in the Caroline archipelago. The total land area is 451 square kilometers (271 square miles), and the estimated population is 74,404 (1980).

The FSM includes high islands, which are volcanic in origin, and the smaller low islands of the coral atolls. Island elevations range from two meters (about 7 feet) on coral atolls to 600 to 900 meters (about 2000 to 3000 feet) on some of the high islands. The largest island is Ponape Island with 334 square kilometers (129 square miles) of land area. The climate is tropical, with relatively even temperatures from the mid-twenties to low-thirties Celsius (high seventies to mid-eighties Farenheit). Rainfall is heavy on the high islands, up to 760 centimeters (300 inches) a year, and lighter on the low atolls. Most islands have dry and wet seasons. The westerly islands are more susceptible to typhoons, but all the islands experience severe storms.

Vegetation varies from high island to low atoll. The atolls have coconut palms, breadfruit, pandanus, and shore plants which can survive in sandy soils. In addition to these plants, the high volcanic islands usually have mangrove swamps on the tidal flats, coconut vegetation on the slopes, and mixed growth on the uplands. The high islands have a somewhat richer soil capable of supporting a wider variety of plant life, but topsoil is thin, often badly eroded, and at best only moderately fertile.

The state governments own the power plants, and general government budgets cover operating costs. Billed revenues account for a small percentage of the expenses, so the cost of electricity is subsidized by local governments, and in turn, by the United States Government. Electricity is usually billed at about 5¢/kWh while the generating costs are around 20¢/kWh. Because of their remoteness and total dependence on imports, the islands are particularly susceptible to supply interruptions and price increases. Outlying villages and remote islands either do not have electricity now or rely on small diesel-powered generators. These communities need electricity for essential minimum services such as communication, refrigeration or lighting. Such systems either do not exist or are becoming increasingly expensive to operate on imported diesel fuel. Maintenance and repairs are a problem because there are few technically trained workers.

Various revewable energy resources such as solar, wind, biomas, hydropower, and ocean thermal are present in the FSM and could help solve energy problems. Technologies harnessing these resources can be used to power centralized, and decentralized energy systems on scales from 1 kw or so for remote communities, to 15 MW and larger for population centers. However, it is difficult to introduce these energy technologies because of general logistical problems caused by remote location; the harsh tropical environment, which includes typhoons and a highly corrosive atmosphere; a lack of local technical expertise; the unfamiliarity of United States manufacturers and suppliers with Pacific problems; and a lack of data for assessing the resources and siting the energy systems.

Chapter 2 discusses the general issues of renewable energy technology readiness, performance and suitability in the Pacific. A number of the technologies that are most promising for the FSM are discussed from the point of view of specific applications in the individual state discussions which follow. Other resources and technologies are so heavily constrained by conditions in the FSM that they are not discussed. For example, although several FSM islands are volcanic in origin, there are no surface features that indicate the presence of a geothermal resource, and therefore the considerable expense of a survey for the resource is not justified. Solar ponds are unlikely to be practical in the FSM because even where solar insulation is sufficient, adequate flat land is unlikely to be available. Solar thermal system technologies are not yet ready for remote locations, and in many FSM locations direct solar radiation levels may be inadequate. Population concentrations are not high enough to make collection and combustion of MSW feasible. Coal, although it is still an imported fuel, has many advantages of cost and supply reliability over oil, but the FSM is too remote and its load demand is generally too small to make those advantages persuasive. Technologies for using currents, waves or tidal energy are not yet reliable for remote locations. Except in certain institutional and industrial applications, solar hot water systems are not expected to be in demand because high ambient water temperatures limit interest.

During the last five years, some renewable energy devices have been introduced in the population centers and on the outer islands. Programs involving these devices are gathering performance testing data at population centers; testing the reliability of certain systems in the Pacific environment; collecting data for selecting or siting additional systems; providing electricity at remote locations where electricity previously has not been available; or improving local well-being in villages with simple, replicable systems. None of these systems contributes to baseload electricial generation. In addition, funds for these projects have been difficult to come by, are small in amounts, compared to funds for similar systems in the United States, and are unpredictable with promised money frequently being withdrawn or attached to unrealistic provisions. Local or United States private funding sources are limited by the remote location and uncertain economic conditions of the FSM.

During the last few years the United States, FSM and TTPI governments have provided funds to establish state energy offices, make general feasibility studies, and to purchase and distribute small energy devices. This work must go further. There is an urgent need to collect reliable, site-specific data; to install large-scale systems (of the MW size) which will contribute to baseload production at central locations; and to install reliable small systems for remote locations.

HISTORY AND POLITICAL DEVELOPMENT

In 1978, the people of the TTPI approved a constitution, written by elected delegates, forming the new FSM government. (Palau and the Marshall Island districts rejected the constitution and subsequently sought their own agreements with the United States). The seat for the new FSM government is in the town of Colonia in Ponape. A President, elected by the National Congress, heads a government which includes executive, legislative and judicial branches. Each state remains internally self governing, with it's own parlimentary body or council, and governor.

In the latter part of 1980, the FSM initiated a Compact of Free Association under which the FSM retains complete sovereignty over the islands and has full domestic autonomy and responsibility for all foreign affairs except defense. The United States would provide specific levels of financial assistance and other services over terms of 15 to 50 years in exchange for exclusive military authority and certain land use agreements on the islands. Both the people of the FSM and the United States Congress must approve any final agreement. In addition, the United Nations must terminate the Trusteeship. Until then, the inhabitants of the FSM will legally be Trust Territory citizens.

POPULATION, EMPLOYMENT AND WAGES

At the time of the first reliable population census, 1973, there were approximately 62,700 persons residing within the four FSM states. Population varied widely among the four states. Truk had 31,600 inhabitants, 50% of the total FSM population, while Kosrae had 3,900 inhabitants, 6% of the FSM total. The 1980 population was about 74,400, an increase of 17% since 1973, with no significant change in distribution among the states. Current (1980) populations are: Kosrae, 5,522; Ponape, 22,968; Truk, 37,742; and Yap, 8,172.

The rate of increase is about 3.5% annually, varying only slightly among the states. At this rate the 1983 population of the FSM will be about 84,400, an increase of over 34.5% since the 1973 census. If current trends continue, the FSM can anticipate a high growth rate for the remainder of this century, doubling the population in about 20 years.

The FSM islands differ in historical development, culture, and traditional socio-political framework. Equally important are the similarities. Colonial heritage; and common people, problems and ideas, create a sense of homogeneity among the islands. A complex system of class ranking and social stratification are common, with variations, to all FSM cultures. An individual's land use rights, which usually extend into the adjacent lagoon and reef areas, largely determine that person's status in society. The close identification of a family with a parcel of land and inheritance rights to that land encourage the development of strong kinship groups or clans with particular land holdings.

The islands are in the midst of significant political and cultural changes. New government systems are being adopted by people more familiar with traditional systems. Societies used to oral means of transferring information, are now immersed in bureaucracies with the accompanying paperwork. Islanders are anxious to acquire modern technologies and yet lack the technical background to select, install and maintain such systems. Four major powers (Spain, Germany, Japan, and the United States) and two major wars during the last hundred years have had great effects on traditional societies. Unemployment and poverty are high by United States standards as are suicide rates among young adults. However, most islanders have not been alienated from the land, which is the fundamental source of wealth in the Pacific. Paved roads are few, most population centers have "water hours" despite heavy rainfall, and power outages are frequent. None of the islands have developed local economies, and all depend heavily on United States Government support.

PRESENT ECONOMY AND INFRASTRUCTURE

Government spending largely sustains the economy of the FSM, and this financing in turn, depends upon transfer payments from the United States Government. External trade figures show the unbalanced state of local economies. (Unless stated otherwise all economic figures are for 1980 dollars. Because of difficulties in gathering reliable data, current figures are often unavailable.) In FY 1977, the FSM trade deficit was $33.9 million. Exports of $2.0 million, made up only 6% of the $35.9 million of imported goods.

Argiculture and fishing make up the largest sector of the private economy. In 1977, 42% of the employed labor force, 7,900 persons, worked in the village (subsistence) economy in agricultural and fisheries activities. Evidence indicates this percentage has not changed recently. The value of this sector's output was about $8.8 million. Output in the village Output in the village economy accounted for 12-24% of each state's gross domestic product (GDP). Productivity in subsistence agriculture and fishing, was quite low; 42% employed people generated 18% of the GDP for the FSM.

The major resource available to the FSM for economic development is the vast expanse of ocean with the 200-mile economic zone. Although the tropical oceanic environment is not noted for it's productivity, there are exceptions at the bottom of the thermocline, island wakes, submerged banks, and current boundries. Tuna is the most valuable fish in international markets and is a major under-exploited resource. Access rights to the extended economic zone of the FSM have been negotiated with a consortium of Japanese fishing groups. This agreement earned $2 million for the FSM in 1979 and 1980. The agreement included a responsibility to provide data on fishing activities and catches to the FSM.

Tourism is another important source of income and employment in Micronesia, and it is an area which has some growth potential. Several hundred jobs are directly or indirectly related to tourism. There are about fourteen hotels and over 200 rooms in the four states. Other tourism-supported jobs exist in resturants, airline agencies, tour operations, boat and dive shops, and handicrafts. The number of visitors to the FSM average over 14,000 a year; their expenditures are about $1 million. Over one-half of the visitors originate in the United States, and about one-fourth come from Japan.

The major industry in Micronesia is copra production and the processing of copra into coconut oil. Copra producers in the FSM sell their output to a private firm for delivery to Japanese mills. Other manufacturing activities in the FSM are mostly cottage-type businesses in the subsistence sector. The few activities that produce for the market economy generally have inadequate capitalization, inexperienced management and an untrained labor force.

There is some small-scale handicraft production, employing fewer than 100 persons. The demand for handicrafts is rising with the increasing number of visitors.

Other industries are small, primarily service oriented. These business, usually family-owned and operated, include auto repair shops, barber shops, restaurants, a sawmill and stevedoring companies. Boat building is widespread but is done by individual craftsmen working at home.

Virtually all merchandise sold in the FSM is imported. The present pattern of merchandising in each state is characterized by one to three large enterprises operating as general import-wholesale-retailer, and many small stores. These small retail stores serve as neigherborhood stores and usually are secondary family activities. Most of them operate on a very limited budget, buying in broken lots of perhaps two or three items at a time.

In summary, the economy of the FSM suffers from several inbalances including consumption exceeding income, and imports exceeding exports. The economic base is underdeveloped. Labor, land, natural resources, capital, and basic infrastructure are meager and scattered over many islands isolated from each other by a great expanse of Pacific Ocean. The gross product comes from largely United States funded expenditures for services and capital improvements, and from tourism, copra, subsistence agriculture, small-scale fishing and the lease of fishing access rights, and handicraft production. The economic status of inhabitants varies from the semi-urbanized resident of the government centers participating in a money economy to outer islanders who may receive only a small amount of cash from copra sales and handicrafts and remittances from relatives in the government centers. Appropriations and grants from the United States maintain the present standard of living of the people and level of government operations in the FSM. Indigenous economic production is low, and the infrastructure needed to meet basic economic needs and support economic development is not in place.

KOSRAE

Kosrae is the easternmost high island in Micronesia and the easternmost, and most remote, of the FSM states. It is also the most sparsely settled state, with 5,522 people, 1,998 of whom live on Lelu (1980). The remainder live in the small villages of Tafunsak, Malem, and Utwe. The population is of mixed European-Polynesian-Micronesian descent.

Kosrae is entirely dependent on imported petroleum for electricity and transportation. It has an extremely narrow economic base and its remoteness limits its development potential. The present generating system at Lelu is adequate. Renewable resource technologies are most likely to be used in rural areas.

Kosrae is 4,112 kilometers (2,467 miles) southwest of Honolulu, 2,000 kilometers (1,200 miles) southeast of Guam and 512 kilometers (307 miles) east-southeast of Ponape island. The roughly circular, 117 square kilometers (42 square miles) island is 13 kilometers (8 miles) wide at its greatest point (see Figure 6-1). The island is mostly mountainous with valleys interspersed between two peaks, one of which, reaches over 610 meters (2,000 feet); the interior is heavily covered with dense forest. A ring of coastal lowlands and mangrove swamps contains the only human settlements, the biggest of which is on Lelu. Lelu is a small adjoining island, connected by a causeway, off the northeast cost of Kosrae. A shallow, flat, reef encircles all of Kosrae.

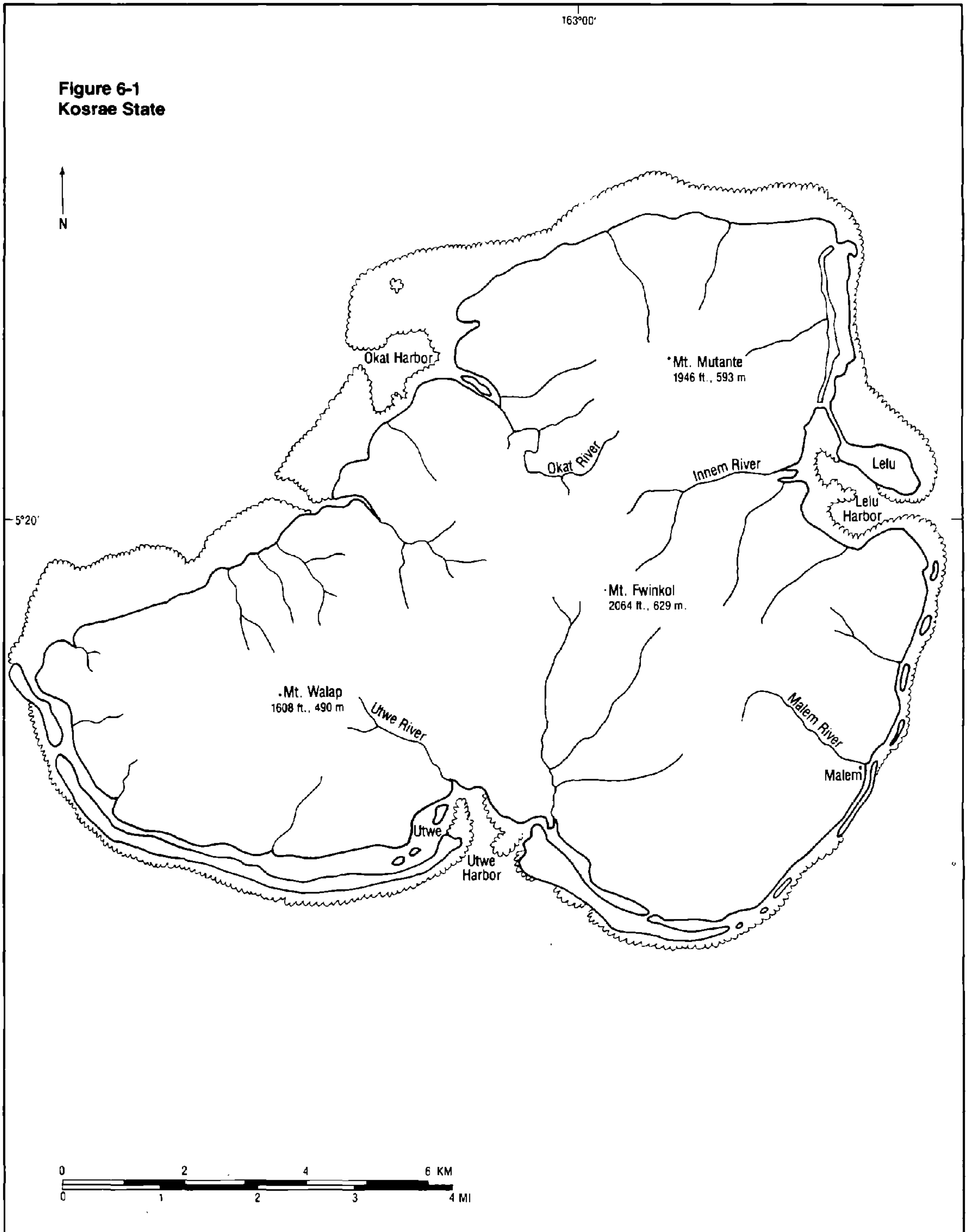
The climate is tropical: Hot and humid with a temperature of about 27°C (80°F) year around. Rainfall is relatively high, averaging 470 centimeters (185 inches) a year on the coast and 635 cm (250 in) on the highlands. Typhoons are rare--the last occurred in 1905--but tropical storms are moderately severe during the rainy season.

HISTORY AND POLITICAL DEVELOPMENT

Micronesian people related to others on the Caroline and Marshall Islands, originally settled Kosrae. The Spanish arrived in 1529, but travelers visited the island infrequently until the great whaling era in the first half of the 19th century. Because of its fine harbors and fresh water supply, Kosrae, then called Strong's Island, became a popular stopover for sailors. The early years were turbulent with sailors provoking several local wars before local rulers restored peace in the 1840s. In the 1860s, with the decline of the whaling industry, missionaries began their work and Kosrae became the evangelical center for the Caroline and Marshall Islands during the next 30 years.

The Spanish did not develop Kosrae commercially during those years because of it's remote location. After purchasing the island from Spain in 1899, the Germans also did little for development. At the start of World War I, the Japanese, who had commercial interests throughout the Pacific, immediately occupied Kosrae along with the other Caroline and Marshall Islands. Again, because of Kosrae's remote location, the Japanese did not develop the island commercially. During those years the island was called Kusaie.

Figure 6-1
Kosrae State



After World War II, a United Nations mandate placed Kusaie under United States protectorate, first under Naval administration and then in 1951 under the jurisdiction of the Department of the Interior as part of the TTPI. At that time it was made an administrative subdivision of Ponape District, one of the six districts of the TPPI. Finally, the High Commissioner of the TPPI approved a petition for separate district status and on January 1, 1977, the inhabitants installed a district government and renamed the island the preferred name of Kosrae. In a constitutional referendum in 1978, its people voted to join the FSM and their own popularly elected legislative government took office in January, 1979.

ECONOMY AND INFRASTRUCTURE

Kosrae is one of the most remote islands of the FSM. Pacific Missionary Airlines flies there a few times a week; government field ships stop by with supplies and some passengers about once every six weeks or so. Lack of more frequent supply trips and travel to Kosrae often causes problems developing, installing and maintaining energy systems. It also makes Kosrae vulnerable to interruptions in petroleum supplies, hinders economic development and discourages tourism.

Kosrae, like the other FSM states, has a very small economic base and is almost totally dependent on government expenditures. Kosrae's Overall Economic Development Committee has established economic goals that depend on developing agriculture, fishing, forestry and tourism through the specific projects:

- Agriculture

  Using the ship, M.V. Kaselehlia, which has recently been assigned to Kosrae, for farmers to export their agricultural produce elsewhere in Micronesia, thereby expanding agriculture;

  Developing farm roads into Kosrae's interior; and

  Building a road around the perimeter of the island as access to the farm roads;

- Fisheries

  Building a solar photovoltaic refrigeration system for Utwe village. This village has the largest group of active fishermen, but does not have refrigeration facilities to preserve the fish.

- Forestry

  Obtaining additional data on forest resources with the help of the United States Forest Service;

  Building a small dip tank preservation facility for preserving wood; and

  Investing in transportation trucks and a tractor cable skidder.

- Tourism:

  Promoting the development of a reliable, scheduled air service;

  Developing room facilities for visitors to Kosrae; and

  Encouraging handicrafts.

A new airport and port facilities are being completed which should improve travel and shipping, and facilitate developing the above projects.

PRESENT ENERGY SYSTEMS

Kosrae is 100% dependent on imported petroleum as fuel for electric power generation and transportation. Table 6-1 lists the amounts of various types of petroleum purchased during 1980 and their end-uses. At present, the largest demand for fuel on Kosrae is diesel oil for generating electricity; 65% of the fuel brought into Kosrae is for this purpose.

The principle source of electricity is the Tofol power plant which has two new (1980) 400 kW mid-speed Caterpillar diesel generators. In addition, there are two 10-year-old White 300 kW diesel

Table 6-1

End Uses of Fuels, Kosrae, 1980

(in 1000's of bbl)

Fuel	Amount Purchased	Price[a] ($/bbl)	Gov't	Private[b]	Comm'l/Indust/ Construction	Marine Transportation Field Ship	Other	Electric Generation
Motor gasline	3.5	54		------------3.4[c]---------		.1		
Aviation gasoline	-0-	137						
Jet fuel-K	-0-	72						
Kerosene	0.8	64	------------ 0.8 -----------------					4.5
Diesel	6.5	55	------------ 2.0 -----------------					

(a) At Mobil Bulk Plant, February 1981, exclusive of taxes and transportation from plant

(b) 325 autos

(c) Includes outboard motors

generators which have never been run and need considerable cleaning up, and a backup 350 kW Caterpillar. The Tofol power plant is able to meet successfully the island's peak electricity demand of 350 kW. This load occurs during the working days at mid-morning, mostly because of the high electrical consumption of government offices for air conditioning. Power plant personnel cycle the two Caterpillar generators to assure even wear--one generator is able to meet the peak demand--and they do a good job of maintaining the plant. Tables 6-2 and 6-3 give additional information on electrical generation.

Table 6-2

Electrical Power Generation, Kosrae, 1980

FUEL			OUTPUT (million kWh/y)	END USE (million kWh/y)				CAPACITY (MW)			LOAD (MW)	
Type	Amount Purchased (1000's of bbl)	Price[a] ($/bbl)		Res	Comm'l/ Indust	Gov't	Milit	Rated	Operating	Standby	Base	Peak
Diesel	4.5	55.44	2.1	-----0.8-----		1.3	0	1.4[b]	0.52	0.42	0.22	0.34
		TOTAL	2.1	-----0.8-----		1.3	0	1.4[b]	0.52	0.42	0.22	0.34

(a) Diesel price at the Mobil Bulk Plant, February 1981, exclusive of taxes and local transportation

(b) Two new 300 KW generators are in storage

Table 6-3

Kosrae Petroleum, Oil, Lubricants (POL) Costs

	Cost to Government	Total Operating Budget
1979:	$100,800	-
1980:	176,800	$1,900,000
1981	284,000	2,100,000

(For 1981 diesel fuel costs alone were about $232,000, based on an average monthly production of 176,000 kWh, machinery efficiency of 12 kWh/gal., and an average price of $1.31 gal.)

Total Energy Production: 180,000 kWh/month
Cost to Kosrae Government: 17-20¢/kWh
Amount of Energy Production Billed: 55,000 kWh/month

(About 70% of electricity is not monitored or billed)

Generated Revenues at 3¢/KWh: $450/month (out of $1,500 billed)

At present, electricity reaches about 40% of the population. Rates are currently 3¢/kWh despite generating costs of around 20¢/kWh (1981). About 70% of the users are not monitored or billed; this includes the government users (60%) and unmetered private users (10%). Of the $1500 in bills sent out every month about $450 are paid. At present there are no meters at the power plant to record energy production and efficiencies. Table 6-3 shows that operating the power plant in such a fashion accounts for a significant amount of the total government operating budget.

In order to remedy some of these misuses and inefficiencies, the FSM Five-Year Energy Plan (1982-1987) proposes a number of solutions. They include:

- Installing meters at the power plant to record energy production and efficiency
- Installing meters for all customers, including the government sector
- Allowing electrical rates to rise until collected revenues equal actual costs

Other recommendations encourage the development and use of renewable resource technologies.

The only renewable resource currently used to any extent on Kosrae is wood and coconut wastes burned for domestic and school cooking. Because of the low population density, fuel supplies are not a problem now; however, cooking in this fashion is time-consuming and smoke from the fires are unhealthy in poorly ventilated cooking shacks. The use of kerosene for cooking is increasing, but the data are not available on the breakdown between kerosene and traditional fuel consumption. A small DOE project is encouraging the use of efficient smokeless stoves on Kosrae; there are no data on how many have been built and are in use.

Another DOE project is for installing a SunSpot solar hot water system for the small hospital on Lelu. This has been a difficult project to complete because of supply problems, but a local contractor, with help for the energy office, should finish the project by early 1983. Data on projected energy savings are not available, but the project's real worth may be in serving as an introduction to renewable technologies and in gathering performance testing data.

ENERGY DEVELOPMENT PLANNING

The diesel powered system at Tofol is new and generally well maintained. To date it has been able to meet the demands adequately. There has been some down time to save fuel and to make repairs. There are plans to extend the electrical lines to the villages of Malem, Tafunsak and perhaps Utwe, for an additional 350 domestic connections or so. These connections sould be made over three years, about a third each year. Each new home is expected to consume an additional 300 kWh/month for an eventual load growth of 100,000 kWh/month. The new harbor and airport that are being built should increase overall demand. Based on current peak demand of 350 kW, mostly from the government sector, and the peak weekend demand of 260 kW, the present system with a nameplate capacity of 1.4 MW should be able to handle this growth. However, the Kosrae government should consider using energy management methods and renewable energy technologies in order to reduce its vulnerability to fuel interruptions, reduce government expenditures for producing electricity, and supply electricity to villages not connected to the grid.

Because of Kosrae's remoteness, sparse and dispersed population, the percentage of villages not connected to the grid and lack of local technical expertise, certain small-scale systems could be a useful part of Kosrae's total energy system. Such technologies would not contribute directly to the baseload electricity production, but would help solve certain local energy related problems. They might also provide some local employment, not require extensive technical backgrounds, and be built and repaired with local materials.

The smokeless stove project described earlier has been quite successful generally throughout the FMS. Other similar projects that might be useful include small solar food/copra dryers, sail-assisted fishing vessels, small solar photovoltaic systems for either refrigeration or communication, or small wind electric systems (0.5 - 3.0 kW).

The type of project should be decided at the village level. The amount of money involved can be small ($5,000 or so), and there should be a high level of local involvement. For the most of these projects, additional data are not needed. Perhaps a small grant could be made through the Kosrae Energy Office to a community or local group to do one of these projects.

Table 6-4 lists renewable resource technologies and energy management methods along with their attractive features or drawbacks for Kosrae.

Energy Management

The present pricing system for electricity is ineffective. Costs far exceed revenues, government uses are not charged, the billing system is ineffective, and these are many unmetered connections. This system encourages consumption rather than conservation. Costs must be shifted to the users in order to foster conservation, achieve energy independence and help with economic development. The Kosrae government should consider using energy management methods, including installing meters at the power plant to record production and efficiencies; installing meters for all customers, and billing each customer, including government agencies, for electricity consumed, and increasing rates gradually so that the revenues eventually at least equal operating costs.

Hydroelectric

The most apparent renewable energy resource on Kosrae is hydropower from Kosrae's substantial rivers, originating in the interior mountains and fed by the heavy rainfall. There have been a number of studies assessing this resource, the most recent of which is the United States Army Corps of Engineers preliminary study (1981) of four major rivers; the Mutante, the Pukussuk, the Malem and the Finkol. All these rivers are near populated areas and three of them have intakes at existing water supply diversion dams. Based upon conceptual run-of-river hydropower plans, potential nameplate capacity varies from 120 kW to 140 kW, and the average annual energy output would be approximately 200,000 kWh at each site. The cost and financial feasibility analyses indicate that none of the sites are financially feasible if outside contractors do the work, because of lack of raods, high mobilization and demobilization costs and the remoteness of Kosrae from construction centers. However, these projects would be financially feasible if local communities (self-help) do the work with professional supervision.

Based on this idea, Kosrae is using $150,000 of HUD/TTPI capital improvement funds to construct a 50kW run-of-river system on the Malem river. This will be a self-help project with the local villages providing much of the labor. Work is just starting. This will be an interesting project for testing the performance and cost-effectiveness of a small hydroelectric system.

Solar

Solar technologies are generally well-suited for Pacific needs, but it is difficult to determine their suitability for Kosrae. Solar insolation data have not been collected and the relatively high proportion of the time the island is under cloud cover casts some doubt on the potential suitability of some solar technologies for Kosrae. The Department of Energy has just delivered a recording

Table 6-4
Technology Selection Criteria

	SOLAR						BIOMASS								
	Solar Hot Water	Photo-voltaics	Solar Therm-al	WIND ENERGY	GEO-THERMAL	HYDRO-ELECTRIC	Tree Farms	Biogas	Liquid Fuels	MSW	OTEC	OCEAN CURRENTS AND WAVES	SOLAR PONDS	COAL	ENERGY MANAGE-MENT
RESOURCE															
proven						●									●
suspected	●	●	●	●			●	●	●		●		●		
unknown					●					●		●			
none														●	
TECHNOLOGY READINESS IN PACIFIC															
high	●	●			●	●	●								●
medium				●				●	●	●			●	●	
low			●								●	●			
RELIABILITY PROBLEMS IN PACIFIC															
high												●			
medium				●					●		●		●		
low	●	●	●		●	●	●	●		●				●	●
DURABILITY PROBLEMS IN PACIFIC															
high			●	●							●	●			
medium	●	●					●	●	●	●					
low					●	●							●	●	●
APPLICATION															
centralized					●	●	●		●	●	●	●	●	●	●
decentralized	●	●	●	●	●	●		●	●				●		●
POTENTIAL CONSTRAINTS															
cultural impact	●				●		●	●	●	●			●	●	●
land availability		●	●	●	●		●	●	●				●	●	
environmental impact					●	●	●	●	●	●	●	●	●	●	
human resources	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
infrastructure	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
CAPITAL COSTS															
high (over $10,000/kW)		●	●									●			
intermediate ($3,000 - $10,000/kW)				●	●	●	●		●	●	●		●		
low (up to $3,000/kW)	●							●						●	●
O&M COSTS															
high			●	●					●			●			
intermediate		●			●	●	●	●		●	●		●		
low	●													●	●
COST EFFECTIVENESS															
near term (0-5 yrs)	●					●	●	●		●					●
mid term (6-15 yrs)		●		●	●				●				●		
long term (16-40 yrs)			●								●	●		●	
EXPECTED OIL SAVINGS OR AVOIDANCE															
high															●
intermediate	●					●									
low		●	●	●	●		●	●	●	●	●	●	●	●	

pyranometer to the Kosrae Energy Office but it is too soon for worthwhile data to have been gathered. These will be the first solar data collected on Kosrae.

As part of the Territorial Energy Assessment, DOE has commissioned a contractor to study specific solar photovoltaic applications throughout the United States Pacific Islands. One potential application for Kosrae would power a freezer for fish in a remote village, such as Utwe, with a 7.5 kW (peak) stand-alone system. Utwe does not have electricity now and this is hindering the development of a fishing industry. Again, solar isolation data are needed.

The solar hot water system being installed at the hospital will be useful for gathering performance testing data that can be used to predict the success of similar systems on Kosrae. There is not much demand for domestic hot water systems because of the high ambient water temperature.

Wind

There may be a potential for wind electric conversion machines to contribute in a fuel saving mode to the base electrical load of Lelu or for stand-alone electricity production in small villages that are not connected to the main system. Many of the Pacific Islands may have adequate wind regimes but it is difficult to assess these regimes without proper site-specific data. To date no reliable or useful wind data have been collected for Kosrae. Data that have been collected are either for short terms, not site-specific, not at heights equivalent to those at which a wind generator would be mounted, not continous, nor at proper locations. For the near term, the most likely use for wind machines will probably be for small stand-alone systems at outlying villages. Siting of larger machines will require substantial data collected over at least a two-year period.

Kosrae's remote location and lack of skilled labor make maintenance and repair of these systems difficult. It would be preferable to erect a small, stand-alone system (1.5 - 3 kW) for performance testing as a precursor to larger, grid-connected systems. Such a system could be similar to those DOE is installing elsewhere as part of its Pacific Island performance evaluation program for wind machines.

Biomass and Liquid Fuels

There seems to be some potential for using the Kosrae's biomass resource but no data are available upon which judgements can be based. One potential use of the resource would be direct combustion of gathered vegetation or the products of tree farms. Large government land holdings could make this technology possible, and it ties in nicely with Kosrae's economic plan to develop agriculture and timber industries. However, there may be barriers to harvesting trees for direct combustion rather than using them for building and other competing uses. Soil erosion on harvested land could well be a problem. Using biomass to make producer gas should be investigated for generating electricity in decentralized, village level systems, as should the combustion of coconut oil.

OTEC

Ocean thermal energy conversion is an appealing technology for most Pacific Islands including Kosrae, because of the technology's potential to make a significant contribution to the baseload. For Kosrae, the drawbacks, despite a potentially execellent resource, include engineering problems that have not been solved, and expense. The smallest economically feasible OTEC plant (5-10 MW) may be far to large for Kosrae's needs for some time to come. The lack of local technical skills is especially a problem because of the many engineering problems OTEC has encountered to date.

FINDINGS AND RECOMMENDATIONS

The power plant on Kosrae is new, generally well maintained and able to meet present demands adequately. Economic development will most likely proceed at a slow pace, so adequate capacity for the near-term should not be a problem. Additional capacity required to extend lines to rural areas should not be a problem either.

The Kosrae government should consider some additional methods for managing energy production and consumption. Properly trained personnel should make energy audits at Lelu and rural areas. To develop a data base for proper energy planning, the government should install meters at the power plant for measuring electricity production and generator efficiency. All users, including government users, should be metered and billed. Operating costs, not including capital replacement costs, greatly exceed revenues and so the government should consider changing the electricity rate structure to reflect true operating costs. Finally, programs should be established to train personnel to install, maintain and service renewable energy systems.

It is difficult to make specific recommendations for alternate energy projects because so few data are available. It does appear for the near-term that renewable energy systems will not be able to make significant contributions to baseload electrical production. Some systems may help for peak or intermittent situations, particularly for decentralized use. Wind and solar resources may not be adequate enough for wind electric and solar photovoltaic systems to contribute to diesel fuel savings. However, additional data should be collected for these resources and for the biomass resouce of tree farms. This latter technology may encounter certain cultural barriers and there may be competition for other uses of the trees. Depending on results from the new Malem river hydroelectric project, hydroelectric systems may have potential, but these systems could be too expensive unless they are done as village self-help projects. Capacity may also be limited. Producer gas or coconut oil systems have promise, particularly on a decentralized basis and a small plant should be built for performance testing. For the mid-term OTEC is promising, but depending on Kosrae's energy needs, there may not be a satisfactory match with end-use.

For rural areas the government sould encourage energy audits to determine needs and ways to meet these needs. Wood cooking stoves, small photovoltaic systems, sail assisted fishing vessels, and perhaps small wind electric machines should be considered. Village ownership and participation in these projects is necessary, as is training of local people to service these systems. Table 6-16 at the end of this chapter lists the various recommendations for the FSM, including those for Kosrae.

PONAPE

The state of Ponape is part of the East Caroline Islands in the Central Pacific Ocean and consists of the 310 square kilometers (112 square miles) high island of Ponape and 39 other small islands, islets and atolls which together have only 11 square kilometers (4 square miles) of land area (see Figure 6-2). The population of Ponape is 22,968 (1980). The immediate energy needs of Ponape are acute. They include deteriorating equipment, frequent outages, transmission lines built, but not connected due to unreliable generating equipment and inability to meet demand for new electrical hookups. Like the other FSM states, Ponape is dependent on oil, and the high costs of diesel fuel are affecting the availability of funds for other services.

The state of Ponape is 5,448 kilometers (3,269 miles) west of Honolulu, 660 kilometers (400 miles) east of Truk and 512 kilometers (307 miles) west-northwest of Kosrae. The largest and most developed island is Ponape Island, a heavily forested, rugged mountain formed by the remains of a basaltic shield volcano. This island has about 90% of the state's population; about 5,500 people live in the capital city of Kolonia. The rest of the population inhabits the principal outer islands of Mokil, Pinge Lap, Ngatik, and Kapingamarangi. The island is 21.6 kilometers (13 miles) in diameter with a deeply indented shoreline which is mostly mangrove swamp. Coral reefs and mostly uninhabited islets encircle the entire island.

The climate is generally humid and hot with very high rainfall. In the interior it can rain as much as 830 centimeters (330 inches) a year and rainfall averages 457 centimeters (180 inches) along the lowlands and coast. Runoff from these rains feed numerous streams and rivers which originate in the interior highlands. Ponape Island experiences direct sunshine only about 50% of the time. Skies are completely clear for only 1% of the time and are almost completely clouded over for 75% of the time. Ponape is not in the typhoon belt, but it periodically experiences short, severe, tropical storms. Destructive typhoons did strike the island in 1905, 1925, and 1958.

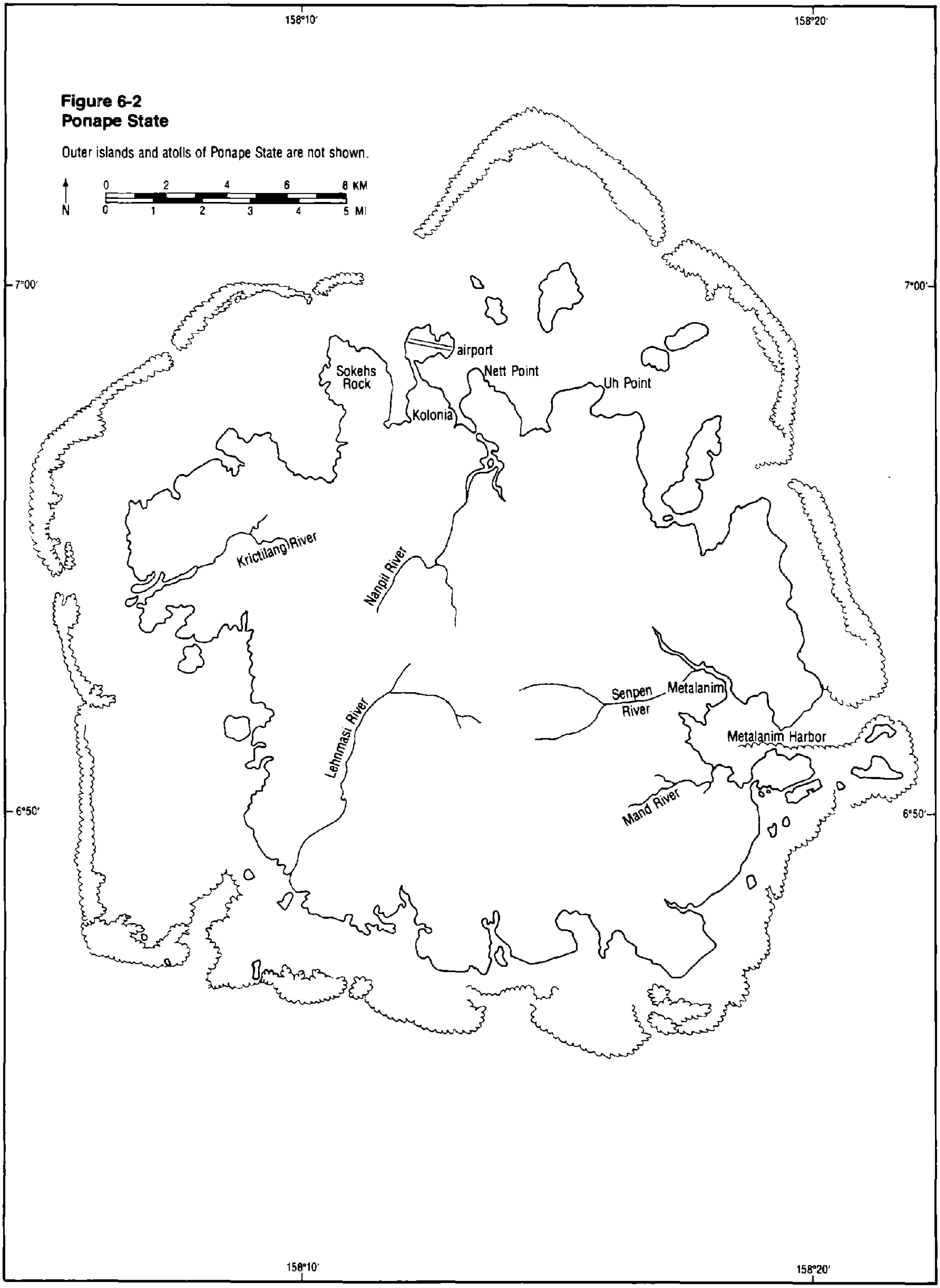
HISTORY AND POLITICAL DEVELOPMENT

Ponape is one of eight distinct cultural areas within Micronesia. The original settlers, about 1500 years ago, were probably canoe voyagers of either mixed Polynesian or Malay descent. The Spanish discovered Ponape in the 16th century but the islands became widely known only in the 1930s when whalers used Ponape Island as a stop for provisions. In those days, it was known as Ascension Island. Christain missionaries came in the last half of the 19th century and ultimately converted most of the population.

In 1881, Spain attempted to solidify it's claim to Ponape by building fortifications and a small mission on the present site of Kolonia. Ruins are still evident there. Germany purchased the island

Figure 6-2
Ponape State

Outer islands and atolls of Ponape State are not shown.



form Spain in 1899 and introduced private land ownership and plantation agriculture for economic development.

The Japanese quickly occupied Ponape at the start of World War I. The League of Nations mandated the islands to Japan in 1921. Ponape became the seat of the Japanese East Caroline administration and more than 8,000 Japanese nationals came to colonize and develop the island by introducing large-scale commercial agriculture and sophisticated fishing methods.

American forces bypassed Ponape during World War II, except for occasional bombing passes. In September, 1945, they occupied Ponape along with the other Caroline Islands. As with many of the Pacific Islands, the wartime isolation from foreign supplies encouraged over-exploitation of land and marine resources, later hindering economic regeneration.

Through a United Nations mandate, Ponape became part of the United States Trust Territory of the Pacific Islands (TTPI) in 1947. After six years of United States naval administration, Ponape came under the civilian administration of the Department of the Interior in 1951 as Ponape District. The years between 1951 and 1978 saw political evolution, educational growth, some infrastructure construction, but little economic development. During that time, Ponapeans formed a local legislature and sent representatives to the Congress of Micronesia. In July, 1978, the people voted to accept the Micronesian constitution, thereby joining the FSM. Subsequently, the new state elected it's own governor for the first time. Ponape now has full internal self-government under the Constitution of the Federated States of Micronesia. As part of the FSM, Ponape is entering into the Compact of Free Association with the United States, whereby the FSM states will receive monetary benefits in turn for granting the United States certain military and land use privileges.

ECONOMY AND INFRASTRUCTURE

Ponape has a very narrow economic base. It's economy depends almost entirely on state government spending, funds for which come from the United States Federal Government. In 1979, of the 3600 people who worked for cash, 1900 were employed by the state government and were paid $8.8 million. A significant segment of the population operates largely outside the wage economy.

Ponape is rare amoung Pacific Islands in that it has ample fresh water, a great aid to agriculture. After government employment, agriculture is the main source of income. Copra and peppercorns are the main cash crops. Subsistence farming is widespread, as is fishing. Handicraft manufacture is a growing, small-scale cottage industry. There is little commercial fishing, and tourism is a minor segment of the economy.

The state has established general projects in the various sectors which should establish an economic base or improve the infrastructure and institutional services. Table 6-5 lists projects according to their priority. The government is also encouraging development of small industries or businesses such as tourist facilities, restaurants, gift shops, pepper processing (the old processing plant burned down), meat processing, a cannery, a feed mill, a charcoal briquette business, ship repair facilities, and fish storage facilities. Most of this planning in in the preliminary stage and projected energy use data are not available.

PRESENT ENERGY STATUS

Ponape is 100% dependent on imported petroleum products as fuel for transportation and electric power generation. Table 6-6 gives details on fuel end-use. In 1980 there were 1,051 registered automobiles, trucks and motorcycles, and 500 outboard motor boats contributing to the transportation demand. Jet fuel is a principal end-use; the government field ships, one of which has been transferred to Kosrae, account for 10% of the total diesel fuel used. Kerosene and liquid petroleum gases are fuel for some cooking in population centers and for some commercial hot water heating. Renewable fuel use includes the widespread burning of wood and coconut wastes for domestic and school cooking; and some small renewable energy devices, mostly serving as performance testing systems.

The Ponape power system consists of two plants; the Nanphomal plant, built in 1977, with three 800 kW Caterpilar diesels; and the older Kolonia power plant with two 750 kW Whites and three 16-year old 500 kW Caterpillars. All the Caterpillars are high-speed, originally designed for peak load supplies. Total electric installed capacity is 5.4 MW; firm capacity with one machine on maintenance and one on standby is 3.8 MW. Average daily peak demand is 2.3 MW (1981), or 43% of rated capacity, and 61% of firm capacity. Maintenance problems and other technical difficulties related to sharing loads between the two plants make it difficult to meet these loads. Table 6-7 gives additional information on electric power generation.

Table 6-5

General Ponape Projects by Priority

Category	Amount (1980 $)
Transportation	
o Circumferential road	$2,000,000
o Airport terminal	1,000,000
o Outer island airstrips	225,000
o Outer island docking facilities	200,000
o Lehnmesi bridge	900,000
Power:	
o Wind/solar power - outer islands	250,000
o Transformers and secondary electric line	
Health and Education:	
o Kapingamarangi dispensary	60,000
o Junior high schools (Phase I)	310,000
Resources and Development:	
o Livestock development center	300,000
o Tuna transhipment/vessel service facility	4,500,000
o Village development program	1,000,000
Total:	$10,795,000

Table 6-6

End Uses of Fuels, Ponape, 1980

(in 1000's of bbl)

Fuel	Amount Purchased	Price[a] ($/bbl)	Gov't	Private	Comm'l/Indust/ Construction	Marine Transportation Field Ship	Marine Transportation Other	Electric Generation
Motor Gasoline	16	52	--------16-------			.1		
Aviation gasoline	1	137			1			
Jet fuel-K	19	72			19			
Kerosene	3	63	.05	------3.0----				
Diesel	47	54	11		9[b]	5[c]		22

(a) At Mobil Bulk Plant, February 1981, exclusive of taxes and transportation from plant

(b) Mainly construction

(c) 1978 data

Table 6-7

Electric Power Generation, Ponape, 1980

FUEL			OUTPUT (million kWh/y)	END USE (million kWh/y)				CAPACITY (MW)		LOAD (MW)
Type	Amount Purchased (1000's of bbl)	Price[a] ($/bbl)		Res	Comm'l/ Indust	Gov't	Milit	Rated	Operating	Peak
Diesel	22.1	53.76	14.8	-----5.4-----		9.4	0	5.4	3.8	2.3
			TOTAL 14.8	-----5.4-----		9.4	0	5.4	3.8	2.3

(a) Diesel price at the Mobil Bulk Plant, February 1981, exclusive of taxes and local transportation

The high costs of petroleum products, complete dependence on imported fuel, and the unreliability of its eight generators, are Ponape's principal energy concerns. The high cost of diesel fuel for power production is requiring government money normally set aside for generator maintenance and other services. The electrical grid now serves on Kolonia, Sokehs and part of Nett. In outer areas there are about 44 kilometers (26 miles) of new distribution lines not yet connected. Electrical service is intermittent in parts of the main island that is served and is unavailable to most of the 3,300 households. Voltage irregularities are destructive to many compressors and appliances, and frequent outages have forced the utility to deny requests for new electrical hookups. As a consequence, some households, businesses and public facilities (hospital, airport) use small gasoline generators.

Total electricity production is from 700,000 to 1,500,000 kWh/month. The wide range is a result of equipment failure. Electrical rates were raised in October, 1980 to 3¢/kWh for the first 1000 kWh and 8¢/kWh for amounts greater than 1000 kWh. Prior rates were a flat 3¢/kWh. In 1980, there were 777 private electrical power users, of which 691 were metered. The government, which uses about 60% of all power generated, it not metered, and does not pay directly for power consumed. Figures vary considering the efficiency of power production revenues received versus operating costs, but the FSM Five-Year Energy Plan estimates that more than 80% of electricity costs are paid by the Ponape state government. In 1980, costs to the state government for petroleum, oil and lubricants, were about $1.5 million, approximately 21% of the total operations budget.

Current contributions to solving the energy problems by using renewable energy technologies are relatively insignificant. Existing renewable energy systems are small (0.5 - 15 kW range) and are mostly for performance testing. Although their production is insignificant when measured against the total energy needs, they are important as precursors to large-scale projects, as facilities for training and technology transfer, and as devices for gathering siting and operational data. The small hydroelectric projects are particularly important and seem to offer the most promise.

The Aramas Kapw School at Nett Point is demonstrating a number of small devices including photovoltaic panels and wind electric machines and is providing some technical training. Finally, there is a small methane digester at the state argicultural station (also not working).

ENERGY DEVELOPMENT PLANNING

The immediate energy needs on Ponape are acute. The state government is contemplating two near-term options: 1) Purchasing three 800 kW diesel units to replace the three 16-year old Caterpillars, or 2) building a 6 MW residual fuel oil (RFO) generating system using a 8.5% 10-year loan arranged by International Power Systems Ltd. of England. (This is the same type of system being built on the Marshall Islands and being considered for Palau.) Three MW would become available in 12 months and the remainder in 24 months. The deciding factors relate to ability to finance the project and the time necessary to have a system operating. Both the RFO-fueled plant and development of the island's hydropower involve considerable more time and money to implement than purchasing replacement diesel generators. An additional problem is providing small electricity producing systems for communities that either do not have electricity now or use small diesel-powered generators for generating electricity.

As with the other FSM states, few data are available for assessing renewable energy resources and the data that have been collected are general and not site-specific. The one exception is Ponape's hydropower potential. Various groups have collected data from the major rivers during the last few years and have issued a number of hydrographic surveys. Hydropower is considered a mid- to long-term solution.

Concerning economic planning, the state government realizes that adequate energy supplies are the key to developing small industries on the island, including fishing and agriculture. Until these economic goals are achieved, the annual population growth rate of about 3.5% will drive future energy demand. It seems likely that by the time hydropower is harnessed, the fossil fuel electrical generating capacity will no longer be able to meet demand no matter what decision is made concerning present options to increase the supply.

Table 6-8 shows attractive features and barriers for renewable energy technologies for Ponape.

Energy Management

Energy management techniques will make the greatest impact on fuel savings for the near-term. The state government paying about 80% of the costs for electricity production (not including capital replacement costs) does not encourage conservation or well-thought out uses of electricity. Although plant maintenance has improved somewhat lately, generating efficiency is low. This is difficult to determine without the proper meters at the power plants. Energy needs for Kolonia, outlying communities and outer islands, should be determined through energy audits.

The recommendations set forth in the FSM Five-Year Energy Plan, if implemented, should make a considerable difference in fuel savings and revenue to the state government. These recommendations include increasing electrical rates over the next few years so that collected revenues at least equal production costs and perhaps eventually include replacement costs; installing meters for all consumers, including the government, and billing these consumers; disconnecting consumers if bills are not paid; and encouraging ownership and operation of the utility through a public corporation or authority. The state government should encourage better maintenance of existing systems by establishing better technical training.

Hydropower

Prior to World War II, the Japanese operated a hydroelectric system on Ponape island. During the last few years there has been a great deal of local interest in using this technology. Various groups including the United States Army Corps of Engineers, the Japan Consulting Institute, the United States Senate Committee on Energy and Natural Resources, the Trust Territory Office of Planning & Statistics, and private consultants have issued or made feasibility and assessment studies of the major rivers on Ponape Island. These rivers include the Lehnmasi (the largest on the island), the Senpen, the Nanpil, the Mand, and the Krictilang. While the surveys to date to not permit precise estimates of the island's hydro-potential, the Army Corps of Engineers believes the potential to be around 5 MW. In the most optimistic scenario, earliest development would be in the 1990's. The most likely dam sites are on the Lehnmasi River, but these sites are remote and without roads or transmission lines, greatly increasing the expenses for developing the resource. Table 6-9, from the FSM Five-Year Energy Plan, summaries the hydropower potential.

There are four hydropower hardware projects on Ponape Island now. Built or planned installations include only one mechanical and three electrical devices:

PICS: At Ponape Island Central High School at Kolonia, a summer workshop group, built a 1.5 kW cross-flow turbine system to provide electricity for a school dormitory. The system is not working now.

Palikir Power: A small private corporation is building a 15 kW cross-flow turbine system for providing electricity for a small village not connected to the grid.

Mand Hydroelectric: A 15 kW hydroelectric system will be built at Mand village.

Table 6-8
Technology Selection Criteria

	SOLAR						BIOMASS								
	Solar Hot Water	Photo-voltaics	Solar Therm-al	WIND ENERGY	GEO-THERMAL	HYDRO-ELECTRIC	Tree Farms	Biogas	Liquid Fuels	MSW	OTEC	OCEAN CURRENTS AND WAVES	SOLAR PONDS	COAL	ENERGY MANAGE-MENT
RESOURCE															
proven						●	●								●
suspected	●	●	●	●				●	●		●		●		
unknown					●					●		●			
none														●	
TECHNOLOGY READINESS IN PACIFIC															
high	●	●			●	●	●								●
medium				●				●	●	●			●	●	
low			●								●	●			
RELIABILITY PROBLEMS IN PACIFIC															
high												●			
medium				●					●		●		●		
low	●	●	●		●	●	●	●		●				●	●
DURABILITY PROBLEMS IN PACIFIC															
high			●	●							●	●			
medium	●	●					●	●	●	●					
low					●	●							●	●	●
APPLICATION															
centralized					●	●	●		●	●	●	●	●	●	●
decentralized	●	●	●	●	●	●		●	●				●		●
POTENTIAL CONSTRAINTS															
cultural impact	●				●		●	●	●	●			●	●	●
land availability		●	●	●	●		●	●	●				●	●	
environmental impact					●	●	●	●	●	●	●	●	●	●	
human resources	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
infrastructure	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
CAPITAL COSTS															
high (over $10,000/kW)		●	●									●			
intermediate ($3,000 - $10,000/kW)				●	●	●	●		●	●	●		●		
low (up to $3,000/kW)	●							●						●	●
O&M COSTS															
high			●	●					●			●			
intermediate		●			●	●	●	●		●	●		●		
low	●													●	●
COST EFFECTIVENESS															
near term (0-5 yrs)	●					●	●	●		●					●
mid term (6-15 yrs)		●		●	●				●				●		
long term (16-40 yrs)			●								●	●		●	
EXPECTED OIL SAVINGS OR AVOIDANCE															
high						●									●
intermediate	●						●						●		
low		●	●	●	●			●	●	●	●	●		●	

Table 6-9 -- Ponape Hydroelectric Potential

River	Head (ft)	Avg. Flow (cu.ft^3 Sec)	Turbine Rating (kW)	Annual Energy Output (millions of kWh
Nanpil[(a)]	-	-	1040	3.65
Lehnmasi	170	22.5	790	2.07
Lehnmasi	130	40	1080	2.82
Lehnmasi	230	54	2500	6.6
Lehnmasi	230	6	700	.77
Senpehn	100	12.3	240	.68
Mand	40	4.0	10	.05
Krictilang	36	4.0	10	.06
		Totals:	6370kW	16.7kWh

a. Incorporates dam; Less dam, annual output drops to 2.5 mil. kwh.
Sources: Army Corps of Engineers, JCI

Mechanical Power: An overshot wheel on a river near Kolonia was providing mechanical power for some wood-working tools for building boxes for exporting pepper. The system is not working now.

None of the above are operating at this time, but the Palikir project should be finished by early 1983. The United States Army Corps of Engineers plans to finish a design study for a 1.3 MW installation on the Nanpil River by the summer, 1983.

Hydropower is well suited for Ponape. The resource is proven and systems have worked on Ponape before; the technology is at a high degree of readiness; performance is not a problem. There are the usual constraints of lack of infrastructure for servicing and lack of technical skills. The latter problem may be partially solved through educational programs at the Community College, PICS, the agricultural stations, and Aramas Kapw.

Capital costs are high, particularly because the river sites are isolated. Community self-help projects and multiple-use reservoirs could reduce these costs.

Solar

The solar resource is uncertain throughout Ponape because of the high amount of cloud cover and the lack of data. The only recorder collecting solar data over a period of time is a sunshine switch at the Ponape Island Weather Station. The Department of Energy delivered a recording pyranometer to the Ponape Energy Office during the summer of 1982, but data are not available yet. There are no significant performance data yet from the solar hot water and photovoltaic systems at Aramas Kapw. on the outer islands, the solar resource has been sufficient to power some small photovoltaic communication and refrigeration systems.

Solar photovoltaic systems are technically ready and well suited for applications on Ponape, particularly on the outer islands, as shown by their success to date. Aramas Kapw's experience with solar hot water and photovoltaic systems will be useful in predicting future success.

Experience has shown that performance issues are usually not a problem with photovoltaic systems. This has not always been true for solar hot water systems because of corrosion, scaling, and storms. In addition, even simple repair parts are often not available, and distributors have only a fair record of servicing their products at remote locations. Lack of technical expertise is a problem, although the educational institutions on Ponape could eventually change this.

Biomass

A DOE contractor at the University of Hawaii is doing a general assessment of the biomass potential for the FSM as part of the Phase II Territorial Energy Assessment; results will be available in early 1983. Despite its rugged terrain, Ponape appears to have an excellent biomass resource, largely because of the fresh water supply and the abundance and variety of plant life. This resource can be used for direct combustion or conversion to liquid fuels.

Direct combustion of biomass is a technology at a high degree of readiness and should not offer difficult technical problems for Ponape. Liquid fuels production is not as established or reliable for remote islands. Using producer gas or coconut oil for generating electricity in small, village-size systems should be considered.

There are potential constraints however, particularly for direct combustion. Part of Ponape's economic plan includes developing a timber industry, and forestry agents seem reluctant to use hardwood timber for combustion. They are also concerned about effects on future wood production, wildlife, and watershed, and erosion of top soil after harvesting. For now, these constraints may preclude using biomass for direct combustion. There is interest in using certain plants for enthanol production.

Wind Energy

The wind resource on Ponape is largely unknown, but as on other Pacific Islands, local people feel there are adequate wind regimes at certain sites. The Ponape Island Weather Station has a continuously recording anemometer atop a 10 m (33 ft) tower, but data may be misleading because steep heights surround the station. Three of the outer islands have nonrecording anemometers. By early 1983, results from the general wind study by a DOE contractor will be available, but these data will not be site-specific.

Wind electric machines have not worked well on remote Pacific Islands primarily because the wind resource is often inadequate, and the wind machines are not reliable or durable in the Pacific environment. There are two small systems at Aramas Kapw now, a 1.5 kW Aeropower atop an 18 meter (60 foot) tower and a 250 W Windcharger. The Aeropower operated successfully for about a year as the school's primary source of electricity, but it is not operating now.

The main barriers to wind machines on Ponape, besides an undetermined but probably marginal resource, include the lack of a developed parts infrastructure and lack of technical expertise. Capital outlay is high, and the machines do require regular maintenance. Access to proper tools, including cranes, for installation and maintenance, can be a problem. Additional performance testing data from the small machines now on Ponape will be useful in predicting the usefulness of other such systems. The more durable and easily repaired mechanical wind machines for pumping water may be a more suitable use for wind energy, particularly on outer islands.

OTEC

Ocean thermal energy conversion (OTEC) seems particularly attractive because of suspected large temperature differentials within the seawater column around Ponape. There is a lack of site-specific data concerning temperature gradients, currents, bathymetry, and environmental effects. The technology has encountered certain engineering problems, particularly regarding cold water pipes. Other problems include lack of infrastructure support for supplies and maintenance, high capital and maintenance costs, and effects on and from the environment. Once these problems are solved and the resource is properly evaluated, OTEC could be an attractive technology for Ponape.

Small-Scale Technologies

The Aramas Kapw School has been worked with small energy devices such as solar food dryers, water catchment systems, mechanical wind-powered water pumps, solar hot water devices, and small wind electric and photovoltaic systems. These devices seem particularly useful for outer islands. PICS, the Community College, and the agricultural station have also been involved in technical training and/or small energy devices.

The most widely used renewable energy resource is wood and coconut waste burned for domestic cooking over open fires on the outer islands, remote villages, and fringes of the more populated areas. These fuels are also used for cooking in the hot lunch program at schools. People are just starting to experience fuelwood shortages around Kolonia; at other villages there are no shortages yet. The Trust Territory Office of Food and Nutritional Services has been encouraging the use of more efficient "smokeless stoves" for domestic and school cooking, and villagers are just starting to build them. There are a number of these stoves on Ponape in schools and homes near Kolonia. The stoves seem to encounter fewer cultural constraints on Ponape than elsewhere, perhaps because wood is becoming scarce around Kolonia. Use of these stoves should increase fairly rapidly during the next few years.

Ponape, with its remote islands, rural villages, limited electrical grid, and educational facilities is a good place to encourage community level projects. Other technologies which should be considered include charcoal making, producer gas and coconut oil, and mechanical hydropower. The constraint to small methane digesters is that small animals are not penned, making it difficult to collect wastes.

FINDINGS AND RECOMMENDATIONS

Present electrical power production on Ponape is just adequate to meet capacity. Production has not been reliable; there have been maintenance problems, although this has improved lately; and there are frequent power outages. The diesel generators at the Kolonia power plant are old, and most of the diesels at both plants are high-speed, designed for peak power production. The state government anticipates that soon existing capacity will not be able to meet demands because of the deteriorating conditions of the equipment and the addition of new customers. The government would like to provide electrical service around the island and anticipate additional commercial hookups through economic expansion.

To solve the near-term problems, the government is considering either purchasing three new diesel units to replace the old units at the Kolonia plant or building a 6 MW RFO plant, similar to the system on the Marshall Islands. Energy technologies using renewable resources and energy management methods can make a small impact for the near-term and a larger impact for the mid-term.

A number of changes in monitoring and charging for electricity consumption should be made. The government subsidizes about 80% of electrical use not by charging rates well below operating costs and by not metering or charging government users and some private sector consumers. These users should be metered and charged. Better collection methods should also be used. The government should consider increasing rates slowly until they at least cover operating costs, and also consider establishing a power authority to make these changes. Properly trained personnel should make energy audits throughout Kolonia and rural areas. Finally, the government should encourage training people to install, maintain, and service renewable energy systems.

Hydropower offers the best near-term possibility to contribute to baseload production. The United States Army Corps of Engineers is completing an engineering study at the Nanpil River for a 1.3 MW run-of-river system. This system could be operating by 1986 or so. Remote sites increase capital expenses for these systems, but work should continue assessing this resource by monitoring water flow at other sites and by starting other engineering studies.

Because of Ponape's large land area and thick vegetation, biomass technologies are promising, but there are some cultural barriers to tree farming, competing uses for the trees, and erosion problems. Producer gas or coconut oil technologies are promising too, and a plant for performance testing should be built. Additional assessments of the biomass resource should be made.

Solar hot water and photovoltaic systems probably will not contribute significantly to fuel savings because of Ponape's cloud cover and limitied radiation. Solar photovoltaics may be useful for some remote applications. Additional solar data are needed before systems using any of these technologies can be designed.

The wind resource is limited, but at a few selected sites wind data would be useful to assess this resource properly. OTEC is not commercially ready.

In remote and rural areas, energy audits, producer gas or coconut oil systems, small hydropower projects, small wind electric and water pumping machines, and small solar dryer, water heating, and photovoltaic systems should be considered. Assessments should continue on the cost-effectiveness and engineering problems of retrofiting the field ships with sails. Table 6-16 lists the various recommendations for the FSM, including those for Ponape.

TRUK

Truk is located in the center of the Caroline Islands, 1,017 kilometers (610 miles) from Guam and 704 kilometers (424 miles) from Ponape. The state consists of more than 100 islands and atolls spread over 500,000 square miles (180,000 square miles) of ocean. All but the Truk Lagoon islands are coral atolls or single coral islands. Truk is the most populous of the FSM states with a population of 37,742 (1980). Most of the people live on the six largest islands within the Lagoon; Moen, the state capital (10,373), Tol (6,781), Dublon (3,233), Fefan (3,096), Uman (2,320), and Udot (1,083) (see Figure 6-3).

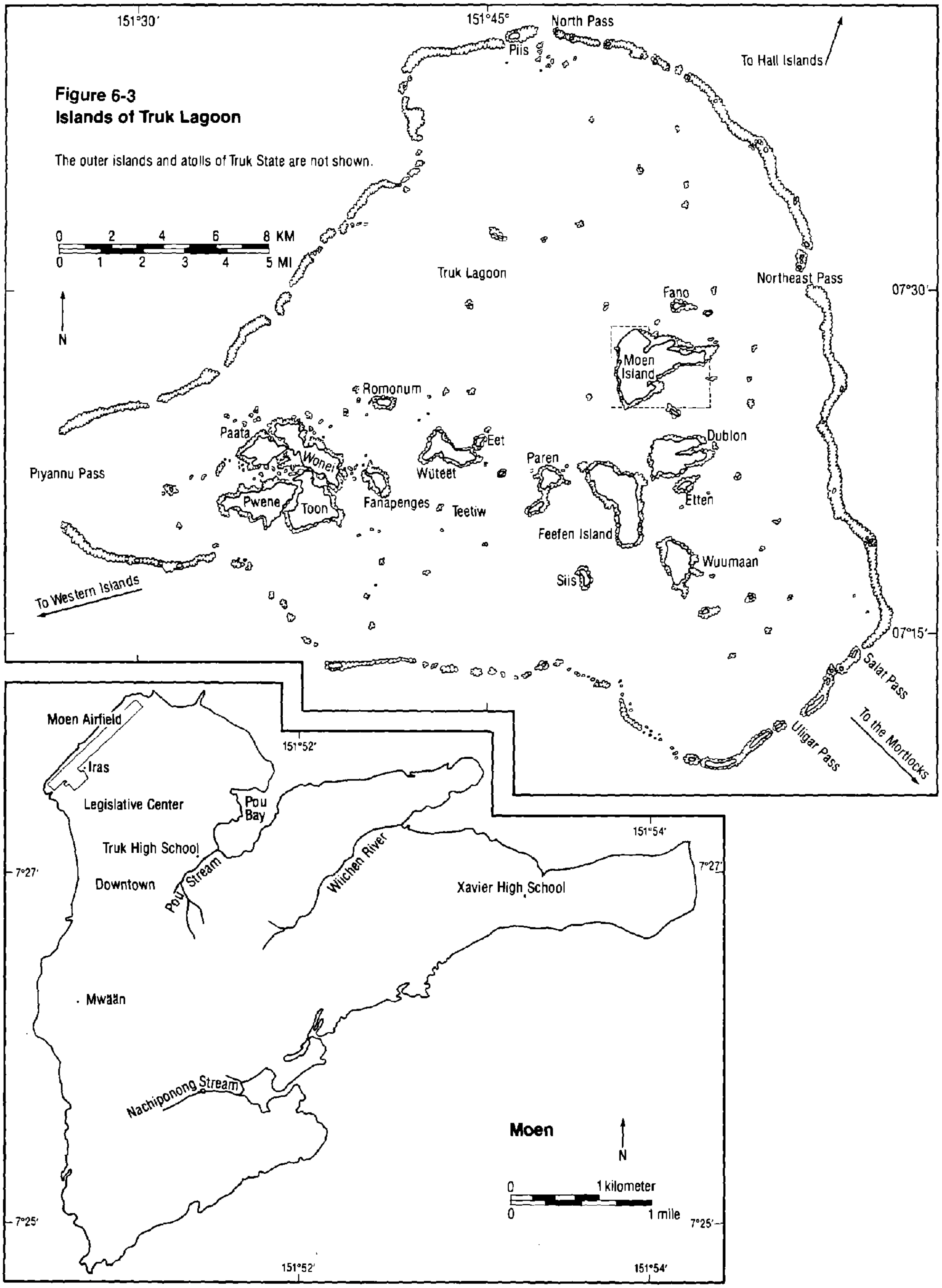


Figure 6-3
Islands of Truk Lagoon

Of the islands of Truk State, only Moen has a central generating system. While its capacity is technically adequate, maintenance problems and outmoded equipment have resulted in inadequate service. Renewable resources are unlikely to contribute much to Moen's energy demand in the near term, but on the outer islands, renewable energy technologies could help prevent additional petroleum dependencies and extend some level of service to areas that do not now have electricity. Energy management and improved fiscal policies could make a significant contribution to Truk's near-term energy picture.

Truk Lagoon, with a diameter of 66 kilometers (40 miles), is one of the largest lagoons in the world and is made up of a great ring of reefs and low coral islets within which rise 17 large volcanic islands. Truk's total land area, including the outer islands and atolls, is under 328 square kilometers (118 square miles); land area within the Lagoon is about 250 square kilometers (90 square miles). The islands outside the Lagoon are truly remote; travel between them and Moen is by small boat or government field ship every six weeks or so.

Truk's climate is hot and humid with little temperature change. Rainfall within the Lagoon averages 305 cm (120 in) a year. There are pronounced rainy to dry seasons caused by changes in the wind system. Truk lies on the eastern edge of the typhoon areas. Typhoons and lesser storms periodically strike the islands causing heavy damage.

HISTORY AND POLITICAL DEVELOPMENT

The Trukese, with their distinct language, technology, social organization, and religious beliefs, are one of eight Micronesian cultures. They, like the other Caroline Islanders, appear to be descendants of eastern-moving migrants of Malay descent. Other islanders also moved to the lagoon islands for refuge from severe storms. When the Spanish arrived on the Truk Islands around 1565, they found a subsistence agricultural and fishing society. Because of Truk's fierce and warlike reputation, whalers and traders avoided the Truk Islands until the late 19th century, and even then they visited the islands with reluctance.

Germany purchased the Truk Islands in 1899, established the capital on Dublon Island, and attempted to build up the copra trade. Their efforts were only mildly successful. At the start of World War I, the Japanese, who had strong commercial interests in the Carolines, occupied the islands, replacing Germany.

In 1920 the League of Nations placed Truk, along with the other Caroline Islands, under a mandate to Japan. The Japanese recognized Truk's strategic location and protected anchorages and began to fortify the islands during the 1930s. At that time, there were about 35,000 Japanese (mostly military personnel) on the islands. During World War II, Truk Lagoon became the home port for major Japanese naval units. Periodic raids by the United States destroyed a number of ships, 60 of which are still in the Lagoon. These relics are now considered interesting diving sites, thereby supplying Truk with a small tourist attraction.

After the war, a United Nations mandate placed Truk under United States naval administration as part of the TTPI. In 1951, administration switched to the Department of the Interior, and the district center moved from Dublon to Moen. The United States developed an educational and governmental system similar to United States models and made some improvements with public infrastructure, but little was done for economic development. Like the other districts, Truk achieved local self-government in 1978 under a charter approved by the United Nations High Commissioner. With the creation of constitutional self-government in 1979, Truk became a full-fledged state and member of the FSM. It now has its own popularly elected governor and state legislature. As an FSM state, Truk will receive monetary benefits from the United States as part of the newly signed Compact Agreement.

ECONOMY AND INFRASTRUCTURE

Truk has very little economic base and depends almost entirely on state government spending, funds for which come from the United States Federal Government. About 95% of the cash flow comes from United States Congressional appropriations. Copra is Truk's principal export; fishing and subsistence farming are secondary industries. Despite diving attractions, dollars from tourism are small. There are 2,100 workers in the private sector, most of whom are in retail trade and light construction. The government is the leading employer with 3,800 workers.

The state government's general strategies for developing Truk's economic base include increasing investments in directly productive activities; reducing private consumption while encouraging increased savings and investment in the private sector; reducing or holding constant imports of consumer goods while increasing exports; and assisting the municipalities outside of Moen to develop economic bases. During the next few years the state government is hoping to build a copra processing plant, a small industrial center for manufacturing soap and furniture, a dry dock with a small railway on Tol Island, and a fishery on Dublon. All of the projects will increase energy demand.

The state government also plans to develop the outer islands selectively. These islands have strong, well-knit communities, with mostly competent leadership by chiefs and elders. The basic economies are subsistence, but the fishing resource appears adequate to provide cash revenues if there were a satisfactory distribution system. Copra sales could also provide additional income.

PRESENT ENERGY STATUS

Truk is almost 100% dependent on imported petroleum products for electric power generation and transportation. The small use of renewable fuel includes the widespread burning of wood and coconut wastes for cooking; some photovoltaic systems on the outer islands for communication radios and dispensary refrigerators; and a 15 kW wind electric machine at Xavier High School. A major photovoltaic project for small systems is soon to be undertaken on the Faichuk region of the Lagoon.

Tables 6-10 and 6-11 show that the major use for petroleum products is for generating electricity and for transportation on Moen. Jet fuel and fuel for government field ships are another principal end-use. Kerosene and liquid petroleum gases fuel some cooking in population centers and some commercial hot water heating. In 1981 there were 750 registered vehicles. Outboard motor boats used for transportation between the populated islands within the Lagoon and for fishing are another signficiant end-use. There are also significant demands on the island groups outside the Lagoon for outboard motor boats and for electricity generation.

Table 6-10 -- End Uses of Fuels, Truk 1980
(in 1000's of bbl)

Fuel	Amount Purch.	Price[a] ($/bbl)	Gov't	Private[b]	Comm'l Indust/ Const.	Marine Transportation Field Ship	Marine Transportation Other	Electric Generation	Export
Motor gasoline	21	53	---21[c]---			0.2[d]			
Aviation gasoline	.05	137			.05				
Jet fuel-K	8	72			8				
Kerosene	3	63	.05	-----3-----					
Diesel	63	54	4[e]		30[f]	5		20	4

(a) At Mobil Bulk Plant, February 1981, exclusive of taxes and transportation from plant

(b) 750 autos, 12 boats - registered

(c) Includes outboard motors

(d) 1978 data

(e) May be high

(f) Mainly construction

Population: 37,383 (Sept. 1980)
Household: 5,373 (Sept. 1980)

Table 6-11 - Electric Power Generation, Truk, 1980

FUEL			OUTPUT (million KWh/y)	END USE(b) (million KWh/y)				CAPACITY (MW)			LOAD (MW)	
Type	Amount Purchased (1000's of bbl)	Price[a] ($/bbl)		Res	Comm'l/ Indust	Gov't	Milit	Rated	Operating	Standby	Base	Peak
Diesel	20.4	53.76	11.4	----4.8----		6.6	0	5.1	3.5[b]			1.9
		TOTAL	R11.4	----4.8----		6.6	0	5.1	3.5[c]			1.9

(a) Diesel price at the Mobile Bulk Plant, February 1981, exclusive of taxes and local transportation

The only central operating electrical system on Truk is at Moen. Installed nameplate capacity at the plant is 5.1 MW, supplied by five 800 kW mid-speed Caterpillar generator sets and a 1.1 MW low-speed Nordberg diesel. Firm capacity is 3.5 MW with one machine down for maintenance and one on standby. All machinery is in fair condition. The state is considering purchasing another diesel generator to increase capacity. There are now about 20 kilometers (12 miles) of electrical lines connected to the plant. This includes 8 kilometers (5 miles) of new line out to Xavier High School. New figures on estimated connections are not available. There are also smaller, privately owned generating units throughout the islands such as the 16 kW and 2.5 kW diesel units at Xavier. Of the other lagoon and outer islands, only Dublon has installed diesel generators and power lines, but this system is not operating because of high operating expenses. Other islands such as Tol and Satawan are anxious to install generators.

Average daily peak demands are around 1.9 MW and occur during weekday mid-mornings and afternoons, the times of greatest government use for air conditioning. According to a recent energy audit by the FSM Office of Planning & Statistics and the Truk Office of Planning & Budget, only about 65% of produced power is accounted for. Many of the largest customers, such as the government, are not metered. It is estimated that the government uses close to 60% of the electricity generated and that the remaining 40% is used in the private and commerical sectors. The average customer uses about 400 kWh/month, mostly for lights and refrigerators; the commerical consumer uses about 2,368 kWh/month; and the more westernized housing uses about 979 kWh/month.

Government agencies recieve the first 1,000 kWh/month free. They pay 6¢/kWh for the next 1,000 kWh and 9¢/kWh for anything over 2,000 kWh. Commerical users pay a flat rate of 10¢/kWh. Residential users pay 6¢/kWh for the first 1,000 kWh/month and 9¢/kWh over 1000 kWh. During part of 1981, average monthly billing was $13,928 and average revenues were $9,368. This amounts to an average payment of about 1.5¢/kWh. Production costs, not including capital replacement, are around 20¢/kWh.

During early 1983, the state government will install $200,000 (HUD) worth of small, stand-alone, solar photovoltaic systems in the Faichuk area to power lighting systems for offices and schools, and refrigerators for dispensaries. This will be the first major solar photovoltaic installation for Truk. One operating solar project found on the outer islands is a solar water heating/wind water pumping system on Satawan. This system is connected to a small health dispensary and is its only source of hot water.

A major wind project involves installing a 15 kW Jacobs wind electric machine and Xavier High School on Moen. This will be the largest wind machine in the FSM. Rocky Flats and Wind Power Pacific personnel are helping with the work; funds come from the DOE Appropriate Energy Technology Grants Program. Xavier is one of the most highly regarded schools in the Pacific, teaching vocational and college preparatory courses to young adults throughout Micronesia.

The most extensively used renewable resource on Truk is wood and coconut wastes for domestic and school cooking. Data are not available regarding cooking with this fuel and with kerosene. The Trust Territory Office of Food & Nutritional Services is encouraging the use of efficient wood cooking stoves.

Despite what appears to be sufficient capacity of the Moen system to handle peak demands, the system is barely able to do this, primarily because of maintenance problems and inappropriate or old machinery. There are frequent power outages caused by machinery breakdown. Poor operating and fiscal policies for the Moen plant have discouraged conservation and fostered unrealistic attitudes towards energy consumption. Another critical problem is to provide reliable electricity through grids on the more populated Lagoon islands. In most places, the Lagoon is shallow enough to allow the Lagoon islands to be connected by cable to a single grid. High costs might prevent such a linkage. Small, reliable systems, which do not require importing fuel, are needed on the outer islands.

Most of Truk's economic expansion plans pertaining to fishing, agriculture, and industry link directly to reliable sources of electricity or liquid fuels. Expanding fishing operations, in particular, will require freezer and ice facilities on the outer islands, a supply of fuel for the boats, and better ship repair facilities. The lagoon and outer islands are not equipped for this now; however, this is an excellent opportunity for small, renewable energy systems. Table 6-12 shows the suitability of various renewable energy technologies for Truk.

Energy Management

Energy management is extremely important, not only to encourage conservation but also to encourage renewable energy technologies by making them more cost-effective. The FSM Five-Year Energy Plan recommends that rates by raised so that revenues equal costs and eventually include replacement costs for machinery; that all customers be metered; that free government use stop; and that energy audits be made. The government should encourage better maintenance of its generating equipment. The state government should consider establishing a power authority to make these changes.

These actions could have a considerable near-term impact on Truk's energy problems. If the ideas are implemented they could generate additional revenue for the state, encourage conservation and wise end-use for electricity, and make renewable energy technologies more cost-effective.

Solar

Truk's latitude and the available, qualitative solar data suggest that there may be some potential for using solar technologies. However, there are no insolation data with which to evaluate the various solar technologies, and at some seasons, Truk does have a considerable cloud cover. A sunshine switch at the NOAA weather station adjacent to the airfield at Moen is the only instrument that has been in place over a period of time. DOE has just delivered a recording pyranometer to the energy office, but it is too soon for significant data to have been developed. Photovoltaic systems are an important and well-established technology for Pacific Islands. It is a particularly appropriate technology for Truk's large and dispersed populations dependent on importing fuel for small generators. The solar resource on the outer islands has been sufficient to power some small solar photovoltaic systems. Operational data from the photovoltaic systems being installed in the Faichuk area will be useful for evaluating the solar resource on Lagoon islands. Experience on outer islands shows that performance issues should not be a problem with photovoltaic systems. There were some problems with the refrigerators during the Trust Territory's recent effort to put these systems on remote islands, but refrigerators, not photovoltaic panels, were the problem.

There is a need for solar hot water systems for health dispensaries and perhaps for some other institutional or industrial applications, particularly on the outer islands. These islands' remote locations may cause problems in operating the more sophisticated systems necessary for such applications.

Wind Energy

The Truk islands may have a promising wind regime at certain locations. Producing electricity by wind machines is a technology of some interest for Truk. However, as on the other FSM islands, very little useful site-specific data have been collected. An anemometer is collecting wind speed and direction data at the Moen NOAA weather station, but the instrument is in a shielded area atop a 7 m (23 ft) tower so data are not useful for siting wind machines there, or elsewhere on Moen. There is also an anemometer at Xavier High School for collecting data for its 15 kW machine. Finally, there is

Table 6-12
Technology Selection Criteria

	SOLAR						BIOMASS								
	Solar Hot Water	Photo-voltaics	Solar Therm-al	WIND ENERGY	GEO-THERMAL	HYDRO-ELECTRIC	Tree Farms	Biogas	Liquid Fuels	MSW	OTEC	OCEAN CURRENTS AND WAVES	SOLAR PONDS	COAL	ENERGY MANAGE-MENT
RESOURCE															
proven															●
suspected	●	●	●	●			●	●			●		●		
unknown					●	●			●	●		●			
none														●	
TECHNOLOGY READINESS IN PACIFIC															
high	●	●			●	●	●								●
medium				●				●	●	●			●	●	
low			●								●	●			
RELIABILITY PROBLEMS IN PACIFIC															
high												●			
medium				●					●		●		●		
low	●	●	●		●	●	●	●		●				●	●
DURABILITY PROBLEMS IN PACIFIC															
high			●	●							●	●			
medium	●	●					●	●	●	●					
low					●	●							●	●	●
APPLICATION															
centralized					●		●		●	●	●	●	●	●	●
decentralized	●	●	●	●	●	●		●	●				●		●
POTENTIAL CONSTRAINTS															
cultural impact	●				●		●	●	●	●			●	●	●
land availability		●	●	●	●		●	●	●				●	●	
environmental impact					●	●	●	●	●	●	●	●	●	●	
human resources	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
infrastructure	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
CAPITAL COSTS															
high (over $10,000/kW)		●	●									●			
intermediate ($3,000 - $10,000/kW)				●	●	●	●		●	●	●		●		
low (up to $3,000/kW)	●							●						●	●
O&M COSTS															
high			●	●					●			●			
intermediate		●			●	●	●	●		●	●		●		
low	●													●	●
COST EFFECTIVENESS															
near term (0-5 yrs)	●					●	●	●	●	●					●
mid term (6-15 yrs)		●		●	●								●		
long term (16-40 yrs)			●								●	●		●	
EXPECTED OIL SAVINGS OR AVOIDANCE															
high															●
intermediate	●						●								
low		●	●	●	●	●		●	●	●	●	●	●	●	

a non-recording anemometer at Puluwat island. Because of Truk islands' varying topography and wide geographical spread, it is essential that site-specific data be gathered.

On Moen, the students and faculty of Xavier High School, with funding from DOE and help from DOE contractors, are installing a grid-connected 15 kW Jacobs machine. The site seems to have a marginally adequate wind regime. Xavier has an excellent vocational staff. Results from this project will be important for determining future plans for wind machines on Truk.

A critical constraint for wind machines, and one that is magnified by the remote location of the Truk islands, is the human resource and parts infrastructure. Until there is adequate technical talent and training locally, and until manufacturers are able to supply parts for machines, outer island use of wind machines will be limited.

Biomass

The biomass potential on the Truk Islands appears excellent with relatively large land areas and dense vegatation. There are, however, a few critical constraints to developing biomass as an energy resource on Truk, despite the otherwise attractive features of this resource.

Truk's Lagoon islands have a steep relief once inland from the shore. Cultivation and harvesting of tree crops is a problem where land is steep and access difficult, and erosion can be a problem. Housing and subsistence agriculture compete for available flat land.

Apart from some agricultural activity on Fefan Island, there is little commerical crop production on the Truk Islands. Only copra is produced in quantities large enough to be considered as a biofuel feedstock. Agricultural production of sugar cane, pineapple, root crops, or other species used in ethanol conversion are limited by an inadequate amount of arable land. Significantly, the State Agriculturist views tree or crop yield enhancement as critical to food rather than energy production.

Coconut oil or producer gas systems suitable for generating electricity with small diesel systems (greater than 50 kW) may be appropriate for the Lagoon islands.

OTEC

Ocean thermal energy conversion (OTEC) is a particularly attractive technology for Truk because of a suspected large temperature differential in the local seawater column. There are no site-specific data for temperature, currents, bathymetry, and effects to and from the environment.

This technology is not ready yet for remote locations such as Truk. OTEC has not operated successfully over a period of time anywhere in the world because of engineering problems, primarily with the cold water pipes. Truk lacks the necessary technical skills and parts infrastructure. Once these problems are solved, high capital costs come down, and the resource is evaluated properly, OTEC could be very attractive for Truk.

Small Scale Technologies

Because of Truk's widely dispersed population, certain small-scale projects may be particularly appropriate in a fuel-saving mode for the Lagoon and outer islands. Solar food dryers, efficient wood cooking stoves, small sail-assisted fishing vessels, mechanical wind water pumps, and small producer gas or coconut oil combustion systems should be useful depending on resources and energy needs. Truk has no hydropower resource.

FINDINGS AND RECOMMENDATIONS

Most of Truk's population is dispersed throughout six lagoon islands, with the greatest concentration on Moen. Moen is the only island that has a central power system operating now. Equipment is in fair operating condition; capacity is just adequate for present demands; and there are frequent power outages. New customers created by economic expansion and extending distribution lines will overburden the present system. The other Lagoon islands are anxious for central power systems, and many of the outer islands need electricity for essential demands. The government is considering purchasing an additional diesel generator to at least take care of Moen's problems for the near-term. Cables should be considered for extending the grid from Moen to other nearby Lagoon islands. An engineering study is needed.

It is doubtful that energy technologies using renewable resources will make more than a small impact for fuel savings on Moen in the near-term. Changes in energy management methods will reduce fuel consumption on Moen, and some technologies may help the outer islands avoid importing diesel fuel. Additional data are needed to assess completely the various renewable resources.

A number of changes in monitoring and charging for fuel usage should be made. The government subsidizes most electrical use now by charging rates well below operating costs. Revenues from electricity generation are about 1.5¢/kWh, well below even fuel and lubricant costs. Much government use is free; many customers are not metered, but are charged flat rates based on estimates; and many people do not pay their bills. All users should be metered and charged for the electricity they consume. The government should consider increasing rates slowly to reflect operating costs at least, and they should consider establishing a power authority to make these changes. Properly trained personnel should make energy audits throughout Moen and should determine energy needs on the other Lagoon and outer islands.

Widespread technical training should be established at all educational levels. The government should train people to install, maintain, and service renewable energy systems. It should also require the Moen power plant to be maintained on a regular basis.

Existing data suggest that renewable energy technologies will not make a significant contribution to fuel savings for the near-term. Solar technologies may make some impact, but additional insulation data are needed before systems can be designed. Cloud cover may be too great for solar technologies to provide significant fuel savings. Performance data from the photovoltaic system at Faichuk will be important to see if such systems will be successful.

The wind regime is not promising for the Lagoon islands, and there are no data for the outer islands. Site-specific data at appropriate heights are necessary to evaluate this resource properly. Performance data from the machine at Xavier High School will indicate how this size machine will operate in areas where wind speeds seem just adequate.

The biomass resource seems good, but rugged terrain, poor land access, and competing land uses may prevent tree farming.

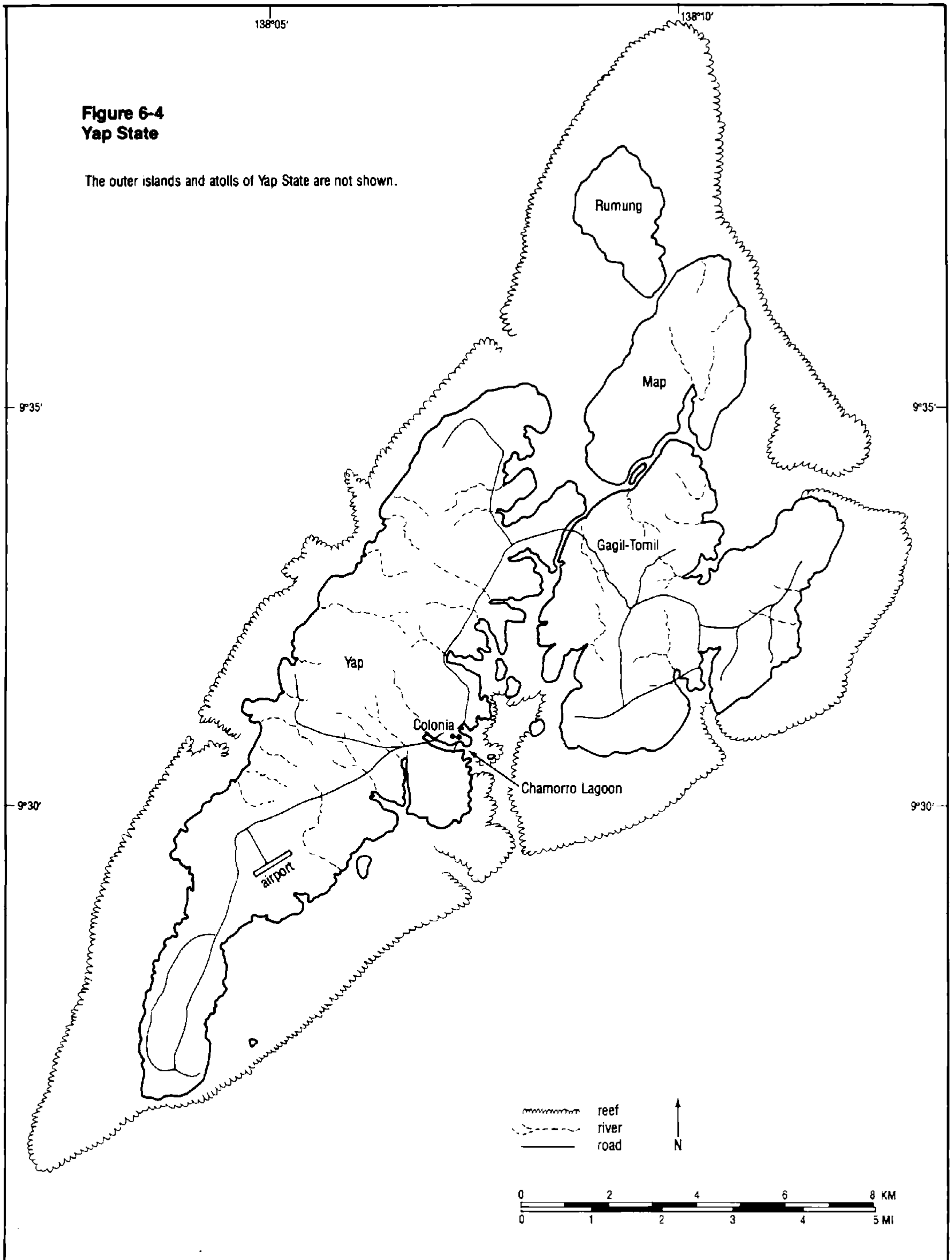
For remote areas, small systems for solar photovoltaics, wind electric and water pumping, and producer gas or coconut oil could help the communities avoid using imported fuel. Efficient wood cooking stoves should be encouraged for urban and rural areas. Sail power for fishing boats is being encouraged and more boats should be built after performance testing of the first one. OTEC is not commercially ready yet, but the progress of the technology should be followed closely.

Table 6-16 lists the various recommendations for the FSM, including those for Truk.

YAP

Yap state is in the West Caroline Islands 750 kilometers (450 miles) southwest of Guam. It consists of 15 atolls and island groups with a total land area of 128 square kilometers (46 square miles). Population is 8,172 (1980). The principal island group within Yap is Yap proper, a high group of four large and seven small islands, on which the state capital of Colonia is found (see Figure 6-4). The land area of Yap proper is 108 square kilometers (39 square miles). The rest of the islands are low, coral atolls, the largest of which is Ulithi (population, 720) about 350 kilometers (210 miles) from Yap proper. The state is widespread; Satawal, the easternmost part of the state is 1,067 kilometers (640 miles) from Colonia, and most atolls are at least 833 kilometers (500 miles) away.

Only Yap proper has a central generating systeem, and it is well-maintained and adequate to meet present and expected demand, including the planned grid extension to Map. The government of Yap would like to alleviate its present dependence on imported petroleum fuels and resultant vulnerability to price increases and supply irregularities. It would also like to provide decentralized systems for outlying villages and islands. Renewable energy resource technologies, especially photovoltaics and wind power, are expected to be used in this effort.


138°05′
138°10′
Figure 6-4
Yap State
The outer islands and atolls of Yap State are not shown.
Rumung
Map
9°35′
9°35′
Gagil-Tomil
Yap
Colonia
Chamorro Lagoon
9°30′
9°30′
airport
reef
river
road
N
0
2
4
6
8 KM
0
1
2
3
4
5 MI
138°05′
138°10′

HISTORY AND POLITICAL DEVELOPMENT

Like the Trukese and Ponapeans, the Yapese, because of their substantially different language, technology, social organizations, and religious beliefs are one of eight distinct Micronesian cultures. The Yapese, of Yap proper, speak a unique language apparently unrelated to any other Micronesian tongue. They probably came from southeast Asia and settled on Yap before the birth of Christ. They evolved a complex village and caste system, founded on local warfare, which enabled them to extend their rule far into the Caroline Islands.

The Yapese are skilled builders and sailors. The layout of today's villages attest to their construction and engineering skills. The huge limestone discs (used for money) the Yapese quarried on Palau 830 kilometers (250 miles) away and shipped to Yap on large canoes are evidenced of their sailing prowess.

Diego DaRocha, a Portugese explorer, discovered the Yap islands for Europeans in the 16th century, followed by various Spanish expeditions. Such explorations did not affect Yap until the American adventurer, David O'Keefe, organized successful commercial trade based on trepang (sea cucumbers) and copra. The Spanish contended with O'Keefe during the 1880s and finally established a Jesuit mission and administrative unit which wrested control and influence from the colorful adventurer. In the 1880s German traders moved into Yap to develop further trade, and Germany eventually purchased the islands from Spain in 1899. By that time, the Yapese population, which had once numbered 50,000, had fallen to 2,500.

Yap proper assumed new importance in German times with the laying there, in 1905, of an undersea communication cable connecting America with Asia. The Germans also dug canals, improved transportation, and upgraded public health facilities.

At the start of World War I, Japan occupied the islands. In 1920, Japan acquired Yap, along with the other Caroline Islands, through a League of Nations mandate. During the 1920s and 1930s, Japan continued to consolidate trade and to exploit natural resources. World War II interrupted these developments. The Americans invaded only Ulithi, using its huge lagoon as an anchorage from which to stage the invasion of the Philippine Islands.

In 1945, the United States Navy assumed responsibility for the islands and made Yap a district of the TTPI. In 1951, the department of the Interior assumed this administrative role. The Yap legislature was organized in 1969, with traditional councils for both the Yap High Chiefs and outer island chiefs. The Yapese approved the FSM Constitution and agreed to join the new government as one of the four states in 1978. Yap elected a state government that year and in 1979 elected the first Yapese governor in modern history. As an FSM state, Yap will receive monetary benefits under the newly signed Compact Agreement.

ECONOMY AND INFRASTRUCTURE

Yap's population is relatively small and young. Sixty-five percent of the 8,172 people live on Yap proper; 60% of the total are under 25 years of age. The work force remains small. There are only 1,300 workers in the money economy (average annual income of $2,510). Yap's gross domestic product in 1979 was only $8 million.

The government employs 70% of the wage earners. Government jobs provide prestige, relatively high salaries, and security of employemnt. Nonetheless, the subsistence sector still provides the principal income and employment for the economy. About 1,600 people live in a village subsistence economy.

Copra production, farming and food gathering, and fishing are the mainstays of the state's economy. Most of this activity is in rural Yap proper and the outer islands. However, the outer islands are rapidly becoming depopulated as the younger people move to Colonia to look for jobs, attend schools, and enjoy urban amenities.

Yap has no economic base, and its cash economy depends almost entirely on state government spending, funds which in turn come from the United States Government. Of the total public capital investment in Yap state (1980), $47.9 million, the United States Federal Government has provided $44.7 million; the remainder has come from FSM and state sources. Of the $47.9 million, about 60% has been invested in the transportation sector and about 2% in economic development projects. A new airport and harbor facilities are being built, and roads are being improved and extended.

Current economic development plans by sector include:

- Agriculture: Developing commercial agriculture and improving subsistence farming are the first priority of the economic development plan. The state is considering developing integrated farms, citrus farms, poultry farms, and coconut plantations throughout the various districts on Yap proper.

- Tourism: Next to agriculture, tourism is the second biggest industry on Yap. The estimated revenue in 1979 was $80,000. General plans to increase tourism include increasing the local economy's involvement in tourism and upgrading the existing tourist facilities and developing new ones.

- Marine Resources: A major natural resource on Yap is its marine resource. In 1978, the FSM assumed control of the 200-mile economic zone. In 1980, the state legislature passed the State Fishing Zone Act, establishing a 12-mile fishing zone under its jurisdiction. Projects for developing a commercial fishing industry include building fish handling facilities, developing ice making and cold storage facilities, acquiring fishing boats, building a repair shop, and studying development of a main fishing port.

- Small Industries: There are no small industries on Yap today except for a sawmill which does not operate regularly. The state is considering developing businesses for meat processing, ceramic and clay products, coconut processing, and fruit processing coconut cream.

The state government needs to identify sources of funds for these projects. All of them, when implemented, will affect energy demand.

PRESENT ENERGY STATUS

Like the other FSM states, Yap depends almost entirely on imported petroleum products as fuel for transportation and electric power production. A very small contribution is made by a few small renewable energy devices, including solar photovoltaic systems, some small wind electric machines, and the widespread use of wood and coconut wastes for domestic cooking and copra drying. The central grid on Yap proper does not extend to many of the rural villages, and most of the outer islands depend on small diesel generators for electricity.

Tables 6-13 and 6-14 show end-uses for petroleum products and consumption of fuel for electricity generation. The major use of disel fuel is for generating electricty at the plant on Yap proper. This plant has two 800 kW Caterpillar and two 750 kW mid-speed diesel generator sets. Installed nameplate capacity is 3.1 MW; firm capacity is about 1.6 MW. The machinery and the plant building, which is similar to the one on Kosrae, are about five-years-old, and are in the best condition and the best maintained of all the FSM systems. Average daily peak load during weekday mid-mornings is about 1.4 kW. The average monthly power production (1980) is 635,000 kWh.

Additional end-uses of petroleum products include jet fuel and aviation gasoline, diesel fuel for the government field ships, gasoline for a mini-bus system serving Colonia and outlying villages, gasoline for outboard motor boats (est.: 500-600 in 1980) and for motor vehicles (est.: 420 in 1977), and kerosene for cooking.

Production costs for electricty are about 18¢/kWh, but the rates charged are 5¢/kWh for the first 1,000 kWh and 7¢/kWh for greater amounts. There are about 400 paying customers of which 150 either have faulty meters or no meters at all. Reimbursement to the government for electricity during 1980 was about $166,000, less than 1.5¢/kWh. Largest users of electricity are the state government, Trust Territory agencies, and Mitsui, a major contractor on the island. Among domestic consumers, United States expatriates consume about five times more than local residents. During 1981, a combination of power hours and conservation measures reduced electricity consumption by more than 3% over 1980 levels.

In the outlying islands, the population center on Ulithi has 150 kW and 60 kW diesel generators, and an outlying community on Ulithi, Asor, has a 15 kW generator. The state government supplies the fuel, and there is no billing system. There are no data for other small, private generators in rural communities.

ENERGY DEVELOPMENT PLANNING

The diesel power plant on Yap is in good condition, well-maintained, and able to meet current peak demand with only occasional outages. Future growth according to the economic plans, including the new

Table 6-13

End Uses of Fuels, YAP 1979/1980

(in 100's of bbl)

Fuel	Amount Purchased	Price[a] ($/bbl)	Gov't	Private[b]	Comm'l/Indust/ Construction	Marine Transportation Field Ship	Other	Electric Generation
Motor Gasoline	7	52	----------	7[c]	---------			
Aviation gasoline	0.1	137			0.1			
Jet fuel-K	6	73			6			
Kerosene	1	63		1[d]				
Diesel	22	54			2[e]	3[f]		17

(a) At Mobil Bulk Plant, February 1981, exclusive of taxes and transportation from plant

(b) 685 autos, 10 boats - Registered

(c) Cars, 6.4; Boats 0.7 (includes outboard motors)

(d) Cooking, lighting

(e) Primarily heavy equipment

(f) 1978 data

airfield and expanded harbor facilities, should not strain the system. Immediate goals on Yap proper are to alleviate as much as possible the vulnerability from complete dependence on imported petroleum products, to operate the existing plant on a more fiscally responsible basis, and to provide electicity through decentralized systems for outlying villages and islands. The Yap government is anxious that this be done while preserving traditional cultural integrity.

A major decision was made in 1982 to extend the grid, which had previously served only Colonia and nearby areas, to the adjoining island of Map. Intense debate preceded this decision as many of the people on Map wished to use a combination of stand-alone solar photovoltaic and wind electric systems for electricity. The gird proponents won and work on the extension has begun.

At this time the state government is taking an aggressive position toward developing renewable energy systems on Yap. Despite having the best-maintained power plant of the FSM states and having adequate capacity, the government is hesitant to extend the central grid to more communities. The Map grid extension is likely to be the last one, and in the future, decentralized systems will provide electricity for outlying communities.

The technologies that have the most promise and raise the most interest are solar photovoltaic and wind electric systems. In introducing new energy systems, Yap has had the advantage of access to good technical help from the local Sea Bees. Wind and photovoltaic systems installed to date are small stand-alone ones (300 W to 3 kW or so) used mostly for refrigeration, communication, lighting and for communication repeater stations. These systems are on Yap proper and the outer islands. The Yapese are starting to use small-scale devices such as efficient wood cooking stoves and simple solar food/copra dryers. Energy management methods will have the most significant near-term impact on reducing fuel consumption. Table 6-15 shows the features of renewable energy technologies for Yap.

Table 6-14

Electric Power Generation, Ponape, 1980

FUEL			LOCALITY	OUTPUT (million kWh/y)	END USE (million kWh/y)				CAPACITY (MW)		LOAD (MW)
Type	Amount Purchased (1000's of bbl)	Price(a) ($/bbl)			Res	Comm'l/ Indust	Gov't	Milit	Rated	Operating	Peak
Diesel	16.8	53.76	Yap Island	7.5					3.1	1.6	1.4
					2.62	1.50	3.90	0			
			Outer Islands	0.52					0.22		0.12(c)
			TOTAL	8.02	2.62	1.50	3.90	0	3.32	1.6	1.52

(a) Diesel price at the Mobil Bulk Plant, February 1981, exclusive of taxes and local transportation.

(b) 364 residences (100 with broken or no meters), 32 commercial customers, 80 government buildings, 15 outer island customers, and an additional 65 hook-ups on the outer islands.

(c) The outer islands' use, primarily Falalop, Ulithi, drops to 0.025 MW (base) and 0.04 MW (peak) during summer months when the high school closes.

Energy Management

The FSM Five-Year Energy Plan mentions a number of energy management techniques which the state government should consider to reduce fuel consumption, increase revenues, and encourage conservation and the wise end of petroleum products. If it is implemented, energy management can have a significant near-term impact.

Meters should be installed for all users, and these users should be responsible for electricity consumed. Rates should be increased slowly to cover at least operating costs and perhaps eventually some capital replacement expenses. The government should establish a power authority to make these changes. Properly trained personnel should determine energy needs through energy audits on Yap proper and the outer islands. Education programs should be established to train personnel to install, maintain, and service renewable energy systems.

Yap should have an excellent solar resource because of its latitude and apparent high amount of sunshine. However, no solar insulation data have been collected either for Yap proper or for the outer islands. The NOAA weather station near the airfield has been recording minutes of sunshine via a sunshine switch. DOE has recently delivered a recording pyranometer to the Yap Energy Office, but it is too early for significant data to have been developed.

Yap has a number of pending or completed solar projects, which should be valuable not only for their contribution to energy production but also for providing information on performance and suitability of the solar resource. Small solar photovoltaic units are powering a few refrigeration, communication, and lighting systems on Yap proper and the outer islands. Performance information from these systems and solar insulation data may show that solar systems, particularly photovoltaics, will be the most suitable technology for displacing petroleum or preventing new petroleum dependencies. Planned projects include a solar water heater for the hospital and a number of photovoltaic systems for the outer islands.

The usual Pacific Island contraints apply to solar technologies on Yap. Some are more severe, including cultural impact, land availability, and environmental effects. The Yapese are particularly

Table 6-15
Technology Selection Criteria

	SOLAR						BIOMASS								
	Solar Hot Water	Photo-voltaics	Solar Therm-al	WIND ENERGY	GEO-THERMAL	HYDRO-ELECTRIC	Tree Farms	Biogas	Liquid Fuels	MSW	OTEC	OCEAN CURRENTS AND WAVES	SOLAR PONDS	COAL	ENERGY MANAGE-MENT
RESOURCE															
proven															●
suspected	●	●	●	●			●	●	●		●		●		
unknown										●		●			
none					●	●								●	
TECHNOLOGY READINESS IN PACIFIC															
high	●	●			●	●	●								●
medium				●				●	●	●			●	●	
low			●								●	●			
RELIABILITY PROBLEMS IN PACIFIC															
high												●			
medium				●					●		●		●		
low	●	●	●		●	●	●	●		●				●	●
DURABILITY PROBLEMS IN PACIFIC															
high			●	●							●	●			
medium	●	●					●	●	●	●					
low					●	●							●	●	●
APPLICATION															
centralized					●		●		●	●	●	●	●	●	●
decentralized	●	●	●	●	●	●		●	●				●		●
POTENTIAL CONSTRAINTS															
cultural impact	●				●	●	●	●	●	●			●	●	●
land availability		●	●	●	●		●	●	●				●	●	
environmental impact					●	●	●	●	●	●	●	●	●	●	
human resources	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
infrastructure	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
CAPITAL COSTS															
high (over $10,000/kW)		●	●									●			
intermediate ($3,000 - $10,000/kW)				●	●	●	●		●	●	●		●		
low (up to $3,000/kW)	●							●						●	●
O&M COSTS															
high			●	●					●			●			
intermediate		●			●	●	●	●		●	●		●		
low	●													●	●
COST EFFECTIVENESS															
near term (0-5 yrs)	●					●	●	●	●	●					●
mid term (6-15 yrs)		●		●	●								●		
long term (16-40 yrs)			●								●	●		●	
EXPECTED OIL SAVINGS OR AVOIDANCE															
high															●
intermediate	●	●													
low			●	●	●	●	●	●	●	●	●	●	●	●	

aware of their cultural heritage and are quite anxious to preserve their traditions. Traditional land use patterns severly limit the availability of even small amounts of land for energy systems. The Yapese are anxious to adopt these systems so perhaps they can accomodate such a land use.

The new pyranometer should provide adequate solar data for Yap proper, but similar instruments should be installed on the outer islands. While the Yap Energy Office is gathering these data and reviewing performance information from existing systems, the office should encourage the installation of additional hot water and photovoltaic systems. If funding is secured for pending projects, such systems may make a significant contribution to energy production.

Wind energy conversion is a technology of great interest to the Yap state government for Yap proper and the outer islands. However, there are very few site-specific data. The Yap Energy Office installed a recording anemometer atop about a 9 meters (30 foot) tower next to the power plant in spring, 1982. There is also a privately owned nonrecording anemometr in Colonia, and there are some general data from the NOAA weather station near the airport. There are no other site-specific data for Yap proper. According to NOAA, reliable site-specific data have been gathered on Ulithi for about 10 years, and wind speeds are averaging about 4.5 n/sec (10 mph). The Yap state government is confident enough of the wind regime on Yap proper to have encouraged the installation of a number of small machines throughout the island. Performance data from these machines will provide valuable information concerning the adequacy of Yap's wind resource.

The technical suitability of wind systems is excellent because there is a good match with end-use for stand-alone systems for outer islands and rural villages and for grid-connected systems at Colonia. Potential constraints include land availability. However, the Yap Energy Office has been able to obtain land for the systems being installed now.

The Department of Energy is installing a 1.5 kW EverTech generator near the power plant as part of the Phase II effort; there is a 1.5 kW Aeropower powering a repeater station atop Mt. Matada near Colonia. The Yap Energy Office will be installing a 4 kW machine (brand unknown) at nearby Map to provide electricity for lighting communication and refrigeration, and there is a Bowjon water pumping machine near the Sea Bee base. The Kedco machine will convert to the grid; the other systems will be stand-alone with battery storage. Performance data will be valuable, but additional site-specific data must be collected at suitable sites on Yap proper and the outer islands. Thought should be given to installing a machine on Ulithi.

Biomass

Soil conditions, type of vegetative cover, and availability of land limit the potential to use biomass to make a significant contribution to Yap's central electricity supply. Small systems for producer gas or coconut oil might play a useful role in rural communities or outer islands. Inhabitants of a village on Map are doing a preliminary study on burning coconut oil there to produce electricity. A contractor for DOE will soon be completing a general assessment of biomass technologies for Yap. For the present, the most suitable biomass applications seem to be for small systems at rural locations.

OTEC

Tokyo Electric Power Services Co., Ltd. (TEPSCO) commpleted a $25,000 preliminary pre-engineering OTEC feasibility study for Yap in 1979. TEPSCO is suggesting a 5 MW plant composed of two 2.5 MW units, but first proposes to do an additional environmental study, collecting and evaluating more data. According to TEPSCO, electricty from the proposed OTEC facility would cost about 32¢/kWh (at about an 8% interest rate). The Yap state government has decided that the OTEC technology is not commercially mature for its purposes and will not pursue this technology for a few more years.

Other Technologies

The Yap government has some interest in investigating ocean current, waves, and tides as an energy source for electricity production, but these technologies are in a developmental stage even for areas with a good technical infrastructure. The University of Guam has made a biological survey of the Yap proper marine area, giving some preliminary current data, but more data specific for ocean applications are needed.

Small-scale technologies have been quite successful for Yap's rural populations. Some of this success is due in part to the work of the Yap Institute of Natural Science. This institute has been designing, building, and encouraging a variety of small energy devices such as wood cooking stoves, solar ovens, solar ventilators, and solar food/copra dryers. A solar food/copra dryer project, under the guidance of the Yap Energy Office and designed for the outer islands, has been quite successful.

There are not enough streams on Yap proper for a hydropower resource.

FINDINGS AND RECOMMENDATIONS

Present electrical power production on Yap is adequate to meet peak demands. The diesel power plant is new and well-maintained. Future economic growth, including the new airport and harbor facilities, and new hook-ups are not expected to overburden the system. The main concern is to reduce Yap's vulnerability to imported fuel price increases and to interruptions in the fuel supply. The Yap government is also anxious to use renewable technologies to provide electricty for remote villages on Yap proper rather than to extend the distribution lines and to use these technologies to provide electricity for essential needs for the outer islands.

The government should consider using certain methods for energy management to reduce fuel consumption and to increase revenues. Meters should be installed for all users, including all government users, and these users should be billed monthly for electricity consumed. Operating costs far exceed revenues so the government subsidizes most of the electricity production. Rates should be increased slowly to eventually cover operating costs. The government should consider establishing a power authority to make these changes. Properly trained personnel should make energy audits on Yap proper and determine energy needs on the outer islands. This information should be used for energy planning. Technically trained personnel are needed to install, maintain, and service renewable energy systems.

The Yap government has been aggressively pursuing an energy policy based on the use of renewable energy technologies, and it is supporting a capable energy office. For the near-term, however, renewable energy technologies will probably not make a significant contribution to fuel savings on Yap proper. Decentralized systems have promise for the remote villages and outer islands. On Yap proper, wind electric and solar photovoltaic systems are the most appropriate technologies. Performance testing data from wind machines being installed and additional site-specific data collected at suitable heights are necessary to predict how successful this technology will be. Yap has an adequate resource to power solar photovoltaic systems; the greatest constraints for this technology at this time are capital costs, land availability, and technical expertise. Available land is also a problem for biomass technologies on Yap proper. Producer gas and coconut oil technologies show promise, and a small plant for performance testing should be built. OTEC has great potential for significant baseload production for the mid- or long-term when the technology is fully developed. On Yap proper and the outer islands there are no hydropower resources.

For the outer islands and rural villages, a number of renewable technologies can help reduce the need to import fuel. If adequate resources and technical expertise are available, wind electric and solar photovoltaic systems have potential. Wind machines for pumping water from shallow lens wells should also be considered. Efficient wood cooking stoves and solar copra/food dryers have worked well to date, and their use should be encouraged. Small producer gas or coconut oil facilities should also be considered.

Table 6-16 lists the overall recommendations for the Federated States of Micronesia, including those for Yap.

Table 6-16. Energy Planning Recommendations for the Federated States of Micronesia

Population Centers

Improve Energy Management.

Install meters at power plants to record electricity production and generator efficiency.

Install electric meters for all users, including government departments and housing.

Bill all users and disconnect service to those who do not pay their bills.

Consider changing the rate structure so that rates will eventually equal operating costs, including capitalization costs.

Consider establishing a local power authority.

Continue to perform energy audits and develop a data base for energy planning.

Develop training programs for local workers in renewable energy system concepts, including installation, maintenance, trouble shooting and repair.

Continue collecting solar insulation data and start collecting wind data at a few selected locations at appropriate heights. Collect performance data on existing systems.

Continue assessing the biomass resource in each state for direct combustion for electricity production and for use in producer gas and palm oil systems. Install a producer gas or palm oil system for performance testing. Test effects of palm oil used as a substitue for diesel fuel.

Continue encouraging the use of smokeless wood stoves for domestic and school cooking.

Monitor the new hydroelectric facility being built on the Malem River to see if such systems can make a contribution to baseload production (Kosrae).

Monitor the newly installed solar hot water system at the hospital (Kosrae).

Continue efforts to develop the hydropower resource on Ponape, particularly the Napil River (Ponape).

Assess performance data from the Xavier wind electric system and the Fairchuk photovoltaic system (Truk).

Investigate the feasiblity of using cables from Moen to provide electricity to the other Lagoon islands.

Investigate the possibilities of retrofitting field ships with sail power (Ponape, Truk, Yap).

Rural Villages and Outer Islands

Perform audits to determine rural energy needs and to develop a plan to address these needs.

Encourage rural training and education in renewable energy system concepts.

Encourage the use of smokeless wood stoves for domestic and school cooking.

Collect solar insulation and wind data at selected sites to determine whether small, stand-alone wind and photovoltaic systems will be feasible.

Develop a small-scale energy project or projects with high community involvement for producer gas, palm oil, hydropower and photovoltaics.

Based on newly acquired solar insulation data, begin enegineering design of a photovoltaic system suggested for Utwe (Kosrae).

Monitor the Palikir Power hydroelectric project to see if similar projects would be useful in other rural areas (Ponape).

Continue to develop sail-assisted fishing vessels (Truk, Yap).

CHAPTER 7: ENERGY PLANNING FOR THE REPUBLIC OF THE MARSHALL ISLANDS

The Republic of the Marshall Islands, located 8400 kilometers (5250 miles) southwest of San Francisco in the Central Pacific Ocean, is the eastern gateway to the 2500 islands of Micronesia. The Marshall Islands share with the rest of Micronesia, and with American Samoa, an almost total reliance on petroleum fuels and consequent economic stresses caused by rising fuel prices and uncertain energy supply. Economic development planning in the Republic is centered on the encouragement of foreign investment, particularly that which offers new industry and employment opportunities for the growing labor force.

The government recognizes the importance of firm, reliable electric power in attracting new investment, and has addressed the problem for the near and intermediate term on Majuro Atoll with a new 12 MW residual oil-powered generating facility and a planned grid extension. This large, grid-connected power plant for the crowded urban centers is only part of the approach energy planners are taking in the Marshall Islands. Dispersed populations on remote islands must also be served. In the longer term, the Republic plans to use renewable fuel resources wherever possible and to extend electrical services to the outer islands to foster economic development and help stem the population flow to Majuro and Kwajalein atolls.

The Marshall Islands consist of two nearly parallel chains of coral atolls and islands which extend over 1000 kilometers (700 miles), about 200 kilometers (300 miles) apart (see Figure 7-1). The islands are coral caps on great dome volcanoes which rise 5490 meters (18,000 feet) from the ocean floor. At no point are any of the Marshall Islands higher than 9 meters (30 feet) above sea level. The eastern, or Ratak (sunrise), chain encompasses 16 major atolls and islands; the western Ralik (sunset) chain includes 18 atolls and islands. Together, these two chains contain 1152 islands and islets dispersed over more than 1.3 million square kilometers (500,000 square miles) of the Central Pacific, but the total land area is only 182 square kilometers (70 square miles).

About 31,000 people live in the Marshalls; the population is divided roughly into thirds, with a third on Majuro, a third on Ebeye Island (Kwajalein Atoll), and the remaining third on the outer islands. With a population of 8800 and a land area of 15.1 square kilometers (6.3 square miles), Ebeye has the highest population density in the Pacific, 583 people per square kilometer (1396 per square miles).

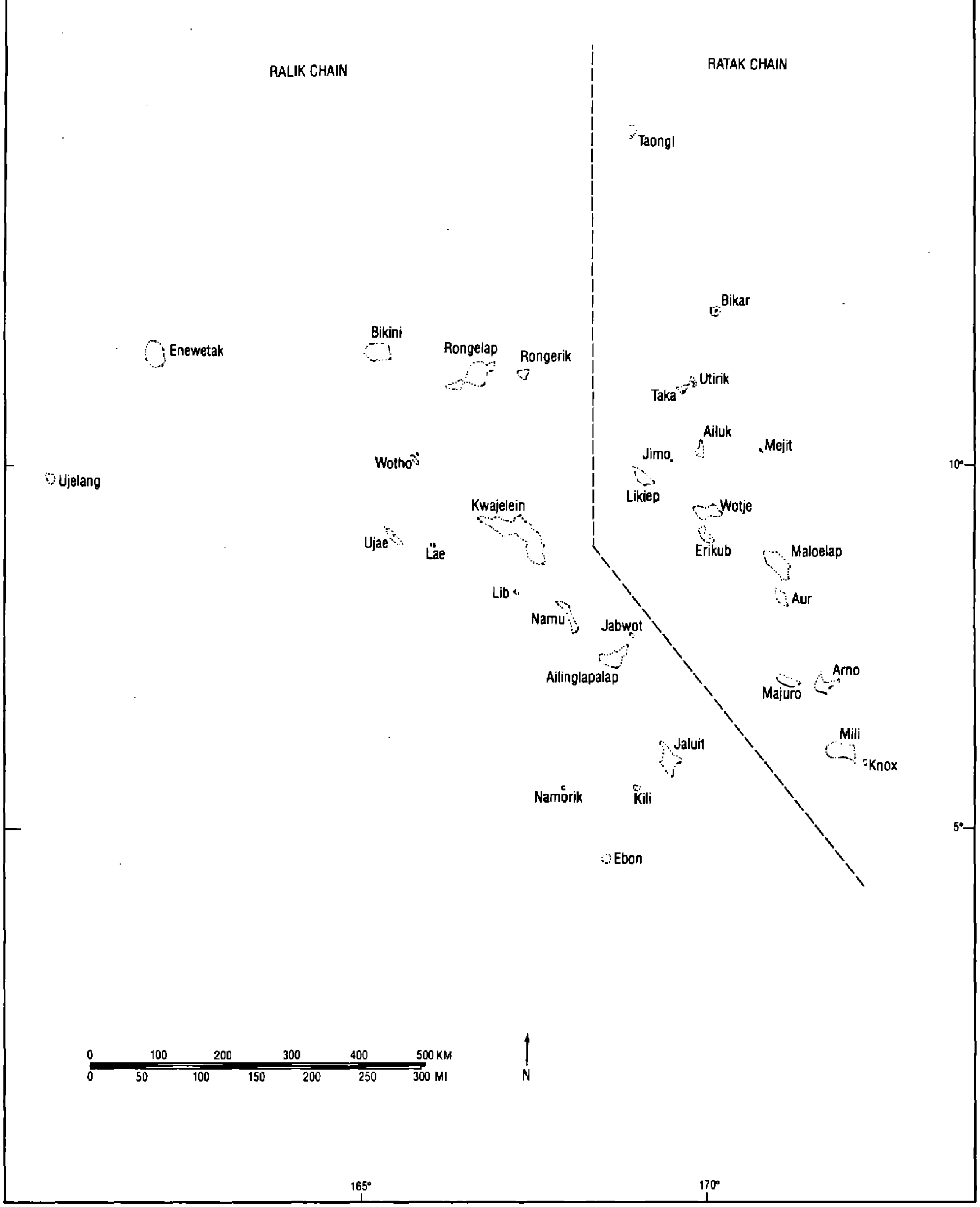
Majuro Atoll consists of 64 islands atop a reef that encloses a lagoon approximately 324 square kilometers (125 square miles) in area. The three interconnected large islands of Darrit, Uliga and Dalap at the eastern end of the atoll make up the municipality of DUD, the government, commercial and transportation center of the Republic.

The climate is tropical--hot and humid with an average temperature of 27°C (81°F) and daily variation of less than 7°C (12°F). The islands are cooled slightly by the prevailing seasonal trade winds. Rainfall averages nearly 460 centimeters (180 inches) per year in the southern atoll, with the wettest group of islands averaging nearly 80 centimeters (70 inches) a year.

The Marshall Islands are generally not considered to be in the typhoon belt, although planning for energy facilities must take infrequent severe tropical storms into consideration. Planning must also recognize that because the islands are true atolls with low-lying reefs and land masses, they are easily flooded during storms and tidal waves. As recently as late 1979, an inexplicable tidal surge struck the most densely populated areas of Majuro Atoll over a two-day period, destroying 1100 homes and causing millions of dollars of damage.

The most important oceanic current affecting the Marshalls is the 480-kilometer-wide (300-mile) Equatorial Counter Current, which flows eastward at an average speed of 0.4 to 1.0 knots, with maximum speeds of up to 2.0 knots. Local current velocities along the islands and reefs within the lagoons are not known, but most have a general flow through the atoll passages into lagoons at rising tide and out

Figure 7-1
The Republic of the Marshall Islands



at the passages at falling tide. Tides are semi-diurnal with a mean range of about one meter (3.5 feet). The extreme tidal range can vary from zero to 2 meters (7 feet).

HISTORY AND POLITICAL DEVELOPMENT

The Marshallese, a Micronesian people of mixed Proto-Malay-Polynesian descent, were skilled navigators and seamen who traversed the seas over great distances. They formed matrilineal clans tied in common to the land in an intricate set of heirarchiacal relationships. A complex land tenure system evolved which affects land use patterns today.

Contact with European whaling ships and traders began in the nineteenth century. The influence of Christian missionaries from the United States is evident today in the presence of many sects and faiths, principally Protestant. German copra traders became active in the Marshalls in the last third of the nineteenth century, and after challenging Spain's claim to the islands in 1885, Germany purchased the Marshalls along with the rest of Micronesia in 1899.

The German period was marked by the prosperous growth of the copra trade, centered on the island of Jaliut, then the capital. It was abruptly interrupted in 1914, when a Japanese naval squadron took posession of the Marshalls at the outbreak of World War I. In the following thirty years, the Japanese further extended the copra industry and attempted to exploit the land and water resources, mostly through the importation of Japanese nationals.

The Marshalls became a World War II battleground and suffered major invasions on Kwajalein, Enewetok, Majuro, and lesser bombardments in the other atolls. In 1944, most of the atolls were occupied by American forces. Before the establishment of the United Nations trusteeship in 1947, Bikini and Enewetok atolls were set aside and, after discussions with and evacuation of the few hundred inhabitants, used for atomic and hydrogen bomb testing until the mid-fifties. Kwajalein, the world's largest atoll 112 kilometers (70 miles) long with a lagoon that totals 2180 square kilometers (840 square miles) became a United States Naval Base, and in 1959, a missile testing facility.

Self-government began with the creation of the first Marshall Islands Congress in 1949. By 1976, the Marshallese had become dissatisfied with the centrally-controlled division of revenue among the Micronesian island districts, the lion's share of which derived from activities related to the Kwajelein missile range. It, therefore, established a political status commission to pursue separate negotiations with the United States. In a 1978 referendum, the Marshallese rejected a closer union with the rest of Micronesia, and in 1979 established a constitutional government modeled after the British parliamentary system.

The Government of the Marshall Islands has its own President, who is elected by the unicameral legislature, the Nitijela. In negotiations with the United States, the Marshall Islands Government has indicated a wish to join the United States in a Compact of Free Association. Under this fifteen-year arrangement, the Marshalls retain full political sovereignty and grant certain defense concessions to the United States in exchange for some services and budgetary support projected to total $800 million over the 15 years. As of this writing, the final details of the Compact have not been determined. The Compact must be approved by a plebisite in the Marshall Islands and by vote of the United States Congress and the United Nations Security Council.

POPULATION, EMPLOYMENT AND WAGES

The indigenous population of the Marshall Islands held relatively steady from 9600 people in 1920 to slightly over 10,000 just before World War II (see Table 7-1). Since WWII, population growth has been fueled by a high annual birth rate of around 3.5%. Preliminary results of the 1980 census put the total population of the Marshall Islands at around 31,000 people. The average age is very low, just over 16 years. Growth projections show the population more than doubling by the year 2000.

Table 7-1. Population of the Marshall Islands

Year	1920	1930	1935	1958	1967	1973	1980	1990 (projected)	2000 (projected)
	9,600	10,000	10,400	13,800	18,600	24,100	31,000	42,500	60,300

The economy of the Marshall Islands is characterized by great divisions between the urbanized areas and the outer islands. About one-third of the Marshallese live in a subsistence economy in the outer islands. The remaining 70% live and work in a wage economy in urban Majuro and on Ebeye Island in Kwajalein Atoll. The government of the Republic is the single largest employer and the major economic force. In the private sector, copra production continues to be the major economic base. The Gross Domestic Product in 1977 (the most recent year for which figures are available) was $24.1 million, which yields a per capita annual income of $892. Significantly, imports exceeded exports by more than four to one.

Employment is centered on Majuro and Kwajalein Atolls. About 40% of the labor force is directly employed by the government of the Republic. On Majuro Atoll, over half of the jobs and nearly 80% of the salary income are provided by the government, while the remainder is provided by trading activities and services, such as taxis, air and sea transport, stevedoring, restaurants, bars, banking, and car repair. A large part of private sector employment in the trades and personal service industry depends on the income generated through employment in the government sector. A small flow of tourists creates some demand for tourism-related services. This industry, however, provides only about 5% of the jobs and income in the economy. Marshallese law sets the minimum wage at eighty cents per hour.

Unemployment has grown rapidly in recent years as unskilled workers from the outer islands flocked to the urban areas seeking to enter the cash economy. Between 1973 and 1979, 50 to 60 new jobs were created annually, while the working age population increased by about 275 people per year. Although only about one-quarter of Marshallese women actively seek long-term employment, limiting labor force growth to approximately 150 people per year, the labor force still grew more than twice as fast as the number of jobs. Unemployment was about 40% of the labor force in 1973 and is currently estimated to be about 45%. More than half of the unemployed are under 25 years of age.

Because most consumer goods are imported, inflation in the country of origin of the goods is also imported. However, the imported inflation is not necessarily the same size as that existing in the country of origin. For instance, the large share that shipping contributes to the product cost may affect the magnitude of the imported inflation. Improved schedules, additional competition, and the worldwide oversupply of shipping capacities caused by a general slowdown in economic growth have helped stabilize shipping costs in the recent past.

Between June 1978 and June 1979, average retail prices increased by 9.5%, while the prices during the following year, to June 1980, increased by 5.9%. Since wages and salaries are not adjusted for increases in the cost of living, the purchasing power of the salary earners has been declining rapidly in recent years.

Fuel costs increased 75% between 1979 and 1981, the highest rate of increase among imports for that period. The costs of manufactured goods increased by 69%; food costs increased by 16%, and those of beverages and tobacco increased by 10%. The costs of transportation and machinery increased by 9%, and crude materials by only 4%.

INFRASTRUCTURE

The industrial activities in the Marshalls are very limited. A coconut oil extraction plant, a machine shop, some small boat building operations, a small handicrafts industry, some agricultural and fishery production and some small service type industries, such as bakeries, tailoring shops and a printing shop, form the industrial basis of the Majuro economy. A deep ship passage on the north side of the Majuro Atoll provides access to the lagoon for the commercial shipping lines which serve the Marshalls. There are docking facilities at DUD, and a new dock is being constructed nearby. The new facility will accommodate deep draft vessels and allow servicing of more than one ship at a time. Ebeye has a major docking facility which is being expanded.

The airport facilities, 11 kilometers (7 miles) west of DUD, include a 2400 meter (8000 feet) runway. Air service is provided by Continental/Air Micronesia to Hawaii in the east, and to the other districts of the Trust Territory, Guam and Saipan to the west. Air Nauru provides connections to the South Pacific and Guam via Nauru. Both airlines fly Boeing 727 aircraft. The Airline of the Marshall Islands (AMI) provides passenger and cargo service on an irregular basis between Majuro and other islands and atolls with landing strips. AMI, a government-supported carrier, is involved in a concerted effort to develop strips throughout the Marshall Islands.

The DUD area has a well-developed public water system with a storage capacity of approximately nine million gallons, roughly a twenty day supply. Most of the water is provided via rain catchment, supplemented during periods of low rainfall by three skimming wells. Major catchments are the airstrip and an adjoining field, and roof catchments at the hospital and Marshall Islands High School. Treatment consists of rapid sand filtration and chlorination. Individual household catchments and approximately 35 shallow wells supplement the public system. About one-third of the DUD population has hook-ups to the system, but many others use taps to the main line that are provided for public access.

Majuro, Ebeye and Jaluit are the only areas consistently served with electricity. Majuro's main power plant was constructed in 1960 and expanded in 1963 to accommodate more generators. At present, peak demand on this power plant is close to installed operating capacity. The existing power plant is a mixture of six different types of machines generating electricity at four different output ratings. All of the generators are high speed units, and most were purchased in the late 1970s. Three, however, were transplanted from diesel submarines and are perhaps the most reliable of the entire assortment.

PROSPECTS FOR ECONOMIC GROWTH

Economic development anywhere in the Marshalls must proceed under constraints of limited land, energy and water. Clearly, a similar shortage of workers is not anticipated, but without education and training programs to prepare workers for the industries and types of development the government wishes to encourage, skilled labor will be in short supply.

One national program now being implemented calls for a significant improvement in infrastructure, particularly in the outer islands, to lay the base for developing agricultural (principally coconut replanting) and marine resources. Some evidence indicates that there are commercial quantities of phosphates in the outer islands. The intention is to reverse the flow of people to the urban centers of Majuro and Ebeye Island by developing the resources of the outer islands and improving services there. While the economic goals and objectives of the Marshall Islands' government are similar to those of the other American influenced islands in the North Pacific, the Marshalls have been more systematic and aggressive in attaining those goals and objectives. For example, the Republic is carrying forward an extensive effort to replant its islands with an integrated crop approach which both increase copra production potential and produce foodstuffs. Coupled with the existing copra processing facility, the Marshalls is in a solid position to diversify and expand the coconut oil refinery and enter into the oil products area.

The economy of the Republic is almost totally dependent on the level of government funding. The government, in turn, has been funded largely by transfer payments from the United States. Other external sources of income are derived from the lease of Kwajalein Atoll and payments for fishing access rights. It is expected that the level of funding from the United States under the Compact agreement will remain relatively constant for several years and then begin to taper off. Other external sources of income are not expected to increase significantly. This means that the level of government spending cannot increase substantially, and consequently, that the growth prospects of that large part of the economy which depends on government spending are dim. Economic growth in the Marshalls, therefore, will rest entirely on the performance of the currently very limited industrial, agricultural and fisheries sectors.

A five-year economic development plan is now being drafted for the period 1982 through 1987. During the plan period, primary emphasis will be given to increasing the Republic's self-reliance in food production. Agricultural extension efforts in the outer islands will receive special attention.

While copra will continue to be the primary export product, efforts to diversify the export base are needed to ensure a healthy economy. World prices for copra are cyclical, often volatile, and beyond the control of any exporting country. Excessive reliance on copra as a foreign exchange-earning crop makes the economy unstable and subject to the same cyclical fluctuations. The Republic's diversification of exports plan includes increasing tourism. While tourism produces no physical goods for export, it contributes to the nations's balance of payments and is therefore an important factor in the Republic's trade program. A new tourist hotel is under construction in Majuro and is scheduled for completion in 1983. The plan also calls for establishing a fishing industry that will eventually produce enough surplus for export; and taking advantage of the Marshall Islands' proximity to important fishing grounds and shipping lanes, to re-export fuel to fishing fleets and other types of ships and, possibly, to other Pacific Island nations.

The Republic has identified specific projects which will expand and diversify domestic exports and re-exports, and which will provide locally-produced goods as a substitute for imported ones. Both approaches are necessary if the goal of narrowing the export-import gap is to be met. The Republic's strategy is to favor the economic development sector in the first five years of its 15-year planning horizon in order to generate an expanding, self-sustaining revenue base.

During the period fiscal year (FY) 1977 to 1981, gross capital formation (GCF) by the government amounted to $43.6 million, or an average of $1.7 million per year. Of the total amount, $34.4 million, or 79% was directed towards economic development projects, and the remainder was used in the formation of social infrastructure (see Table 7-2). The single largest project within the five-year period was

Table 7-2. Gross Capital Formation, FY 1977-1981.

	thousands of 1980 $	% of capital formation
ECONOMIC DEVELOPMENT PROJECTS		
Majuro Power Plant/Fuel Farm	25,307	58.1
Docks	7,092	16.3
Aircraft	2,000	4.6
Sub-Total	34,399	79.0
SOCIAL INFRASTRUCTURE		
Water	4,308	10.0
Electrical	1,286	2.9
Sanitation	1,589	3.6
Airstrips	2,000	4.6
Sub-Total	9,183	21.0
Total	$43,582	100.0%

the Majuro Power Plant and Fuel Farm, which is expected to provide returns on the investment through domestic electricity sales and the sale of fuel to fishing fleets and to other nations.

Two primary sources financed the gross capital formation that occurred between fiscal year 1977 and 1981: overseas borrowing, and the Capital Improvement Program (CIP). Loans were directed primarily to economic development projects, and CIP funding was used for both social infrastructure and economic development.

The Capital Improvement Program is a multi-year program initiated by the United States in 1976 to put infrastructure in place in the Trust Territory governments. During the plan period, $34.4 million will be spent in the Marshall Islands to complete the CIP. All of the funds have been allocated to programs, and some of the projects have been started.

During the next five years, the Republic will spend $39.4 million for payment of principal and interest on previous capital investment projects. This debt service schedule amounts to $7.9 million for 1983; $9.4 million in 1984. (see Table 7-3). Current and future debt service will draw down heavily on the Marshall Islands' ability to initiate new projects beyond the scope of projects that have already been identified. Over half of the Republic's Compact monies will be utilized for debt service over the next five to ten years. This will severely limit flexibility in developing capital projects, and could prove to be a decided deterrent in the long run.

The bulk of the Marshalls' debt service will be for the new power plant being constructed on Majuro. However, this investment has fairly well assured the Republic of a ready and reliable source of energy, one which will meet the atoll's demands for some time to come. Small-scale renewable energy projects are playing an important role in the outer islands as the government has placed a high priority in meeting basic energy needs throughout the Marshall Islands.

The Republic is also committed to meet the basic housing needs of its citizens and to provide more community utilities and services. An adequate salt water sewer system for the DUD area is needed, and smaller scale systems are needed for other areas. The government wants to maximize the fresh water potential of Majuro Atoll, using all available sources. An adequate solid waste management program is needed, as is an economical and predictable public transportation system for both land and water.

Table 7-3. CIP Account: Funding for New Projects, 1983-1987

	FY83	FY84	FY85	FY86	FY87	TOTAL
	(millions of 1980$)					
Basic Grant Allocation Capital	10.4	11.2	11.9	12.8	13.7	60.0
Energy Allocation	2.0	2.0	2.0	2.0	2.0	10.0
Communications Allocation	3.0	-	-	-	-	3.0
	15.4	13.2	13.9	14.8	15.7	73.0
Less: Debt Service	(7.9)	(9.4)	(8.2)	(7.2)	(6.7)	(39.4)
Available for New Projects	$7.5	$3.8	$5.7	$7.6	$9.0	$33.6

Fisheries

The Marshall Islands fishing industry is presently constrained by a lack of storage, marketing and transportation facilities. Because marine resources have an important income-producing potential, the Development Plan makes development of marine resources a first priority. The Plan objectives include providing a secure supply of domestic fishery products for a significant proportion of the population to substitute for imported canned meats. The government would also like to develop a fish export industry.

Both of these objectives call for a support infrastructure, including the construction of reefer plants (refrigeration/freezing facilities that blast-freeze fish) on selected outer islands and the placement of fish freezers on the field ships so that catch from the outer islands can be transported to the urban centers. The government intends to establish the fish export industry through many small-scale producers.

Now that a residual oil tank farm has been established at Majuro for ship bunkering, a crew rest and recreation and medical and operational support base is planned for Majuro. The base would serve the Japanese fishing fleet, stocking spare parts for the vessels and offering a ship repair facility and a railway to drydock vessels.

A substantial cold storage facility is also planned so that vessels can offload their catch for further trans-shipment. The current alternative is to offload in refrigerated containers, which are available at the Port of Majuro. It may be more feasible to develop a corning facility or a cannery to process the catch at the Port of Majuro.

Agriculture

It has already been noted that the government of the Republic plans to minimize food imports through increased crop and livestock production. To do this, it will be necessary to promote farming as a wage-earning enterprise for outer island inhabitants and to provide marketing outlets and reliable transportation. Projects intended to increase production of fish, poultry and eggs, vegetables and pork will include the establishment of breeding stock as well as of facilities for adequate refrigeration, transportation and marketing.

The Plan objective for the copra sector is to increase exports by an average of 5% per year. In the first year of the plan, the Tobolar facility on Majuro is expected to process nearly 9000 metric tons (10,000 short tons) of copra, about 40% of its current capacity. Production increases during the next five years will be accomplished through the following measures:

- o Rehabilitate, during the five years, a total of 2025 hectares (5000 acres) of overmature coconut groves
- o Establish replanting projects in many of the other islands, including replanting with high-yield types of coconut palms

- Complete construction of outer-island warehouses by the end of 1984
- Begin a program to place solar-powered copra dryers in outer islands communities
- Increase purchases of unprocessed copra from the country of Kiribati to the south

Coconut Rehabilitation Project

The coconut rehabilitation project will be tied closely with a sawmilling project that will use overmature coconut trees. It is planned that the Agro-Forestry Section will clear selected atolls of overmature palms, sawing them on a portable sawmill now being refurbished in Majuro. Some logs will be shipped to Majuro to keep the second sawmill supplied. Replanting will be done on a cooperative system, whereby supervision will be supplied by the Agro-Forestry Section, but seednuts and labor will be provided by the landowners. Twenty-five percent of the sawn lumber will be returned to the landowner, and the Department of Natural Resources will retain 75% for clearing the land and for sawing the timber.

Tobolar Oil Refinery and Oil Products Plant

The government is reserving over one million dollars for a direct equity injection into the Tobolar Copra Processing Plant on Majuro to install an oil refinery, soap factory, bottling plant, soap packaging facility, and a warehouse. A feasibility study will be initiated in 1983 with assistance from a United Nations Advisory Team to determine the costs, economic potential and marketing area for the refined products, which will include cooking oil and soap. If the project proves feasible, the second phase will be the construction of bottling and packaging plants. The products will probably need to be marketed in other Pacific nations for the concept to be feasible.

The primary advantages to this diversification would be an increase in the overall economic base of the Marshall Islands, an increase in the skilled labor force, and a stabilization of the raw product price, which currently fluctuates with the world market.

Fuel Tank Farm

The Government plans to enter into a joint venture professional management contract to maximize use of its fuel tank farm for the import and re-export of fuel to other nations and shipping fleets. The fuel tank farm, which has a capacity of 4.5 million gallons, was completed in September 1982 as part of the Majuro power plant projects. The joint venture company will begin selling fuel to Japanese and Taiwanese fishing fleets, as well as to commercial cargo carriers, in 1983.

PRESENT ENERGY SYSTEM

The government of the Republic recognizes that if the planned economic development projects are to succeed, the present energy system will have to be expanded and made more reliable. This applies to the centralized electrical grid systems on Majuro and Ebeye as well as to extending dispersed electrical supply systems to the outer islands.

Diesel oil is the main fuel used in the Marshall Islands in all non-military end-use sectors. It is used for all electrical power generation, ship fueling, construction equipment, and as a boiler fuel for industrial applications. Twenty-nine percent of all the fossil fuel consumed is used to produce electricity. Of the 26 inhabited atolls in the Marshall Islands, three have government-owned and operated electrical generating plants. These plants provide electrical power to almost 60% of the Republic's total population. Domestic power requirements for the remainder of the population are met almost exclusively through the use of kerosene for both cooking and lighting. There is limited charcoal production, and firewood is used where available.

Electrical Generation

At the time of this writing, November 1982, total electrical generating capacity in the Marshall Islands is presently 7.7 MW (rated) and about 5 MW (operating). Peak demand is slightly less than 5

MW, while the base load totals less than 4 MW (Majuro 2 MW; Ebeye 1.4 MW; and Jaluit less than 0.4 MW). All generators currently in service are high speed units, most of which were purchased in the mid-1970s. Table 7-4 defines the electric power of generation capacity of the Republic based on the most recent data available.

Table 7-4

Table 7-4. ELECTRIC POWER GENERATION, MARSHALL ISLANDS, 1980[a]

FUEL			LOCALITY[b]	OUTPUT (million kWh/y)	END USE (million kWh/y)			CAPACITY (MW)			LOAD (MW)	
Type	Amount Purchased (1000's of bbl)	Price[c] ($/bbl)			Res	Comm'l/ Gov't Indust	Milit	Rated	Operating	Standby	Base	Peak
Diesel	34	53.76	Majuro	10.4	---5---		4.9	4.5[e]	3.0	0.5	1.9	2.4
			Ebeye	4.8				2.4	1.4	0.3	0.9	1.4
			Jaluit	1.7[d]				0.8	0.5		0.3	0.5
			TOTAL	16.9	---5---		4.9	7.7	4.9	0.8	3.1	4.3

(a) Not including Kwajalein

(b) Population: Majuro 11,893; Ebeye 6629; Jaluit 1485

(c) Diesel price at the Mobil Bulk Plant, February 1981, exclusive of taxes and local transportation

(d) Estimate

(e) There are two additional 800 kW generators in storage

On Majuro Atoll, 53% of the electric power generated is consumed by the private sector, with the largest private user being a commercial department store that uses about 2400 kWh per month. As of 1980, there were 802 private electrical connections served by the Majuro power plant. The slim margin between peak demand and rated capacity on Majuro has led the government to decline all requests for new electrical connections since 1979. An estimated 1 MW in latent demand for electricity has been created by this moratorium on connections.

The existing power distribution network on Majuro consists of approximately 19 kilometers (12 miles) of overhead transmission lines. The distribution lines are presently being extended to add another 27.5 kilometers (17 miles) to the system. An additional 1.5 MW of demand is expected to be served upon completion of the transmission line extension to Laura village.

Costs associated with electric power generation in the Marshall Islands have grown significantly in recent years with the rise in world oil prices. Total utility expenditures for petroleum, oil, and lubricants in FY 82 will be approximately $3 million. Utility staff costs will be on the order of $250,000, while maintenance costs for the present generating plant are expected to be over half a million dollars.

On the island of Ebeye, electrical power supply remains unreliable. The present Ebeye power plant consists of about 2 MW installed generating capacity, although on the average, only half of this capacity is in service. The low operating capacity of the plant, and increasing population pressures on the island create a significant amount of unfulfilled electrical demand.

On Jaluit, some 700 kW of generating capacity is in place, with a baseload of 300 kW serving a total of 109 residential, commercial, and government connections.

Metered customers throughout the Marshall Islands are charged 8¢/kWh for electricity, on a flat rate basis. Unmetered customers pay a charge of $8.00 per month. Electricity production costs on

Majuro are estimated at 21¢/kWh. The 13¢ difference between cost of production and rate charged per kWh of electricity is paid for by government subsidy to the publicly-owned utility.

Across the remaining atolls of the Marshall Islands, the government has provided some 53 solar photovoltaic-powered units for radio communication. There are also small water pumping stations on both Kwajalein and Majuro that are powered by mechanical wind energy conversion systems.

Liquid Fuels

Recent data indicate that there are now over 800 registered automobiles in the Republic, plus some 45 outboard motor boats. Aggregate consumption of liquid fuels across all use sectors is presented in Table 7-5.

Table 7-5. END USES OF FUELS, MARSHALL ISLANDS, 1980 [a]
(in 100's of bbl)

Fuel	Amount Purchased	Price(b) ($/bbl)	Gov't	Private	Comm'l/Indust/ Construction	Marine Transportation Field Ship	Marine Transportation Other	Electric Generation
Motor gasoline	22	52	-----------	22[c]	----------	0.2[d]		
Aviation gasoline	0							
Jet fuel-K	33	73			33			
Kerosene	4	62		4				
Diesel	98	54			33	15[d]	14[e]	36

(a) Not including Kwajalein Atoll

(b) At Mobil Bulk Plant, February 1981, exclusive of taxes and local transportation

(c) 700 autos, 20 registered boats and outboard motors

(d) 1978 data

(e) Includes fuel for outer islands

Population: 31,045 (Sept. 1980)
Households: 1952 (Sept. 1980)

The Republic of the Marshall Islands operates a domestic fleet of four field trip ships to provide outer island passenger and shipping service. Until the advent of the Airline of the Marshall Islands, this fleet provided the only trading, supply, and administrative links for the outer island communities. Presently, field ship service to the outer islands consumes approximately 15% of the total diesel consumed in the Republic. The domestic fleet is comprised of three Micro class ships and one Islander class vessel. Each Micro class ship has a cargo capacity of 800 tonnes (789 gross tons) and is equipped with 2.7 and 4.5 tonne winches to provide dock side loading and unloading. The fuel consumption rate for these ships is 1200 gallons per 24 hours. The Islander class vessel is a 493 metric ton vessel equipped with identical working load winches. The fuel consumption rate is also 1200 gallons per 24 hours.

There are plans to replace the engines of two of the Micro class ships with slow speed, residual fuel oil-burning engines to increase fuel efficiency and reduce maintenance requirements. The energy savings potential of this measure has not been determined yet. A feasibility study has also been undertaken on the sail-assist retrofit of the Republic's international carrier.

The Republic has recently established the Marshall Islands Maritime Corporation as a government owned and operated corporation to improve international shipping services to the Republic. The major asset of the company is a 6045 metric ton vessel which is both a break bulk and cargo vessel. The ship consumes about 60 barrels of MDO and 11 gallons of lube oil each 24 hours.

The Republic established the Airline of the Marshall Islands (AMI) in 1980 as a wholly owned government corporation. The airline's present inventory consists of one 14-seat and one 16-seat Nomad plane, and one 48-seat BAC-HS748 aircraft. The government began an intensive program to construct outer island airstrips in 1980 with the goal of providing air transportation capability to all outer islands. To date, fourteen domestic airports are in operation, and there is one international airport in Majuro that is capable of accommodating 707 jets.

Now that air transportation is possible in many cases of medical emergency in the outer islands, field ship operation has become more reliable. Ship schedules were often affected in the past when ships were diverted for medical emergencies or evacuations.

In 1981, 33,000 barrels of jet fuel were purchased in the Marshall Islands; the principle consumer was Air Micronesia. This figure is expected to increase annually with expanded routing of the AMI 748 and completion of all outer island airstrips.

PLANNING FOR THE FUTURE

The single most important development influencing the present energy system status in the Republic of the Marshall Islands is the new residual fuel oil-fired power plant on Majuro. When it is complete, the new plant will be a four-unit, 12.8 MW system, and will include fuel storage tanks and maintenance facilities. When fully installed, the plant will be operated at 60% (7 MW) of rated capacity. The four individual 3.2 MW units are mobile, and will be brought on line over a four-year period. The first unit came on line toward the end of 1982.

The decision to replace, and substantially increase, existing generating capacity reflected a desire on the part of the Republic to reduce operating costs and to provide sufficient power to encourage new industry to locate on the island of Majuro. The use of residual oil rather than diesel is expected to bring a considerable fuel cost savings to the government. Residual fuels have a higher Btu value per gallon than does diesel fuel, and generators using residual oil run more efficiently than diesel units. Operating efficiencies of 17-18 kWh/gallon are anticipated with the new units, compared to the 11-12 kWh/gallon rating of the present diesel generators. Annual fuel savings to the government are expected to reach nearly $750,000.

In proceeding with the new central power plant, the government has recognized the importance of firm, reliable power in attracting new investment. As the first units of the new generating facility come on line, domestic demand is expected to rise, based on the number of requests for new electrical connections already on order. Likewise, the grid extension to Laura will open the remainder of Majuro Atoll to the central power network and increase demand on the order of 1.5 MW.

Historically, the government sector was not charged for electricity consumption, and most government buildings went unmetered. To begin reversing this inherited policy of substantial electric rate subsidization, the Government of the Marshall Islands has an effort underway wherein all government departments shall budget for electricity consumption. In addition, power from the new plant will be sold according to a substantially revised and tiered rate structure, not at the low, flat rates now in effect. These measures are expected to have a positive effect on efficient energy management, and to encourage, over time, the introduction of added conservation techniques and energy-efficient technologies.

The government is also mandating energy-efficient designs for all new buildings. The Public Works Department is replacing incandescent bulbs with fluorescent fixtures wherever possible to reduce energy consumption and costs. Lighting needs surveys are being conducted in government facilities to identify unneeded lights.

Energy planning for the outer islands has followed a different approach because there is little or no government supplied conventional fuel on the remote atolls of the Republic. Photovoltaic modules have replaced a network of small diesel generators once used to power communication radios on the outer islands. The solar systems now perform that function at no annual fuel cost to the government. Additional energy supply options for the outer islands will depend on the Republic's outer island development priorities. Increased government services to these remote locations, intended to support improved living conditions and out-migration efforts within the Republic, are also expected to increase demand in those areas.

The government has expressed a broad commitment to consider the use of renewable energy technologies in meeting low power requirements on the outer islands. Such a step will preclude the need for expanded use of diesel generators with their inherent fuel costs and maintenance requirements. A range of alternate energy resources and technologies, including energy management, available in the Marshall Islands has been considered, and some conclusions may be drawn about the relative attractiveness of each. The criteria presented in Chapter 2 relative to selection of alternate energy systems can be applied to the variety of renewable energy sources and conversion techniques that have been suggested for application in the Pacific Islands. Their relative appropriateness for the Marshall Islands can be better understood after screening against resources, conditions, and policies unique to the area. These technology assessments follow below with findings summarized in Table 7-6.

Energy Management

Within the Marshall Islands, several potential energy management actions have been identified. Each would contribute significantly to the more efficient use of electrical energy from the Majuro power plant. This, in turn, would free capacity at the plant for use by new commercial and industrial users, and help support the Republic's goals for economic development. Among the many energy management steps which can be taken, those with the most oil savings potential are:

- Institution of an electric power rate structure that better reflects the costs of production on Majuro, Ebeye, and Jaluit
- Installation of kilowatt-hour meters, first in all government sector buildings on Majuro, and eventually on all buildings that are not now metered
- Institution of a budget mechanism to begin billing government agencies for electricity consumed
- Development of energy efficiency standards to be applied to all new government and commercial buildings on Majuro
- Demonstration of passive cooling retrofit on selected government buildings
- Implementation of energy conservation measures beyond those already taken within the government sector, including replacement or removal of inefficient or unnecessary electric end-use devices
- Development of an energy audit and data management system to increase awareness of how energy is being used in the Marshall Islands and to support all of the above energy management activities
- Development of an energy education and training program across all branches of government, and extension of such a program to the commercial and residential sectors upon completion of metering and rate reform steps
- Initiation of fundamental training in the installation and Operations and Maintenance (O&M) of photovoltaic systems, and the conduct of building energy audits

Most of the above steps have already been identified for implementation by the Government of the Marshall Islands. Success will depend on the efforts of many different individuals and groups. The perception of both individual and social benefit as a result of such actions must be cultivated among the target populations, perhaps starting with a pilot program and then expanding to a wider audience. A high priority should be assigned to consensus building for each step. Such preparation will have more to do with the success of energy management than the relatively simple and cost effective measures themselves.

Photovoltaics and Solar Water Heating

Solar resource data are being collected on Majuro, Enewetok, and Utirik atolls. Preliminary returns from Majuro suggest a daily insolation of 4.8-5.5 kWh/m^2-day. Although no long-term insolation data have been collected, solar energy conversion devices have been installed and are working well in the Marshall Islands. Photovoltaic modules and solar hot water heaters have been performing well in the Marshalls' relative to the available resource.

From the standpoint of technology readiness, both solar hot water applications and photovoltaic systems are proven quantities. The main questions that remain to be answered about the use of solar technologies concern the operational lifetimes that can be expected for installed systems in the harsh environmental conditions posed by the humid, salt-laden air that is constantly present on the atolls. Experience with solar systems now in place will be useful in gauging the vulnerability of future installations to corrosion.

Table 7-6
Technology Selection Criteria

	SOLAR						BIOMASS								
	Solar Hot Water	Photo-voltaics	Solar Therm-al	WIND ENERGY	GEO-THERMAL	HYDRO-ELECTRIC	Tree Farms	Biogas	Liquid Fuels	MSW	OTEC	OCEAN CURRENTS AND WAVES	SOLAR PONDS	COAL	ENERGY MANAGE-MENT
RESOURCE															
proven	●	●													
suspected				●							●				●
unknown			●		●			●	●			●	●		
none						●	●			●				●	
TECHNOLOGY READINESS IN PACIFIC															
high	●	●			●			●		●				●	●
medium				●			●						●		
low			●						●		●	●			
RELIABILITY PROBLEMS IN PACIFIC															
high			●		●		●	●	●	●	●	●			
medium				●									●		
low	●	●												●	●
DURABILITY PROBLEMS IN PACIFIC															
high			●	●	●		●	●	●	●	●	●	●		
medium	●														●
low		●												●	
APPLICATION															
centralized	●	●	●	●	●		●		●	●	●	●	●	●	●
decentralized	●	●		●				●							
POTENTIAL CONSTRAINTS															
cultural impact							●	●	●	●			●		●
land availability			●	●			●		●	●			●	●	
environmental impact					●		●	●	●		●	●	●	●	
human resources			●	●	●		●	●	●	●	●	●	●	●	●
infrastructure	●	●	●	●	●		●	●	●	●	●	●	●	●	●
CAPITAL COSTS															
high (over $10,000/kW)		●	●		●					●	●	●	●		
intermediate ($3,000 - $10,000/kW)				●			●	●	●					●	●
low (up to $3,000/kW)	●														
O&M COSTS															
high			●	●	●					●	●	●		●	
intermediate							●	●	●				●		●
low	●	●													
COST EFFECTIVENESS															
near term (0-5 yrs)	●	●		●											●
mid term (6-15 yrs)			●											●	
long term (16-40 yrs)					●		●	●	●	●	●	●	●		
EXPECTED OIL SAVINGS OR AVOIDANCE															
high															●
intermediate		●		●										●	
low	●		●		●		●	●	●	●	●	●	●		

Both solar hot water and photovoltaic applications lend themselves well to the Marshalls' small and frequently isolated centers of demand for energy. These systems are modular in nature and can be added to a site in increments, depending on the size and growth potential of the load. Construction and installation times are short, and there are few economies of scale to penalize the phased introduction of individual systems. The overall demand for hot water in the Marshall Islands is not high at present, although increased tourism will add to the end-use category.

There is no adequately defined infrastructure for spare parts, servicing, or even installation support for any of the solar energy conversion systems. This may not be too constraining for hot water and photovoltaic applications because the technologies are relatively simple to install, and they carry little in the way of Operations and Maintenance (O&M) requirements. Nevertheless, in anticipation of having to replace an occasional photovoltaic panel, voltage regulator, or length of wiring, a satisfactory on-island service capability will be needed. Solar system distributors, rather than the government, should be looked to for assistance in this task.

As with most renewable energy systems, there will be relatively high capital costs associated with solar system purchase and installation, particularly of the current generation of photovoltaic applications. Cost reductions in photovoltaics are expected to minimize the capital cost disadvantages of the technology in the near term. O&M costs for photovoltaic and hot water systems will not be significant. For many sizes of demand, both photovoltaics and solar hot water applications are now cost-competitive with diesel generators or grid extensions. All remote islands are cost-effective locations for the use of most low-power photovoltaic applications, including village electrification.

Wind Energy

The wind energy resource in the Marshall Islands is attractive. Wind measurement stations, operated by NOAA, are maintained on the islands of Mili, Jaluit, Ailinglaplap, Wotje, Utirik, Kawajalein, and Majuro. In the northern atolls, northeast tradewinds blow steadily from December to March at an average speed of 9.3 meters/second (nearly 21 mph). Average wind speeds from July through November are approximately 5 m/s (11 mph). In the southern region, winds average 5 and 2.7 m/s (11 and 6 mph) respectively, during the trade and non-trade wind seasons. These are average values. There are occasional periods of calm which would not support continuous power output from any wind turbine.

A significant amount of open ocean wind speed data have been collected for the Marshall Islands. Because all of the Marshall Islands are atolls, open ocean data are good indicators of land wind speed, and these data suggest that the northern Marshall Islands possess a highly favorable wind resource. Strong average annual wind speeds from 5.7 to 8.4 mps (13-19 mph) are found over and north of the northern Marshall Islands. The wind energy density corresponding to the upper part of this range is over 400 Watts per square meter. The North Pacific trade winds originate from a quasi-permanent anti-cyclone located in the northeast Pacific.

At many locations and in many applications in the United States, wind energy conversion systems are at a proven state of technology readiness. The transfer of this technology to the Marshall Islands does not necessarily reveal a similar level of readiness, however, because both reliability and durability issues remain to be solved. Reliability is affected by the success of routine maintenance operations, while durability requires that system designers take into account the corrosive effects of salt air on turbine operation as well as tower and support structure integrity. The use of special materials, plus preventive design steps (i.e. isolation of particularly vulnerable metal parts and bearings), will be needed to insure that wind energy systems perform to their intended capacity and lifetimes.

Few cultural, environmental, or land use constraints affect the potential of wind energy conversion in the Marshall Islands. However, the mechanical nature of wind turbines will always require some technical expertise to be available, if only to provide routine maintenance on a system. Should malfunctions occur, there will be a need for even more skilled labor to troubleshoot and then repair problems. There will be a concomitant need for facilities and equipment (such as cranes) to use in reaching and repairing system components. There is clearly a lack of such an infrastructure in the Marshall Islands, particularly in the distant northern atolls where the wind regime is the most favorable. These factors represent perhaps the most limiting constraint on wind energy technology in the Republic.

Capital costs of wind energy systems, on an installed kilowatt basis, are higher than conventional diesel generators, but lower than photovoltaics. The larger the individual system, the more attractive the total cost per installed kW. There is, of course, no fuel cost. O&M costs are likely to be higher in the Marshall Islands than they are on the United States mainland, because of the remoteness of likely sites and the effect this has on both crisis and routine maintenance operations. From the standpoint of cost effectiveness, wind energy conversion appears most attractive in the high wind regimes of the northern atolls. Commercially available wind turbines can be expected to perform at near rated capacity in such environments. However, the unknown factor of maintenance costs, as well as system lifetime limits posed by corrosion potential, all caution against too rapid an introduction of the technology. The use of higher priced materials to deter corrosion, plus the design of less complex systems, may be needed for the advantages of the Marshall Islands' wind resource to be used fully.

OTEC

General oceanographic maps of the North Pacific indicate a potential ocean thermal energy resource in the waters surrounding the Marshall Islands. However, to date, no temperature gradient or other offshore profiles have been conducted to verify the existence of necessary thermal and bathymetric conditions for OTEC. Apart from experimental work underway in the Republic of Nauru, there is no operating OTEC facility anywhere in the world at present. The technology is not considered to be well established enough for either near or mid-term application in the Marshall Islands. If OTEC does develop successfully, it could become an excellent source of base load power for many Pacific Island locations.

Biomass

Biomass productivity in the Marshall Islands is constrained by limited land availability, the relatively poor regenerative capacity of atoll soils, the pre-emptive use of existing agricultural land and vegetation for food production, and the general cultural distaste toward agricultural employment that is common throughout much of the Pacific. The overwhelming historical tradition in agriculture has been one of collecting rather than planting and harvesting. In the Marshall Islands, this factor further limits the potential of labor-intensive, decentralized agricultural production for energy, barring the importation of labor to perform such tasks.

Tree Farms

Removing tree stands and other vegetative species for energy conversion would result in erosion of the very thin layer of soil nutrients that are now found on most of the atolls in the Republic. The potential development of introduced tree species has not been examined, but given the condition of the soil, it is unlikely that acceptable growth rates could be achieved, and the erosion problem remains. Tree farming, even if biologically sustainable, would be likely to require large acreages of land to achieve economies of scale. The electric power produced from even a minimally sized facility would be a poor match for most small demand centers in the Marshall Islands.

The infrastructure required to establish, harvest, transport and convert a tree farm resource to energy would be substantial on a remote atoll. This would be reflected in high capital and O&M costs for plantation-generator complex. Without acceptable rates of growth, and sustainability of the resource, neither of which exist in the Marshall Islands, tree farming is an unlikely option for the Republic.

Biogas

The readiness of biogas technology has been effectively demonstrated in rural areas throughout Asia and the South Pacific. The technical suitability of biogas and liquid-fuels conversion matches well with the limited energy demands found in small remote villages, providing the resource feedstock is in ample supply. Anaerobic digestion, however, requires high-moisture content vegetative or animal waste. No centralized supply of these resources exists in the Marshall Islands.

One potential biogas resource is represented in the abundance of coconut husks which remain from copra production and which could be converted to biogas via a thermochemical process. Now burned to dry copra, the husks might become more available for biogas conversion if waste heat units at the new Majuro power plant could be directed to the copra drying task.

The high sugar content crops that are useful in ethanol conversion, are grown in only limited quantities throughout the Marshall Islands. Any efforts to increase acreage under cultivation (now about 40 hectares, or 100 acres) will likely be in support of food self-sufficiency program goals rather than energy development through the production of liquid fuels.

Residue disposal from ethanol and biogas conversion may also damage water quality if significant amounts of waste are involved. However, if properly treated, the residue from biogas and liquid fuels conversion processes could be made to yield fertilizers capable of soil enhancement on the atolls. Other constraints include the cultural aversion of Marshall Islanders to the handling of animal waste of any kind. The otherwise attractive biogas digester technology is precluded from at least near term feasibility as a result.

Capital and O&M costs of biogas and liquid-fuels options are low, unless high wages are required for the labor involved in resource collection. Cost effectiveness of both technologies appears favorable in the present to near term, again depending on resource availability.

MSW

MSW resources exist in appreciable quantity only in the population centers of Majuro and Ebeye. Annual tonnage data are available only for Majuro. Based on extrapolation of 1975 data, over 3085 tonnes of MSW will have been generated on Majuro in 1982. Combustible paper and plastics comprise over 40% of this amount, while the Btu-limiting moisture content has been found to be a high 23%. No definitive analysis of the energy value (i.e. Btu/tonne) of major MSW has been conducted.

MSW combustion technology has been proven worldwide, however its appropriateness for the Marshall Islands may be limited by low population (and MSW) density, infrequent or nonexistent collection, as well as by the unknown energy value of the resource. Moreover, a near to mid-term energy supply option for Majuro Atoll will soon be in operation, and should prevent consideration of MSW as a fuel source based on the sunk costs of the new facility alone. Similarly, additional oil-fired generating capacity now being considered for Ebeye is expected to restrict early use of MSW at that location.

Solar Ponds

The insolation resource throughout the Marshall Islands is considered sufficient to support salt-gradient solar pond development. However, the atolls of the Republic offer little unused land which could be committed to solar ponds. A pond size of one hectare (2.5 acres) has been suggested as an economically minimum design dimension for the technology. This requirement would eliminate from consideration several inhabited atolls in the Marshall Islands with total land areas less than .5 to .8 hectares (1-2 acres).

The use of reef shelf solar ponds has been suggested as an alternative approach to on-land applications. Throughout the remote atolls of the Marshall Islands, there may easily be conflicting uses of the reef shelves (such as their role in shellfish production/harvesting) that preclude islander interest in the technology. The fact that the reef-based approach has never been demonstrated also weighs against any early interest in its adoption in the isolated atolls of the Marshall Islands.

Solar Thermal Electric Conversion

Solar thermal electric conversion (STEC) applications have been demonstrated outside the Pacific Islands, but there have been no STEC applications in the islands to date, and the technology is at an early stage of readiness. There is an uncertain match between potential loads and the size of high temperature STEC applications because system standardization has not fully evolved. It is expected, however, that custom sizing and design that includes energy storage could allow a good match between system performance and the loads to be met.

Land availability may be a constraining factor in large STEC applications, although community or village-sized systems should not encounter such a limit. The complexity of high-temperature solar thermal systems will require skilled workers for operation and maintenance and repairs. It is unlikely that such skilled labor is now present in the Marshalls. O&M expertise will have to be imported should the technology prove itself ready on technical and economic grounds in the near future. Parts and repair infrastructure would also need to be imported or developed.

High-temperature STEC systems appear to be at least five years away from being cost competetive, and STEC may be further away from actual application in the Republic, given its O&M and infrastructure requirements. Because STEC systems, with proper storage, can provide baseload power, however, the development of the technology to a state of readiness for the Pacific is worth following closely.

Coal

Near to mid-term electricity requirements on Majuro are expected to be satisfied by the new residual oil-fired power plant now being installed. There are no other demand centers for electricity of sufficient size to warrant even the smallest coal-fired steam electric system. Also, transportation, storage and handling of very small amounts of coal for applications other than Majuro would be likely to be prohibitively costly. There is no support in the Marshall Islands at the present time for any proposals to import coal for electric power generation.

Geothermal

There are no known geothermal resources in the Marshall Islands. Where such resources exist, the technology is at a high state of readiness and can be most cost effective. However, the scale at which most geothermal resources must be extracted to be economical renders this technology a poor match for the remote and widely scattered population centers of the Marshall Islands.

Hydroelectric

There are no rivers in the Marshall Islands and no land higher than 9 meters (30 feet) above sea level. The combination of these two factors rules out any consideration of hydroelectric energy coversion in the Republic.

Ocean Tidal and Currents

No resource assessments have been performed to characterize either the tidal or ocean current resources of the Marshall Islands. Tidal resources are not expected to be of a magnitude to allow harnessing for energy conversion, given the absence of estuaries or other necessary geographic features. Both naturally occurring and artificial channels between ocean and lagoon sides of atolls may offer potential sites for ocean current energy conversion. As yet, however, the technology for exploiting this resource is not well developed. As the technology matures, there will be implementation issues related to infrastructure and skilled labor requirements, as well as initially high capital and O&M costs.

FINDINGS AND RECOMMENDATIONS

Energy development planning in the Republic of the Marshall Islands must encompass both urban and remote rural energy demand patterns. Anticipated economic development activity on Majuro has led to the decision to install new and expanded electrical generating capacity. The new plant is expected to provide ample, reliable power for both current and projected needs through the near to mid-term. The decision to construct this new, residual oil-fired generating plant is likely to preclude serious consideration of alternate technologies to displace petroleum as the primary fuel for electricity generation for many years to come.

Given this eventuality, energy planning for Majuro should then concentrate on energy management activities designed to make more efficient use of the imported fuel used to produce electric power at the new generating facility. These activities should include extension of metering to all electricity consumers, conduct of building energy audits, and development of energy efficiency standards for new construction. All feasible energy conservation practices, including rate structure reform, that are consistent with the productive use of electric power, should be introduced, particularly in the government sector.

The success of economic development planning for Majuro Atoll will rest in the ability of the new power plant to provide reliable energy to all potential consumers whose uses contribute to selected development goals. In the absence of both energy conservation in the government sector and efficient energy use in the commercial sector, the new increment of generating capacity now being added will not be available to serve as much economic expansion as planned. There is every incentive, therefore, for the government to encourage energy-efficient design and conservation in all new commercial and industrial facilities attracted to Majuro by the availability of firm electrical power. Finally, the economically unproductive energy requirements of the government sector should be moderated to make available as much generating capacity as possible for the income-producing activities outlined in the economic development plan of the Republic.

For areas outside of Majuro, energy development planning should focus on the introduction of appropriate renewable energy technologies to serve both economic development and social service needs. Given the limited use of petroleum products on the outer atolls, the principal energy planning objective should be to avoid, wherever possible, the addition of new petroleum dependencies throughout the Republic.

The technology which appears most feasible for remote area applications is photovoltaic energy conversion. Hybrid applications using both photovoltaics and back-up diesel systems could offer additional cost savings and reliability in some demand centers. Additional investigation of this option should be made. To the extent that hot water demand develops in the outer islands, low-temperature solar hot water technology would be feasible and cost-effective. Wind energy conversion is both technically and economically attractive in the wind regimes of the northern Marshalls' atolls; however, the lack of support infrastructure for the technology will constrain its applicability in the near term.

At present, the possibility of coconut husk utilization presents the best biogas potential in the Marshall Islands. Resource supply, environmental, and cultural factors limit all otherwise feasible technology options. This is also true of MSW.

Given the scarcity of land on the atolls of the Marshall Islands, and the unproven readiness of reef-based solar ponds, the technology is not considered a likely option for the Republic in the near to mid-term.

Based on the review of technology reflected in Table 7-6, and the understanding of energy consumption patterns presented in this chapter, a set of recommendations can be made relative to future energy planning activities needed in the Republic of the Marshall Islands. Recommendations for urban areas (Majuro Atoll) focus on those actions which contribute in a major way to the displacement of oil, based on more efficient use of existing electric generating capacity, particularly by the government sector. Recommendations for remote rural areas (outer atolls) concentrate on offering primary near-term benefit by avoiding new oil dependencies within the Republic, while still providing a desired level of energy consumption. These recommendations are presented in Table 7-7.

Table 7-7

Energy Planning Recommendations

Republic of the Marshall Islands

Majuro Atoll

- Improved energy management
    - rate structure reform
    - metering of all electrical connections
    - development of energy efficiency standards for all new buildings
    - implementation of energy conservation measures in the government sector, including passive cooling building retrofits, replacing light fixtures, and more energy efficient appliance measures
    - development of an energy data system to monitor and audit energy use in buildings
- Infrastructure development to support outer island renewable energy technology O&M and Majuro energy management activities
    - personnel training in photovoltaic and wind-energy system installation, repair and troubleshooting, and conduct of building energy audits
    - education curriculum and teacher training in basic energy use concepts

- o Implementation of renewable energy technologies in the reduction of government sector electricity use

  - solar hot water retrofit of the Majuro hospital

Outer Islands

- o Analysis of infrastructure requirements needed to support specific levels of wind energy use in the northern atolls

- o Wind energy resource assessment, including data collection, statistical analyses, and technology performance projections based on such data, for selected outer islands in the northern atolls

- o Engineering design of a photovoltaic-diesel hybrid system for a selected atoll application

- o Refrigeration design of a photovoltaic powered ice making/ice storage box for remote island use

- o Specification of design and materials modification and costs for effective corrosion protection of commercial wind and photovoltaic energy systems

- o Installation of diagnostic equipment to measure performance of planned and already installed photovoltaic energy systems in the outer islands

CHAPTER 8: ENERGY PLANNING FOR AMERICAN SAMOA

The Territory of American Samoa, an insular possession of the United States, is the only United States territory south of the equator. It consists of seven tropical islands in the South Pacific about 3700 kilometers (2200 miles) southwest of Hawaii and about 2575 kilometers (1545 miles) northeast of New Zealand (see Figure 8-1).

The energy problem of American Samoa is threefold. First; the islands are 100% dependent on imported petroleum products for electricity generation and transportation and are therefore quite vulnerable to interruptions in petroleum supply and to price increases. This dependence hampers economic development and if petroleum supply uncertainties, and price increases similar to those of the seventies were to occur again, the existing economy and standard of living would be severely affected. Second, although the American Samoa Government (ASG) has recently tried to improve the power system, additional capacity and improved reliability are still needed. Power outages occur frequently and capacity is barely adequate to meet present demands. Finally, the ASG must find ways to supply electricity to the outer islands that depend on local fuel deliveries. Such fuel is expensive, and there are often interruptions in supply.

American Samoa includes the seven eastern islands of the Samoan group; the western islands make up the independent nation of Western Samoa. Tutuila, the main island, has 147 square kilometers (53 square miles) of land area, and Aunu'u, 1.6 kilometer (1 mile) off the southeast coast of Tutuila, has 1.6 square kilometers (0.6 square miles) of land area. The Manu'a group is 115 kilometers (69 miles) to the east. Rose Island, 400 kilometers (240 miles) east of Tutuila, is only 0.56 square kilometers (0.2 square miles) in area. Swain's Island, 450 kilometers (270 miles) to the north, is 2.8 kilometers square (1 square miles). All of the islands are inhabited except for Rose Island, which is a wildlife preserve.

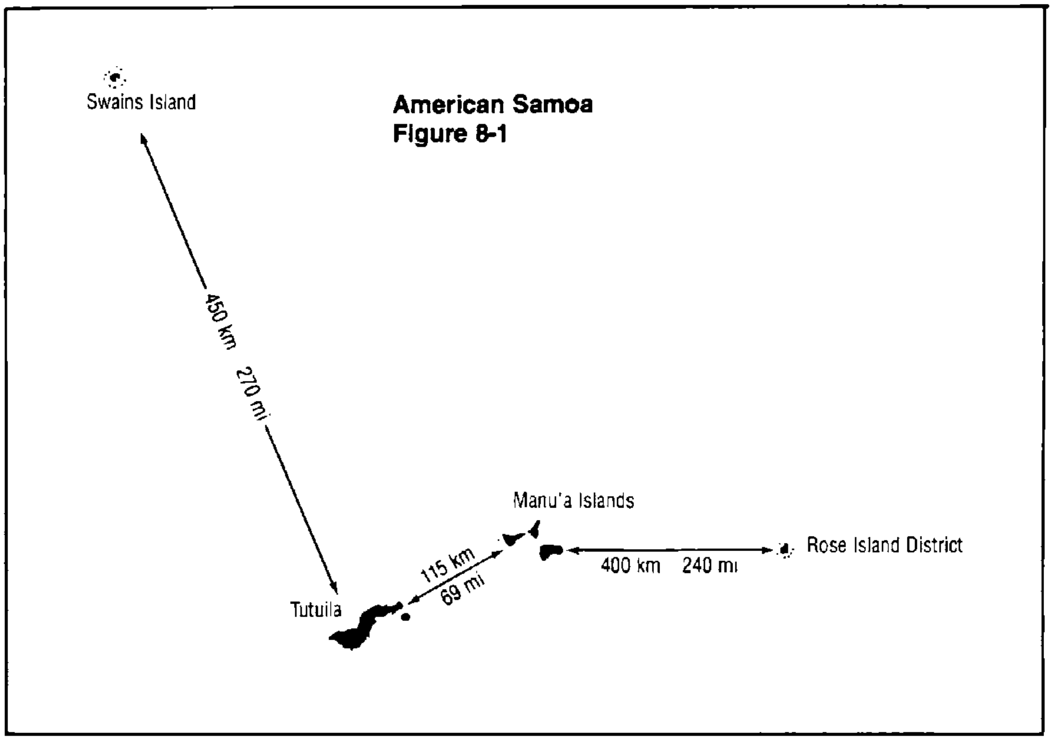
Tutuila's topography is rugged. The island is a continuous, narrow irregular volcanic ridge rising steeply from the ocean. The Tufuna Plains on the southwestern portion of the island are the only expanse of relatively flat land. The ridge forms a drainage divide for the entire island. Numerous short, intermittent streams descend from the mountains through steep valleys. Larger streams have formed wide, flat, delta-shaped valley floors where they emerge from the highlands to enter the sea. Many of the villages are located near the stream mouths.

Tutuila is about 33 kilometers (20 miles) long, 10 kilometers (6 miles) wide at its widest extent, and less than 1.6 kilometers (1 mile) wide where Pago Pago Harbor intersects the ridge near the center of the island. The ridge rises abruptly from the sea, and numerous peaks range in elevation from 305 to 457 meters (1000 to 1500 feet). Mt. Matafao at 652 meters (2141 feet) is the highest peak.

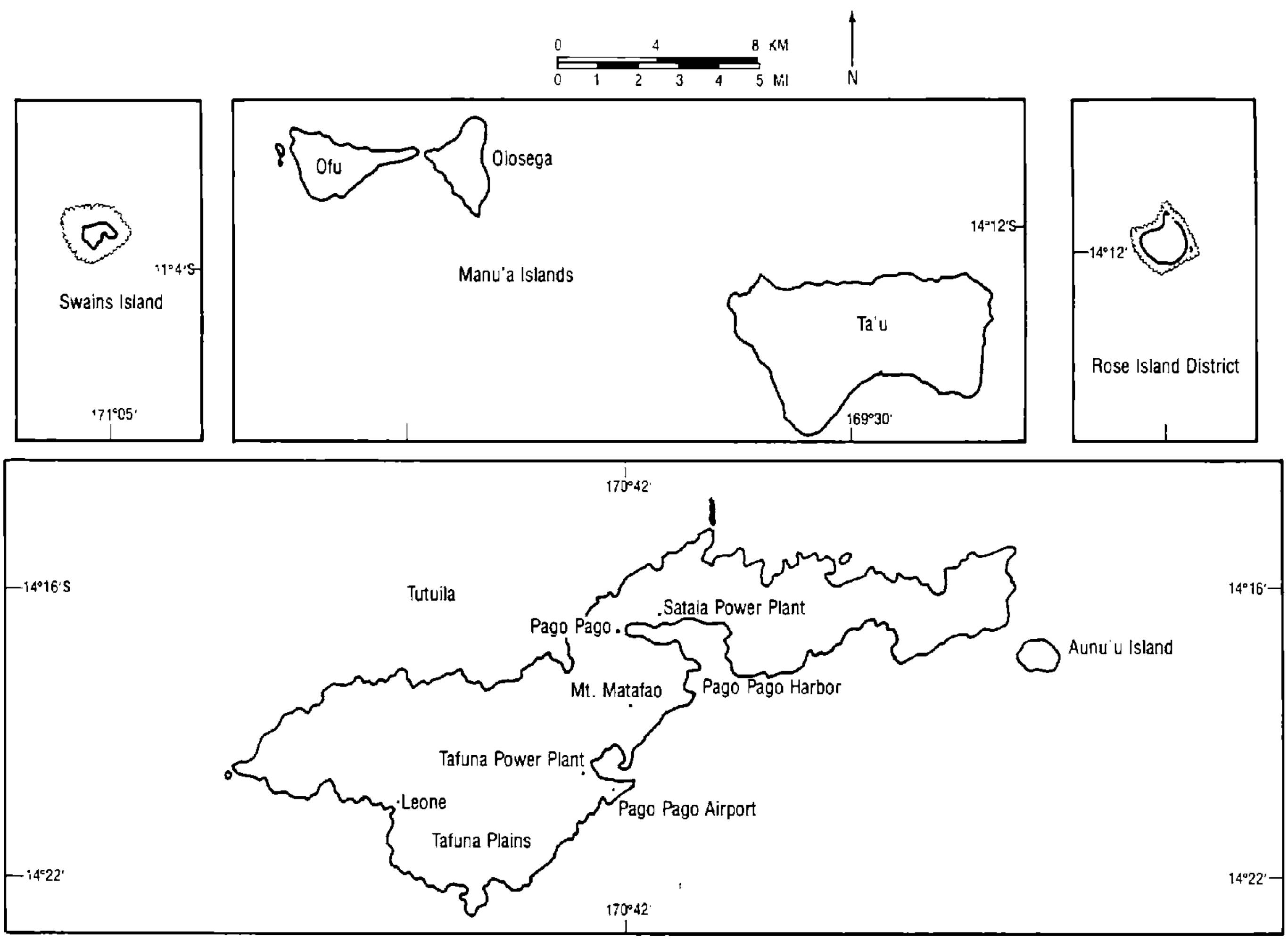
The steep slopes, heavy rainfall, and rapid runoff keep the natural residual soil cover thin. The soil on the steep slopes is held in place only by a dense growth of tropical vegetation. Overlying the narrow belt of coral around the edge of the island is a thin cover of sandy, organic material that also supports abundant vegetation. A few inland valleys contain thick deposits of alluvial soil, but even there the heavy rainfall leaches the soil, making commercial farming difficult without fertilization.

The Manu'a group consists of three separate islands: Ofu, Olaosega, and Ta'u. Ofu and Olosega are remnants of a single volcanic island and are separated by a 150 meter (500 feet) wide strait. Both islands rise abruptly from the ocean with little flat land other than a narrow band along the coast. There are few well developed drainage basins on either island. The combined land area of Ofu and Olosega is approximately 13.5 square kilometers (4.9 square miles).

Ta'u is the largest of the Manu'a islands, covering 49 square kilometers (17.7 square miles). The south side of the island consists of spectacular cliffs and cascades dropping directly into the sea. Most of the coastline along the northern and western sides of the island is fringed by a fairly wide



Swains Island
American Samoa
Figure 8-1
450 km 270 mi
Manu'a Islands
Rose Island District
115 km
69 mi
400 km 240 mi
Tutuila



0 4 8 KM
0 1 2 3 4 5 MI
N
Swains Island
11°4'S
171°05'
Ofu
Olosega
Manu'a Islands
14°12'S
Ta'u
169°30'
14°12'
Rose Island District
170°42'
14°16'S
Tutuila
Satala Power Plant
Pago Pago
Aunu'u Island
Mt. Matafao
Pago Pago Harbor
Tafuna Power Plant
Leone
Pago Pago Airport
Tafuna Plains
14°22'
14°16'
14°22'
170°42'

coastal plain fronted by narrow beaches. The villages on the west end of the island are built on terraces a few meters above sea level which are composed of sand dunes and storm benches of coral sediments.

American Samoa's climate is tropical with a relatively dry season, June through August, and a wet season, January through March. Average annual rainfall is between 315 and 630 centimeters (125 and 250 inches), depending on location, and can vary widely from year to year. The average temperature is about 27° C (80° F) with little seasonal variation. Relative humidity is high during most of the year, ranging from 70 to 90% during the wet season and 60 to 70% during the dry season. Trade winds blow almost continually.

HISTORY AND POLITICAL DEVELOPMENT

The Samoans are among the last remaining true Polynesians. Samoan traditional stories describe Manu'a as the heart of Polynesia. The first inhabitants of the Samoan islands, Polynesian seafarers, came from the west, possibly by way of Indonesia, Vanuatu, and Fiji, at least 1600 years before the birth the Christ. They are closely related to the Tongans, Tahitians, and Hawaiians, who are also Polynesians. During these early years, the Samoans evolved a complex social structure around the aiga, or extended family, which may include as many as several hundred relatives. At the head of the aiga are the matais, or chiefs, who guide the communal economy, look out for the clan's well being, control the lands, and represent the aiga in the village and district councils. Life revolved around fishing and the subsistence farming of taro, breadfruit, and bananas. Now American Samoans are concerned with preserving these traditions, and the extended families are still the most important element of the social structure. For example, the extended families own about 95% of the land on Tutuila. This factor could act as a constraint on developing renewable resource energy technologies that are land intensive.

First contact with the western world came when a Dutchman, Roggeveen, happened upon the islands in 1722, followed 46 years later by the French explorer, Bougainville. The islands were out of the way of the growing shipping traffic and whale fleets, and did not attract European interest until the 1830s when Christian missionaries arrived. In 1839, a United States expedition explored the Samoan islands, mapping the harbor and several bays. The natural, deep water harbor, one of the finest in the South Pacific, was of particular interest to the United States. In 1872, the United States ship, Narragansett, visited Tutuila, and its commander, Richard Meade, entered into an agreement with High Chief Mauga that granted the United States harbor facilities and rights for a naval station.

International rivalry and confrontation between Germany and Great Britian, as well as warring among various Samoan factions, with the United States on the periphery, occasioned agreements in the later 19th century which divided the Samoas between the United States and Germany. In 1900, the United States annexed Eastern Samoa, as it was called then, under the Deeds of Cession. They added the Manu'a chain in 1904, but the United States Congress did not ratify the act until 1929.

The United States Navy assumed administration of American Samoa, as the islands became known, in 1901. The peaceful islands and quiet, South Pacific naval station acquired stategic importance during World War II when Pago Pago became a training area for the United States armed forces. This exposed the Samoans to the United States way of life and started the migration of Samoans to Hawaii and the United States mainland.

The Deeds of Cession granted American Samoans United States national status, protected them under the United States Constitution, and prevented their lands from being alienated. Day-to-day government derived from United States Naval regulations, which today, form the basis of the Code of American Samoa. The Fono, a bicameral legislature, was formally organized in 1949 and became the Territory's law-making body. In 1951 an executive order transferred administration of American Samoa from the Navy to the Department of the Interior. In 1960, the American Samoans held a constitutional convention, and the resulting constitution became effective later that year. In 1977, Samoa elected its first governor and lieutentant governor, a step which nearly completed the process of local self-government. The government now consists of three branches: executive, legislative, and judicial. Samoa also elects a congressional delegate, who became a non-voting member of the United States Congress in 1981.

The current relationship of American Samoa and the United States is spelled out in Secretary Order #2657 of the Department of the Interior. With the installation on January 3, 1978, of the first popularly elected government in Samoan history, the American Samoans initiated an aggressive development program. This program called for economic and infrastructure development to bring the territory closer to self-sufficiency; greater economic and social participation in the community of emerging South Pacific nations; and greater self-government and political development within the United States community.

POPULATION, EMPLOYMENT, AND WAGES

American Samoa's resident popluation in 1981 was 33,160. Ninety-three percent (30,212) of the people live on Tutuila, mostly in rural communities. Less than 3000 people live on the Manu'a group and the atolls. Pago Pago Bay on Tutuila is the economic center of American Samoa, however, a new industrial center is being built in the Tafuna area. There is a significant amount of emigration out from American Samoa, mostly to Hawaii and the United States mainland. There are between 80,000 to 100,000 Amercian Samoans living in the United States now, including those serving in the armed forces.

Since 1980, the population has been increasing by about 2% per year. Fifty-six percent of the population was under 19 years of age in 1979. The territory is expected to experience a steady increase in population during the next decade, primarily in the Tafuna Plains and West Tutuila areas where the greatest amount of flat land is available. Populations of the Pago Pago Bay and northeast and southeast island areas will increase only slightly because land for residential, commercial, and industrial purposes is scarce. Population of the Manu'a group will probably increase slightly because of expected improvements in inter-island travel and minor improvements in job opportunities.

The wage economy for American Samoa centers around the Pago Pago Bay area. The principal industry is tuna processing. The two canneries located on Pago Pago Bay employ about 20% of the work force. Subsistence family agriculture and small, family-owned businesses are also found throughout Tutuila and on the outer islands. The labor force for 1980 was 10,596, about 31% of the population. The unemployment rate for 1980 was about 12%.

It should be noted that many aliens are employed in American Samoa's nongovernmental economic sector. Privately owned businesses and industry hire employees at the lowest possible wages, and employment at the canneries fluctuates widely. Over 3000 guest-workers from Korea and Taiwan live in Tutuila and work in the tuna fishing and processing industries. American Samoans do not generally seek employment in these industries. Government remains the chief employer of local people, accounting for 46% of the labor force. Government employees' wages constitute 64% of employment income on the islands. Workers in the private, retail, and services industries, including the canneries, earn about 25% of the income. The other 11% presumably comes from subsistence level activities such as farming and fishing.

PRESENT ECONOMY AND INFRASTRUCTURE

American Samoa differs from most of the other United States Pacific Islands in that it has a substantial export industry; tuna processing from two large canneries, Van Camp and Star Kist. Sources of tuna are the 125-boat, long-line fishing fleet owned largely by Koreans and Taiwanese, and about ten United States-owned purse seiners, docked within Pago Pago Bay. The boats are individually owned, but both fleets have contracts with the canneries. Like the canneries, the fishing fleets are encountering hard times caused by increasing expenses and long layovers. In 1977, tuna exports were $73 million; in 1978, $96 million; and in 1980, $125 million. However, 1982 was a bad year for the industry; sales have dropped considerably, and one of the canneries closed for a month.

Historically, Pago Pago has also been an important fueling station for South Pacific sea traffic because of its deep water port. It continues that role today with expanding port and servicing facilities, and diesel exports are high. The Marine Railway facility near the canneries does ship repairs and maintenance.

Tourism is a slowly growing industry. There is only one tourist hotel on Tutuila, and there is a general reluctance to change traditional ways to accomodate visitors. This industry is vulnerable to changes and cutbacks in air schedules, and two major international airlines stopped flying to American Samoa in 1982.

American Samoa has a relatively well-developed public and institutional infrastructure. The ASG Public Works Department and some of the villages own and operate the water systems. The Public Works Department system provides water service to the Pago Pago Harbor area, the airport, industrial, and residential areas at Tafuna, and several villages in Futiga. Most of the public water comes from wells; some water also comes from catchment systems. The ASG is extending the large-capacity transmission mains and distribution lines and is increasing the amount of water available by constructing new wells and storage tanks. The village systems ususally consist of water catchment systems on streams with pipelines carrying water to the villages. Indoor plumbing is a recent addition in many villages.

Tutuila has two major ASG wastewater systems at Tafuna and Utulei. The Utulei system consists of about 12 kilometers (7 miles) of sewer mains, and the Tafuna systems has about 3.3 kilometers (2 miles) of mains. The primary treatment plants discharge effluent into the ocean. The ASG collects and disposes of solid waste material from villages that have paved roads. Other villages and the outer islands use open pit dumps. Disposal of the 30,000 gallons of waste tuna sludge the canneries produce each day is a problem. The sludge is currently dumped at sea.

The southern coast of Tutila and inland areas have about 75 kilometers (45 miles) of paved roads. Much of the south shore road is built along the shoreline, making it susceptible to erosion. The ASG is reinforcing sections to prevent this. Almost every village has unpaved secondary roads. The villages own these roads, but the ASG helps with road improvements.

Pago Pago International Airport is located along the ocean by an artifical lagoon in the Tafuna area. This is where the largest area of flat land on Tutila is found. There are also small air strips on Ta'u and Ofu in the Manu'a group. South Pacific Island Airways, Polynesian Airlines, and Air Nauru, provide service to the Manu'a group, Western Samoa, and other Pacific Islands. There is a daily flight to Hawaii.

Pago Pago Harbor is one of the best deep water harbors in the Pacific. Its deep water extends from the Bay entrance to the inner harbor, and the right angle bend in the Bay provides the inner harbor with excellent protection. There is regular inter-island shipping service between Tutuila and the outer islands. Port facilities are just now being greatly enlarged.

The Lyndon B. Johnson Hospital in the Tafuna area is one of the best hospitals in the Pacific. American Samoa has four private and 24 public elementary schools, two private and four public high schools, and one community college. There are a local radio station, a television station, and a newspaper.

PROSPECTS FOR ECONOMIC DEVELOPMENT

The first prioirity of the American Samoa Government is economic development. However, the ASG does not want to develop with absentee ownership; only Samoans can own Samoan land. Therefore, economic development will probably occur at a deliberate pace.

The main economic activities at present are government, fishing and canning, port operations, an industrial center and a small tourism industry. Specific goals for expansion of these areas include enlarging the port facilities, developing the industrial park area, providing additional recreational sites and activities, fishing for additional varieties of seafood, encouraging expansion of the fishing and canning operations, and perhaps building more hotels.

The ASG is developing a major cargo handling center for the South Pacific. The government is working on a major extension of the main dock. This dock serves 182-meter (600-foot) tankers and refuels fishing vessels. A 42-meter (140-foot) inter-island dock serves smaller vessels up to 91 miles (300 feet) in length. The Marine Railway Authority is also expanding so that it can service the largest purse seiners in the Pacific.

Expansion of agriculture is a high priority because it is necessary to slow the large flow of food imports. The subsistence family farm is common on American Samoa, but cash crops that could be important to the economy are not widely grown. Land availability is a key factor, and much of the available land is too steep for cultivation. Nonetheless, some farms are now extending into the steeper areas of Tutuila. The large supply of rainwater could be used for agriculture or other purposes if there were adequate collection and storage facilities. Multiple use reservoirs could be useful for both agriculture and developing hydropower.

Van Camp is rebuilding and expanding its facilities, and this expansion should increase the plant's energy demand by about 10%. The company has considered a proposal to utilize tuna sludge wastes for biogas generation but does not regard it as economically attractive for now. Star Kist presently uses propane for cooking and fork lift operation, and if diesel fuel becomes too expensive, the company plans to switch all diesel-fueled operations to butane. In 1981, Star Kist envisioned a future increase in electric power demand of 10% to 25%, but with the 1982 cutback in operations these figures may be high. Star Kist's research laboratory is also considering using tuna sludge to generate methane.

PRESENT ENERGY STATUS

Like the other United States Pacific Islands, American Samoa depends almost entirely on imported petroleum products for electricity generation, process heating, and transportation. A number of renewable resources suitable for energy conversion are found in American Samoa, but contributions by such resources now are slight. Table 8-1 shows the end uses for petroleum products.

TABLE 8-1. END USES OF FUELS, AMERICAN SAMOA, 1980
(in 1000's of bbl)

Fuel	Amount Purchased	Price[a] ($/bbl)	(b) Gov't	(c) Private	Comm'l/Indust/ Construction	Marine Transportation Government	Exports	Electric Generation
Motor gasoline	76	60	10	64[e,f]	2[d]	0.02		
White gas	0.2	103		.2				
Aviation gasoline	2	60			2			
Jet fuel-K	241	50			193			
Kerosene	4	52		4				
Diesel	953	42	120[g]		664[d,h]	0.5	43	126[i]

(a) Wholesale prices include 11¢ tax/gal except for diesel, June 1981
(b) 402 government vehicles
(c) 2702 private vehicles 3435 total
(d) 331 commercial vehicles
(e) Local noncommercial registered fishing boats, 11
(f) Includes outboard motors
(g) Includes 1200 bbl for construction--heavy equipment (estimated)
(h) Includes industry plus fishing fleets
(i) Estimated from FY 80
Population: 32,395 (Sept. 1980)
Households: 4724 (Sept. 1980)

Total electric installed capacity on Tutuila is 30 MW, with an available reserve margin fluctuating between 0 and 2 MW. Minimum daily demand is 8 MW, and average daily peak load is 13 MW. There are two power plants on Tutuila, one at Satala near the canneries on Pago Pago Bay (16 MW), and the other at Tafuna near the airport (14 MW). They are about 20 kilometers (12 miles) apart and are connected by a tie-line for transmission of power from either one. Satala is the older of the two stations; its first generator system was installed in 1962. There is on-site storage for 48,000 gallons of diesel fuel. The system serves mostly the canneries and the industrial part of the island. The first generator was installed in the Tafuna station in 1974. This station serves the western part of the island which includes the airport, a new industrial park, and a large residential area. There is on-site storage for 200,000 gallons of diesel fuel. The actual amount stored is never more than 60,000 gallons. Generators at both stations run at 400 to 900 rpms. The grid connects to every village on Tutuila, and an underwater cable connects the grid to Aunu'u Island.

The ASG owns these stations, and until recently the ASG Electric Utility Division (EUD) operated and maintained them. In 1981, the new American Samoan Power Authority replaced the EUD. The new Power Authority has the right to make contracts, purchase and lease property, and suggest rates. Rates are set by vote of the people. Over the years, maintenance programs and plant conditions have ranged from fair to good. Both plants are in fair condition now. Power outages are common, and the ASG recognizes that generating reliability and capacity must increase and the total dependence on imported fuel sources must change if American Samoa's energy program is to encourage economic development.

There are two generating systems on the Manu'a group: two diesel generators each at Ofu and Ta'u with a total installed capacity of 1 MW. All Manu'a Group villages are connected to the grid. Swain's Island has a small diesel generator which is not working now.

Other major generating equipment on Tutuila include stand-by generators at the canneries in case of power outages. Van Camp has three 500 KW diesel generators purchased in 1980, and Star Kist has one 125 KW unit. The hospital, ASG computer center, and the airport also have stand-by systems.

Diesel fuel arrives by tanker monthly from the Marlex (Long Beach, California) and Pacific Resources, Inc. (Honolulu, Hawaii). Fuel is piped from the dock to the Punaoa Valley tank farm operated by Marlex. Table 8-2 lists the liquid fuel storage facilities on Tutuila. Union Oil, through an exchange agreement with Marlex, distributes 30% of the petroleum products on the island. Fuel is sent by barge to the Manu'a group. Storage reserves for diesel fuel and jet aviation fuel total about two months supply. Gasoline storage is about four months supply, although this is the potential not

TABLE 8-2 - LIQUID FUEL STORAGE FACILITIES ON TUTUILA

Major Storage Facilities	Capacity (Gal)	Demand (Gal/Day)	Reserve Capacity (Days)
Marlex Tank Farm (Punaoa Valley)			
Diesel	4,536,000	80,276	57
Jet Fuel	1,701,000	25,659	66
Unleaded Gas	512,400	3,899	131
Regular Gas	411,600	3,249	127
Supreme Gas	100,800	886	113
Aviation Gas	100,000	298	338
Satala Electric Plant			
Diesel	48,000	12,600	4
Tafuna Electric Plant			
Diesel	200,000	9,366	21
Airport			
Jet Fuel	110,000	25,659	4
Aviation Gas	25,200	298	85
Canneries			
Diesel	39,000	4,600	8

Source: Territorial Energy Office, ASG Geothermal Energy For American Samoa, Pago Pago, 1980.

the actual reserve because the storage tanks are not usually kept filled. There are also storage facilities for 200 tons of butane, which is shipped from Australia three or four times a year.

Table 8-3 gives additional information on electricity production, costs, and revenues. It is a policy that almost all electrical customers are metered. Individual government offices are held accountable for their energy consumption. According to the Territorial Energy Office 1981 Energy Statistics Booklet, of the 5651 users in 1981, 4867 were residential, using an average total of 1,668,571 kWh month; 500 were commercial, using an average total of 2,346,967 kWh/month; and 284 were government, using an average total of 1,725,648 kWh/month. In order to encourage commercial growth, the graduated rate structure favors large users with lower rates. Failure to pay results in discontinued service, so there is a high remittance rate. Even so, revenues do not cover the costs of producing electricity which are known to at least exceed 20¢/kWh.

The present production of electricity on Tutuila is barely adequate, despite new equipment and improved maintenance. Economic expansion will be difficult without additional capacity, the present system is inefficient, and price increases or interruptions in fuel supply will have drastic effects on the Territory's economy and well-being.

American Samoa has an aggressive Territorial Energy Office (TEO) which is addressing energy problems. To date most of its efforts have been for conservation, education, and energy management. The TEO is also encouraging resource assessment and feasibility studies, and renewable technology installations, primarily for performance testing.

There are a number of specific renewable energy projects on American Samoa. The TEO has just moved into the American Samoa Energy Efficient Demonstration House near the airport. This building combines passive cooling architectual features with renewable energy technologies, such as solar photovoltaics, solar hot water, a heat pump, and wind electric systems. In 1977, a contractor for the

TABLE 8-3. Electric Power Generation, American Samoa, 1981

Fuel Type	Fuel Amount purchased (1000's of bbl)	Locality	Output (million kWh/y)	End use (million kWh/y) Res	Comm'l/ Indust	Gov't	Capacity (MW) Rated	Operating	Load (MW) Base	Peak
Diesel	130	Tutuila	72.2	20.0	28.2	20.1	30.0	13.0	8.0	13.0
		Ofu	0.4	Incl	Incl	Incl	0.5	0.5	0.05	0.05
		Tau	1.2	Incl	Incl	Incl	0.5	0.5	0.10	0.20
		Total	73.8	20.0	28.2	20.1	31.0	14.0	8.15	13.25

ASG installed 36 domestic solar hot water systems on government housing. These were simple commerical thermosiphon systems, but the contractor had problems installing them, and only one or two of the systems are operating now. A DOE Institutional Conservation Program project, which is just being completed, is constructing a solar adsorption air conditioning system at the hospital. DOE has also financed 24 solar hot water systems which have recently been installed on Federal Aviation Administration housing.

Burning wood or cocunut husks for cooking is common in rural areas throughout the United States Pacific Islands and usually represents the largest use of renewable fuels on these islands. About 70% of American Samoans cook their traditional Sunday meals over covered fires (Umu), and about 10% use wood or coconut husks for cooking on a regular basis. This is considerably less than other Pacific Islands, and fuel is not scarce.

ENERGY DEVELOPMENT PLANNING

The central generating system on Tutuila just suffices for reliability and capacity. Despite the new generating equipment installed in 1982, American Samoa is as susceptible as ever to hardship from fuel shortages and price changes. Although the present diesel-powered systems can be expanded, the TEO is pursuing a number of alternatives to diesel fuel in order to reduce this vulnerability and to achieve the necessary reliability and capacity. The government would like to do this while maintaining local control over generating systems and without sacrificing local traditions.

American Samoa is fortunate in having a wide variety of renewable resources to consider. Conversion and conservation technologies for the near term include energy management; solar water heating and solar photovoltaics; biomass, including producer gas and direct combustion of palm oils; wind-powered mechanical water pumps; and possibly, wind generation. These systems show promise either because small systems have succeeded, the somewhat limited historical data indicate success, or intuitive analysis suggests apparently adequate resources. For the mid- to long-term, technologies worth investigating include geothermal, OTEC, MSW, solar thermal for process heat, solar ponds, and possibly hydroelectric technologies. Of all the energy systems discussed in Chapter 2, only coal and ocean current technologies do not now seem suitable for American Samoa, and even this could change with technological developments (ocean currents), new harbor facilities (coal). End uses, include base and peak load electricity generation, process heating, and transportation. Some technologies, such as photovoltaic systems, seem to be most promising for rural applications while others, such as geothermal or OTEC, could make significant contributions to baseload production.

All of these energy systems encounter the same general constraints throughout the United States Pacific Islands. They include lack of technical training, undeveloped repair and maintenance infrastructure, harsh environmental conditions, land availability, cultural attitudes, and lack of data. Some technologies that appear promising are not at a sufficient state of technical readiness. ASG educational institutions will need to provide technical training to young adults in order to reduce American Samoa's dependence on outside technical help. Tropical storms and a highly corrosive atmosphere will affect the durability of systems, such as wind and solar devices, that work well in the milder climate of the United States mainland. Because of American Samoa's rugged topography and complicated land tenure system, land availability will often be the controlling element for developing energy systems. This applies to all technologies that use even small amounts of land. Historical data for many resources--solar, wind, hydroelectric, and geothermal--have not been gathered or are not site-specific. Cultural barriers, such as the Samoans' land tenure system prohibit developing technologies such as geothermal. Some alternate technologies, such as OTEC, are not commercially ready, and other technologies, such as coal or LPG, still depend on imported fuels. Finally, technologies such as efficient wood cooking stoves or small solar photovoltaic systems may improve rural community well-being and limit further oil dependence, but they will not make significant contributions to energy production.

On the positive side, there are educational facilities such as the community college which can provide technical training. Some facilities such as the Marine Railway Authority and Department of Public Works can help with construction and maintenance. The various alternate technologies for near- and mid-term use complement each other. Certain systems if developed now, such as fuelstorage, energy management, and solar water heating, would help solve some of the energy problems for the short-term, allowing mid- and long-term technologies such as geothermal and OTEC time to mature. American Samoa is fortunate to have a relatively wide array of energy resources to select from and a government which is making this selection on a deliberate and realistic basis. Table 8-4 shows the suitabilities of various energy technologies for American Samoa.

Energy Management

American Samoa, through the TEO and with support from various DOE programs, is spending a good deal of effort on energy management.

The TEO is making energy audits of government and commerical buildings, offering public educational programs, monitoring electricity production and end uses, and may help determine the true cost of electricity generation. The TEO is also developing energy data bases to support energy management decisions.

Current data are not available on how effective these measures have been, but indirectly they are certainly reducing cultural constraints on developing alternate energy technologies. The TEO should continue these programs as an integral part of energy management.

Solar

American Samoa has some historical solar insolation data. The NOAA Geophysical Monitoring for Climatic Change Station (GMCC) at Cape Matatula, Tutuila began measuring solar insolation with four Epply pyranometers in January 1976. A sunshine switch is operating at the Tafuna airfield NOAA station, and during 1982, the TEO installed recording pyranometers at the hospital and at the Energy House.

Daily total global solar energy values show variations due to cloud cover and atmospheric scattering and seasonal variations due to austral summer and winter. For July 1979 (austral winter), the total global values ranged from 1.2 kWh/m^2 to 5.1 kWh/m^2, with a mean of 4.1 kWh/m^2. For January 1979 (austral summer), the range was from 2.7 kWh/m^2 to 7.6 kWh/m^2, with a mean of 5.6 kWh/m^2. These data adequately characterize the solar resource in areas of Tutuila, such as the flat coastal areas where many solar energy applications might occur and show that the resource could support a number of such applications. However, the insolation data recorded at the GMCC station probably exaggerate the solar resource of the more cloudy areas of Tutuila such as the harbor area. This area receives some 200 cm (80 in) more annual rainfall than the southeastern coast. Using the GMCC data to design solar systems in the harbor area could result in selecting sub-optimal systems.

In the Manu'a group, the solar resource should not vary significantly from that measured at the GMCC station since the islands are beyond the climatic influence of Tutuila. Measurements from the GMCC station should also be adequate for Swain's Island.

Table 8 - 4

Technology Selection Criteria

	SOLAR						BIOMASS								
	Solar Hot Water	Photo-voltaics	Solar Therm-al	WIND ENERGY	GEO-THERMAL	HYDRO-ELECTRIC	Tree Farms	Biogas	Liquid Fuels	MSW	OTEC	OCEAN CURRENTS AND WAVES	SOLAR PONDS	COAL	ENERGY MANAGE-MENT
RESOURCE															
proven															●
suspected	●	●	●	●	●	●		●	●	●	●		●		
unknown							●					●			
none														●	
TECHNOLOGY READINESS IN PACIFIC															
high	●	●			●	●	●								●
medium				●				●	●	●			●	●	
low			●								●	●			
RELIABILITY PROBLEMS IN PACIFIC															
high												●			
medium				●					●		●		●		
low	●	●	●		●	●	●	●		●				●	●
DURABILITY PROBLEMS IN PACIFIC															
high			●	●							●	●			
medium	●	●					●	●	●	●					
low					●	●							●	●	●
APPLICATION															
centralized					●	●	●		●	●	●	●	●	●	●
decentralized	●	●	●	●	●	●		●	●				●		●
POTENTIAL CONSTRAINTS															
cultural impact	●				●		●	●	●	●			●	●	●
land availability		●	●	●	●		●	●	●				●	●	
environmental impact					●	●	●	●	●	●	●	●	●	●	
human resources	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
infrastructure	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
CAPITAL COSTS															
high (over $10,000/kW)		●	●									●			
intermediate ($3,000 - $10,000/kW)				●	●	●	●		●	●	●		●		
low (up to $3,000/kW)	●							●						●	●
O&M COSTS															
high			●	●					●			●			
intermediate		●			●	●	●	●		●	●		●		
low	●													●	●
COST EFFECTIVENESS															
near term (0-5 yrs)	●					●	●	●		●					●
mid term (6-15 yrs)		●	●	●	●				●				●		
long term (16-40 yrs)											●	●		●	
EXPECTED OIL SAVINGS OR AVOIDANCE															
high					●										●
intermediate	●						●			●					
low		●	●	●		●		●	●		●	●	●	●	

Solar Water Heating, Air Conditioning, and Photovoltaics

Both solar hot water and photovoltaic systems are in a good state of readiness and are durable and reliable enough for American Samoa. There are 24 systems operating in Federal Aviation Administration housing on Tutuila now, at least two private systems, and one or two of the old government housing systems. However, most American Samoan homes do not have hot water now, so while solar systems may prevent new petroleum dependencies, they will not save fuel. There is a good match with end use. American Samoa has a large demand for process heat for industry and tuna canning, and this is a good use for solar heated water. Because this end use is located mostly in the Pago Pago Harbor area with its greater cloud cover, concentrating solar collectors more sophisticated than those used in homes would probably be needed, thereby affecting durability, reliability and maintenance.

The solar absorption air conditioning system at the hospital will be the first one on the United States Pacific Islands. Air conditioning is a large energy end use, particularly for government buildings, but this is also a highly sophisticated application for solar technologies. Performance data from this system will be useful in predicting how successful other such systems will be on American Samoa, at least for the near-term.

Solar photovoltaic systems are in a satisfactory state of readiness for American Samoa as shown by their success on other United States Pacific Islands. The GMCC station is just now installing a 1 kW array at its station at Cape Matatula. The Department of Agriculture also installed a small photovoltaic stand-alone array for electrifying fences on farms on Ta'u of the Manu'a group. A tropical storm destroyed the fence in 1981, showing once again the critical role environmental conditions play on these islands. There is also a 1.6 kW (peak) demonstration system at the Energy House for performance testing and backup power, and two schools have 0.8 kW systems for powering ventilation systems.

There is a good match for solar photovoltaic systems for individual home applications in urban areas and for critical demands in rural areas. The DOE Phase II report, Photovoltaic Applications for Remote Island Needs, gives information on sizing a small photovoltaic system for powering the lights of a small aircraft landing strip on Ofu in the Manu'a group.

The most critical constraints are the ones found with almost all energy systems on American Samoa: lack of available land and lack of repair and parts infrastructure. The largest pieces of available flat land now are near the airport at Tafuna. A number of potential uses, including energy systems, may be competing for this land. The TEO is sponsoring various public education programs which may eventually result in more land being made available. The parts and repair infrastructure must develop at the same time.

Solar hot water and small photovoltaic systems could be cost-effective in the near-term, depending on the size and sophistication of the systems. Potential oil savings or avoidance for both is intermediate as both provide energy for highly consumptive demands. Oil savings will depend in part on the amount of land and capital available, and on the effectiveness of the repair infrastructure. Performance data from the hospital's solar air conditioning system will be particularly useful for determining the near-term effectiveness of sophisticated solar systems. The TEO needs to collect more insolation data for cloud locations on Tutuila where the solar hot water systems for process heat will be needed. Because of high capital costs for photovoltaic systems and uncertain insolation, photovoltaics may be most valuable in the near term for providing electricity in remote areas.

Biomass

The extensive vegetative cover on the American Samoan Islands seems well suited for developing biomass technologies. However, other considerations affect the possibilities for using this resource. As on other Pacific Islands, land is limited and needed for agriculture, housing, and economic development. These uses, along with the land tenure patterns of American Samoa, compete for biomass resources which might appear attractive from an energy-producing perspective alone. Over 75% of the land mass on Tutuila has a greater than 30% slope; on the other American Samoan Islands, this percentage is even higher. Biomass harvesting and conversion activities are difficult and potentially uneconomic on such steep terrain. There are, however, two biomass resources which appear attractive and worthy of additional investigation.

The two tuna canneries on American Samoa produce about 30,000 gallons of waste tuna sludge daily. A preliminary sludge-to-methane experiment conducted for the TEO showed a significant energy value for this resource, and an accompanying economic feasibility report projected a pay-back period for a full scale waste conversion facility of less than three years. This resource is privately owned, however, and neither cannery considers methane conversion attractive at this time. Undoubtedly, the depressed state of the tuna industry affects this decision.

The second biomass technology, which may be more important for rural applications, concerns producer gas and associated technologies such as the direct combustion of palm oils to generate electricity. Although these technologies are marginally cost-effective at this time and may pose some environmental problems, they could alleviate dependency on imported fuels and be quite effective at the village level. On Tutuila and the outer islands it might be best to use a decentralized approach with small conversion units meeting individual family or community needs. Anaerobic digestion, ethanol production, palm oils, wood-charcoal conversion, and producer gas processes are all interesting options. Of these, palm oils and producer gas appear to be the most suitable at this time for generating electricity.

Performance issues and technical suitability are not a problem, except with some liquid fuel conversion technologies. Long-term data are not available on the effects of burning coconut oil in diesel generators, and there are no producer gas facilities in the Pacific from which to gather operational data. Potential constraints which could be of critical importance include the cultural impacts of village level conversion facilities, environmental impacts, land availability and competition for land for agricultural purposes, and maintenance and parts support, particularly on a rural level.

Geothermal

American Samoa has an unmeasured but promising geothermal resource. A study funded by DOE in 1980, Geothermal Energy for American Samoa, identifies the Samoan Islands as one of five Pacific sites where volcanism has occurred in historic time at or near sea level. The signs of recent volcanism, along with normal faulting and rifting and volcanic activity at widely scattered locations along the Samoan Island chain are characteristic of areas with geothermal potential. There are no known hot springs, but one significant temperature anomaly was discovered while a 91 meter (300 feet) water well was being drilled. A good deal of expensive reconnaissance work is needed to identify and quantify potentially useful geothermal reservoirs. The DOE report discusses a three-stage survey which includes geologic mapping of surface characteristics, geophysical and geochemical exploration methods, remote sensing of temperatures, and finally, drilling several test wells to measure temperatures and flow. Most of these methods are expensive, especially the last; all require off-island help; and no single method by itself will give conclusive data. Nevertheless, this technology deserves attention because it has the potential to provide large amounts of baseload power.

Potential constraints, besides land availability, include certain environmental effects which might be critical, considering the role that land traditionally plays on American Samoa. These effects include noise, release of toxic or offensive gases, possible surface or reservoir water contamination, and land subsidence. If the resource were to be developed it would be on a large-scale, 10 MW or so, thereby requiring additional off-island service and maintenance support. Capital costs to develop the resource would be high, and conversion systems must be specifically designed for each site. Operating costs would be quite economical.

Geothermal production of electricity is making significant contributions to baseload supplies at a number of places in the world, including New Zealand and Hawaii. Because of this potential for providing large-scale electricity production for baseload demands on American Samoa, we recommend that at least the preliminary measurements suggested in the DOE report be made.

OTEC

American Samoa appears to have an excellent site for an on-shore OTEC plant by the lagoon near the airport. The water is deep enough nearby to provide the needed temperature difference of at least 20° C, the plant could be built on-shore, the land is available, the site is near the Tafuna power plant, and there should be some natural protection from storms. Some useful site-specific data have not been collected, but there is no reason to believe that temperature differences, currents, and environmental conditions do not favor a plant at that site. Other near- or on-shore sites might also be appropriate. The 10 MW plant that has been suggested is a good size to make a significant contribution to American Samoa's electricity production.

Because of these favorable conditions, the ASG has maintained an active interest in the progress of OTEC technology. In 1976, Purdue University did a preliminary study of the possibilities of installing an OTEC plant on Tutuila. In 1981, the ASG established an industrial and financial consortium headed by Science Applications, Inc., prepared a proposal for DOE for a 10 MW plant to be located by the lagoon near the airport. This proposal was withdrawn because the Commonwealth of the Northern Mariana Islands had submitted a similar proposal, and there was not enough time to prepare a competitive response.

OTEC has encountered certain engineering problems, particularly regarding the cold water pipes, and at this time there are no operating plants anywhere in the world. Development of this technology is proceeding well, however, and a number of commercial firms are developing prototype installations. Eventually, OTEC should be an extremely interesting technology for American Samoa, offering considerable potential for long-term cost effectiveness and oil savings.

Potential constraints, including land availability, cultural acceptance, and environmental effects, may be minimal at the proposed site. At this time there is a critical constraint concerning local technical resources and a parts, operations, and maintenance infrastructure. This constraint might be overcome by the time OTEC becomes commercially feasible. The chief drawback to OTEC at this time is that the technology is at a low state of readiness for Pacific Islands such as American Samoa. We recommend that American Samoa conduct a pre-feasibility study for an on-land OTEC plant at the lagoon, taking into consideration such factors as the thermal resource, optimum plant size, specific site location, additional hydrographic data, and technical, environmental and economic feasibility.

MSW

In 1978, Dames & Moore, Hawaii, developed a municipal solid waste management plan for American Samoa. According to this study, Tutuila disposes of approximately 87 tons of domestic waste and 26 tons of commericial and industrial waste daily. The total solid waste generation on Tutuila, including waste from uncollected miscellaneous sources, is approximately 0.40 to 3.43 kilograms (0.88 to 7.56 pounds) per capita per day. Dames & Moore estimates that total wastes will be 174 metric tons (192 tons) in 1983 and 252 metric tons (278 tons) in 1993. There are no data on composition of the waste, but field observations estimate that 70% to 75% is combustible. Trucks collect the solid wastes and dispose of them at a sanitary landfill site near Futiga. The remote villages are required to collect and bury their wastes.

Based on a figure of 129 metric tons (142 tons) of total, collected solid waste per day, a semi-suspension system for burning shredded and sorted waste, similar to systems on Hawaii and Fiji for providing steam from bagasse, could generate about 30,000,000 kWh/year. This would represent a significant amount of Tutuila's total electricity production.

Constraints include the high capital costs of a recovery and processing facility, high operating costs, and air pollution. There may be problems collecting the full 129 metric tons of waste per day. In addition, highly skilled labor would be required over the long term. The range of figures given for amounts of available solid waste is wide and the upper limit is high when compared to an upper limit of 2.26 kilograms (5 pounds) per capita per day for the United States mainland. Finally, there is the environmental barrier of odors from burning, and there may be additional cultural barriers.

Burning MSW to generate electricity is an established technology, but it is fairly complicated to operate successfully. Nonetheless, this technology may eventually have potential for American Samoa because of the manner in which the population is distributed on Tutuila, the amount of solid waste generated, and the amounts of waste that are presently collected. The Department of Public Works should begin to collect long-term data on solid waste amount and composition. If these data verify the Dames and Moore estimates, the ASG should undertake a preliminary feasibility study to investigate various MSW technologies and provide costs analyses. Some Phase II funds are set aside for a portion of this work; at this time DOE has not awarded the contract.

Wind

American Samoa has prevailing southeasterly trade winds throughout the year. From December through March, the winds tend to be directly from the east; during the rest of the year the winds come predominantly from the east-southeast and southeast. Wind speed measurements are recorded at the GMCC station and at the Tafuna airport NOAA station. The TEO is also installing a recording anemometer at the Energy House. One NOAA anemometer, 8.4 meters (28 feet) above ground, records wind speed and direction for the airfield station. A second NOAA anemometer at this location continuously reads wind speed data; however the data are only periodically recorded by hand. The anemometer at Cape Matatula is 14 meters (46 feet) above ground, where it receives uninterrupted trade winds. None of these anemometers are mounted as high as a wind electric generator would be. No wind speed data are being collected elsewhere on Tutuila, Aunu'a, the Manu'a group, or Swains's island. Average wind speed at the GMCC station in 1978 ranged from 3.0 meters per second (6.7 mph) in April to 6.1 meters per second

(13.6 mph) in June, with an annual average of 4.5 meters per second (10 mph). At the NOAA airport station, the annual average wind speed was 4.8 meters per second (10.8 mph) in 1980. From April through October, the average monthly wind speed exceeded 4.8 meters per second (10.7 mph). The lowest monthly speed was 3.2 meters per second (7.1 mph) in January. These data suggest the wind resource in American Samoa has only marginal potential to make significant contributions to electricity production. Measurements should be taken at the heights at which a wind generator would actually be mounted.

On the United States mainland, wind energy technologies are at medium state of readiness, but wind machines have not been successful in remote Pacific islands. Reasons include typhoon and storm damage, corrosion, lack of repair parts, and lack of technical skills. Phase II of the DOE Territorial Energy Assessment is sponsoring the installation of two machines on Tutuila. The first machine is a 3 kW Kedco on a 18 meter (60 foot) tilting tower at the Energy House near the airport. The machine generates DC power which is inverted to AC and then fed into the grid. The TEO, working with off-island consultants, completed the installation. The machine failed five months after installation, probably as a result of corrosion-induced blade failure, and is now inoperative. The second machine, a 1.8 kW EnerTech, will be installed atop an 18 meter (60 foot) free-standing tower at the 'ᶜalava Quarry near Aoloau Fou village. This machine generates AC directly and also will connect to the grid.

Experience from this first machine along with operational data from machines installed elsewhere in the United States Pacific Islands as part of this same program shows that problems can be expected with these and larger machines until corrosion problems can be solved and more local expertise and a parts and repair support system are available.

Because wind speeds in American Samoa are only marginal for large-scale electricity production by wind machines, the best end use match will be for intermittent electricity production by small generators at remote locations. Land availability could be a problem, particularly for tilting towers.

In order to assess thoroughly to what extent wind can be used on American Samoa, more site-specific data should be gathered at actual wind machine heights. Recording anemometers should collect these data at suitable locations on Tutuila, perhaps inland where wind speeds might be topographically enhanced, and at suitable outer island locations. Additional performance testing data should be gathered from operating small wind machines with an emphasis on corrosion prevention. Wind water pumps should also be considered, especially for remote villages.

Hydroelectric

American Samoa will not have the same success that nearby Western Samoa has had with hydroelectric systems because the resource is more limited. A general study by the United States Army Corps of Engineers (1979), in conjunction with earlier studies by the United States Geologic Survey and Dames & Moore, shows that only six streams within five of 23 drainage basins are worth investigating, and none of these rivers has enough year-around flow to be adequate for reliable, year-around hydroelectric power generation. Run-of-the-river systems without storage facilities rely on adequate, continuous flows of water. The lowest 7-day flow on streams within these drainage basins over a 10-year interval is from 0.22 to 0.48 cubic feet per second, making them inadequate for generating electricity. Long penstocks would not provide enough head to overcome such low flows. The United States Armys Corps of Engineers' economic evaluation of single-purpose reservoir systems show that although such systems with long penstocks would provide an adequate combination of discharge and head, the costs would be prohibitive.

Hydroelectric technologies for Pacific Island locations are at an appropriate state of readiness. They are reliable and durable for such locations, and depending on the type of system selected can provide either baseload or peakload production for rural or urban use. Potential constraints include environmental effects; effects on other water uses, particularly with reservoir systems; land availability and access; and parts and maintenance support. Because of the technology's readiness, its reliability and its success elsewhere in the Pacific, additional studies on hydroelectric power as an intermittent supply technology or in conjunction with multi-purpose reservoirs might be worthwhile.

Solar Ponds

Solar ponds are at a medium state of technological readiness for Pacific Islands, and have some potential for contributing to baseload electricity generation on Tutuila or the Manu'a group. The chief constraint may be land availability. One possible site is the lagoon area near the airport; other possible sites exist on the Manu'a Group.

Coal

Coal appears at first to be an attractive technology for American Samoa because obtaining a supply of coal from Australia would not be a problem. However, land and environmental constraints are severe. Coal shipments would probably require a new harbor, and American Samoa would still depend on imported fuel.

Ocean Currents and Tides

Ocean current and tidal energy conversion systems are operating on a limited basis elsewhere in the world but are at a low state of commercial readiness for American Samoa. The resources are unmeasured for American Samoa but are likely to be insufficient and inconveniently located.

Other Technologies

Small-scale technologies can make a small contribution by helping communities avoid the use of petroleum products. The small photovoltaic-powered electric fence was working successfully at a remote farm until a storm destroyed it. Small photovoltaic sytems such as this would be useful for essential electricity generation for Swain's Island or other remote sites. Mechanical wind-driven pumps might be useful for remote village applications.

Data are not available on the amount of cooking done with wood fuel. In most communities, Sunday feasts are cooked over wood fires. Efficient wood cooking stoves would reduce wood consumption but there may be cultural barriers for such stoves, particularly for the Sunday feasts.

There is some interest in increasing petroleum reserves with an expanded fuel supply system, thereby reducing supply vulnerability. The TEO is investigating various ways to do this. The TEO is also interested in studying the use of heat pumps in commercial and public buildings, and in encouraging the American Samoa Power Authority and private industry to work with them in developing cogeneration ideas.

FINDINGS AND RECOMMENDATIONS

American Samoa's present power system on Tutuila, which depends entirely on imported diesel fuel, has a fair maintenance program and barely adequate capacity. The Territory is extremely vulnerable to interruptions in petroleum supplies and to price increases, and this has a direct effect on the economy and community well-being. Energy systems are needed at remote sites and outer islands that either do not have operating electricity generating systems (Swain's Island) or that depend on importing fuel for small diesel power plants (Manu'a Group). American Samoa is fortunate to have a number of renewable energy resources to consider and an effective energy office with strong government support to investigate these resources.

Based on recent studies, geothermal, MSW, and OTEC offer excellent potential for significant baseload electricity production. Extensive investigation is needed to identify and quantify the geothermal resource, but this technology deserves particular attention because of its overall suitability for American Samoa. MSW conversion is attractive, but existing data should be verified, new data gathered, and studies done on what type of conversion system would be most suitable. OTEC will offer excellent mid-range possibilities when the technology reaches a higher state of readiness.

American Samoa is using an increasing amount of process heat for canning and other commercial and industrial operations, and therefore solar thermal applications are promising. Domestic solar hot water systems have had mixed success because of design and installation problems, but they offer the potential for some electricity savings. Major constraints for solar ponds include competition for land use and the technology's medium state of readiness for island locations.

Constraints to biomass technologies include the rugged land, the small amount of flat terrain, the land tenure system, and competition for land use. Palm oils and producer gas are promising technologies for generating electricity on the outer islands. Hydroelectric and wind technologies have limited possibilities because of limited resources. Additional site-specific wind data should be collected at proper heights, and multiple-use reservoir systems for hydroelectric generators might show these technologies to be cost-effective in certain places. Land availability, environmental effects, and continued dependence on an imported fuel, are problems for coal, and this technology might also require a new harbor.

Wood cooking stoves, wind-driven water pumps, and small photovoltaic systems would reduce or avoid petroleum fuel use on the outer islands and remote villages.

The TEO's energy management efforts have been very effective in promoting conservation and energy awareness, assembling a data base, and achieving energy savings with institutional projects. It should continue with these efforts. Table 8-5 lists the various recommendations for American Samoa.

Table 8-5

Energy Planning Recommendations For American Samoa

Tutuila

- Continue with energy management for conservation, rate structure reform, and data accumulation
- Continue retrofitting, especially for heavy air condiditoning loads, and investigate effeciencies of water pumps and other heavy equipment
- Collect more site-specific data for OTEC
- Monitor the hospital solar cooling project, and use data to project feasibility of similar projects
- Develop a plan for preliminary investigations of the geothermal resource and begin these investigations
- Develop more MSW data, verify existing data, and investigate various MSW conversion technologies
- Continue installing domestic solar hot water systems and start preliminary studies of solar thermal systems for process heat
- Investigate the use of palm oils or producer gas for electricity production
- Collect additional site-specific wind data at actual wind machine heights
- Investigate multi-use reservoirs for use with reservoir hydroelectric systems

Remote Villages and Outer Islands:

- Determine village energy needs through energy audits
- Continue installing small photovoltaic systems, investigate installing such a system on the airstrip at Ofu, and consider applications on Swain's Island
- Collect site-specific wind data at actual wind machine heights
- Investigate using wind-driven mechanical water pumps for remote applications
- Investigate using solar hot water systems for public buildings on the Manu'a Group
- Investigate building a solar pond on the Manu'a Group

CHAPTER 9: FINDINGS AND CONCLUSIONS

The principal objective of this assessment is the identification of near-term, cost-effective energy planning options for each of the Pacific Island governments, based, to the extent possible, on the use of indigenous renewable energy resources. The intention of this effort, as reflected in the language of the enabling legislation (P.L. 96-597), is to help reduce island dependence on imported fuels and to contribute to overall economic development goals in the region.

Previous sections of this assessment have: 1) outlined the context of the current energy situation in each island group; 2) presented a framework in which alternate energy technologies can be evaluated; and 3) discussed the status of current and future energy options for each government. This last step has resulted in the identification of specific energy planning recommendations for each government, based on three critical factors: availability of an alternate energy resource base; readiness of technologies that can exploit that resource base; and the attractiveness of various technology applications given site-specific economic, social and environmental considerations.

Each step of the overall assessment occurred as an outgrowth of two years of interaction between the Department of Energy and the responsible energy, economic, and resource development officials of the island governments. This interaction featured on-site data collection, a Phase I Report based on preliminary data, follow-up meetings and on-site technology assessment work, computer analyses, plus review and comment periods for island energy planners on all written material produced during successive stages of the project. The technology-specific analytical work conducted during the second phase of the project helped support determinations made in this final report about the appropriateness or inapplicability of various technologies in the locations under consideration. Table 9-1 identifies the technology and resource analyses conducted during the project's second phase. Copies of the final reports of each will be available as supporting documents to this final report.

TABLE 9-1. -- Phase II Technology Assessments

Wind Energy Assessment for the Western Pacific Based on Ship Reports, Thomas A. Schroeder and Arnold M. Hori, University of Hawaii, December, 1982.

Coal as an Option for Power Generation in the United States Territories of the Pacific, I.Y. Borg, Lawrence Livermore National Laboratory, Novermber 30, 1981.

Suitability of Salt-Gradient Solar Ponds for Electrical Power Generation in the United States Trust Territory of the Pacific Islands, Guam and American Samoa, Thomas B. McCord et al., SETS, Inc., Honolulu, Hawaii, October, 1982.

Photovoltaic Applications for Remote Island Needs, Davad A. Schaller and Ronal W. Larson, Black Hawk Associates, Denver Colorado, December, 1982.

Biomass Resources for the United States Pacific Territories, James L. Brewbaker, University of Hawaii, December 1982.

Municipal Solid Waste Energy Conversion Feasibility for Guam and American Samoa, James R. Roney, Inter Energy, Inc., March, 1983.

Technical and Economic Feasibility of Sail Assist for Field Ships, Charles W. Case, Pacific Energy Technology, Inc., March 1983.

As a consequence of political, economic, and social developments during the two-year period of this project, the energy status of nearly every government included in the analysis has evolved since P.L. 96-597 was enacted. Even though the crisis in international oil pricing which helped amplify the energy dependencies of the Pacific Island has abated some-what, island oil dependencies remain. The current stabilization in world petroleum prices has moderated, at least temporarily, the imported fuel cost burden, the steady oil price rises of the late 1970s placed on island governments, but imported fuel costs continue to claim a disproportionate share of island wealth. This reduces the amount of capital available to develop the resources needed for economic growth and limits the provision of necessary public services.

Spurred by the vulnerability they experienced during the last oil price rise, some island governments have recently taken actions which are likely to result in more stable, though still costly, electric power generation for at least the near to mid term. The Marshall Islands government has purchased an entirely new residual oil-fired central generating facility, complete with guaranteed fuel supplies and a service agreement for plant operation and maintenance. The governments of the Republic of Palau, American Samoa, and the Federated States of Micronesia are considering similar action. Though they perpetuate dependence on outside sources of energy, such actions are intended to add stability and efficiency to the central generation of electricity until the transition to indigenous energy resources becomes more feasible.

Another development which has occurred during the time periods of this assessment has been the introduction of several renewable energy technologies at selected island locations. Photovoltaics, small hydroelectric, wind energy, and solar hot water technologies, as well as energy-efficient wood stoves for village use, have each been installed in one or more of the island groups. System installation, operation, and maintenance experience is being developed at the local level, and equipment performance is being evaluated. The results from these pioneering efforts with renewable energy technology have been noted in previous chapters and underlie many of the recommendations of this assessment.

One final development has taken place, the Compact of Free Association, which will influence greatly the ability of several of the island goverments to control their energy planning futures more directly. Under one of the provisions of this agreement, the United States has agreed to provide annual funding grants to the governments of the Federated States of Micronesia, Republic of Palau, and Republic of the Marshall Islands to be used in support of energy self-sufficiency. Additionally, major infrastructure development projects will be constructed for each of these three governments as an outgrowth of the Compact.

It is too early to identify the individual energy projects to be supported by this expected new funding. However, the respective governments will soon have the opportunity to begin moving away from the conditions which made the "crisis management" approach to energy planning so commonplace in each of the island groups just a couple of years ago. The new generating station in the Marshall Islands, to be financed in part with new Compact funds, represents that government's willingness to discard its existing patchwork of unreliable diesel units and to begin to assume full responsibility for its own energy future.

As this assessment has proceeded, perhaps the greatest uncertainty and debate has been over the relative potential for one or more of the renewable energy technologies to emerge as a ready, cost-effective option for island governments. Several technical achievements in the last few years have lowered the acquisition cost of many renewable energy conversion systems. Still, the high first cost of most of these systems masks their economic attractiveness, which emerges when they are compared with conventional energy systems to a life-cycle basis. Capital costs of many renewable energy systems are expected to drop considerably in the near to mid-term, making the potential for island applications even more attractive. Table 9-2 presents current cost and operational characteristics for most of the major technologies examined in this report. These cost ranges were used to support the economic evaluations of each technology for each island group in the preceding chapters.

As the chapters for each government indicate, technology options vary widely based on their present state of technical readiness, economic feasibility, and their suitability for meeting local needs. Each island group appears to possess one or two principal renewable resources which should receive first attention as technology options are considered in coming years. It is not possible to generalize across island groups because each differs in either the resource base or site-specific characteristics needed to make best use of available resources. The recommendations included at the end of each of the preceeding six chapters, and summarized below, present the most favorable renewable energy resource and technology options for each area.

Considerable promise has been held out for the role that renewable energy resources will at some point play in the Pacific Islands. However, local governments face energy problems that are both immediate and pervasive. Island planners do not have the luxury to take time to anticipate what technological advances and cost reductions will be possible for future energy systems. As a consequence, energy planning activity in the islands, and in this assessment, has proceeded along two general fronts: the urban setting, where either rehabilitation or replacement of existing

Table 9-2. Characteristics of Technologies for Production of Electricity Under Consideration for Pacific Territories

Technology	Size/Description of System	Current[(a)] Capital Cost Estimate K$/kW	Current[(a)] Cost/kWh	Capacity Factor[(b)] Range (%)	Area Required	Temporal Characteristics
Wind	Few to tens of kW, not grid connected	3-6	$ .50-1.00	10-30	Little	Intermittent, needs storage
Wind	Few to tens of MW, grid connected fuel-saver mode	1-2.5	$ .25-.50	10-30	20 ha/MW	Intermittent, fuel storage mode with no storage
Photovoltaic energy	Several kW range, not grid connected	10-15	$1.00-2.00	15-25	$20m^2$/kWp	Intermittent, needs storage
Photovoltaic energy	Few to tens of MW, grid connected fuel-saver mode	10-20	$1.00-2.00	15-25	2 ha/MWp	Daily cycle, intermittent, fuel-saver, no storage
Solar Thermal energy conv.	Several kW to tens of MW, stand alone or grid connected	5-20	$ .50-2.00	15-25	3 ha/MWp 15 ha/MW	Intermittent, needs storage; or fuel-saver, no storage
Hydropower	Few MW, grid connected	0.8-1.3	$ .10-.50	50-70	Little	Water availability dictates limitations
Geothermal energy	Tens of MW, grid connected	1.5-2	$ .10-.50	70-90	As required	Baseload power
Ocean tidal/ current	Harness ocean currents or tidal flow	Unknown	Unknown			
OTEC-shore based	5 MW 40 MW	8-10 5	$ .20-.40 $ .50-.40	70-90	Little	Baseload power
Solar pond	5 MW salt gradient excavating/diking	2-20	$ .25-.50	70-90	20 ha/MW	Baseload power with peaking possibilities
Wood	Few MW and up, boiler gasifier	1-2	$ .12-.15	70-90	800 ha/MW	Baseload power
Coal	Few MW and up	1.3	$ .10-.15	70-90	1 ha/MW	Baseload power
Diesel	Fractional to several MW engine generator	1[(c)]	$ .40-.50	70-90	Little	Baseload power
Residual oil	Several of tens of MW boiler	1[(c)]	$ .15-.20	70-90	Little	Baseload power

(a) "Hawaii Intergrated Energy Assessment," LBL 12061, January 1981; "Cost of Energy from Some Renewable and Conventional Technologies," SERI/SP-741-1022, April 1981; other sources.
(b) Fraction of time source can produce energy, averaged over a year of operation.
(c) Environmental protection equipment will increase cost.

petroleum-based systems are needed just to maintain day-to-day operation of government and commerce; and the remote island and village environment, where the high cost of introducing or maintaining small, diesel-powered generating systems cannot be supported.

The potential for displacing petroleum fuels in the island population centers rests largely on: 1) the opportunities which exist for governments to improve the operating efficiencies of existing generating facilities; and 2) efforts at energy management in all end-use sectors, particularly the government sector. These steps can save petroleum on a day-to-day basis and free system capacity to support economic development or other revenue-producing activities. Even those island groups which are moving to new, more efficient residual oil-fired generating systems can benefit in fuel savings and government outlays by adopting proven energy management techniques. Significant savings also should be realized by those governments willing to adopt rate structures, billing, and collection practices more designed to generate revenues. The present practice of most governments is to subsidize electrical consumption.

In the many scattered remote villages and outer islands of the region, energy use continues to be dominated by the gathering and combustion of fuelwood. Yet, as the frequency of communication and travel increases among the people of the region, even those remote areas are becoming candidates for some form of energy technology. In fact, governments perceive extension of electrification and its benefits to outer islands as a way to help stem in-migration to already overcrowded island centers. As a consequence, government efforts to provide energy to these areas is expected to accelerate in the near term. The application of certain renewable energy technologies in these instances appears both technically and economically justified, and should help avoid further dependence on imported fuels. Specific recommendations for each of the island groups include those renewable energy measures believed to have reached a degree of readiness and cost effectiveness that warrants immediate exploitation.

Another issue posed in this investigation of alternate energy options for the Pacific Islands is the appropriate locus of responsibility for actions needed to implement findings and recommendations made in the report. The role of the private sector in initiating changes to assist in displacing petroleum fuels appears constrained by the overwhelming presence of government involvement in decisions affecting energy use in any of the areas studied; thus the local governments have total responsibility for electricity production. Until and unless private utilities evolve in the region, government responsibility for energy technology selection will remain exclusive.

In addition to direct control over electricity production and distribution, government decisions often indirectly influence future energy options. The most apparent examples include the siting and construction of new roads, the approval of new infrastructure developments (airfields, hospitals, etc.), and control of permits for new commercial and residential construction. Such actions influence the energy use opportunities that will be available to future end users, and can have the effect of forcing energy technology choices at later dates. Road extensions are often followed by power line extensions, thus encouraging central power distribution at the expense, perhaps, of a more decentralized renewable resource technology option which would otherwise be cost-effective.

There are some areas in which the private sector will be able to initiate energy-efficient activities in the islands. Information dissemination, product distribution, and system servicing are among the most needed. Many of the energy management techniques and renewable energy systems of potential application are too new to have received widespread understanding among even the government technical and administrative staff responsible for energy decision-making in the islands. For example, the replacement of electromagnetic ballasts with electronic ballasts in flourescent lights is a relatively recent technology development which promises energy savings in many lighting applications in the islands.

Given the time lag and an often random flow of technical information to the Pacific, private sector product distribution and service companies are needed to disseminate product data aggressively on all aspects of alternate energy and energy conservation hardware. Only with more complete information can government decision-makers be expected to choose accurately among the technology options available to them.

To the extent that United States government agencies remain responsible for technical assistance in the islands, they should assist the United States private sector to recognize the market opportunities of the region. Once the private sector commitments have been made, governments should provide reasonable direct assistance to project developers to insure that initial efforts succeed. This assistance could include, at a minimum, communication and transportation services where they are operated exclusively by the government. Historically, the islands have attracted little commercial interest compared to other areas in the region, largely because of the distances and logistical difficulties that have to be considered in moving people and products. Government can assist in mitigating these conditions so that there is less a deterrent to United States companies' investment in the islands and more chance of successful projects.

Private renewable energy companies have been active elsewhere in the Pacific Basin, and often work closely with host governments to advance the use of one or more technologies. Technical assistance should not be limited to the narrow definition of "energy technology", but should encompass the larger economic arena in which energy use takes place. Therein, the private commercial and industrial activity necessary to support energy investments can be developed. For example, private repair and maintenance facilities could provide skills needed to support new energy technologies, particularly those smaller, decentralized systems which may not be directly owned by the government.

Many island governments now provide or soon will provide tax and other financial incentives to encourage outside investment in economic development activities. The use of such mechanisms similar to the many innovative and successful third-party financing arrangements for renewable energy systems in the United States should be pursued to promote energy-related investment. The United States government, together with each of the island governments, should make a serious effort to highlight to potential investors the opportunities that exist in the context of these tax benefits.

The introduction of new energy systems, all largely developed and pioneered outside the Pacific, will have to be a joint effort between an informed public sector and a willing and cooperative private sector, with technical assistance provided by United States agencies where it is appropriate. Governments must realize how the unique circumstances of remoteness and unfamiliarity have limited United States private sector interest in the Pacific Islands in the past. The most crucial role for government, therefore, apart from striving for more complete information on the costs and benefits of each energy option available, will be to encourage private investor interest in energy development. Governments should also realize that, in some instances, such as on unusually remote islands with small populations, private sector initiative may be unlikely under any circumstances. In these cases, governments must decide whether to maintain the status quo or to make changes strictly as management decisions aimed at reducing overall operating costs.

Given the broad context in which future energy planning must occur, it is possible to itemize the specific findings and conclusions that have resulted from this assessment. Many of these were presented in the Phase I Report and remain valid at this time.

TERRITORIAL ENERGY ASSESSMENT
FINAL REPORT

FINDINGS AND CONCLUSIONS

1. All areas included in this analysis depend on imported petroleum for nearly 100% of their energy needs.

2. Electricity is the principal energy form supporting economic development in the region. Electricity generation also presents the greatest number of opportunities to use alternate technologies and indigenous, renewable energy resources. Given the present state of development of synthetic fuels production or alternate transportation technology, there is little likelihood that the island governments will be able to meet a significant portion of liquid fuels demand for aviation, marine transportation or construction in the near term with indigenous resources.

3. The island governments are the principal suppliers of electrical energy. There are no private utilities.

4. The fuels local governments purchase are used primarily to generate electricity which, in turn, is used by households, commercial and industrial enterprises and government public services. The fuel cost of generating electricity is generally not recovered from the end-user, except on Guam and American Somoa. Given local wage levels, full cost quite possibly cannot be recovered. Thus fuel costs alone have weakened the local governments' ability to continue to provide, let alone extend, essential electrical services. This has limited opportunities for growth in the developing economies of the Pacific.

5. The total cost of generating electricity in the Pacific Island groups is not known, but estimates place it between 17¢/kWh and 25¢/kWh. Mainland United States costs range from 2¢/kWh to 15¢/kWh, with a national average of 7.2¢/kWh in late 1982. The high cost of fuel oil, a tropical climate which results in a high generating system derating factor, and often inadequate operation and maintenance practices all contribute to high generating costs.

6. Major private commercial and military operations often provide their own power because government run central systems are insufficient or unreliable. This is believed to be the major reason that new commercial enterprises have been reluctant to locate in the islands.

7. Though not provided by the local governments, the fuels consumed by private or military operations are extremely important to the overall energy picture of each government. The presence of military facilities and the few major commercial enterprises generally represents the critical underpinning of the host government's economy.

8. All of the island governments express an adamant desire for energy self-sufficiency coupled with economic independence. There is a common need for assistance in comprehensive energy planning, technology evaluation, and the development of alternate energy resources.

9. Economic development plans generally have not given in-depth consideration to energy requirements for the future. Therefore, there is a need to bring some emphasis on future energy demands into the long range planning processes of each government. Linkages between new economic development and energy demand must be quantified wherever possible.

10. Energy management and greater energy efficiency of existing production and end-use systems offer some immediate fuel savings potential in each island group. However, high birth rates, the high percentage of population without electricity in many island groups, the potential for rapidly expanding demands as economies develop, and other factors all indicate the value of long-term emphasis on new sources of supply.

11. All of the island groups appear to possess various renewable energy resources which, when proven and developed, could substantially relieve the current dependence on imported petroleum for electric generation. Additional resource assessment is required for some island groups, and more exhaustive performance testing of hardware is needed before large immediate expenditures on some technologies could be justified. In addition to indigenous renewable resources, coal may be a possible transition fuel on Guam.

12. The current high costs of fuel, operating, and maintenance of conventional electricity generation equipment make several renewable energy technologies appear economically attractive for the islands. Renewable energy technologies generally have fairly high capital costs but relatively low operating costs. In selecting technologies appropriate for specific island groups, special consideration must be given to problems unique to the area, such as the frequency of maintenance in the highly corrosive tropical environment; social, cultural, and political compatibility; and training of operating and maintenance personnel.

13. A transition to alternate energy systems will require some years to complete. The energy problem in most island areas is both long term and immediate. Steps must be taken to improve the efficiency and reliability of existing energy systems while the transition to longer range solutions unfolds.

14. Investment in the most favorable alternate energy systems can and should be made as soon as possible. Given that the existing energy supply systems are now inadequate, and that the United States has an ongoing commitment to Guam, American Samoa, and the Commonwealth of the Northern Mariana Islands and a minimum 15-year commitment to the economic, social, and political well-being of the emerging nations of the Trust Territory of the Pacific Islands, this is a critical and opportune time to invest in energy supply systems which will strengthen the developing economies of the islands and lead to greater self-sufficiency. Such investments will eventually lower costs to the United States government as well as to the local governments, and will allow for creation of a broader economic base across all of the island groups.

Chapters 3 through 8 discussed each government's energy situation in detail and provided the supporting data and analyses to justify several major recommendations for energy planning and energy technology selections in both the central, urbanized islands and remote outer islands and villages.

THE CARIBBEAN REGION

PUERTO RICO

UNITED STATES VIRGIN ISLANDS

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CARIBBEAN ENERGY ASSESSMENT

EXECUTIVE SUMMARY

In December 1980 the Omnibus Territories Act was passed to assist the insular areas in the Caribbean in the development of their renewable energy resources and to aid in the achievement of greater energy self-sufficiency. Since that time, these geographically isolated islands continue an almost total dependence on imported petroleum products as an energy source. Although petroleum prices have stabilized, the continued high cost of oil results in strain on these local economies and utilizes capital that is critical for needed economic development. In view of this situation, the U.S. Department of Energy has prepared this energy analysis for the benefit of Puerto Rico and the Virgin Islands in response to the mandated objectives of the Omnibus Territories Act, P.L. 96-597.

In meeting the requirements of the Act, this planning effort was conducted in cooperation with each insular area. The DOE sought out and obtained the active participation of the Governor's energy office of the Commonwealth of Puerto Rico and of the U.S. Virgin Islands in the completion of these energy programs. Grants were awarded to these offices in support of this work and the results are published here in full. Puerto Rico will continue to complete a detailed wind energy resource assessment utilizing its remaining funds through the balance of Fiscal Year 1983.

The Puerto Rico assessment evaluates the potential for the renewable energy resources of wind, hydropower, solar, bioenergy and OTEC and for cogeneration. Each resource is evaluated for its feasibility in displacing oil-fired electric generating capacity. Projected savings, in millions of barrels of oil, are provided through the year 2000 for the major renewable energy resources which have significant development potential. Emphasis is given to the wind resource due to its potential for significant contribution in the relative near term. A wind resource assessment will be a primary focus of the Puerto Rico Office of Energy for continued renewable energy development. During 1982, thirteen of the more feasible hydropower sites were visited and assessed for restoration on a cost-benefit basis. Due to the high costs of power, these abandoned hydropower sites are now deemed feasible for redevelopment. Evaluations of the remaining renewable resources were also provided with cogeneration and bioenergy showing significant near term oil displacement potential. The Puerto Rico Office of Energy concludes that these technology assessments and other work under way, "will allow realistic achievable goals to be set and policies adopted that will lead Puerto Rico to a more energy 'self-sufficient' future."

The U.S. Virgin Islands Energy Office also recognizes a potentially major role for indigenous renewable resources. This office projects that by the year 2005 a significant portion of electricity required could be produced from these resources. The preliminary economic analysis shows that these resources could compete favorably now with current oil price levels. The rate at which these indigenous resources can be exploited, however, depends more on the availability of capital and rate of technological development than on oil price. The Virgin Islands Energy Office report concludes that replacing imported petroleum with indigenous energy resources can have a beneficial effect on the Islands' economy. In addition, energy conservation efforts could lead to substantial reductions in electricity and gasoline consumption.

In addition to the submission from the Governor's energy office of Puerto Rico, detailed studies on hydropower, cogeneration and solar insolation measurements were also provided, which are available separately. The Caribbean submissions are the work of the energy offices of Puerto Rico and the U.S. Virgin Islands, or their consultants, and represent their response to the Act. The submissions are published without alteration. Any follow-up questions on the technical data presented should be referred to the concerned energy office.

In Part II of this document particular emphasis is given to estimating future energy needs, based on broad ranges of economic development possibilities. Additional in-depth assessments of the potential for development of the several indigenous energy sources are also provided. A broad range of proposed actions were developed as a result of this analysis and these constitute the proposed energy program in the long term. Estimates of costs to implement the resultant recommendations are provided for the use and benefit of Puerto Rico, the U.S. Virgin Islands, and interested energy planners.

The major findings of this work can be summarized as follows:

- In the period 1950 to 1973 the economy of Puerto Rico grew at an annual average rate of 6.1%. The impact of the OPEC oil price increases reduced the growth to -2.0% in 1975. The economy rebounded to a 5.9% growth in 1979, but dropped to 0.7% in 1981 and to -3.9% in fiscal year 1982. The economy has changed from a predominantly agricultural system (17.5% of gross product in 1950 to 3.2% in 1981) to a predominantly industrial system (15.9% in 1950 to 42.9% in 1981). The petroleum refining and petrochemical industries are significant components of Puerto Rico's economy. They were developed when Puerto Rico had a significant cost advantage over mainland U.S. facilities due to the then lower price of foreign crude oil.

- Two economic growth scenarios have been postulated for Puerto Rico. The high growth scenario estimates growth at 3.7-4.0% per year for the period 1983-2020. The low growth scenario estimates growth at 2.5-2.8% per year.

- The Puerto Rican economy depends almost exclusively on petroleum products and on electricity derived from petroleum products for its energy supply. Current consumption (1981 data) is 315 trillion Btus; approximately 54% is in the form of petroleum fuels, 43% is electricity (virtually all oil-fired), and 3% is from bagasse combustion. Industry consumes 45% of the energy, transportation 22%, and the residential/commercial sector 22%. Under the high economic growth assumptions, the energy consumption will be almost double by the year 2000 and will more than triple by the year 2020. Under the low economic growth assumptions, consumption will slightly more than double by 2020.

- Puerto Rico's reserves of fossil fuels are unproven. Some earlier geological explorations have indicated that oil- and/or gas-bearing formations might exist, but there have been no confirming exploratory test wells.

- There is a sizable petroleum refining operation in Puerto Rico (284,000 barrels per day) and sizable petrochemical facilities. These are facing complex problems of crude oil and feedstock supply and prices, transporation costs, and considerations under U.S. oil entitlements, quotas, and price controls. The future of these industries, and any downstream secondary industries using their outputs, will depend on the resolution of these problems.

- The electric system in Puerto Rico is about 4200 MW in size. Peak loads are in the range of 2100 MW. The system experiences reliability problems because of its isolation, the large size of several units relative to total system size, limited quick response capability, and maintenance problems. The system is about 98% oil-fired with the small balance coming from hydroelectric facilities.

- There is currently very little use of renewable resources in Puerto Rico. The potential is, however, high because of the tropical location. Cost is a major factor influencing the use of renewable resource technologies. A series of incentives will be needed for these technologies to make any significant market penetration. With a large number of alternatives available, a major concern is the allocation of limited resources to the development of the most promising technologies.

- Direct use of solar energy has a high potential for utilization in Puerto Rico. Average daily insolation levels are among the highest in the world. It has been estimated that solar water heating can save 630,000 barrels of oil per year in the year 2000, solar ponds could save 2,190,000 barrels per year, and photovoltaics could save 1,550,000 barrels per year.

- Wind systems offer a special opportunity for Puerto Rico. A 200 MW demonstration unit is currently in operation. It is estimated that the maximum technical market based on implementation of wind systems at all the favorable sites, is 300 MWe.

- Biomass, in the form of agricultural crops, residues, and urban waste is estimated to be able to save 6,650,000 barrels of oil in the year 2000.

- Ocean thermal energy conversion (OTEC) is an attractive alternative since Puerto Rico has the proper conditions of water depth and temperature gradients. Plants of the 40 MW size range have been proposed.

- Hydroelectric stations offer the potential of 100-200 MW of electrical power by the Mid- to late-1990s. It has been estimated that 3,280,000 barrels of oil could be saved by the year 2000.

U.S. Virgin Islands

- The economy of the U.S. Virgin Islands is dominated by the tourist, industrial, and government services sectors. In the decade 1970-1980, total employment grew at an average rate of 2.1% per year. In 1981 the growth rate was 0.1%. A significant component of the economy is the Hess Oil Virgin Islands Co. refinery, which is the third largest in the world. The Martin Marietta alumina plant is another major component of the economy.

- Two economic growth scenarios have been postulated for the Virgin Islands. The high growth scenario assumes a growth rate in employment of 2.5-2.7% per year out to the year 2020. The low growth scenario estimates employment growth at only 1.3% per year.

- The Virgin Islands are almost exclusively dependent on petroleum for energy. Approximately 65% of the energy consumed is in the form of electricity (all of it oil-fired) with the balance in the form of petroleum products. Current consumption (1980 data) is 76.5 trillion Btus. Under the high economic growth scenario this will increase by 170% by the year 2020. For the low growth scenario this will increase by 70% in 2020. The Hess Oil refinery and the Martin Marietta alumina plant currently account for 90% of the energy consumption in the Islands; they are both self-sufficient with respect to fuel, electricity and water supply.

- The electric system is divided between St. Thomas and St. Croix. St. John is connected to St. Thomas via cable. The installed capacity on St. Thomas is about 115 MW and on St. Croix about 88 MW. The capacity for some units is derated as steam is extracted for water desalination purposes. The peak loads are 39.5 MW for St. Thomas and 29.0 MW for St. Croix. Despite the large reserve margins, the system experiences reliability problems because of its isolation and because of maintenance difficulties.

- Electricity costs are high by U.S. mainland standards - 18 to 21 cents per kilowatt hour. All of the electricity generation equipment is oil-fired, which contributes to the high cost.

- There is currently very little renewable resource use in the Virgin Islands, although the potential is very high.

- Solar water heating is the technology likely to be the most cost-effective in the near term due to the high cost of electricity, its largest market competitor.

- Wind systems have some potential but the wind resource data are sparse. It has been estimated that 5-10 MWe of wind power might be implemented on each grid.

- Biomass has some potential but is not very large because of limited land availability.

- Ocean thermal energy conversion (OTEC) has some potential and some sites have been proposed for small units.

- Hydroelectric potential is limited because of the terrain and climatic conditions. Water supply, itself, is a critical problem for the Islands.

PART I: ANALYSIS OF ENERGY IN PUERTO RICO AND THE UNITED STATES VIRGIN ISLANDS

This part contains two reports. The first was prepared by the Puerto Rico Office of Energy and is entitled Alternative Energy Resource Assessment of Puerto Rico. The study conducted by the Office of Energy is reproduced here in its entirety with the exception of three appendices. These appendices, because of their size, are not included and can be found as the following references:

Appendix I: Gebhard, T.G., Brief Reconnaissance Studies for the Addition of Hydropower in Puerto Rico, submitted to U.S. Department of Energy, Atlanta, Georgia (October 1982).

Appendix II: Cogeneration Potential in Puerto Rico's Commercial and Industrial Sectors, submitted to Puerto Rico Office of Energy by Energy Research and Application, Inc. (December 1981).

Appendix III: Lopez, A.M. and K.G. Soderstrom, The Availability of Insolation in Puerto Rico, to be published in the 67th Annual Technical Conference, Solar Energy Division, ASME.

The second report in this part was prepared by the Virgin Islands Energy Office and is entitled Territorial Energy Assessment for the United States Virgin Islands. It is reproduced here in its entirety.

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ALTERNATIVE ENERGY RESOURCE ASSESSMENT FOR PUERTO RICO

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Office of the Governor of Puerto Rico

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November 12, 1982

Mr. William H. Rankin
Technical Project Manager
U. S. Department of Energy
Savannah River Operations Office
Aiken, South Carolina 29801

Dear Mr. Rankin:

We are pleased to submit a preliminary resource assessment of alternative energy sources for Puerto Rico. As you know, the resource assessment as originally planned was not fully funded. At the reduced funding level, a comprehensive assessment as previously planned was not possible, therefore, the report has been prepared by the Puerto Rico Office of Energy staff utilizing the various sources of available data.

I trust the report will assist you in fulfilling the Department of Energy's commitment to the requirements of Public Law 96-597.

Should you have any questions, please feel free to contact this Office.

Sincerely,

Eduardo López-Ballori

Eduardo López-Ballori *por cmf*
Director

ELB:RDS:cim
Enclosure

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ACKNOWLEDGMENTS

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2. Dr. Thomas Gebhard, Consulting Engineer and author of the Hydropower reconnaissance study.

3. Dr. Angel López, Center for Energy and Environment Research, Mayaguez, Puerto Rico, for his paper on Solar Insolation.

I PREFACE

Since 1973, the economic impact of rapidly rising world oil prices has been particularly severe on the U.S. territories, the Trust Territory of the Pacific Islands and the Commonwealth of Puerto Rico. Though these localities vary greatly in the size and complexity of their economies, their political status, and social and cultural backgrounds, they all share certain traits: they are geographically isolated island groups with an almost total dependence on imported petroleum products as an energy source. Dramatically rising oil prices, coupled with the uncertainty of supply over the near as well as long term, are resulting in severe strains on local economies and capital that is badly needed for economic development.

In order to address the critical needs of these insular areas, Congress included Section 604 in P.L. 96-597, the Omnibus Territories Act (December 1980), which requires the development of comprehensive energy plans with the goal of reducing the reliance on imported oil through making maximum use of indigenous energy resources:

<u>MANDATED OBJECTIVES</u> (Highlights of Section 604 of P. L. 96-597)

"(c) The Secretary of Energy...shall prepare a comprehensive energy plan with emphasis on indigenous renewable sources of energy for Puerto Rico, the Virgin Islands, Guam, American Samoa, the Northern Mariana Islands and Palau. The plan shall be prepared with the approval of the Secretary of the Interior and in cooperation with the chief executive officer of each insular area by:

1. Surveying existing sources and uses of energy;

2. estimating future energy needs to the year 2020, giving due consideration of economic development possibilities;

3. assessing, in depth, the availability and potential for development of indigenous energy sources;

4. assessing the mix of energy sources (including fossil fuels) and identifying those technologies that are needed to meet the projected demands for energy; and

5. drafting long-term energy plans for such insular areas with the objective of minimizing their reliance on energy imports and making maximum use of their indigenous energy resources.

(d) The Secretary of Energy...with the approval of the Secretary of the Interior, as part of the comprehensive energy planning, may demonstrate those indigenous renewable energy technologies which are determined to be most cost effective through the use of existing programs.

(e) Within two years from the date of enactment of this Act, the Secretary of Energy...shall submit the comprehensive energy plan for each insular area to the Congress.

(f) There are hereby authorized to be appropriated such sums as may be necessary to carry out the purposes of this section."

This section of P.L. 96-597 was authorized but unappropriated. Recognizing the serious nature of the situation, however, the Acting Under Secretary of DOE directed in April, 1981, that a three-phased approach to meeting the intent of the legislation be defined. The first step was to characterize the current energy situation in each territorial entity and to provide an estimate of the cost connected with developing comprehensive territorial energy plans. The Savannah River Operations Office (SR) was assigned responsibility for the Caribbean region (Puerto Rico and Virgin Islands), and the San Francisco Operations Office (SAN) for the Pacific entities (Guam, American Samoa, Northern Marianas, Palau, Federated States of Micronesia, and Marshall Islands). The Office of Intergovernmental Affairs, Territorial Affairs Branch (HQ/IR), was assigned DOE Headquarters responsibility for overall coordination.

Consistent with the Acting Under Secretary's direction, a strategy for the conduct of this effort was written and approved in May, 1981 which defined a three-phase approach:

Phase I, was intended to provide a current perspective on territorial energy problems; to identify existing energy supply and demand data; to identify energy resources that might be developed and appropriate technology options. Based on these findings, Phase I defined and estimated the cost of the technical assessment and economic analysis activities required to support the development of specific energy plans.

Phase II would involve the conduct of the technical assessments defined under Phase I. Successful completion of these tasks would provide the information necessary to understand and compare alternate energy development options in each territorial entity.

Phase III would complete the process with the preparation of energy plans for each territorial entity. Involved would be an integrated analysis comparing alternative energy options, the coordinated selection of proposed energy projects, the subsequent drafting of energy plans, and territorial/DOE/DOI coordination and concurrence before the plans would be submitted to Congress.

In executing Phase I, SAN and SR each named a team of energy specialists to visit the Pacific and Caribbean regions. The SAN team of seven included individuals from SAN, the DOI, the Solar Energy Research Institute, the Lawrence Livermore National Laboratory, and Advanced Technology Associates, a private consulting firm. The SR team of six was composed of specialists from the Argonne National Laboratory. These team visits to the territorial entities were conducted in May-June, 1981. During this time the information presented in the Phase I report was collected and tentative agreement reached with the territorial energy offices on recommendations for Phase II.

As noted above, the primary purpose of the Phase I report was to present the results of Phase I alone with the recommendations of SAN, SR and HQ/IR as to those technical assessment and economic analysis activities required to allow DOE and DOI to meet the intent of Congress under P.L. 96-597. The total estimated cost of these proposed assessments for both the Pacific and Caribbean entities was $3.94 M.

In the case of Puerto Rico, the cost proposal developed by DOE in the Phase I report to conduct Phase II and Phase III was $996,591. Subsequent to the completion of the Phase I report on September 22, 1981; the DOE requested the Puerto Rico Office of Energy to submit for planning purposes a program plan which would define an approach to accomplish Phase II and III at a reduced funding level. On January 15, 1982; PROE submitted to SR three Planning options, indicating Phase II could be accomplished for $395,000. Further communications from SR indicated that the total funding allocation for Puerto Rico and the VI to conduct the effort would be $125,000. At this dramatically reduced level a priority was established by the PROE to conduct a Wind Energy Resource Assessment. A program plan was submitted to the DOE/SR on March 16, 1982; indicating two options at the $121,750 and a reduced scope option of $87,000 to conduct an Island Wind Resource Assessment with heavy reliance on existing data.

On April 15, 1982, the DOE provided a Grant of $80,000 to aid in a Wind Energy Resource Assessment for Puerto Rico.

This background is provided to place this report in perspective. It is not an indigenous energy resource assessment of all the alternative energy sources, but is a reflection of the work accomplished to date and planned for next year in two specific areas; Wind Energy and Hydropower Resource potential for Puerto Rico.

Section III of this report, utilizing existing data in the several alternative energy areas: undertakes a projection of the energy potential from these sources to the year 2000.

Even though the projections are based on a limited resource data base, the information should prove useful for developing implementation strategies and plans for the future.

II ALTERNATIVE ENERGY RESOURCE ASSESSMENT

A. INTRODUCTION

The Puerto Rico Office of Energy reports directly to the Governor and has the responsibility to coordinate and integrate all energy related programs. Specifically, the Office formulates policy, monitors petroleum and other energy usage, administers an Energy Conservation Program, develops and promotes Alternative Energy Sources and Systems; and, in general, assures the availability of energy for the Island.

Because the Government of Puerto Rico is convinced that alternative energy can make a significant contribution to the long-term solution of the Island's energy problems, the Government has appropriated about $5 million to be available for the development of alternative energy sources for Puerto Rico.

In order to expend this sum most efficiently, it is important to quantify the potential and the "technology readiness" for commercialization for the various sources.

Alternative Energy Sources is a term utilized to describe a range of technology options that would diversify the fuel sources for energy production. Traditionally, this has included the "Solar Technologies" which includes all Renewable Energy Sources. For Puerto Rico, alternative energy could be viewed as any source other than petroleum, since 97% of the Island's energy production is derived from this source.

Currently, there is a surplus of oil on the world market. Supplies flow freely and during periods like this, we tend to forget the fragile balance between world supply (production) and demand (consumption).

The opportunity exists to begin a steady transition to renewable energy sources over the next decades, and bring on line those technologies which are proven and ready for the marketplace.

The Island is blessed with a great solar resource in the form of wind, hydro, bioenergy, ocean, and direct sunlight. What is not known is the exact magnitude of this resource. One of the first steps that must be undertaken before wide-scale deployment of these technologies by the private sector will occur, is the quantification of the renewable resource potential of Puerto Rico. This is one of the key activities in the Energy Sources Area this fiscal year and the subject of this report.

The overall objective of the program is to promote the wide-scale exploitation and utilization of energy sources which are reliable, cost-effective and environmentally acceptable.

The overall strategy of the Energy Sources Program is to create a favorable environment for the various technologies such that the private sector (with the cooperation of the Government) can develop and deploy (commercialize) their products.

The implementation of this strategy will vary for each technology option. In some cases it may be policy statements and/or tax incentives; for other technologies, it may include research, development and demonstration. In any case, if the energy source is environmentally acceptable, economically viable and technology readiness proven; then wide-scale deployment would be expected.

The purpose of this report is to describe the methodology we have established to evaluate the various energy sources based upon the existing resource data base.

B. CURRENT USE AND PROJECTIONS FOR PUERTO RICO

To understand the "energy problem" of Puerto Rico, one must understand that 97% of the energy consumed is imported petroleum; however, to obtain a clear picture, the energy use by sector must be analyzed.

In brief overview, the total energy consumption peaked in Puerto Rico in 1979 at just over 358×10^{12} Btu per year. It has steadily declined since then to an overall consumption of 315×10^{12} Btu in 1981. Indications are that a further reduction to approximately 290×10^{12} Btu can be expected in 1982. Economic and energy use models predict a continuing decline to around 260×10^{12} Btu in the 1985 timeframe.

Table 1 reflects the energy consumption in Puerto Rico since 1976 by Fiscal Year. For the same years, the relationship between energy consumption and Gross Domestic Product has been declining (e.g., 1979 - 78.3×10^3 Btu/GDP $; 1981 = 68.6; and in 1985, it is projected at 56.6).

Table 1 Energy Consumption in Puerto Rico
Fiscal Years

ITEM	1976	1977	1978	1979	1980	1981
QUANTITY (TRILLIONS OF BTU)						
TOTAL CONSUMPTION............	320.1	335.5	344.6	357.8	337.6	315.9
FUELS........................	177.5	182.1	188.4	204.3	188.3	169.2
REFINERY GAS..............	21.1	21.2	19.2	21.1	20.8	18.1
MIDDLE DISTILLATES........	24.0	25.2	16.0	19.5	17.1	10.6
RESIDUAL FUEL OILS........	45.9	43.0	50.9	56.8	49.2	43.0
MOTOR GASOLINE............	77.2	82.1	86.6	90.1	87.2	84.0
AVIATION FUEL.............	9.3	10.6	15.7	16.9	14.1	13.4
ELECTRIC ENERGY..............	125.2	138.1	142.4	142.3	138.3	135.8
THERMOELECTRIC............	123.7	137.2	141.3	141.1	136.2	134.5
HYDROELECTRIC.............	1.5	0.9	1.1	1.1	2.1	1.3
BAGASSE.....................	17.5	15.3	13.8	11.1	11.0	10.0
PERCENT DISTRIBUTION (%):						
TOTAL CONSUMPTION............	100.0	100.0	100.0	100.0	100.0	100.0
FUELS.......................	55.4	54.3	54.7	57.1	55.8	53.7
REFINERY GAS..............	6.6	6.3	5.6	5.9	6.2	5.7
MIDDLE DISTILLATES........	7.5	7.5	4.7	5.5	5.1	3.4
RESIDUAL FUEL OILS........	14.4	12.8	14.8	15.9	14.6	13.7
MOTOR GASOLINE............	24.1	24.5	25.1	25.2	25.8	26.7
AVIATION FUEL.............	2.9	3.2	4.6	4.7	4.2	4.3
ELECTRIC ENERGY.............	39.1	41.2	41.3	39.8	41.0	43.1
THERMOELECTRIC............	38.6	40.9	41.0	49.5	40.3	42.7
HYDROELECTRIC.............	0.5	0.3	0.3	0.3	0.6	0.4
BAGASSE.....................	5.5	4.6	4.0	3.1	3.3	3.2

As in every story there is good news and bad news. The good news is that we are conserving more and becoming more efficient; the bad news is that several energy intensive industries have closed and the trend reflects the current state of world economics.

If we examine the total energy consumption by sector, in Puerto Rico, we find the following:

Electricity production accounts for	43%
Fuels	54%
Bagasse	3%
	100%

This percentage distribution has remained relatively constant over the last five years, and will probably remain that way through the mid-1980s.

An interesting statistic is that fuels account for 54% of the total consumption, approximately half of which is gasoline (Reference Table 1). As shown in Table 1 while gasoline consumption for automobiles declined approximately 12% in the U.S. during Fiscal 1981, it declined only 3% in Puerto Rico. Liquid fuel consumption must therefore become a prime target if energy self-sufficiency is to be realized.

At the same time as the total consumption of energy in the near-term is projected to decrease, the percentage for electrical power generation will remain significant; therefore, another target of opportunity will be reductions in petroleum usage for electrical power generation.

C. TECHNOLOGICAL FORECASTING, OR "MARKET PENETRATION TAKES TIME"

All new technologies encounter a limited initial acceptance in the marketplace during the years of commercialization. Numerous studies have found the average time from first discovery to a product in the marketplace was approximately 15-20 years. Heat pumps introduced in the late 1950s never really penetrated the marketplace until the 1970s. Historically, the commercialization process for new products has followed an S-shaped curve typical to the one shown in Figure 1.

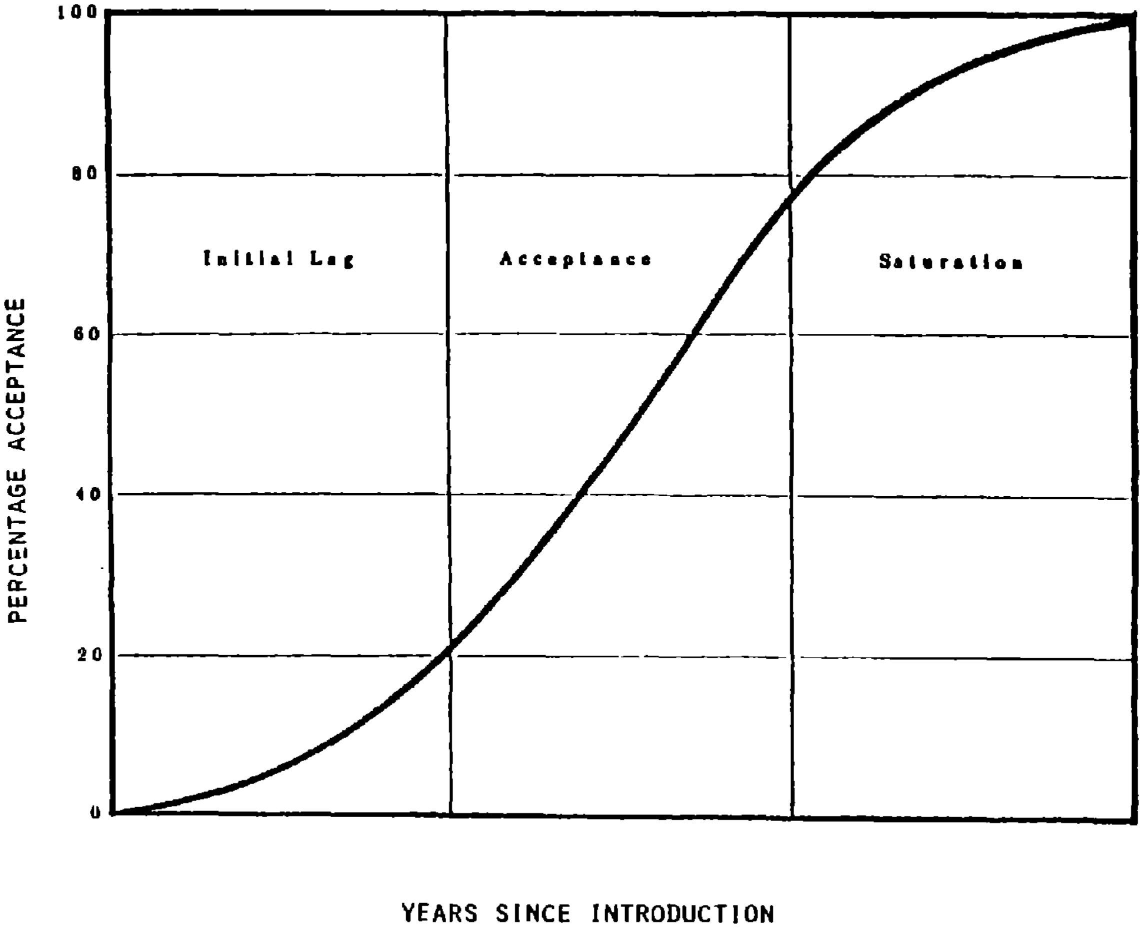


Figure 1 Typical Commercialization Curve

The first phase is characterized by an initial lag in the marketplace resistance to change and perception of high risk, cost and uncertainty. The second phase is the "bandwagon" period. The innovation rapidly gains marketplace acceptance coupled with reduced cost; which comes about by the learning curve effect of increased production volume and refinements in the technology. The final phase reflects saturation of the market by the mature version of the initial innovation.

In the case of alternative energy technologies, the time for each phase will vary significantly. There are several reasons for this:

1. First, the resource potential (ultimate market share) will vary.

2. The level of technology can vary significantly (solar hot water heaters vs. photovoltaic systems).

3. The characteristics of the ultimate user (individual, industry, utilities, etc.) will affect the rate of market deployment.

In order to develop a methodology for use in technological forecasting of alternative energy market penetration, it is necessary to estimate the manner in which alternative energy technologies will replace a petroleum-based society. To accomplish this purpose, three tasks will be performed.

1. The resource potential needs to be analyzed and quantified.

2. The various technologies must be listed and their "technology readiness" assessed.

3. And finally, the method, time and rate of entry into the marketplace for each technology must be estimated.

With exception of step functional variations produced by the addition of large centralized energy plants, all technologies are assumed to follow an S-shaped market penetration curve; with only the time to market saturation and the percent of the total potential to be anticipated as variables.

The establishment of the limits of these variables, however, is a most difficult task. Expert option and a modified Delphi process may be utilized to establish a consensus. With this established, projections of alternative energy futures can be made by varying the magnitudes of the parameters and the source of energy combinations. The projection becomes not what will be, but what is possible should policies be adopted and plans implemented to achieve the market goals in technologically feasible time frames.

The scenario of what is technologically possible must then be subjected to the economic, social and political considerations and analyses which can result in a definitive policy and implementation plans.

The material which follows, focuses primarily on the technologically feasible scenario for Puerto Rico and must await further analysis in order to allow the proper establishment of policies in regard to the future development and deployment of the various technologies.

The following sections address alternative energy technologies considered for this report.

The technologies are as follows:

1. Wind Energy
2. Hydro Power
3. Direct Solar
4. Bioenergy and Solid Waste
5. Co-generation
6. OTEC

Wind energy and hydropower are addressed first in the report, because a large body of information exists and definitive resource assessments are currently being conducted by the PROE under grants from the Department of Energy. This work has just been initiated under contract and more definitive material will exist at the end of this fiscal year.

The remaining technologies are addressed in summary fashion; first indicating the estimated resource potential based on existing data, the status of commercialization, and finally the market development potential for the year 2000.

A. WIND ENERGY IN PUERTO RICO

1. Introduction

The atmosphere of the Caribbean Basin is affected by strong, consistent easterly winds known as the trade winds. The trade wind system covers on the average about one-third of the earth's surface. The winds are high directional; over 80% of direction observations are within 45 degrees of East-Northeast.

Puerto Rico is geographically located within this system and, therefore, is well-positioned to harness the wind as a source of power for electricity generation. The known behavioral characteristics of the trade wind system, however, are not sufficient to determine the adequacy of the wind resource for conversion to usable energy and power in Puerto Rico. The variety of topographic attributes of the Island, including height above sea level, surface roughness, land-sea breezes and local terrain features, affect the flow, magnitude and turbulence of the Island's wind characteristics. Because of this, wind as a potential source of energy must be quantified as a function of these influencing factors.

Past studies and preliminary investigations of Puerto Rico's wind resource have indicated that certain broad areas exhibit wind speeds with the potential to economically produce power. Some interest has been expressed by potential small wind turbine system users and large windfarm developers. However, the meteorological data do support site specific systems analyses and economic feasibility studies are inadequate for most of the Island.

2. Existing Data

Previous studies of Puerto Rico's wind resource have been limited to data collection activities performed on coastal locations associated with airports (San Juan, Ramey AFB, and Roosevelt Roads Naval Station) as shown in Figure 2. As a result, little wind data exists for broader coastal areas and no measurement data has been collected for the interior of the island. Additional sporadic wind data collections activities have been performed in conjunction with planned conventional power system development in Puerto Rico. The Puerto Rico Electric Power Authority (PREPA), for example, has gathered wind data over varying time periods at existing or proposed power plant sites (Palo Seco, Tortuguero, Islote, Guayanilla and Aguirre).

Pacific Northwest Laboratory (PNL) has produced the most recent document on Puerto Rico's wind resource (published January 1981). In this study, currently available and historic data were used to estimate wind power density throughout the Island. Data from non-documented locations were derived using extrapolations of existing upper air data. The authors of this study stated that their findings are

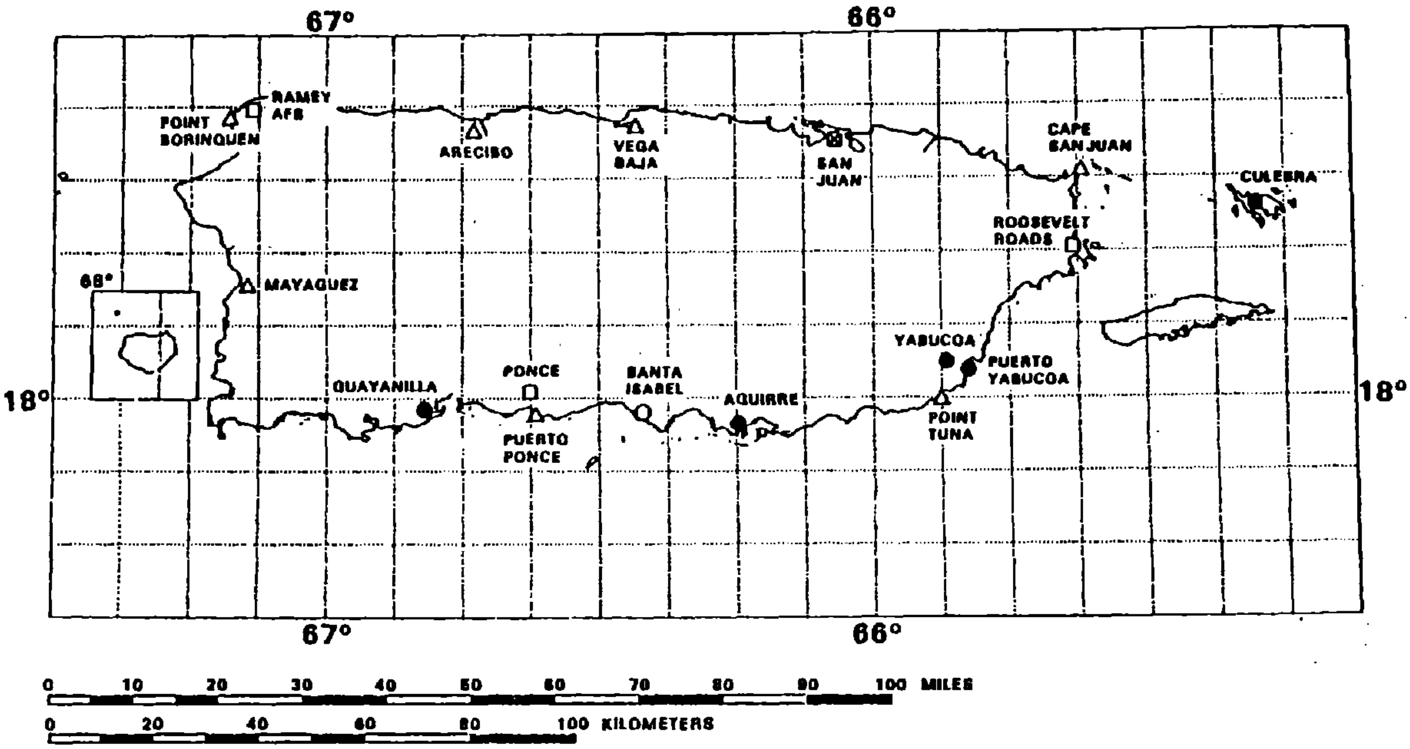


Figure 2 Locations of Data Stations (Source: Wind Energy Resource Atlas)

approximations since much of the available data tended to be inconsistent on a source-by-source basis and since extensive modeling was employed to compensate for the paucity of data over much of the Island. Even with these approximation, the document is currently the best source of information on Puerto Rico's wind resource. Wind power estimates (Figure 3) are encouraging in terms of the potential for cost-effective wind generated electrical power. The findings of the reports were summarized below:

- Approximately 0.06% of the Island is designated Class 4 (6.0 m/s winds with a wind power density of 250 watts/m^2). These areas are located on Cape San Juan on the northeastern coast.

- Approximately 4% of the land area showed Class 3 characteristics (5.6 m/s and a wind power density of 200/watts/m^2). These are the exposed coastal locations in the north and northeastern coast as well as exposed ridge crests in the mountainous interior.

- Approximately 21% of the Island has been estimated as Class 2 (5.1 m/s and a wind power density of 150 watts/m^2). These areas include the northern plains, northern slopes, valleys in the interior, and less exposed mountain tops.

- The remainder of the Island (75%) was designated as Class 1 (4.4 m/s and a wind density of 100 watts/m^2). The area includes the southern and southwestern coast and slopes.

These estimates of wind speed and wind power density in the PNL document were dependent upon the subjective integration of several factors: quantity of wind data, qualitative indicators of wind speed or power, the characteristics of exposed sites in various terrain, and the familiarity with the meteorology, climatology and topography of the region. Due to the lack of knowledge of many of these factors, the degree of certainty with which the wind power densities have been estimated for Puerto Rico tends to be very low.

Figure 4 indicates the certainty ratings given to estimates in the regions developed by the PNL study. Very large areas, mostly in the mountainous interior, are given the lowest degree of certainty rating (1). A few regions, mostly in the eastern and southern parts of the Island, have a certainty rating

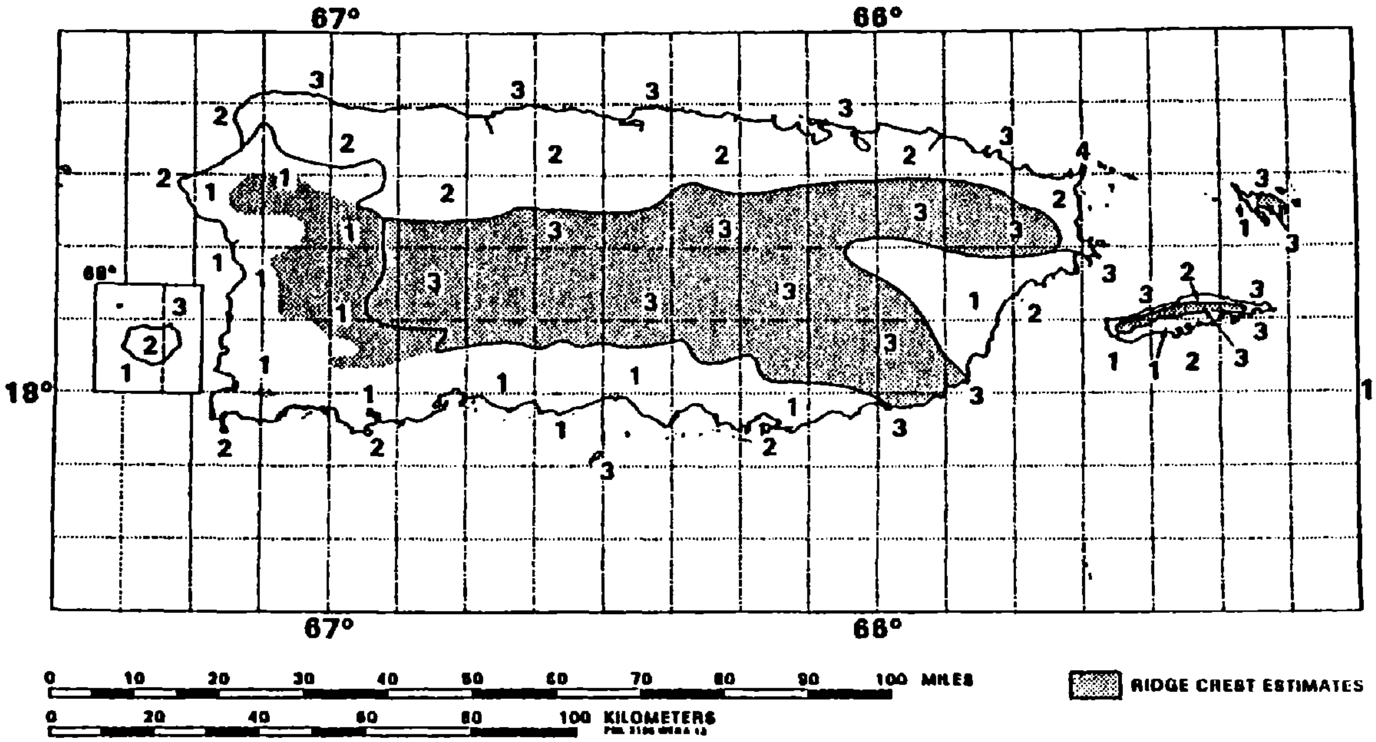


Figure 3 Annual Average Wind Power in Puerto Rico
(Source: Wind Energy Resource Atlas)

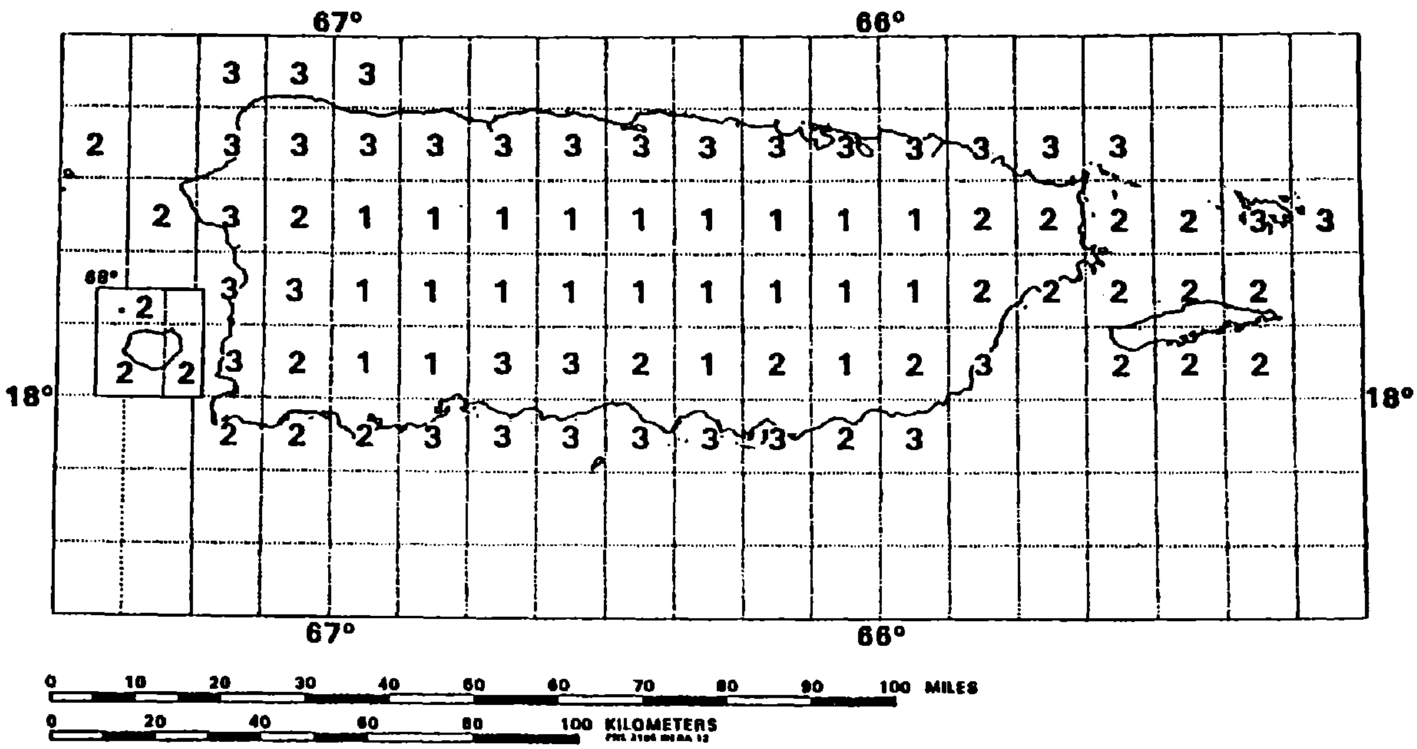


Figure 4 Certainty Rating of the Puerto Rico Wind Resource
(Source: Wind Energy Resource Atlas)

of 2, that is, a low to intermediate degree of certainty. Only the north, western and south coastal regions are classified with a rating of 3, a high to intermediate degree of certainty. These areas tend to have a terrain of low complexity and site where data had been collected previously. No region was given the highest certainty classification (4).

The low certainty ratings, resulting from the fact that previously gathered wind resource data has been sporadic and limited, indicate the need for a carefully designed, more comprehensive wind resource assessment program to adequately assess the wind energy potential for Puerto Rico.

3. The Puerto Rico Office of Energy Wind Program

Current wind energy activities of the Office of Energy include:

- An anemometer loan program for individuals interested in measuring wind characteristics at particular sites. Interested citizens - after filling out a questionnaire - have been selected to receive, without charge, wind measuring instrumentation from PROE. The loaned instruments allow them to determine if their site has a potential, worthy of a more detailed study. Since the instruments do not log data automatically, readings have to be estimated by the user, introducing a large degree of uncertainty. Average wind data would be suspect due to sporadic data recording, however, peak wind velocity can be evaluated more accurately. Though the instruments lack the necessary accuracy to permit inclusion of the data gathered by the users in the Wind Resource Assessment Program, their utility to potential residential users has been demonstrated.

- Development and implementation of a set of regulations to be required of all wind turbines manufactured or marketed in Puerto Rico. The purpose of this activity is to assure that wind turbines perform according to specifications claimed by the manufacturer and to enable consumers to compare turbine options. Using the general guidelines established by the American Wind Energy Association through industry concensus, a methodology has been developed whereby the wind turbine is subjected to a series of tests to ascertain and certify its power curve and energy production.

- Dissemination of information with respect to all aspects of small and large scale wind turbines, their performance, and their potential in alleviating the Island's energy problem. Information services are provided through conferences, booklets and personal interviews to private citizens and educational institutions. This program provides the general public with first-hand information concerning wind energy development potential for different applications.

- Design and implementation of the Wind Resource Assessment Program. This last task is the focus of this report and is described in detail below.

4. Wind Energy Resource Assessment Program

a. Potential Large and Small Scale Users

The potential users of the Wind Resource Assessment results include small scale, residential users and large scale (windfarm or MW size turbine) developers and users. Members of the first group are citizens seeking information concerning the wind potential in the area where their farms or residences are located. Companies interested in developing large windmills or windfarms comprise the second group. An evaluation of the average wind conditions within the different meteorological regions of the Island is beneficial to the needs of the first group. It answers a basic question: Is the particular site located in an area with a good wind resource potential? Those seeking to install large wind turbines or to develop windfarms need to determine the locations of the maximum wind speeds in Puerto Rico in addition to the degree of variability and turbulence at the sites. Other considerations such as land availability, distance to transmission lines and access to the site are also important issues. On a short-term basis, windfarms can make a more significant contribution toward alleviating the Island's dependency on foreign oil. On a long-term basis, as small wind turbine technology improves and becomes more cost-effective, and as the public becomes aware of the program and the benefits of wind power, the former group will also contribute to a less oil dependent society.

b. Purpose

The Wind Energy Resource Assessment Program is a joint effort between Meridian Corporation and PROE to achieve the following objectives.

1. Augment the data coverage of previous studies especially as developed in the Pacific Northwest Laboratory Wind Energy Resource Atlas (Wegley et al., 1981).

2. Provide wind data over the Island's mountainous interior region to estimate the wind-power density of this area.

3. Provide the future users of both small- and large-scale wind turbines with a basic guide to assist in turbine sizing and siting efforts.

c. Methodology

Two sets of instruments will be deployed over a period of at least one year to measure wind characteristics: four fixed meteorological towers and one mobile meteorological station.

The fixed tower locations will tentatively be selected from the sites designated in Figure 5. Preliminary selection of these sites was based on the following general conclusions:

1. Quality and reliability of historical meteorological data. In general, the wind data gathered by the National Weather Service, PREPA, U.S. Navy and Air Force are of good quality. Consequently, the fixed tower sites will not be located in areas where adequate historical data exists.

2. Location of the meteorological stations used in previous studies. Without variation, they are located over the Island's coastal plains very close to the shore, at or near sea-level. The fixed towers will initially be located in the interior highlands.

An analysis of the location, altitude, type of instrumentation, instrument height, accuracy, data collecting procedure, reliability, time period over which data was collected, and data format has been initiated for sites with historical wind measurement data. Data from other collection sources area also being gathered for the analysis.

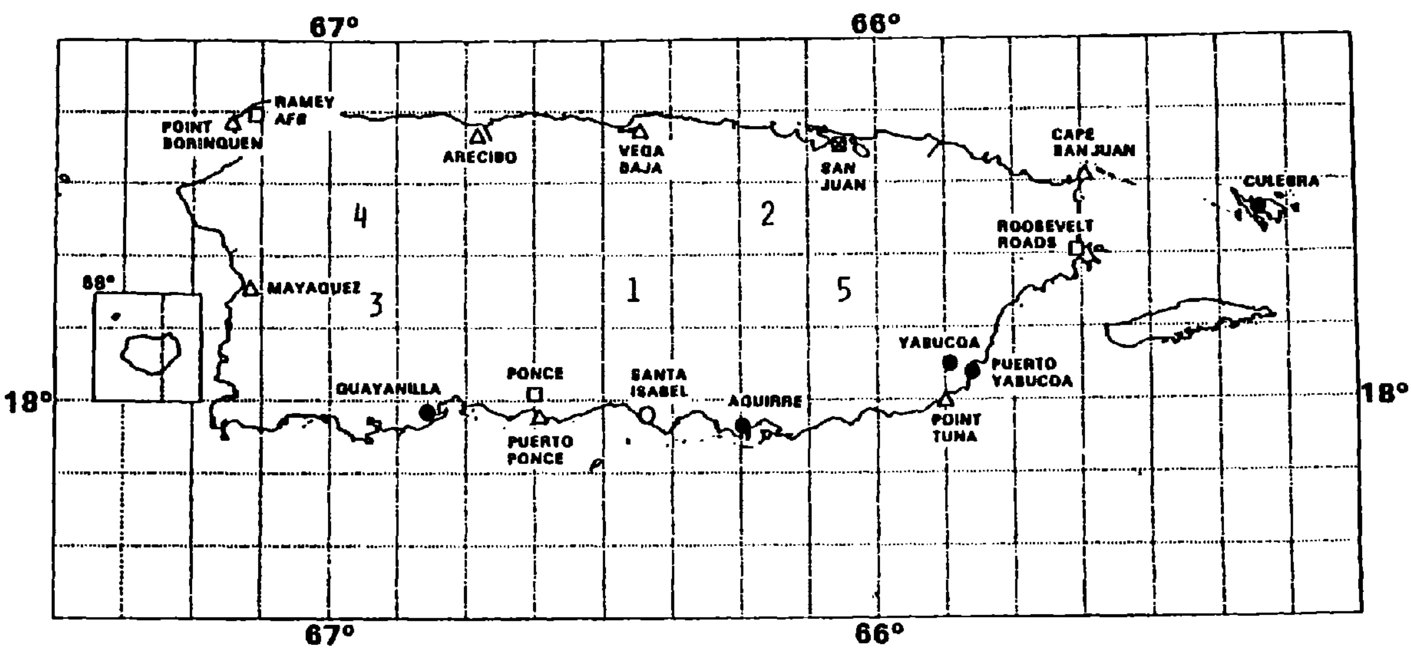


Figure 5 Tentative Selection for Fixed Measurement Stations
(Source: Wind Energy Resource Atlas)

The mobile meteorological station will "prospect" for those sites which appear to have potential for high wind speeds, most likely on mountain ridges. Measurements with the mobile unit will be taken over periods of two to four weeks at various locations. The mobile station will also be used to gather wind data for:

- The validation of data from existing instruments.
- The acquisition of wind data to correlate measurements taken at different stations.
- The acquisition of wind data to investigate phenomena like the land-sea breeze and localized wind characteristics.

A kite anemometer will be used in conjunction with the mobile instrument to investigate turbulence and vertical wind shear at heights representative of installed large scale wind turbines.

d. Site Selection: Fixed Measurement Towers

Figure 5 depicts the sites which have been tentatively selected for the initial installation of the fixed measurement towers. They are:

1. Cerro Maravilla in the Toro Negro Reservation. Some of the Island's highest ground is within this area, including Cerro Punta which is the highest mountain (1338 m). The site was selected in order to assess the wind speeds over the highest ground, to explore the effect on the trade winds to the NE (in conjunction with site 2), and to determine the penetration of the sea breeze since the site is about 25 km from the southern seashore. Existing communication towers at this point will facilitate the deployment of the instruments.

2. Corozal Area. Located approximately 20 km from the northern shore over mountains with intermediate heights of approximately 300 m. In conjunction with the San Juan station, the site allows for the study of the change of the trade winds as they traverse the Island from the NE direction. By correlating this data with that of Vega Baja and San Juan, the penetration of the sea breeze in the northern coast can also be explored.

3. Cerro La Santa. Located around the eastern-central part of the Island at a height of 903 m. Data acquired at this station will be correlated with that of Aguirre, Yabucoa and Roosevelt Roads. Television towers in this area will make the deployment of the instruments easier.

4. Pileteas Area near Lares. This location represents a plateau over ground of intermediate heights (400 m) in the central northwestern part of Puerto Rico. Correlations with the data from Arecibo and Ramey will be made to examine the penetration of the seabreeze, if present at that point.

5. Cerro Gordo near Maricao. Located over the central western part of the Island at a height of 883 m. The data will be correlated with that from Mayaguez and possibly Guayanilla.

5. Contractors

Meridian Corporation is working in close cooperation with PROE in carrying out the diverse tasks necessary for the successful completion of the Wind Resource Assessment Program. They are performing the following activities:

1. Definition of the Wind Resource Assessment Project operating parameters,

2. Establishment of field equipment specifications,

3. Development of a methodology for siting, installation operation and collection of recorded data,

4. Establishment of equipment maintenance procedures,

5. Establishment of equipment maintenance procedures,

6 Assistance in the selection of the field operation subcontractor and in the supervision of the field operation,

7. Analysis to correlate the new data received from the field operations to the historical data set,

8. Development of a computer model for windfarm and dispersed wind turbine performance evaluation,

9. Identification of highest potential windfarm sites,

10. Development of wind resource maps for the Island,

11. Provide software and analytical instrumentation to enable PROE to perform in-house wind analysis and modeling,

12. Socio-economic analyses for both small wind energy turbines and windfarms as directed by PROE.

6. Future Development

By this time next year, a better understanding of the Island's wind energy potential will be evolving. An estimate of the prevailing wind power density over much of the interior of the Island and an identification of specific regions with a potential for windfarms will have been made. Additional, more comprehensive studies are planned to extend the findings of the initial project for site-specific development.

In the meantime, the following projections have been made assuming that wind speed and sites will prove favorable.

a. Small Wind Machines

Individual small wind electrical generators (2 to 50 kw) to replace imported oil which is used to generate electricity for residences in Puerto Rico, is an attractive alternative energy source. They are marginally cost-effective at this date; however, with the recent passage of tax incentives and the consumers anticipation of rate increases, this technology is ready for commercialization in Puerto Rico. It is conservatively estimated that the commercialization potential, by the year 2000, is 7500 units for an annual energy production equivalent of 1.35×10^{12} Btu/year. Because wind technology uses a free source of energy, its rate of deployment could be quite rapid as it becomes more cost-effective. This could change these projections by an order of magnitude, or more, depending on these socio-economic factors. A plot of the Btu output from the conservative 1% acceptance scenario stated above is shown in Figure 6. This produces the following estimates of oil savings, assuming the electricity which is generated replaces fossil fuel generated electricity:

Year (FY)	80	81	82	84	85	86	88	90	95	2000
Millions of BBls of oil savings	0.00	0.00	0.00	0.08	0.16	0.22	0.38	0.47	0.63	0.77

b. Large Wind Machines (Wind Farms)

Large wind machines are an attractive alternative as wind farms or central wind generating plants (greater than 40 MW) to replace imported oil which is used to generate electricity for the residential and industrial sectors of the Puerto Rico energy economy.

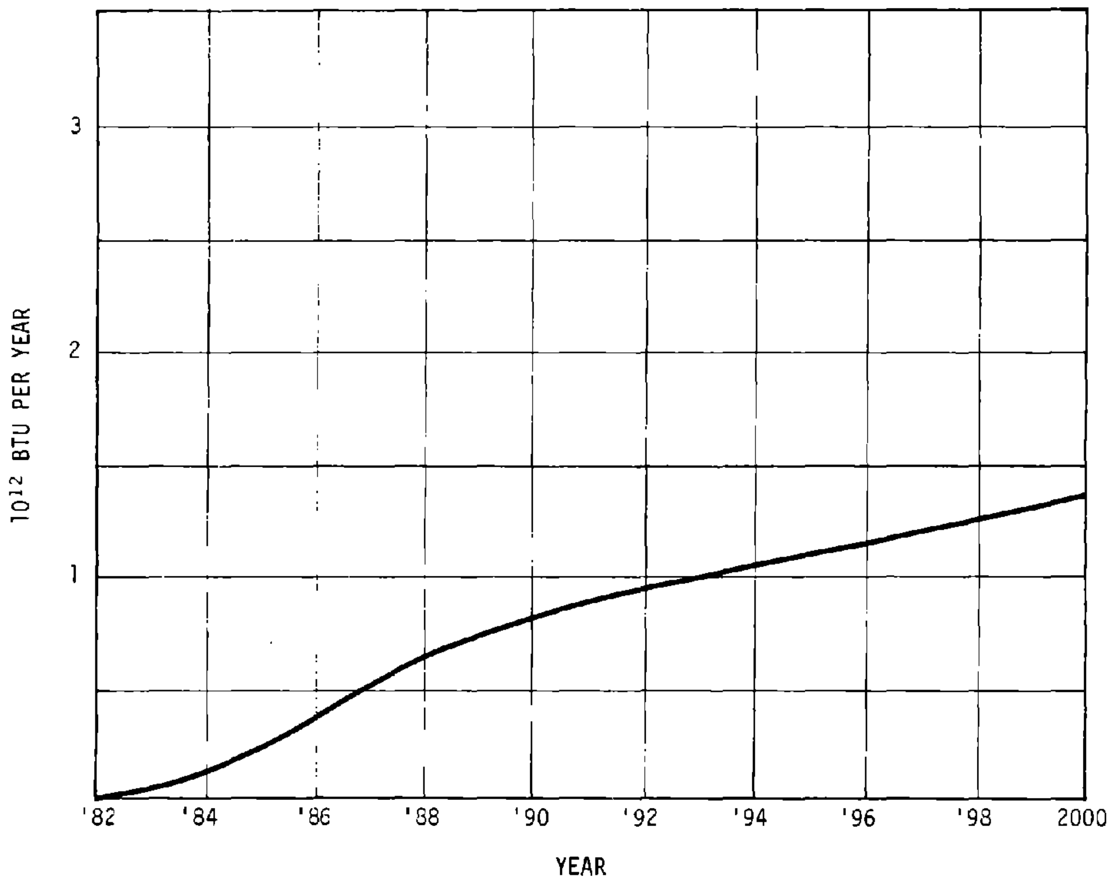


Figure 6 Electricity from Small Wind Machines

The wind resource potential and the site availability for large wind farms is in the process of being evaluated. The third generation large wind machines will not be under test and evaluation until the 1984 time frame. A reasonably conservative scenario suggests that the first 40 MW facility will go on line in Puerto Rico in 1988, with a second one being added in 1991, and two more in 1995, for the combined contribution of 160 MW. This represents a total of 3.8×10^{12} Btu/year by 1995.

A plot of the probable Btu output of this commercialization scenario is presented in Figure 7. The BBls of oil year savings, as far as replacement of imported oil is concerned, is listed as follows:

Year (FY)	80	81	82	84	85	86	88	90	95	2000
Millions of BBls of oil savings	0.00	0.00	0.00	0.00	0.00	0.00	0.55	0.55	2.20	2.20

Obviously, the cost effectiveness and ultimate success of wind farms is highly dependent on the electricity purchase rates established by the utility in response to the PURPA legislation.

B. HYDROPOWER IN PUERTO RICO

During the first decades of this century, hydropower was a significant element in the Island's energy picture, supplying close to 90% of the electric power needs. As the demand for electricity grew and petroleum fuels became competitive, the expansion of the Island's hydropower system slowed. Eventually, the expansion stopped altogether and existing facilities were allowed to deteriorate. At present, hydropower supplies less than 1% of Puerto Rico's electricity needs.

The potential for hydropower in Puerto Rico has not been fully evaluated. Recent estimates by the U.S. Corps of Engineers (COE) suggest that at least 106 megawatts are available from 19 existing and

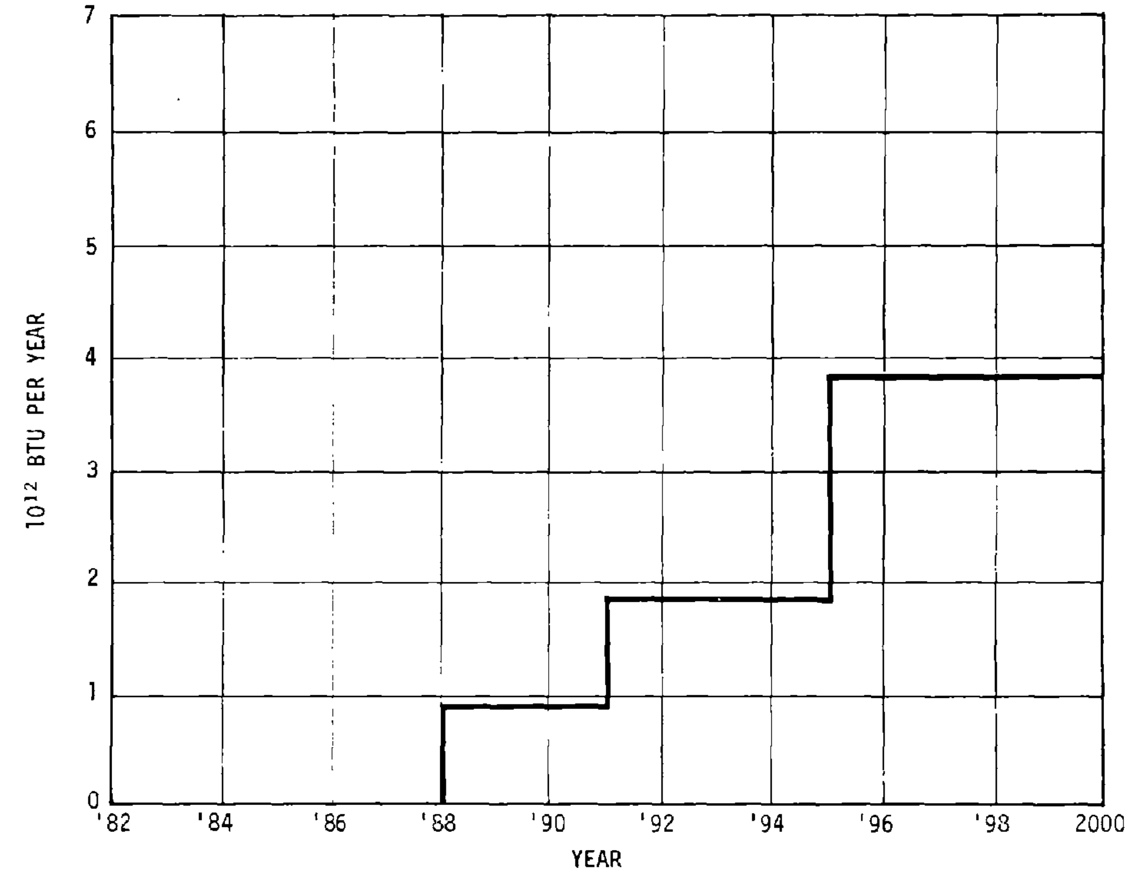


Figure 7 Electricity from Large Wind Machines

potential sites evaluated. This potential, which does not cover all possibilities, doubles the existing installed capacity of hydropower on the Island. Excluded from this estimate are low head (under 50 feet) installations. An additional potential 74 dam sites were evaluated by COE, but hydropower information for these is not immediately available. In addition, there is an undetermined potential for small scale, low head installations that could be made for low demand applications in rural areas.

Puerto Rico's hydropower potential in the short- to mid-term future lies in the development of very small (micro) installations and in the retrofitting and renovation of existing facilities. The construction of new major impoundments presents many problems in a densely populated region such as Puerto Rico. Consequently, the Office of Energy with support from DOE has conducted a brief reconnaissance study for the addition of hydropower in Puerto Rico. In addition, an overall resource assessment is presently being undertaken whose purpose is to stimulate timely investment of private and/or public funds in two hydro projects, each a prototype of the above-mentioned types of installation. These prototypes will serve to:

- Demonstrate to other potential investors the viability of hydro installations.
- Expedite the development of the necessary regulations and procedures at the pertinent local agencies.
- Create confidence by lending institutions in this type of investment.
- Provide experience that will serve to guide investors, government and the utility in the future.

The work will require the following:

- Identify the prototype projects to be assisted. Several prospects are already available for the micro dam project, and one local government has shown interest in retrofitting an impoundment about to be built for water supply and recreation. Selection of the prototypes will be on the basis of how advanced the project is at present and the availability of assured financing for the project.

- Lead the project proponents through the permitting process. Since there is no explicit permitting procedure currently in place, the PROE will assist the proponents in receiving timely and equitable responses from the pertinent agencies, as well as assist and urging the agencies in implementing straight forward procedures for future hydro proponents.

- Assist in equipment selection. The PROE will provide information from its files on equipment and manufacturers.

- Assist in negotiating the terms of the interconnection of the facility to the utility grid.

1. Summary of Reconnaissance Study for Hydropower Potential in Puerto Rico

Recently a reconnaissance study was performed on potential hydropower on the island. The following are observations and insights on the potential development for small scale hydroelectric power in Puerto Rico.

a. Objectives of Study

This study had two objectives: 1) to collect site specific data for brief reconnaissance studies on suitable sites in Puerto Rico, and 2) to determine the potential for the development of small scale hydroelectric power in Puerto Rico.

Thirteen dams and hydroelectric sites were visited during a four day trip to Puerto Rico in September 1982. Ten brief reconnaissance reports have been prepared to describe the potential at those sites. Information on the remaining three sites - Lago Garzas, Lago Loiza, and Lago Cidra - was insufficient to develop a meaningful report. Nevertheless, some judgments can be made.

To develop an insight into the potential for the development and use of hydroelectric power in Puerto Rico, the types of dams were categorized into three types: 1) abandoned hydroelectric sites, 2) dams that have been dedicated for other beneficial uses, and 3) dams that were a part of an active, existing hydroelectric system. Brief reconnaissance reports have been prepared on five abandoned hydroelectric plants, two dams dedicated for other uses, and three active hydroelectric generating plants.

b. Summary of Results

All of the hydroelectric plants visited and described appear to be financially feasible for the development of hydroelectric power, but one site, Lago La Plata, is not practical for development because of future plans for development.

The abandoned sites, Comerío 1 and Comerío 2, are excellent sites for the development of run-of-the-river hydroelectric plants. Presently, the reservoirs are filled with sediment, but enough sediment could be removed inexpensively, to enable the reservoirs to function as run-of-the-river facilities.

The three abandoned Carite sites are excellent sites for the development of small scale hydroelectric power. The facilities and equipment appear to be in excellent condition for abandoned equipment and could be repaired for a relatively small investment. The hydrologic data used in this study was based on estimates, and better hydrologic data should improve the economic feasibility of these three sites.

La Plata Dam appears to be economically feasible for the development of hydroelectric power at the site, but the study was based on the current withdrawals for municipal water supply. The dam was built to provide potable water for residential and industrial use. Hydroelectric power is practical at this site only if the excess water that passes over the dam is sufficient in quantity and frequency. This is the objective of current plans. Lago Cidra and Lago Loiza are similar to La Plata Dam in their water management. In fact, a hydroelectric power plant exists at Lago Loiza, but it has, been abandoned due to the lack of water.

Patillas Dam appears to be economically feasible for the development of hydroelectric power on the water released for irrigation. The dam was built to provide irrigation water for agriculture. The quantity of the water produced and the frequency with which it is released, make the generation of hydroelectric power appear to be practical at this site. The data obtained on the quantity of the irrigation releases is meager, but better data should improve the economic feasibility for the development of hydroelectric power at the site.

The operation of the three active hydroelectric plants which form the Dos Bocas-Caonillas system indicates that the system was well conceived and properly designed to operate as an integrated system to produce the maximum amount of power from the geographic area. Water is diverted by tunnels between watersheds to sites that have very high head. The system is operated in a manner to reduce the amount of water that flows over any spillway and to produce the maximum amount of power. No data was obtained which would indicate that the existing equipment should be replaced. It is apparent that the operation of integrated systems provides for high base loads and that the operation of run-of-the-river facilities at these sites does not offer any economic advantage. The published streamflow data on this system was meager and could not be used to develop any reliable data.

c. Potential For Small Scale Hydropower

The potential for the development of small scale hydroelectric power in Puerto Rico appears to offer significant economic advantages. Certainly, the terrain and the streamflow characteristics enhance the potential for small scale hydroelectric power. The Corps of Engineers has developed and extensive body of information on the potential for additional base load by the development of hydroelectric power. It does not appear that many hydroelectric sites or systems can be economically developed to provide new base load.

Run-of-the-river operations characterize most small scale hydroelectric facilities. When streamflow is available, the units generate hydroelectric power. When streamflow is not available, the units cannot generate hydroelectric power. A modest storage capacity in a reservoir can enable a facility to produce hydroelectric power during the daily peak demand period when the streamflow is below the average. One can store water during part of the day and generate during the periods of peak demand.

As the storms that produce rainfall on Puerto Rico yield a high volume of 'water in the streams, many days exist during which hydroelectric power can be generated on a dependable basis. This would allow for a reduction in the use of fossil-fueled generation units. If run-of-the-river hydroelectric units were scheduled into the operations of the electrical system, it is possible to reduce the spinning reserve of the system by saving larger hydroelectric systems to meet the instantaneous demand for power.

The economic evaluation of small scale hydroelectric power should be based on values which reflect the economic condition of PREPA. As PREPA has excess generating capacity and additional capacity is not needed in the near future, the value of power should be that which would properly reflect the savings in operation and maintenance to the utility. As the current cost of fossil fuel for electrical generation is approximately eight cents per kilowatt hour, this should be used as a standard on which to evaluate the use of run-of-the-river hydroelectric operations. This value was used in this study, and the value was sufficient to indicate that small scale hydroelectric power can provide benefits to the utility.

Another potential resource for small scale hydroelectric power that has not been evaluated is the potential for new small diversion dams. A small, ten foot high, diversion dam can be constructed without excessive expense. The dam can be used to divert water into a penstock which is constructed to a small powerhouse downstream. This type of facility is becoming popular in regions with terrain similar to the mountains of Puerto Rico. A cursory analysis indicates that a potential of more than seven megawatts of additional capacity exists. These seven megawatts could produce an average of 33,000,000 kwhr per year. This type of hydropower development is extremely site specific and depends on the terrain and the streamflow.

In summary, it appears that the terrain and streamflow characteristics are favorable to the development of small scale hydropower in Puerto Rico for the existing economic conditions. Small scale hydropower would not solve the existing problems of the electrical utility, but the development of small scale hydropower would be beneficial to the utility.

2. Common Data

In the course of this study, it became apparent that a lot of the data gathered for a brief reconnaisance study of a site was similar for all sites seen by the author. Thus, to improve the presentation of the data, data common to all sites is presented in this chapter.

a. Value of Power

In developing the comparison of benefits to costs for a reconnaissance study, the value of the power is one of the most important items as it establishes the benefits. In Puerto Rico, it is more important, because it can seriously effect the financial condition of the electrical utility. In most other places, the value of the power equals or exceeds the customer's purchase price of the power. This higher value is accepted because the electrical utility can postpone the development of new generating facilities. In Puerto Rico, PREPA has excessive generating capacity, and, thus, there can be no capital savings to the utility. Additional hydroelectric capacity would be beneficial to PREPA if it can reduce the operating and maintenance expenses, specifically the cost of fuel. The cost of fuel is approximately eight cents per kwhr and is the major component of the 11-13 cent per kwhr average charged. For this study, the value of electricity will be eight cents per kwhr so that the benefits to PREPA will not be inflated.

b. Potential Developers

If the development of small-scale hydroelectric power is beneficial to PREPA, the utility could develop the hydroelectric sites. If PREPA cannot acquire the money to make the developments, the utility could provide for development by entrepreneurs and purchase the power at a rate equal to or less than eight cents per kWhr for an extended time period.

It is also logical that PREPA develop the majority of sites investigated in this study, because PREPA owns most of the sites.

3. Institutional Data

This section contains information of the alteration of the existing dam usage, the existing flows, and the ownership of the right of access to develop the site and to acquire right-of-way for the transmission of power.

a. Changing Use of Flow

If a site is not currently generating hydroelectric power, the existing usage of the dam will be altered by putting the water to beneficial use. For run-of-the-river operations, most of the flows would not be altered. However, many of the abandoned sites do have some small storage capacity which, if used, would alter the flow regimes.

If a site is currently generating hydroelectric power, the existing use of the dam should not be modified. If a site is currently operating as a storage facility to control the generation of hydroelectric power, then the operations should not be altered to reduce base load potential.

If a site is currently serving as a water supply facility for residential, industrial, or irrigation water, then the patterns of operation and flow should not be changed unless the change also benefits the other users. High flows that are not stored could be used for power generation. Hydroelectric power can be generated from flows to other dedicated uses, if the flow has excess head that would be lost during transmission to the point of use. For example, the irrigation flows out of Patillas Dam have head which is lost, thus, hydroelectric generation with irrigation releases has merit at that site. However, the domestic and industrial water supply at La Plata Dam must be pumped from the reservoir, thus, hydroelectric generation does not have merit at that site.

b. Right of Access and Development

At all dams visited in this study, a governmental agency or authority owned the dam. Thus, the right of access and development would have to be acquired from the agency before the site could be developed by anyone other than the owner.

Electrical transmission lines were adjacent to all sites visited. Thus, no additional right-of-way for transmission facilities would have to be acquired.

4. Safety Data

All of the dams visited in this study have had Phase I Dam Safety Inspections performed on the structure. All dams were listed as high hazard structures, because of the potential for loss of life downstream if failure occurred. No dams were listed as unsafe. A copy of the Corps of Engineers data is appended to the discussion of each site.

5. Environmental Data

This section contains a description of the existing environmental data that would effect the development of hydroelectric power at a site.

a. Restricted Development

No site in this study was on any stream segment designated as a Wild or Scenic River. Nor could any evidence be found that any stream segment has been listed as a potential site by the Federal Government.

No site was listed on the National Register of Historic Places.

No sites were found to be in any park, wilderness area, wildlife preserve, recreational area, or in other restricted activity area.

b. Migratory Fish

No data was found to indicate that migratory fish were present in the stream segments adjacent to the sites; nor was any data found to indicate that the life cycle of a fish would be adversely affected by the installation of hydroelectric power at any site visited.

Fish passage should be concern of any hydroelectric development. Screens should be constructed to reduce the opportunity that adult fish may go through a turbine. There is no apparent need for fish ladders on any stream segment adjacent to a site visited during this study.

c. Rare And Endangered Species

Rare and endangered species have been identified for Puerto Rico by the U.S. Fish and Wildlife Service and the Puerto Rico Department of Natural Resources, Division of Coastal Resources and Wildlife Planning.

Both agencies have determined critical habitat areas. In a review of this data, no information could be found to indicate that a species of critical habitat would be damaged by the development of run-of-the-river hydroelectric power at any site in this study. Nevertheless, both agencies should be contacted early in any feasibility study to determine if additional, specific investigations are needed.

6. Projections For The Future

Based upon the reconnaissance study and local expertise, approximately 200 MW of potential exists on the island.

Therefore, a hydropower scenario based on 24 hour per day operation, at a capacity factor of 90%, the Btu equivalent of this electrical energy is 5.70×10^{12} Btu/year. The output currently equals 1.5×10^{12} Btu/year, and may reach the full potential in 10 years.

Figure 8 plots this estimate over a technologically realistic time frame. If it is assumed that the energy output from this alternative is used directly to replace fossil fuel produced electricity, then a multiplication ratio for savings is imported oil, which is similar to that used for the solar hot water technology results. The resulting savings in terms of fiscal years for this commercialization scenario are the following:

Year (FY)	80	81	82	84	85	86	88	90	95	2000
Millions of BBls of oil savings	0.86	0.86	0.86	0.86	0.89	0.98	1.73	2.73	3.28	3.28

C. OVERVIEW OF ASSESSMENT AND PROJECTIONS

1. Direct Solar Energy Overview

When viewed from the broad perspective, solar energy is the base source for all the energy resources, fossil or renewables, which provide the power, light, and heat for Puerto Rico as well as the rest of the world. For practical operational purposes, however, it is necessary and convenient to consider the direct radiation as a discrete energy source and discuss the appropriate technology required to tap it.

Puerto Rico, as with all the areas situated in the tropical belt is endowed with the climatic conditions which favor extensive utilization of direct solar energy in thermal systems or photovoltaics. Of

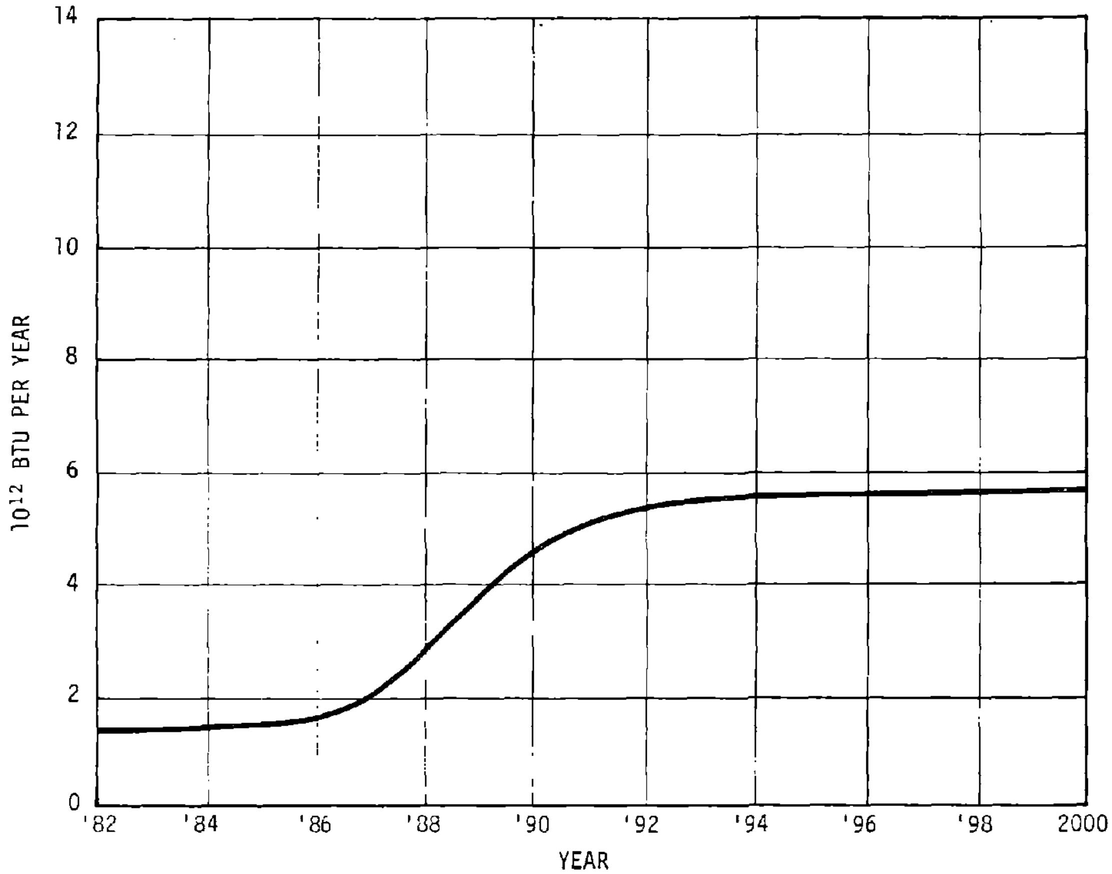


Figure 8 Hydroelectric

the two technologies, the thermal application has had early implementation right at the onset of the energy crisis; precipitated by the oil embargo in 1973. Photovoltaic systems, on the other hand have been slow in making their appearance in the island due primarily to their high capital cost and the fact that there are really very few sites so isolated from the utility grid, that PV installations would be immediately cost effective.

Residential solar water heaters, by virtue of their relative technical simplicity, potential for local manufacture, and the high cost of electricity, have had a high degree of acceptance in Puerto Rico. In view of the normally high tropical temperature ranges, extensive assessment of solar insolation on a site specific basis has not been carried out. Data from the few metered sites and the generalized solar insolation maps published by DOE and other institutions have provided sufficient information to design, construct, and install solar water heaters up to the present time.

The more sophisticated area of solar thermal technology - the production of process hot water for industrial use - has been relatively slow in being implemented. Only a few systems have actually been designed and built and a much more thorough characterization of the solar insolation of the entire island will be necessary before the technology gains wider acceptance by local industry.

The most recent review[8] of the assessment of solar insolation for Puerto Rico carried out by López (CEER) has described the instrumentation, the siting, and analyzed the available data. Figure 9 illustrates the distribution of the instrumentation. Table 2 presents the average daily insolation measured at each station taken between the last two and four years. Insolation in a monthly basis for a one year period for six stations is shown in Figures 10 and 11.

Both solar pond technologies and photovoltaic applications are still in the early stages of being considered for Island application, while proposals are at present being evaluated, the consensus is that much better site specific solar insolation data will be required in order to assure maximization of the resource.

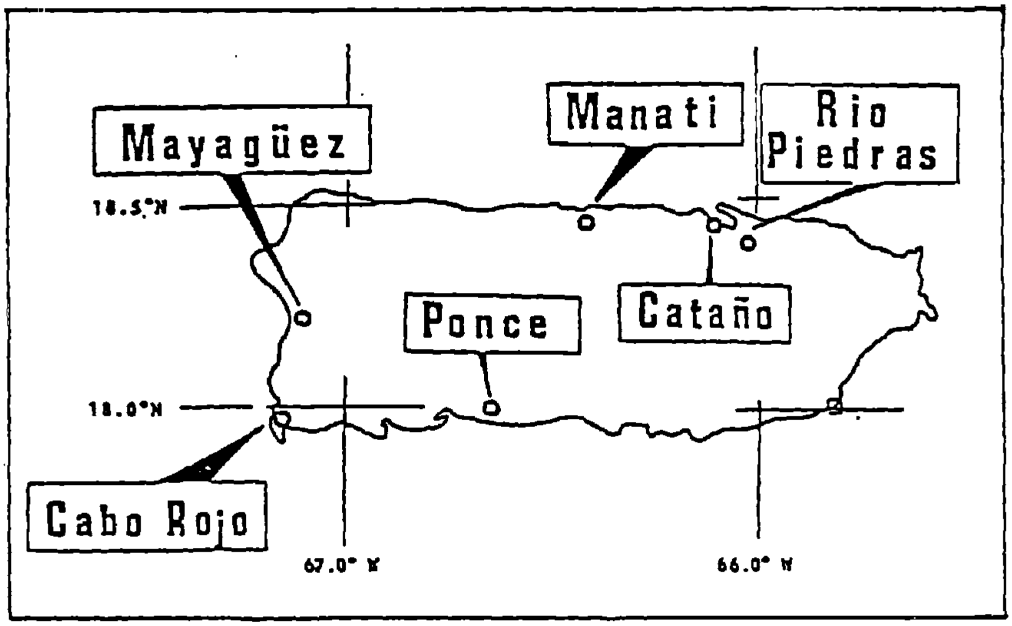


Figure 9 CEER Stations in Puerto Rico (Source: Dr. A. López and Dr. K. Soderstrom, CEER, 1982)

Table 2 Average Daily Insolation on a Horizontal Plane

Station	Component	Dates	Insolation (J/m^2)
MAYAGUEZ	Global	Jan. 1976 - present	16.0
	Diffuse	June 1977 - present	6.9
	Global	June 1978 - present	16.6
RIO PIEDRAS	Diffuse	July 1978 - present	7.7
PONCE	Global	March 1978 - present	19.3
	Global	July 1978 - June 1979	18.1
CATAÑO	Diffuse	July 1978 - June 1979	7.9
MANATI	Global	Sept. 1979 - Feb. 1981	18.6
CABO ROJO	Global	April 1980 - present	19.9

Source: Dr. A. López and Dr. K. Soderstrom, CEER, 1982.

a. Solar Hot Water Heaters

The use of solar hot water heaters in Puerto Rico, as an alternative to heating water with electricity, is an alternative energy technology which is currently cost-effective, and which shows promise to continue in this status for the rest of this century. Since 1976, the annual installation of units on residences has steadily increased from about 2,000 units per year to an estimated 5,800 units per year in 1981 as shown on Table 3. There are presently about 17,000 units installed in the residential sector. If the rate of installation is assumed to increase linearly to 12,000 per year in the year 2000, there will be an estimated 187,737 units in place by that time, which represents about 23% of the estimated 800,000 residences which will exist in Puerto Rico at that time. A capacity factor of 0.50 is estimated.

It is assumed that each collector averages 40 sq. ft. in area, and that the average collector efficiency is 40%. It is further assumed that an average of 2000 Btu per sq. ft. per day is available as solar

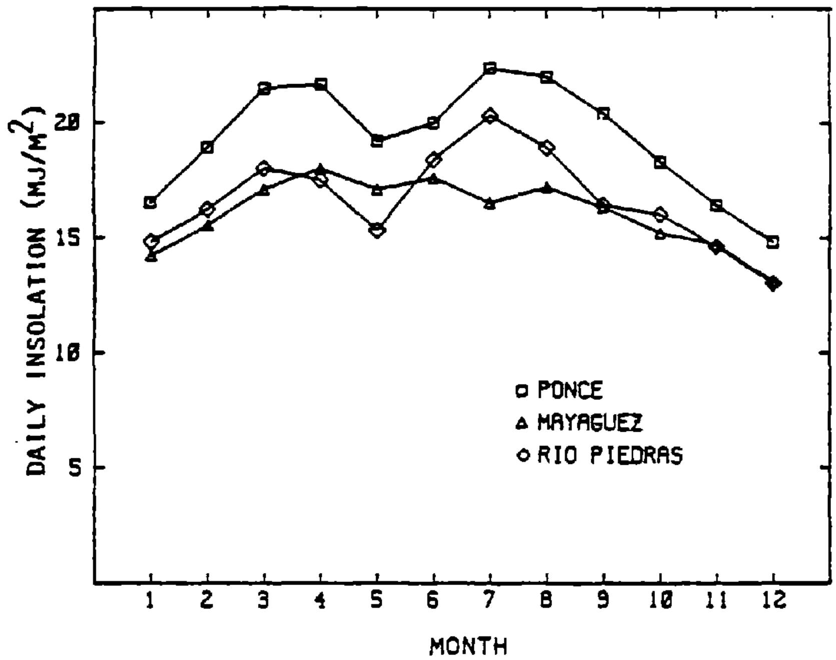


Figure 10 Average Daily Insolation on a Horizontal Plane vs. Month

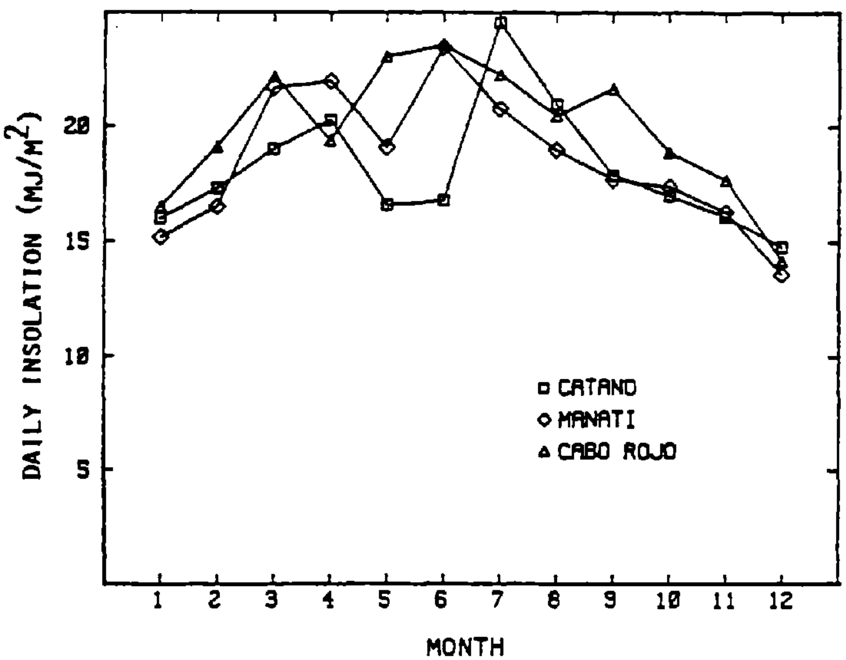
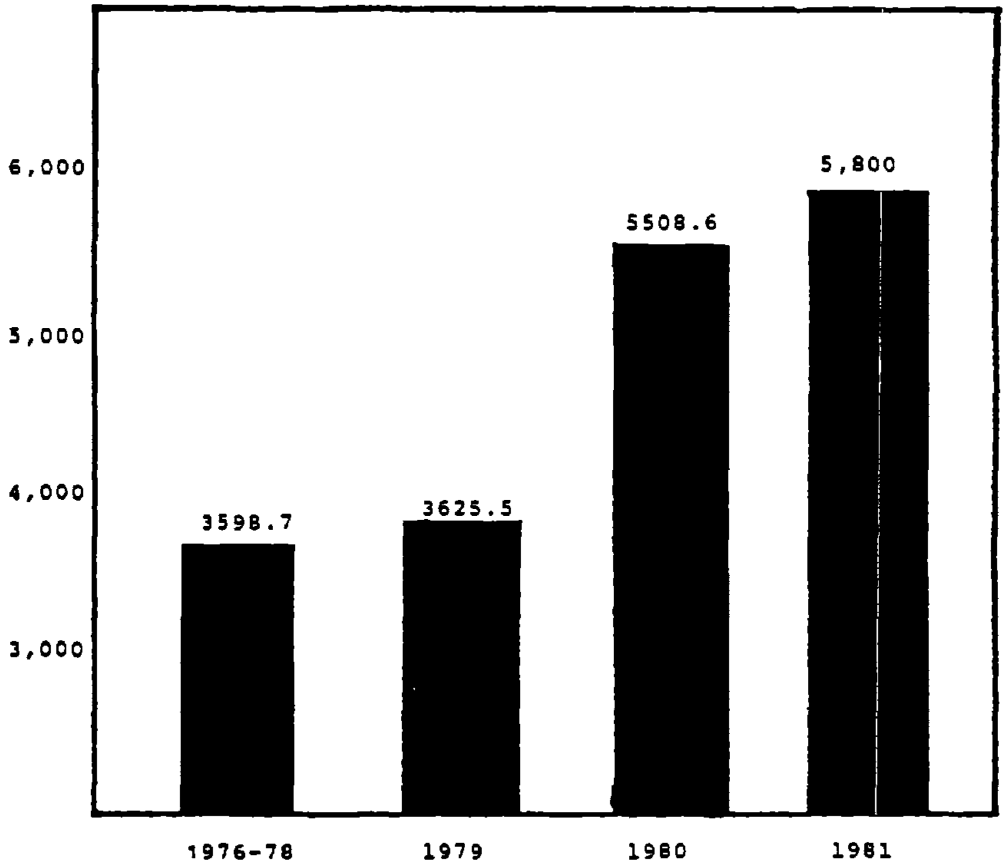


Figure 11 Average Daily Insolation on a Horizontal Plane vs. Month
(Source: Dr. A. López and Dr. Soderstrom, CEER, 1982)

Table 3 Yearly Installation of Solar Water Heater in Puerto Rico



energy which may be collected. Consistent with these assumptions, a plausible commercialization curve for this technology may then be produced. This curve is shown in Figure 12.

A Btu of energy which has been generated by an electric heating element, replaces 3.33 times as much energy in the form of imported fuel if an overall conversion efficiency rate for electrical generation and transmission for central fossil fueled power station is taken as 30%, and if it is assumed that the power plant is operated with imported fossil fuel.

At a rate of 5.8 million Btu per barrel, it is possible to predict the barrels of imported oil which may be saved by the predicted solar hot water heater commercialization. This has been done for this case, and the results are as follows, in terms of fiscal years for the commercialization scenario described:

Year (FY)	80	81	82	84	85	86	88	90	95	2000
Millions of BBls of oil savings	0.03	0.06	0.09	0.11	0.15	0.18	0.25	0.33	0.52	0.63

b. Solar Ponds And Industrial Process Heat

An additional alternative energy source with potential in Puerto Rico is the shallow salt-water pond collector which produces hot water or electricity to replace imported oil which has been used for industrial process heat or for generating electricity. In addition, focusing and flatplate collectors may also contribute.

Solar ponds are state-of-the-art and are operating in Israel. The potential in Puerto Rico is inhibited by land values, and by lack of level terrain. An assumed region one-half mile in width

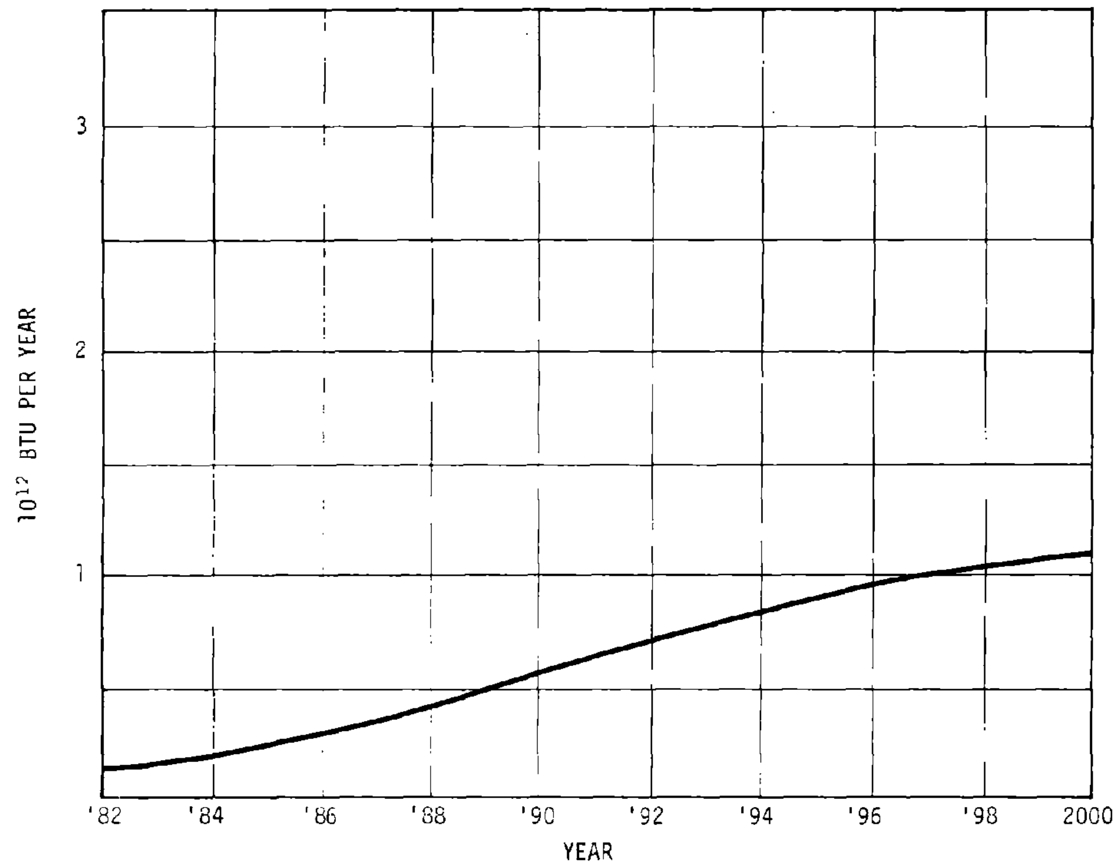


Figure 12 Solar Water Heating

surrounding the island, with 1% of this area, or one square mile in width surrounding the island, with 1% of this area, or one square mile, being converted by solar pond would produce a usable heat energy of 2.85 x 10^{12} Btu/year by the year 1995. A doubling of this figure, to account for the additional contribution from other collectors, yields a usable heat of 5.7 x 10^{12} Btu/year by the year 1995.

A plot of the contribution from this resource is Btu per year is shown in Figure 13. The imported oil which is replaced by this technology, under this commercialization scenario is the following:

Year (FY)	80	81	82	84	85	86	88	90	95	2000
Millions of BBls of oil savings	0.00	0.00	0.00	0.05	0.05	0.08	0.21	0.40	1.03	1.19

c. Photovoltaics

Another promising energy alternative from a technological point of view is the use of photovoltaic devices which generate electricity.

Photovoltaics is state-of-the-art technology, and has been used widely in space and remote applications, where the economics have proved viable. Should the U.S. program cost goals be achieved (70 cents per peak watt by 1986) then wide-scale utilization of this technology could be expected. It is that commercialization of this technology in Puerto Rico will be initiated in 1988, with its full potential of 2.69 x 10^{12} Btu/year being realized in the year 2000. As was the case with small wind systems, this commercialization potential is highly dependent upon cost factors, an estimates could vary by an order of magnitude.

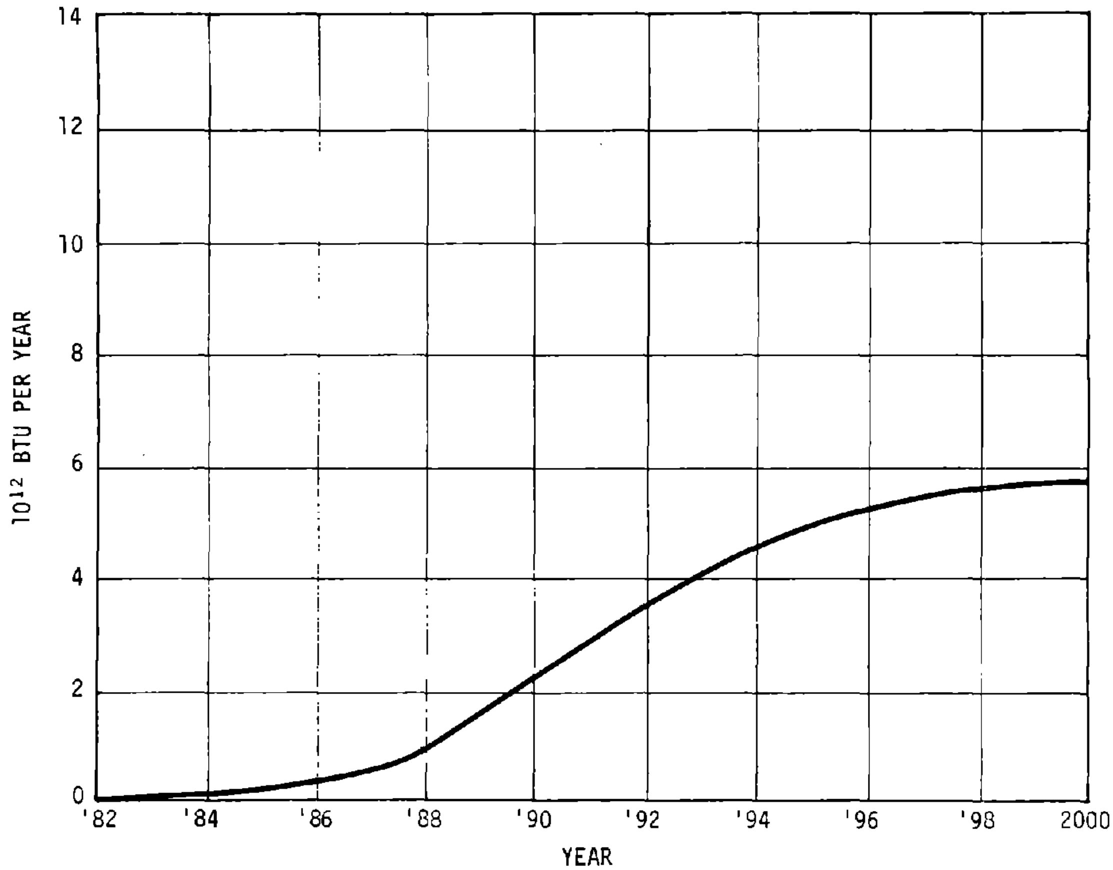


Figure 13 Solar Ponds

In preparing the estimates for this technology, an assumed conversion efficiency of 11% was used for an ultimate area of photovoltaic cells which was equal to an average of 200 sq. ft. per home for 100,000 homes, at a capacity factor of 0.90. In addition, an 86% increase was allowed for industrial and commercial applications.

The forecast for Btu output for this solar energy technology is shown in Figure 14.

The predictions for BBls of imported oil savings is the following:

Year (FY)	80	81	82	84	85	86	88	90	95	2000
Millions of BBls of oil savings	0.00	0.00	0.00	0.00	0.00	0.00	0.66	0.20	1.26	1.55

2. Bioenergy Overview

Abundant rainfall, a high level of insolation, and a tropical climate provide the optimum condition for the existence of a rich and varied biota in Puerto Rico. During the peak of its agricultural period the Island was a primary producer of sugarcane and a wide variety of tropical fruits and vegetables. With the onset of industrialization, however, agriculture declined as the economic and political emphasis shifted towards the establishment of industrial complexes which were planned to enhance the economic level of the population.

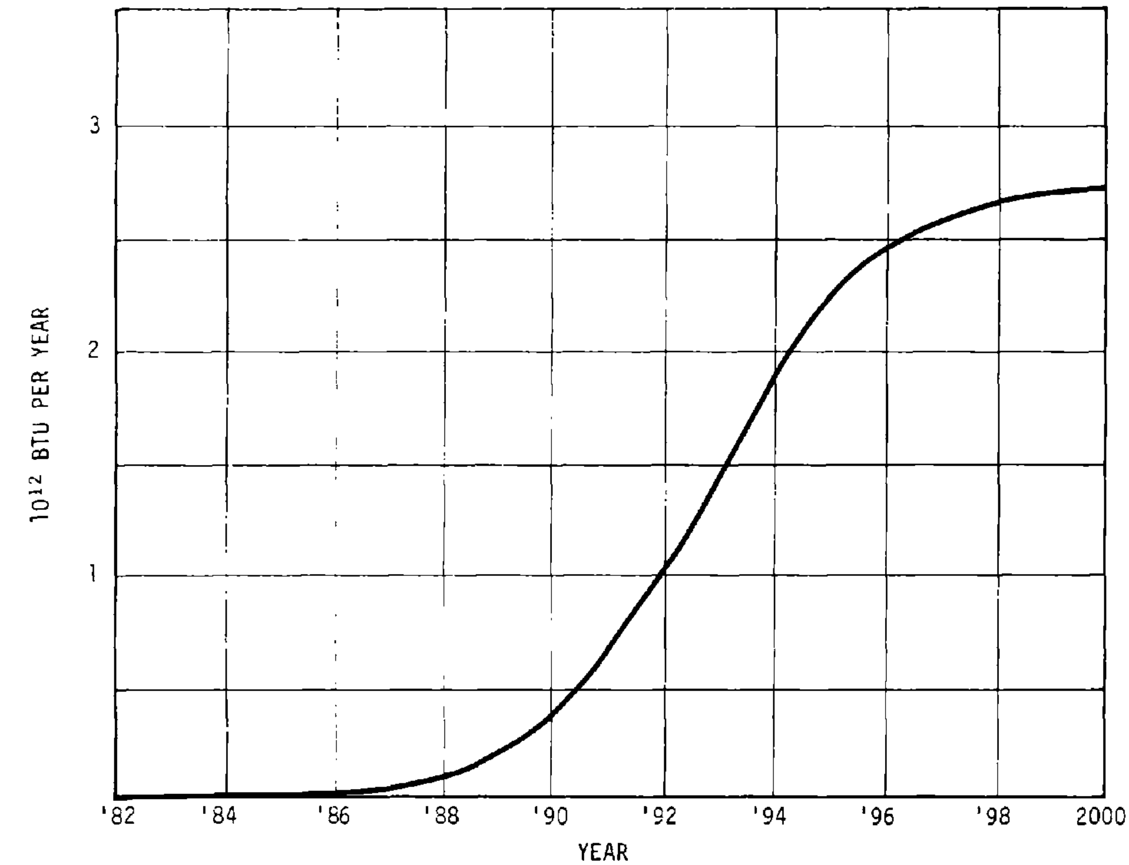


Figure 14 Photovoltaics

There still remains a fairly substantial agro-industry which produces enough organic matter, from which a considerable amount of bioenergy could be derived. Using this waste material and planning future agricultural projects specifically oriented towards energy production, could be a significant factor in Puerto Rico's future energy scenario.

The bioenergy resource is quite diverse. Sugarcane and bagasse can provide fuel for direct combustion or, via various bioconversion technologies, liquid or gaseous fuels. Agro-industry wastes and field residues can also be a source of fuel and animal waste and municipal garbage can be anaerobically digested for small site specific energy resources.

The PROE has been able to do a limited amount of assessment of the resources (see Table 4) and has funded a few small projects to assess and quantify specific agricultural and municipal waste sources. Plans are presently being formulated for a full scale, island wide systems analysis effort which will integrate bioenergy resources, institutional requirements and constraints, and the policies which can be promulgated or revised to expedite the development of a viable bioenergy industry for the Island.

With an adequate assessment of the resource and its judicious development, a substantial potential impact can be seen as the Puerto Rico energy scenario develops over the next decade.

a. Bioconversion

Bioconversion is a technology which can be best applied at agricultural farming facilities. It serves both as a fuel producer (methane) and a waste management system for animal organic waste, derived from dairy, chicken and hog farms. The products resulting from this system, are the biogas (composed of 60% CH_4), a liquid effluent, and a sludge. The methane is a valuable fuel and both the liquid effluent and sludge are suitable for fertilizing purposes. In utilizing a waste of this kind, which under normal conditions is discarded haphazardly, and which can also cause contamination problems in the environment, we can obtain a large amount of energy production with considerable economic value.

Table 4 Estimated Potential of Currently Available Bioenergy Sources

	RESOURCE	AMOUNT OF WASTE	POTENTIAL ENERGY (HEAT VALUE)	METHODOLOGY
Municipal Solid Waste[1]	Residential & Commercial at Landfills	1,510 Thousand ton/year for 1980	6,000 Btu/lb of dry solids	Direct Combustion; methane generation
Sewage Sludge[2]	Waste water treatment	47.82 dry TPD (Tons Per Day)	Digested Primary Sludge: 7,600 Btu/lb dry solids; Digested Primary & Secondary Sludge: 8,550 Btu/lb dry solids	Methane Generation
Slaughterhouse Waste[3]	Cattle & Hog	8,741 ton/year for '80	3.85×10^{10} Btu year	Methane Generation
Agricultural Waste[4-5]	Animal Waste &	4,350 ton/day (liq. waste) 760 ton/day (dry waste) for 1980 Animal Waste	3.01×10^{10} Btu/yr of liq. waste 5.27×10^{9} Btu/yr of dry waste	Agriculture Methane Generation
	Biomass	83-110 ton/acre/year	4.5×10^{8} Btu/acre/year	Direct Combustion

REFERENCES:

1. Solid Waste Management Authority, Islandwide Resource Recovery Plan, Brown and Caldwell Assoc. April 1982 - Preliminary copy.

2. Ibid

3. Ibid

4. Environmental Quality Board, Data on Agricultural Waste, 1980.

5. Alexander, Alex C., UPR/CEER, Rio Piedras, The Energy Cane Alternative - UPADI '82.

The advantage of using a bioconversion system on agricultural or animal facilities is that it can be sized specifically for each individual project.

b. Methane From Animal Waste And Biomass

Anaerobic digestion of animal waste and biomass residues to produce methane gas which may be used to replace imported fossil fuels in heating and power generation is an alternative energy technology which is current state-of-the-art, small scale, and highly dispersed. It is difficult to estimate the potential, but it appears to be at around 14.94 x 10^{12} Btu per year. A capture rate of 22% would thus yield about 2.63 x 10^{12} Btu per year by the year 2000 at a capacity factor of 0.80. A plot of this production rate is shown in Figure 15. Because the methane that is produced would tend to be used in applications which directly substitute for imported fossil fuel, the multiplication as far as savings in imported fuel is less than for the solar hot water technology by about a factor of 3. The estimated savings in imported oil from this commercialization scenario follows:

Year (FY)	80	81	82	84	85	86	88	90	95	2000
Millions of BBls of oil savings	0.03	0.03	0.03	0.04	0.06	0.08	0.13	0.22	0.43	0.46

c. Biomass

Diversity of biomass resources for energy planning is extensive for regions that have tropical agricultural capability. Such is the case for Puerto Rico. Terrestrial biomass forms include both woody

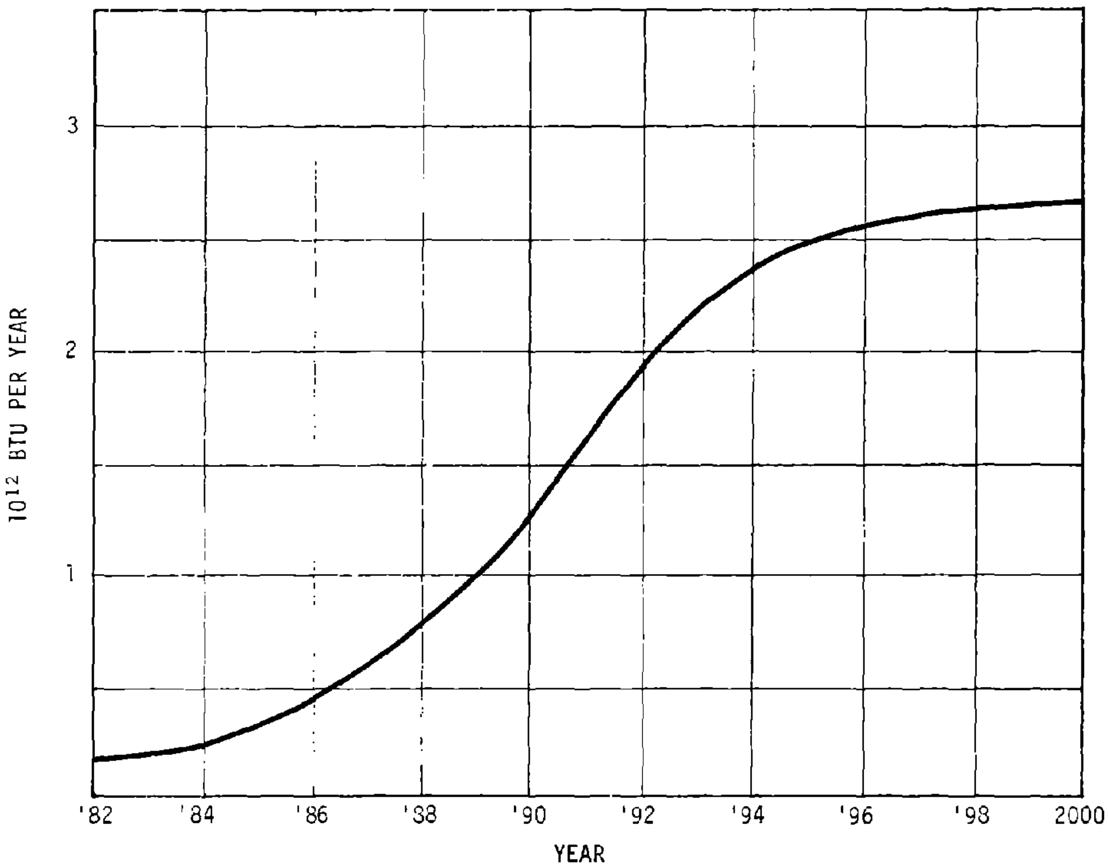


Figure 15 Methane from Animal Waste

and herbaceous species. Each group has members suited to intensive cropping, "conservation" cropping, minimum tillage, and growth in the wild state. Added to this are the terrestrial aquatic plants (water hyacinth, water lettuce, cattail, etc.) which have the ability to cleanse and beautify the environment as well as to produce biomass feedstocks. Other potential resources which have scarcely been examined are the coastal aquatics and marine species.[1]

Consideration of the potential utilization of sugar cane or related fibrous species of grasses as biomass for the production of energy in Puerto Rico leads to the necessity of analyzing production and conversion systems on a near and far term basis.[24]

d. Electricity From Bagasse

The burning of bagasse in boilers to produce steam generated electricity is a form of alternative energy which may be used to replace imported fossil fuels which are used to generate electricity. Currently the burning of bagasse consumed 10×10^{12} Btu/year which is in the form of electricity and process heat. It is estimated that 450 MW equivalent potential could be achieved by 1992. This converts to a total energy of 26.5×10^{12} Btu/year, or an electrical equivalent of 8.0×10^{12} Btu/year by 1994, at an assumed efficiency of 30%. A plot of this production rate is shown in Figure 16.

Estimates of the contribution of this technology in savings of imported oil are the following:

Year (FY)	80	81	82	84	85	86	88	90	95	2000
Millions of BBls of oil savings	1.75	1.75	1.75	1.79	1.97	2.18	2.75	3.42	4.81	5.41

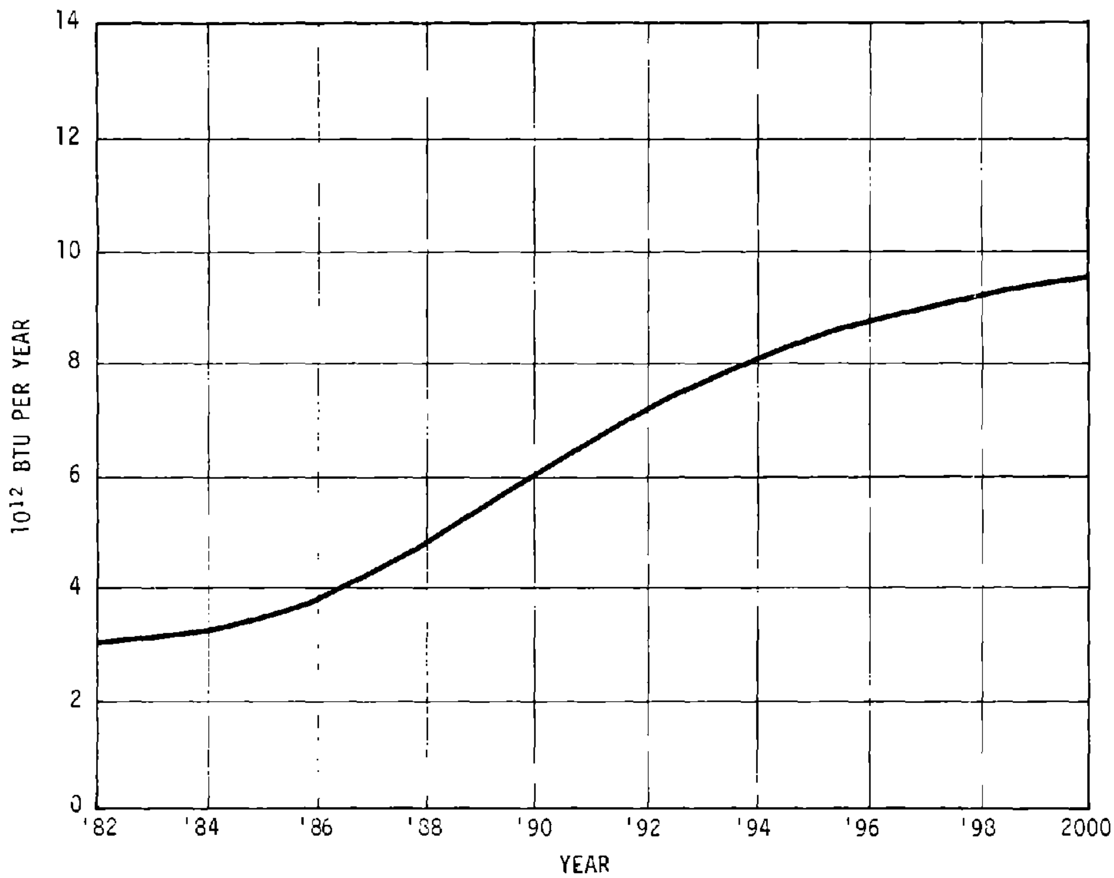


Figure 16 Electricity from Bagasse

The realization of this projection requires favorable agricultural policy, and a conscious decision to divert land use to the production of sugar cane, and in this case the more prolific bagasse producer, or "energy cane" would need to be implemented.

e. Solid Waste

Electricity that is generated from steam which is created by burning solid waste represents an alternative energy source.

It is estimated that in the city of San Juan, the first 20 MW increment of solid waste energy conversion will be on-line by 1986. The introduction of additional units is under study at this time, and it is estimated that the success of the San Juan facility will result in another 20 MW increment being added by 1990. The Btu output of these facilities is plotted in Figure 17. If it is assumed that the electricity produced by these plants replaces imported fossil fuel generated electricity, then a multiplication effect occurs similar to that experienced for the case of solar water heaters. The resulting savings in imported oil, consistent with this scenario, are the following:

Year (FY)	80	81	82	84	85	86	88	90	95	2000
Millions of BBls of oil savings	0.00	0.00	0.00	0.00	0.00	0.31	0.31	0.65	0.92	1.24

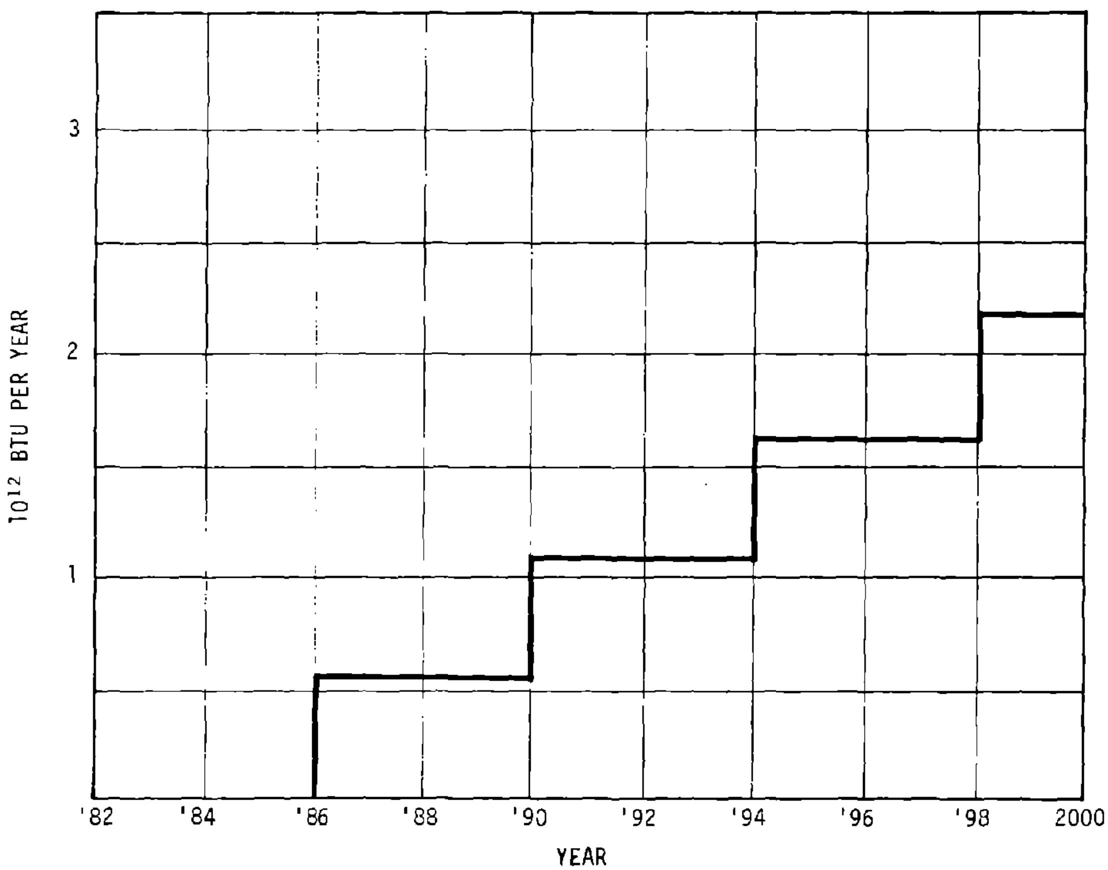


Figure 17 Electricity from Solid Waste

f. Current Projects

Puerto Rico has an excellent biomass production potential which includes not only agricultural crops and wastes but also human and industrial wastes. Therefore, any energy production from locally produced renewable sources will not only benefit the specific community but also will enhance to economy of the Island.

The following is a description of two on-going projects which fulfill some of the objectives stated for the Bio-Energy Program.

1. Systems Analysis and Design of an Energy Integrated Tropical Dairy

Energy-integrated farming technologies are essentially needed in Puerto Rico. Significantly, the development of alternative energy sources at the small farm level is an acceptable concept on the Island.

This year an important project was initiated involving systems analysis of an energy integrated farm in Puerto Rico. Its objectives are:

- To design a safe and simple system of energy-integration technologies that will reduce signficantly the farm's reliance on external feed and energy sources.
- To design an energy-integrated system which will reduce farm wastes to an environmentally-acceptable level.
- To perform a preliminary assessment of the system's technical and economic feasibility.

These approaches will be integrated into one facility for the production of energy from available wastes, the collection and use of available solar and wind energy and the recycling of valuable waste nutrients.

In addition to the proposed demonstration project which will produce energy from animal wastes, collateral benefits in terms of energy savings will also become apparent as noted below:

1. Energy requirements for waste disposal would be reduced.
2. Utilization of digested residue as a fertilizer will decrease the need for synthetic fertilizer which requires a very energy intensive process to manufacture.
3. Use of the effluent as a growth medium for algal protein production can also be considered an energy conservation practice because of the decreased imported feed requirements of the farm.

Farming technology in Puerto Rico and Third World countries is not substantially different. Therefore, the success of the proposed project will not only be beneficial to Puerto Rico in terms of energy production and conservation but also to other countries with similar farm management practices.

2. A project which is expected to be initiated this fiscal year is a Systems Assessment of Biomass Potential for the Production of Energy and Other Products in P.R.[9]

The Commercialization of biomass as a potential energy source could prove to be an economically viable venture. This project has as its goal to stimulate the private sector development of a commercially viable biomass-to-energy industry on an accelerated basis. The following objectives are to be accomplished by this assessment:

A. To compile, integrate and document previously developed Puerto Rican biomass resource analyses.

B. To assess the market potential for biomass based energy products and by-products.

C. To identify commercially feasible conversion technologies.

D. To assess the role of existing Puerto Rican industry and infrastructure in the Program.

E. To integrate the social and economic needs and objectives of the Commonwealth into the Program and estimate the potential impacts of the Program upon them.

F. To analyze, via a systems approach, the options available and identify targets of high opportunity for in-depth, commercialization evaluation and socio-economic impact analysis.

G. To provide the Commonwealth with an overview and perspective as to long-term direction of a Biomass Commercialization Program.

H. To recommend Government policy options toward these target areas and biomass development such that the commercial sector has a consistent framework within which investment decisions can be made.

I. To recommend Government programs where necessary to stimulate rapid private sector participation.

J. To develop specific recommendations for the performance of a Phase II Program Development and a Phase III implementation.

These objectives are to be approached within a systems framework of resource-through-end-use wherein the various system elements including land, labor, capital, management, environment, and other elements are considered and the interaction of these elements with the available technologies and their marketable products are evaluated with respect to optimizing the benefits to Puerto Rico.

An overall approach will be taken from a systems perspective, where to the extent possible, all factors having an influence on resources-through-end use are integrated into an overall evaluation framework.

Accomplishment of these objectives will provide not only an overview assessment of biomass potential for Puerto Rico but also indicate specific near-term activities and longer-term policies which can be inacted if desirable.

3. Co-Generation

Co-generation technology may be defined as mechanical devices which generate electrical energy at the site of use, and which are designed to provide heat energy to other processes at the same time, thus replacing imported fossil fuel which was formerly used for thes processes.

In 1981, the PROE undertook a study to determine the overall theoretical co-generation potential of all commercial and industrial consumers in Puerto Rico (Ref. Energy Research and Applications, Inc., Appendix II)

The general approach was as follows:

- Establish listing of all electricity customers with annual consumption greater than 200,000 kwhr.
- To ascertain which customers are candidates for co-generation based upon thermal requirements, ratio of thermal load to electric demand, potential power each could generate.
- Enlist the services of experienced firm to conduct the analysis - Energy Research and Applications, Inc.

A methodology was established which allowed systematic evaluation:

- Acquire a list of utility customers above a minimum size by kwhr/yr consumed (2,000,000 kwhr/yr).

- Screen the list by SIC (Standard Industrial Classification), excluding operations inherently unsuitable for co-generation retrofit.

- Acquire operating schedules, heat rate, temperature, and electricity consumption data from representatives of the SIC's remaining on the list.

- Use the process description data to generate average co-generation potential (indexed by average kw demand) for each SIC.

- From generic co-generation system costs develop SIC-Specific economic evaluations of co-generation installations.

- Apply the results of SIC process and economic analyses to the screened list of PREPA customers and calculate co-generation potential (kw) and simple payback (years) for each power customer.

- Draw general conclusions about calculated potential. Qualify the results with a discussion of incentives and deterrents to the installation of actual co-generation units.

From this effort a final list of 788 were screened. Further analyses identified 347 potential co-generators; 183 "Classical Co-generators" 56 "High Electricity Users" and 108 "Process Industries."

From this grouping, Energy Research and Associates estimates that approximately 473 MW co-generation potential, now exists in Puerto Rico. Of this total, 150 MW is readily achievable, and could be put in place by 1986. This represents 12.73×10^{12} Btu per year (energy equivalent of electricity generated at 90% capacity factor). A plant efficiency of 60% is assumed.

The technology is current state-of-the-art. The rate at which the co-generation will be brought on line is highly dependent upon institutional constraints and how the PURPA legislation is implemented with respect to the tariff (stand-by and payback at avoided cost).

On the basis of these figures, a plausible commercialization curve for this technology may be developed. This scenario is shown in Figure 18. If the Btu per year values are converted into BBls of oil per year replacements as far as imported fuels are concerned, the increased in plant efficiency, over conventional electricity generating methods, allows a credit to be realized. The following savings in imported oil then results, consistent with the described scenario:

Year (FY)	80	81	82	84	85	86	88	90	95	2000
Millions of BBls of oil savings	0.00	0.00	0.00	0.21	0.42	0.77	1.59	1.82	1.83	1.83

4. Ocean Thermal Energy Conversion (OTEC) Overview

Tapping the energy potential which exists in Puerto Rico's surrounding oceans is one of the long-term objectives of the Island Energy Program. The OTEC technology which has been rapidly developing over the last decade has raised the expectation for its commercial implementation during the latter part of this Century. The Island energy interests (PREPA, CEER, and PROE, among others) have been very much involved during the period in which the various proposals responding to the DOE Program Opportunity Notice (PON) were being developed.

The resultant loss of potential federal funding has constrained further active development of this technology in Puerto Rico. The current plans of the PROE regarding OTEC is to continue monitoring developments in the private sector until such a time, as potential commercial interests can become actively involved.

The resource itself, has been well researched and categorized. The critical criterium (Delta Y) has been clearly defined and other parameters (site proximity to shore; near shore ocean dynamics; and environmental considerations) have also been investigated and documentated.[13]

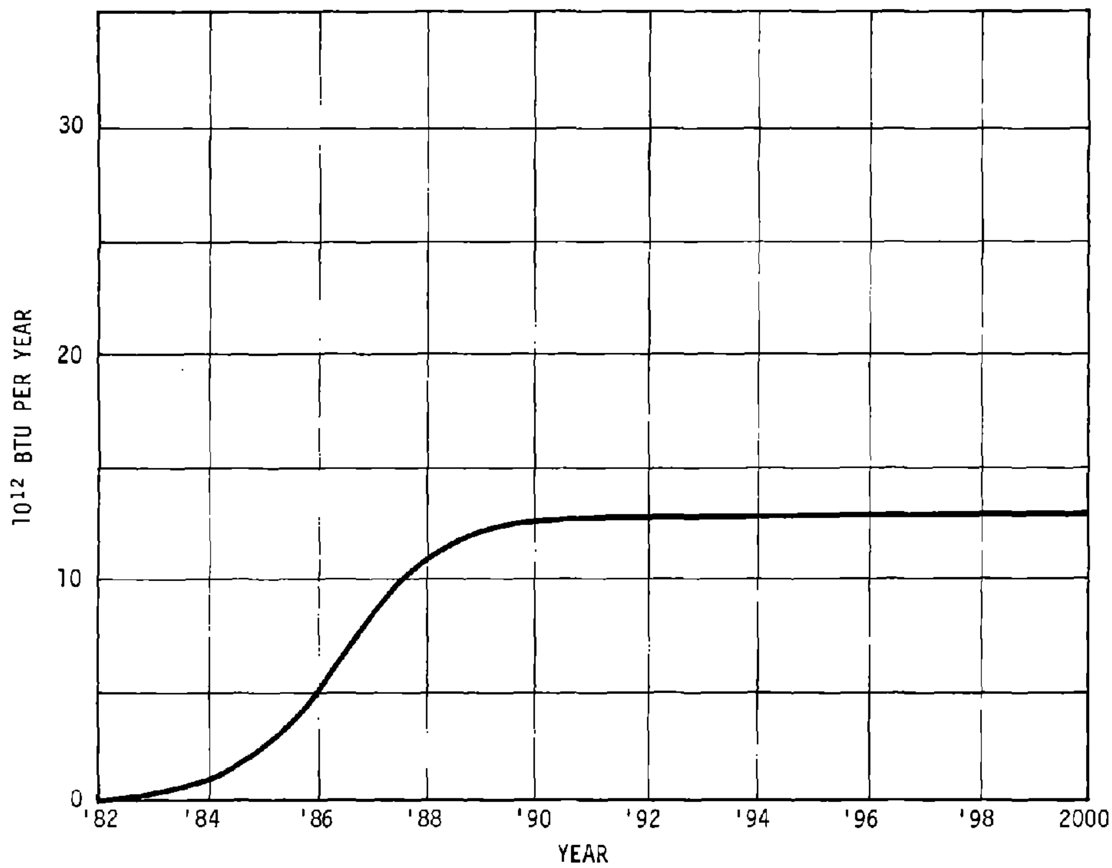


Figure 18 Co-Generation

An extremely valuable component of the OTEC resource assessment was developed in Puerto Rico as a result of a PROE-DOE cost shared project contracted to CEER for a study of the biofouling effect of tropical marine organisms upon heat exchanger tubes.

Based on the results of a continuous experiment it appears that only slight differences exist between aluminum and titanium heat exchanger tubes, with respect to their heat transfer loss resulting from exposure to circulating sea water. It was also shown that biofouling was progressively more difficult to dislodge later in the experiment. The information gained from this series of experiments provides valuable site specific data in making future assessments of the OTEC resource for Puerto Rico.

Additional heat exchanger studies funded by NASA and the Kaiser Co. were directed at determining the effect of the site specific corrosion differences between the materials intended for use in OTEC heat exchangers. While this project was not specifically directed at resource assessment, the results will be equally valuable as the various geographically dispersed potential OTEC sites are reviewed.

At the present time, Ocean Thermal Energy Conversion is yet to be proven as a viable cost-effective energy producer. Further development must proceed, but it is assumed that 40 MW may be on-line by 1994, with 80 additional MW being added in 1998, for a total electrical energy equivalent of 3.5 x 10^{12} Btu/year by the year 2000, as shown in Figure 19.

The contribution in terms of savings of imported oil follows:

Year (FY)	80	81	82	84	85	86	88	90	95	2000
Millions of BBls of oil savings	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.62	1.86

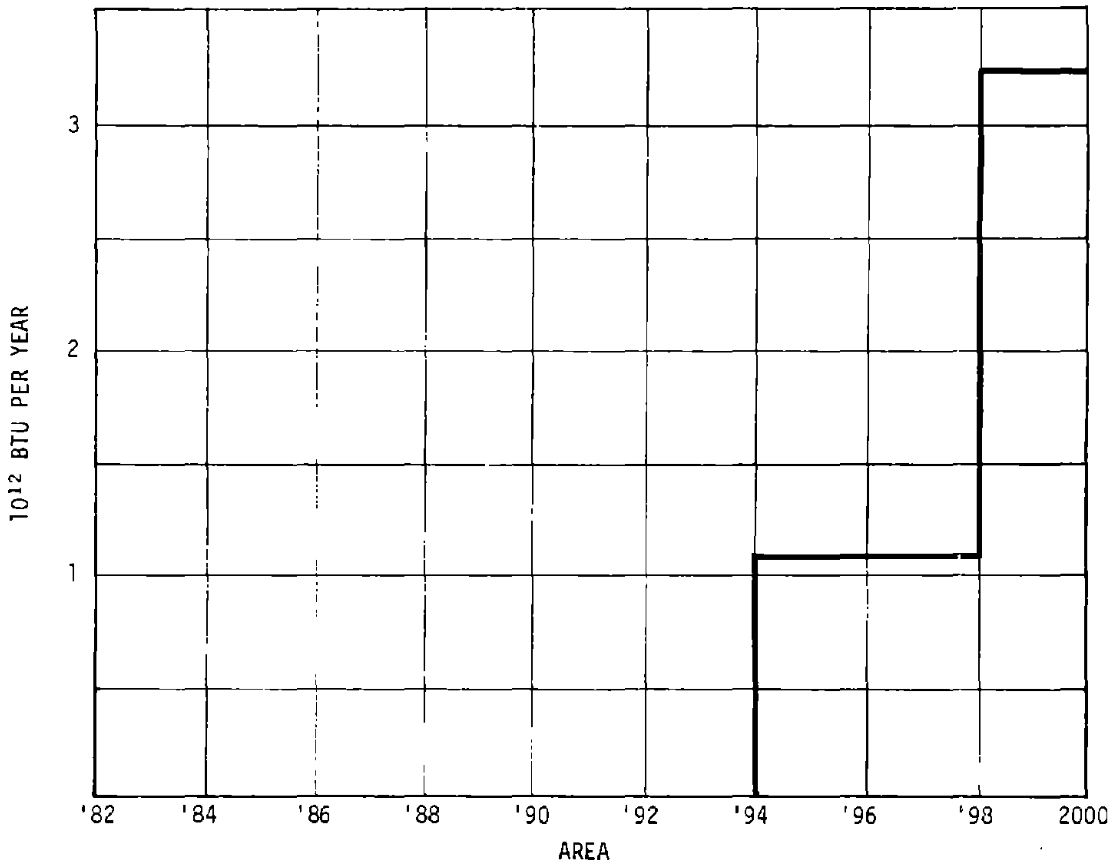


Figure 19 Ocean Thermal Energy Conversion

IV SUMMARY

A. ENERGY SELF-SUFFICIENT

The previously described technologies, together with others which remain to be identified, each possess the capability of contributing technologically to a degree of energy self-sufficiency for Puerto Rico, as far as freedom from dependency on imported oil is concerned. Although it is obvious that variations may exist in the degree and time at which each is commercialized, a summation of the estimates of the contribution does yield useful insights to the composite technological potentials of an alternative energy program.

Figure 20 presents just such a summation for imported fossil fuels which are used in the electric power generation sector, and Figure 21 presents a composite for total energy imports. It should be noted that a 1.5% per year growth rate in energy consumption is assumed after 1985. This is an "assumed" value to reflect economic growth; however, it could vary significantly, depending upon continued conservation measures and economic policies adopted in future years.

If it is assumed that the forecasts made previously are achievable within all applicable socio-economic and political constraints, then it may be said that a major degree of energy self-sufficiency for Puerto Rico is an idea, whose achievement is definitely possible. As a matter of fact, it may be observed that with the introduction of each new alternative energy technology, savings in imported oil tend to accumulate with increasing rapidity. The degree to which this self-sufficiency is realized is obviously dependent on numerous economic and non-technological factors, but such a forecast provides an excellent first step in the identification of the achievable. The technological forecasts on which this scenario has been based have been intentionally pragmatic and conservative, but the results appear to be very promising. With sufficient incentives and technological breakthroughs, some of these projections could increase by orders of magnitude, with the result of shortening the data to a more self-sufficient state as far as imported energy is concerned.

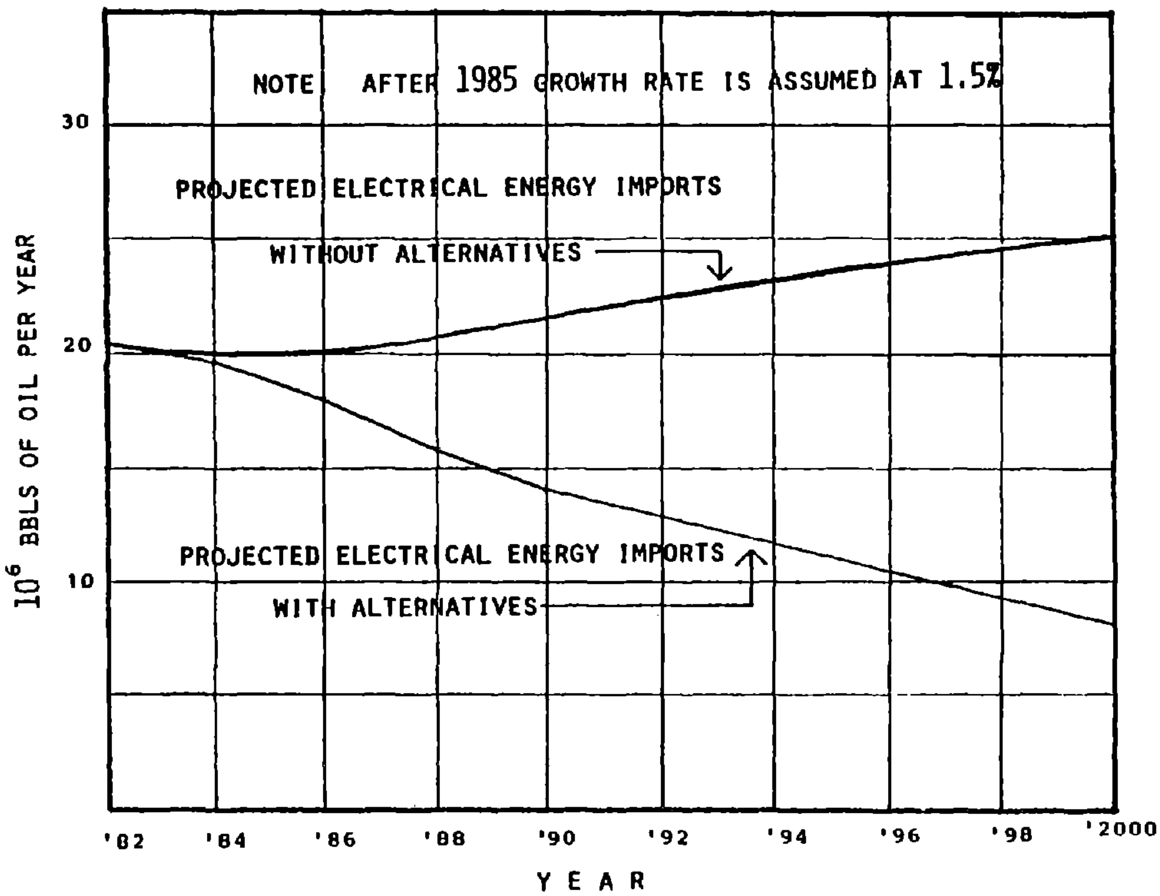


Figure 20 Composite of Electrical Energy Imports

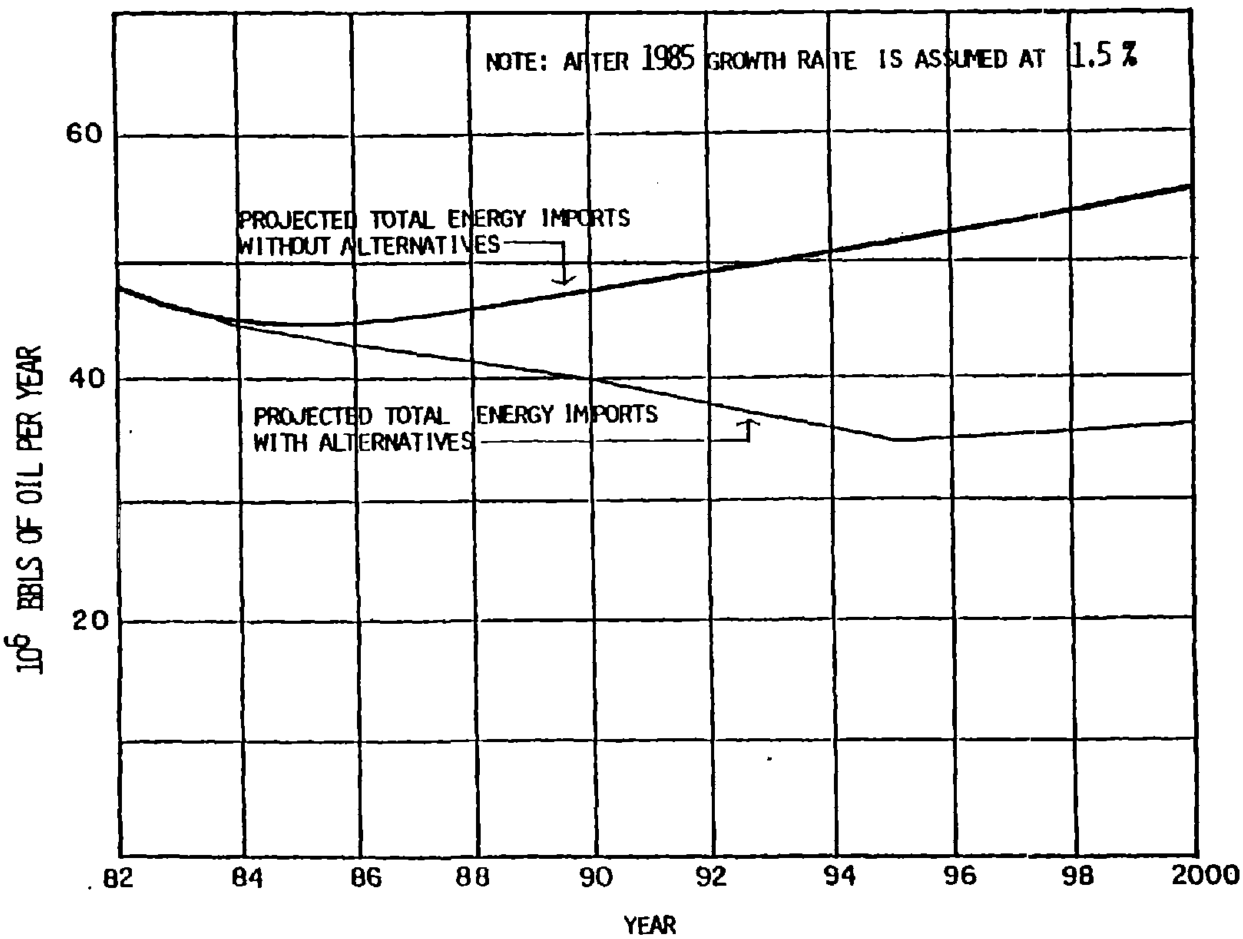


Figure 21 Composite of Total Energy Imports

B. CONCLUSION

The information and data presented reflect a first projection of what is technologically feasible and has not been subjected to economic and social considerations and further policy studies.

Refinements in the resource potential for wind may indicate that only certain areas of the Island have wind speeds of sufficient magnitude and consistency to warrant deployment of wind machines. This finding would result in a reduced projection of this technology's energy contribution. Similarly, further analysis may indicate that land availability for "energy cane" production is limited and the initial assumption will be modified to reflect the potential constribution of bagasse as a fuel.

The capital cost of some of the technologies may remain too intensive and never have an opportunity to compete in the marketplace. An example of this is photovoltaics. The installed system's cost may never achieve their cost goals. On the other hand, this particular technology could experience a technological breakthrough in efficiency and cost and our first projections would have to be modified upward significantly.

These examples are shown to indicate the fragility of technology forecasting and planning itself; however, not to forecast and to plan is to leave the future unaffected; for the decisions made today determine what path we take into the future.

It is our conclusion that the methodology and the modeling underway that considers all elements of the economic, social and political systems will allow realistic achievable goals to be set and policies adopted which will lead Puerto Rico to a more energy "self-sufficient" future, and it is to this end that all of us are dedicated to serve.

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PHASE II

TERRITORIAL ENERGY ASSESSMENT FOR THE UNITED STATES VIRGIN ISLANDS

Prepared by

Royal Energy Management
as part of a contract with

The Virgin Islands Energy Office
Frederiksted, St. Croix, and
Charlotte Amalie, St. Thomas
and The Department of Energy
Savannah River Operations Office

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U.S. VIRGIN ISLANDS
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Phone: (809) 772-2616

November 5, 1982

Mr. William Rankin
Project Officer
U.S. Department of Energy
Savannah River Operations Office
Box A
Aiken, South Carolina

Dear Mr. Rankin :

Pursuant to our application for federal assistance for a Territorial Energy Assessment Program, enclosed you will find a final submission of the Phase II Assessment Plan.

The Document is open for your review and comment. I do hope that the short time frame allowed for the development of this plan has not taken away from its thoroughness or feasibility.

I look forward to hearing from you soon. Should any questions arise, please do not hesitate to contact me.

Sincerely,

John Abramson Jr.

John Abramson, Jr
Energy Director

cc: M.C. Kirkland
Walter Butler

Enclosures

OFFICE OF THE GOVERNOR

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INTRODUCTION

The United States Virgin Islands has a generous endowment of indigenous, renewable energy resources which could help to alleviate our almost total dependence on imported petroleum. With 99% of its energy derived from imported oil - most of that from foreign sources - the Virgin Islands is highly vulnerable to the full impacts of rising oil prices and the growing risk of supply interruptions. This study addresses the questions of how, when, and to what extent wind, solar, ocean thermal and biomass energy resources can be harnessed to displace oil during the next 25 years.

Projections of the means by which our future energy demands can be met will be based on evaluations of technologies considered appropriate to the Virgin Islands, estimates of their future costs, and directly relevant projected economic parameters. Environmental impacts, institutional structures, the relevant body of laws and regulations, and social attitudes that may affect resource development were also taken into account.

Three energy demand-supply projections are possible to quantify the transition to the commercial use of indigenous resources. Energy Projections 1 and 2 will take form partly in response to an average 3% per year increase, over inflation, in the price of oil. Projection 2, however, will incorporate improvements in end-use energy efficiency and conservation beyond those induced by oil price alone. Projection 3 will be shaped by a high rate of increase in world oil price - 10% per year over inflation. While a sustained price escalation at this rate would be severely disruptive to society as a whole, it serves the purpose of providing perspective on the sensitivity of a transition to indigenous resources attributable to oil price alone.

This analysis excludes petroleum products refined in and exported from the Virgin Islands by Hess Oil Corporation on St. Croix, although energy consumed by the refinery operations are included in our energy consumption figures.

When we provide an approach to integrated energy analysis for the Virgin Islands, this assessment will offer a model for decision-makers in the Territory who must plan to meet the needs for energy in a time of possible short supply and high oil prices. This report is intended to help us plan conversion to available resources without relying entirely on one technology or one source of energy. Only after all the feasible options have been examined can a reasonable emphasis be placed on those most likely to meet our energy needs. Future events will certainly alter specific details, but the method of analysis used in this study is highly adaptable and should give decision-makers a basis for flexible response to changing circumstances.

MAJOR CONCLUSIONS

1. Electricity. By the year 2005, the Virgin Islands could produce as much as 80% of its electricity with indigenous, renewable resources. Economic analysis shows that these resources could compete favorably under a wide range of oil prices and levels of energy conservation. The rate at which indigenous resources can be exploited depends more on the rate of technological development and the availability of capital than on oil price. If oil prices continue to rise, the use of renewable resources for electricity generation would help stabilize electricity prices.

2. Liquid Fuels. The prospects are less bright for liquid fuels, which represent about 40% of all the energy used in the Territory. This is largely because there is no indigenous substitute for the large amounts of diesel fuel consumed by Hess Oil and Martin Marietta Aluminum on St. Croix. At least 10% of the gasoline consumed could be replaced by liquid fuels produced from biomass, making it possible for all vehicles in the Territory to run on a 10% alcohol/90% gasoline mixture. Little liquid fuel should be needed to generate electricity in 2005.

3. Undersea Cable. A submarine transmission cable is critical to the energy future of the Virgin Islands. Two-thirds of the land mass on the island of St. John is designated as Park area by the Department of Interior. This would restrict the amount of land available for alternate energy development on that island, and its electric power might have to be continually supplied from St. Thomas power stations by undersea cable.

4. Economic Impacts. Replacing imported petroleum with indigenous energy sources would have a beneficial effect on our economy. Over the next 25 years, the use of renewables could save the Territory between $50 and $120 million, depending on the price of oil. Constructing new energy facilities would not have a major economic impact on the Territory, but the Water and Power Authority would encounter financing difficulties during the peak construction period unless present financing rules and practices were modified.

5. Conservation. Energy conservation could lead to substantial reductions in electricity and gasoline consumption. Improved appliance and building efficiencies and the use of heat pumps and solar water heaters could cut electricity use by 25%.

6. If plans to use domestic coal were made immediately, the Virgin Islands could be released from its dependence on imported foreign oil sooner than it would if we waited for renewables to reach maturity. The use of coal would pose environmental problems, particularly with air pollution and solid waste disposal. Complete loading facilities with crusher and conveyor would have to be constructed.

7. Public Opinion. Virgin Islands residents consider energy costs to be a major contributor to the high cost of living in the Territory. Consumers know less about energy and uses and will not necessarily place energy savings above convenience in purchasing new cars and appliances. Increasing energy costs seem to affect energy use patterns more than a desire to conserve. Strategies for increased public support of conservation programs include strengthening public information programs, providing accurate and timely information on proposed projects, and making energy data more readily available to consumers.

THE UNITED STATES VIRGIN ISLANDS

The Virgin Islands population of approximately 120,000 people is distributed among three islands, St. Thomas, St. Croix, and St. John. These are separated by ocean channels of 7 to 40 miles wide. The three islands are divided into two political districts (St. Thomas-St. John and St. Croix) with each having its own electrical supply system. St. John's electrical power is supplied by undersea cable from St. Thomas, but it has an emergency diesel generator for stand-by power.

Located on the island of St. Croix is the third largest oil refinery in the world (capacity: approximately 750,000 bbls crude oil per day) yet, residents of this Territory itself purchase gasoline fuel at the pumps at much higher prices ($1.60 per gal.) than on the United States mainland. The large quantity of crude oil imported does not necessarily signify a large supply of fuel available to motorists and other consumers, since most of the refined produce is "exported" to the United States mainland for sale. The only advantage derived from having a "local" refinery is that fuel is more readily available than it would be if it had to be brought in from any other part of the country thereby eliminating problems of transportation.

The distributors of fuel in the Territory are the same major distributors as on the United States mainland, ESSO, Shell, and Texaco, all of whom purchase fuel from the Hess Oil Refinery on St. Croix. The Hess refinery is also a major distributor of diesel fuel - supplying diesel directly to various industrial units like the Cruzan and Brugal Rum Distilleries, some construction companies, the V. I. Water and Power Authority, and Martin Marietta Alumina.

Energy supply and demand systems are complex and do not lend themselves readily to prompt, precise reporting. For the present purpose, however, the most recent, highly detailed data available for the Virgin Islands which are for 1978, 79 and 80 are adequate to characterize trends in recent energy demand.

Figure 1 shows the relative proportions of major liquid fuels and electricity consumption in the Virgin Islands and, for comparison, the Nation in 1977. It is evident that an important feature of our energy picture is the large proportion of energy used for industrial processes by Hess Oil and Martin Marietta Aluminum which accounts for approximately 90% of our total energy consumption. The energy used in the form of electricity is particularly significant because electricity generation possesses the greatest potential for a major shift from oil to indigenous resources. Electricity represents about 65% of our total energy use, yet, it accounts for 25% of the total demand for oil. The Virgin Islands uses less energy per capita than the country as a whole because it has little heavy industry and no space heating.

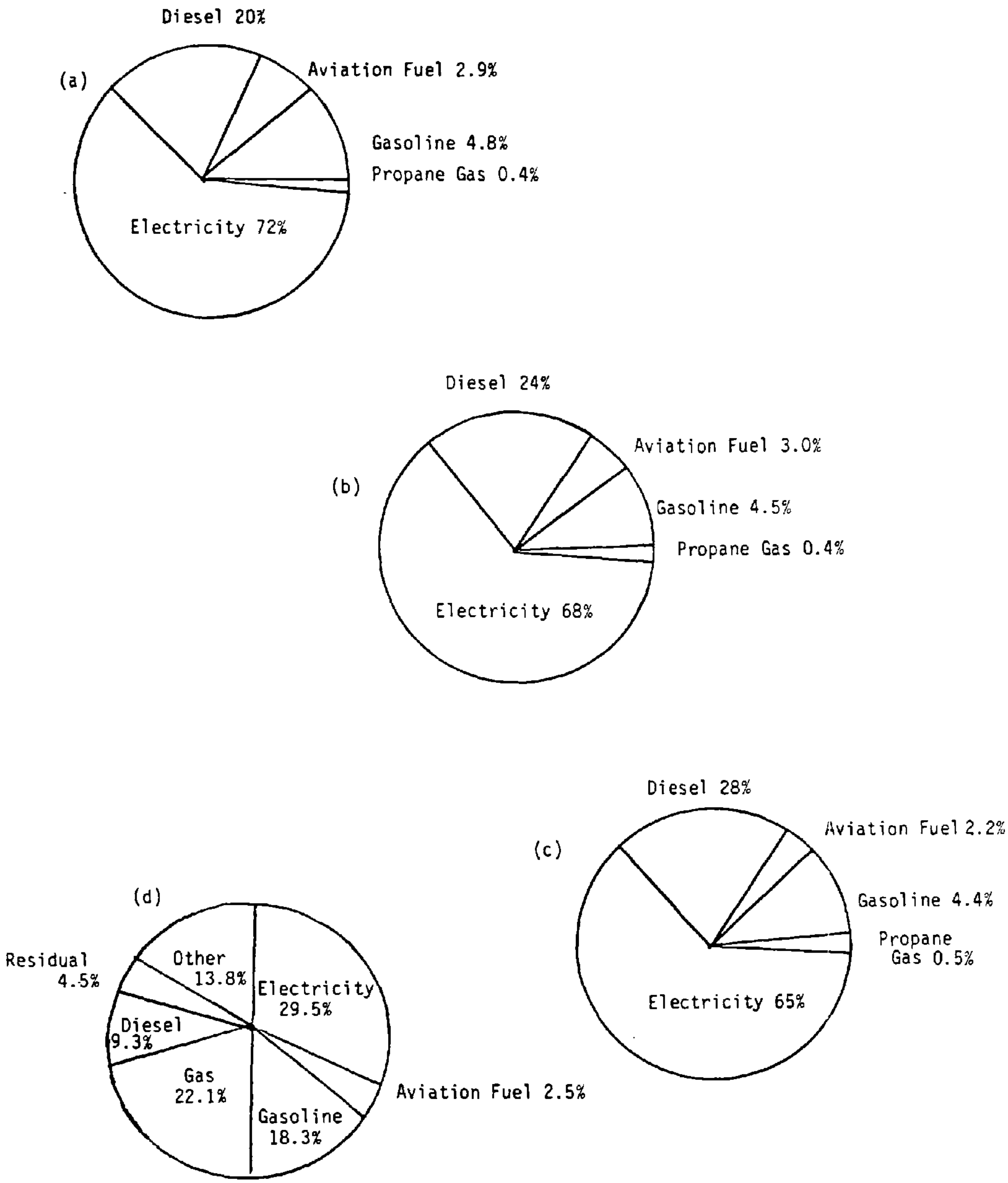

Fig. 1 Energy Consumption by Energy Type United States Virgin Islands: (a) 1978, (b) 1979, (c) 1980, and (d) 1977 U.S. Mainland

The demand for diesel fuel, residual oil and gas has increased about 5% per year since the Arab oil embargo of 1973. In contrast, sales of electricity and gasoline have remained fairly stable since 1973. Gasoline now represents about 5% of the Territory's energy consumption, which is a 2% decrease from 1978.

Among data that have been assembled on end uses of energy, those compiled by the Virgin Islands Energy Office afford the most detailed scenario. In general, however, highly detailed data on energy end use have not been collected. Such information will be essential for evaluating specific opportunities for energy savings and creating effective energy conservation and end-use efficiency programs.

ENERGY CONSUMPTION

The major form of energy that is utilized by residents in the United States Virgin Islands is electrical energy. This is produced almost exclusively by oil-fired generators using three different types of diesel fuel which are obtained from Hess Oil Virgin Islands Corporation on St. Croix. In 1978, approximately 68 Quads of energy were consumed in this Territory with an average 4 Quads per year increase in 1979 and 1980. Electricity accounted for 72% of total energy consumption in 1978 but fell off to 68% and 65% respectively in 1979 and 1980. The second major energy form utilized in the Virgin Islands was the chemical energy found in diesel fuel. This source contributed 20% of our energy needs with a 4% increase per year through 1979 and 1980. Gasoline consumption remained virtually constant (4.5%, 2M gallons per month) during the same period, inspite of an increase in population and the number of automobiles. We believe that this is a result of a switch to more fuel-efficient small cars as the price of gasoline jumped from approximately $.75 per gallon to $1.30 per gallon.

Propane gas, which is used mainly for cooking, remained at the 0.4% level of total energy consumption during this period. Aviation fuel was at the 3% level for 1978 and 1979 but fell to approximately 2.2% in 1980, reflecting the reduction in the number of inter-island flights and flights to the United States mainland caused by increased airfares.

ALTERNATE ENERGY TECHNOLOGIES

The alternate energy technologies discussed in this study rely on resources indigenous to the Virgin Islands and they are expected to be ready for large-scale commercial use, primarily to generate electricity, in the next 25 years. The selection process took into account the present state of development of the technologies, projections of their technical and economic feasibility, and potential environmental, social and institutional constraints on their development.

Table 1 Energy Consumption Statistics for the United States Virgin Islands

Energy Source	Consumption Total (In Gals. Except kWh for Electricity) 1978			1979			1980		
	Amt. $(x10^6)$	Btu $x10^{12}$	%	Amt. $(x10^6)$	Btu $(x10^{12})$	%	Amt. $(x10^5)$	Btu $(x10^{12})$	%
Diesel Fuel	110.00	13.8	20.0	141.00	17.6	24.0	17.3	21.60	28.0
Gasoline	25.40	3.3	4.8	25.60	3.3	4.5	25.9	3.40	4.4
Propane Gas	3.22	0.3	0.4	3.59	0.3	0.4	4.0	0.37	0.5
Jet Fuel	13.00	1.7	2.5	14.20	1.9	2.6	11.1	1.40	1.8
Aviation Gas	2.40	0.3	0.4	2.38	0.3	0.4	2.2	0.3	0.4
Electricity	439.00	49.0	72.0	445.00	49.6	68.0	443.0	49.40	65.0
Total	-	68.4	100.1	-	73.0	99.90	-	76.50	100.1

Conversion Factors: Diesel - 125,000 Btu/Gal, Gasoline - 130,000 Btu/Gal, Propane - 92,000 Btu/Gal.
Jet Fuel - 130,000 Btu/Gal, Aviation Gas - 130,500 Btu Gal.
Electricity - 11,150 Btu/kWh

Does not include figures from Hess Oil and Martin Marietta who generate their own electricity.

None of the technologies has had significant commercial operating experience in the Virgin Islands to date. Expert estimates of capital and operating costs and rates of commercial penetration therefore differ, sometimes widely. In recognition of a tendency to underestimate costs and development times, the estimates used in this study are not the most optimistic. Table 2 lists the alternate technologies that can be expected to contribute to our electricity supply during the next 25 years. All costs are expressed in 1980 dollars.

Among potential changes in the end uses of energy, only the electric vehicle and solar water heating were considered. Other end uses are amenable to improved efficiency and conservation without major shifts in technology.

Our land area is limited and each of the renewable energy technologies has huge land use requirements. Planning for a transition to renewables should include an extensive land use survey to identify the best sites for power plants fueled by indigenous renewable resources. Location of the resource will have to be considered in the context of present land use patterns and laws, land costs, expected trends in population growth, the presence of other energy sources and environmental impacts.

All of the alternate energy technologies likely to be utilized will need some government backing to carry them to full implementation. All will have some environmental and social impacts. Construction always involves considerable site disturbance and noise; increased transportation, especially trucking; and

Table 2 Alternate Energy Technologies

Technology	When Commercialization Expected in Virgin Islands	Suitable for Base, Intermediate or Peak Load	Capital Cost/KW 1980 (1980 $)	Assumed Maximum Resources Potential in 2005
OTEC	Mid term	Base	8,000	10 MW for St. Croix Grid
Wind	Near term	Intermediate	2,500	5 MW for each of the two Grids
Biomass	Near term	Peak	1,500	2 MW for St. Croix Grid
Resource Recovery	Mid term	Intermediate	1,200	5 MW each for St. Thomas/St. John - St. Croix Grids
STEC	Mid term	Intermediate	3,000	5 MW for each Grid
Photovoltaics	Long term	Intermediate	18,000	6 MW for each Grid
Hydroelectric	Near term	Peak	800	2 MW for each Grid
Pumped Storage	Mid term	Peak	1,000	4 MW potential for each Grid
Submarine High Voltage DC Transmission Cable	Near term	Not Applicable	800	No theoretical limit; to be used to transmit power from island to island

[a]Near term, present to 1985; mid term 1985-1995; long term 1995-2005 or later.

[b]Baseload power sources run 24 hours a day, intermediate load, 17 hours a day, and peak load 2 to 3 hours. Wind, hydroelectric power, biomass, and its subset municipal solid waste, can power baseload facilities only when supplies are uninterrupted by seasonal or daily variations.

[c]STEC - High Temperature Solar Systems
OTEC - Ocean Thermal Systems

often the creation of new access roads. Even when the final plant is relatively inoffensive, access roads will remain and transmission lines will become a new feature of the landscape.

Ocean Thermal Energy Conversion

Ocean Thermal Energy Conversion (OTEC) is an emerging technology well suited for the Virgin Islands because of our warm outdoor temperature year-round and our ocean shelf near to shore. OTEC taps the large energy potential created by the temperature difference between sun-warmed surface water and cold deep ocean waters to generate electricity. Theoretically, the resource is virtually infinite. Just off the north shore of St. Croix, the sea floor rapidly descends to the required depth to meet the projected demand for an OTEC plant site.

In the past two years, research on Mini-OTEC, Hawaii's 50 KW experimental platform, has shown that OTEC is technically feasible. Commercial scale components still need to be developed, and the economic feasibility of the system must be demonstrated. If the existing federally-funded programs are continued, OTEC should be carried through the complete research, development and demonstration cycle by the early 1990s.

The design of several major OTEC plant components is not final, and therefore all capital cost figures for commercial scale plants are speculative. However, OTEC is expensive because its extremely low (average 3%) thermodynamic efficiency necessitates very large water flows and huge heat exchangers.

Bio-fouling of the components necessitate the use of special construction materials and cleaning resulting in high material and operating costs. Present estimates place capital costs at about $8,000/KW of capacity for prototype plants. Operating costs are expected to be in the neighborhood of 5 mills/KWh, compared to 2 mills/KWh for the other renewable technologies.

The major visual impact of OTEC development will take place where the cable from a plant comes onshore, although some plants may be visible from the shore. The magnitude of OTEC development planned for the Virgin Islands is expected to have little or no negative impact on marine life.

Biomass

Fuels can be derived from several types of biomass resources; organic wastes of many kinds, agricultural residues, and crops grown specifically for their energy-producing potential. Because the exact nature of the biomass used determines the conversion technology, it is difficult to generalize about the costs of biomass energy technologies or the environmental problems associated with them, but combustion usually produces air pollution and solid waste problems, and fermentation can add water pollution to the list of problems to be solved.

Bagasse (a fibrous sugarcane residue), wood chips, and coconut shells can be burned in conventional steam plants to generate about 5% of the electricity consumed in the Virgin Islands. The Virgin Islands now plans 5 MW of generating capacity to be fired by municipal solid waste.

With government subsidies, successful cultivation of 2,000 acres of land in St. Croix could produce enough bagasse to generate up to 10% of our total electricity by 2005. It would require 6,000 to 7,000 acres of sugarcane to fuel a 10 MW power plant, if one assumes a 2-year cutting cycle, which means that 300 to 350 acres would be harvested each year.

Biomass could also supply 10% of our liquid fuel needs by 2005 if feedstocks were available. Barring the collapse of the international sugar market, molasses will be the most readily available feedstock for producing alcohol over the next decade or so. Cane trash, wood, and other cellulose materials could be processed into ethanol or methanol, but they are most economically used in direct combustion as boiler fuels. Because biomass resources are valuable for many uses, it would take a drastic shift in market values or government incentives to redirect potential biomass resources in the Virgin Islands to an energy-producing program.

Variable Sources

Some of the most promising sites in the world for implementing solar technologies are found in the Virgin Islands. However, solar technologies, with the exception of OTEC, are intermittent power sources.

Their output varies with the sunlight, or wind velocity and peak power does not often correspond with peak demand. Present energy storage technology is not yet adequate to allow the Virgin Islands to meet its electricity needs with intermittent sources alone. Potential pumped hydro-storage sites are not numerous, large or fortuitously sited enough to make a significant contribution to our energy picture. Lead-acid batteries remain the only potentially suitable storage in the near future, but at a first cost of $125/KWh they are prohibitively expensive except possibly for short-term storage. Advanced batteries and other storage systems such as molten salts may become feasible by the end of the century. However, even without storage, wind is already competitive with oil, and other intermittent energy sources will become so later in the century.

Wind

Wind generators could contribute significantly to our electricity supply in the next 25 years. Many excellent wind power sites have been identified and the technology is advanced enough to be practical and economical.

Wind generators are modular and adaptable to add-on capacity. Installation and electricity production can be realized by increments and with a lead time of only 2 or 3 years, compared to 8 to 12 years for conventional oil-fired plants. In addition, wind generators can be installed on each island and do not require a Territory wide grid.

The major problem with wind power is that the source cannot be controlled or matched to load requirements. Utilities have had little experience with long-term, large-scale, grid-connected wind generation, and problems with grid operation and reliability will arise. As a result, most utility system planners hold that wind should not represent more than 20% of installed generating capacity. This study projects 10 MW of wind generation for each of the two electric grids in the Virgin Islands.

Current costs for wind generators are about $2,500/KW but by 2005, costs are expected to drop to $700/KW. This would make wind highly competitive with other indigenous energy sources.

Wind energy appears to have minor environmental impact. Bird kills, insect kills, and climate modifications will be expected. The generators require land and emit low-level noise. Safety could be a problem with wind machines that are located near population centers. Visual impacts will be present unless remote siting in the National Park on St. John, neighboring uninhabited islands or on larger St. Croix is utilized.

Solar Thermal Energy Conversion

Solar thermal energy conversion (STEC) uses mirrors, lenses, and other focusing devices to concentrate solar energy to produce high heat which can then be used to produce industrial process steam. The most likely near-term use for STEC in the Virgin Islands is powering of steam generators and Absorbtion Chillers, augmenting or even substituting for oil as the energy source to produce electricity or solar cooling. One study places STEC's entry into commercial electricity generation near the end of the century.

It is difficult to make overall cost estimates for STEC. Efficiency of conversion is highly variable, depending upon the design of the heliostat system, receiver system and generators used. In addition, there is no commercial production of STEC components at the moment, and prototype plant costs include research and development.

Molten salt storage for heat rather than electricity is often mentioned in connection with Rankine-cycle STEC. The main problems with this type of storage appear to be economic rather than technical.

A major limitation for STEC use in the Virgin Islands is the need for sufficient amounts of suitable land at affordable prices. STEC requires two square miles of land for each 100 MW of capacity. Potential solar sites for these large-scale generating facilities could be found on the island of St. Croix, but a survey and feasibility study including site-specific insolation measurements is needed.

Some proposed high temperature fluids for heat storage and heat exchange are toxic and could cause injury or fire in the case of accidental release. If solar radiation from the collectors were misdirected, it could also cause serious injury and fires.

Photovoltaics

Photovoltaic (PV) power systems use solid-state semiconductors which convert solar radiation directly into electricity. PV's are reliable, but because of their high cost they have been used only in remote off-grid, installations. PV's are used to power distant weather stations, seismic monitoring equipment, space craft, and satellites.

Nearly all of the photovoltaic devices produced to date have employed very thin (200 to 250 micron) slices of purified, single crystal silicon. They display a conversion efficiency of 10% to 14% and last about 10 years. Further research is expected to raise conversion efficiencies to 18% and to double the lifetime of the cells.

High production costs of silicon solar cells have led to research on other semiconductor materials. The technology is evolving rapidly, and while current capital costs can be set as high as $18,000/KW, it is expected that by 2005 costs will drop to $2,600/KW.

In the meantime, photovoltaic power systems may be used to power drip and trickle irrigation systems in the 1980s. This could find use in the Virgin Islands where electricity costs are high. Grid-connected photovoltaic power systems may be competitive with conventional electric generation by 1990 in isolated areas that now rely on costly diesel fuel. The Virgin Islands which has small, high-cost power grids is a prime candidate for photovoltaic applications.

New toxic semiconductor materials will lead to health hazards in manufacturing and end-use. Land requirements for central station receivers are expected to be similar to those for solar thermal power: about two square miles per 100 MW of capacity.

Hydro-Electric Power

There are a few potential hydropower sites which are undeveloped, and and are found on St. Thomas and St. Croix. These are mainly old and poorly developed dam-sites whose potential vary with seasonal rainfall. There are no natural rivers or large waterfalls for exploitation. A complete feasibility study will have to be undertaken to evaluate the potential of this technology in the Virgin Islands.

Pumped Hydro-Storage

St. Thomas would appear to be an ideal place for pumped storage for peaking power because it has high elevation regions suitable for storage and an ocean nearby. However, if salt water were used, potential problems of salt water intrusion into the fresh water system would reduce the attractiveness of this resource. Despite the existence of promising sites, pumped storage is not expected to occupy a significant place in our future electricity supply system because of frequent power outages and problems meeting peak demand.

Nuclear Power

The only nuclear reactors now available are in the 1,000 MW range, and small reactors will probably not be available in the United States for at least 15 years or longer. Several European corporations have plans to develop small reactors, but their production will depend largely on the development of a market for them in the third world, and the growth of this market is uncertain.

It should be particularly noted that a climate of acceptance for nuclear energy does not prevail in the Virgin Islands. Surmounting political, regulatory and social barriers, plus our lack of technical personnel could consume much of the next five decades. Most importantly, the smallest proposed Nuclear Power Plant(200 MW) already exceeds by far all current and projected requirements of our electric grid.

Electric Vehicles

Since 100% of our electricity is still generated by oil-fired power plants, electric vehicles would use petroleum indirectly, and use it less efficiently than gasoline-powered cars. If alternate energy technologies begin to supply most of our electricity in the 1990s and the current high cost is reduced in

1990 dollars, electric vehicles could reduce oil demand. However, their effect on a subsequent increase in oil-fired peaking power would have to be taken into account.

A second level of problems results from the inadequacies of present batteries. Today's lead-acid battery has 1/1000 the specific energy (Watt-hours/kilogram) of gasoline. State-of-the-art electric vehicles have a range of about 50 miles, and they do not perform well on hilly terrain, common on St. Thomas and St. John. They are small but heavy and cost more than conventional cars.

Once battery technology is advanced enough to make electric vehicles feasible, they might find use in the Virgin Islands because of our short distances travelled. It would take over five years before enough EV's would be in use to affect oil consumption. In addition, all facilities for repair and maintenance, as well as for recharging, will have to be developed.

Solar Ponds

A solar pond is a body of still water that absorbs solar radiation and stores it as thermal energy. This thermal energy can then be used for a variety of purposes including electric power generation and industrial process heating.

If a salt concentration gradient can be maintained between surface and deep water, a pond becomes an efficient solar collector. The gradient at the Salton Sea Project, California is maintained by washing the surface with low-salinity water from the sea adjacent to the pond and pumping concentrated brine through a horizontal diffuser submerged near the pond bottom.

The upper layer collects and the lower layer of the pond stores solar energy with temperatures approaching 90°C (194°F) or more. Evaporation cools the upper layer of the pond so that it serves as the power plant cooling medium and eliminates the need for cooling towers.

The complete system shown in Fig. 2 acquires a more efficient temperature difference than OTEC systems.

Through a heat exchange process in a closed Rankine Cycle system similar to OTEC, electricity is produced. Organic solvents such as Toluene and Carbon Tetrachloride are used as the working fluid instead of Ammonia.

Although there are several natural salt ponds in the Virgin Islands, and cost of electricity produced by this technology is low (8-9¢/kwh), our limited land mass and inclement weather would seriously hinder the development of this concept in the Territory.

Coal

Coal could offer an economically attractive, lower risk alternative to oil. Conventional coal handling and burning technology is well established, and ample coal is available from the United States and foreign sources.

However, for small utilities such as the Water and Power Authority here in the United States Virgin Islands, coal-fired generation will be difficult. The delivered price of coal has become volatile; and capital investment in new conveyors, crushers, storage bins and ash removal systems by WAPA might be prohibitive. Martin Marietta Co. on St. Croix has begun construction of a 15 MW coal-fired plant, but plan to use some of their bauxite handling facilities for the coal.

The use of coal in the Virgin Islands would present difficult air plus water pollution and solid waste problems. Coal-fired power plants would face some public disapproval and resistance from the tourist industry, which depends on our unique environment. Compliance with emission standards might be difficult to achieve at acceptable costs, and the disposal of ash and sludge would be a particularly demanding problem to solve. Coal, like oil, is not a renewable resource, and it too must be imported.

ENERGY CONSERVATION

Virgin Islands energy consumers are far more responsive to high electricity prices (18¢/Kwh) and gasoline prices ($1.60/gal) than to any other conservation pressure. The potential for conserving energy in the Territory must be assessed in terms of our unique energy use pattern. Unlike the rest of the Nation, we

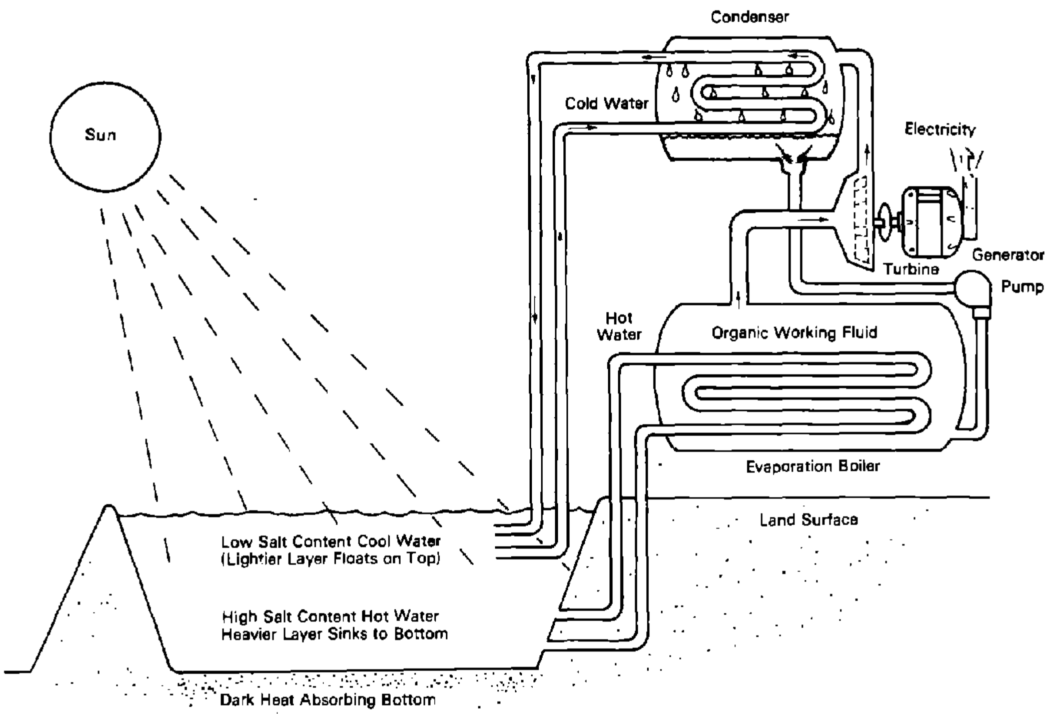

Fig. 2 Solar Pond Generating Concept

use no energy for space heating, and except for the Hess Oil Refinery and Martin Marietta Aluminum Co., we have very little energy-intensive industry.

The Virgin Islands' major conservation savings could be realized in the realms of electricity consumption (65% of total energy use now) and civilian ground transportation (5%). The combined effects of technical innovation in the form of improved energy efficiencies, increased energy prices, and consumers' efforts will change not only the amounts of energy Virgin Islands residents consume, but also the way in which they use it. Estimates of these energy savings are given in a separate section. These assumptions make it possible at least to forecast basic trends in the reduction of energy consumption.

Residential energy use is characterized by an almost complete reliance upon electricity (35% of daily electricity consumption). Heating water is the major residential energy use (35%), followed by refrigeration (20%) and cooking (10%). The introduction of solar water heating, along with energy-efficient electric heat pumps could reduce residential energy use by the year 2005. Other savings will be realized over time as more efficient appliances, including refrigerators, replace existing ones.

Commercial buildings, hotels, and hospitals are almost the only buildings that require space cooling in the Virgin Islands. They use approximately one-third of the total electricity consumed. It is estimated that electricity use in the service sector could decline depending upon the size of expected utility rate increases.

Rising gasoline prices, coupled with a switch to smaller cars is already reducing present gasoline use in the Territory. The development of electric-powered mass transit could further reduce transportation dependence on petroleum fuels.

The Virgin Islands Energy Office (VIEO) has a number of energy conservation programs in effect and their staff monitors and collects energy savings data from these projects. Some of these are summarized and described below and resulting estimated energy savings shown in Table 3.

1. Thermal Efficiency Standard

   This is based on an energy conservation building code which set standards for wall and roof specifications in new and renovated building construction that assures efficiency for air-conditioning and lighting.

2. Solar Hot Water Heating

   This is part of the Schools and Hospital program in which electrical resistance heating used for domestic hot water in eligible institutions is replaced by Thermosyphon Systems.

3. Energy Efficiency Procurement Purchase

   By setting efficiency standards for the purchase of energy-intensive items such as Thru-The-Wall Air Conditioners, Refrigerators, Hot Water Heaters and Automobiles by the Virgin Islands government, one can reduce total energy consumption when these devices are in use.

4. Thermal Window Films

   Application of a thin, dark, polyester film to windows in air-conditioned rooms can reduce the heat gain by the building interior, thereby reducing the air-conditioning load.

5. Roof Insulation

   In the tropics it is estimated tha 90% of the heat gain in a building comes through the roof. Roof insulation therefore becomes an effective method for reducing the air-conditioning load in a building.

6. Industrial Savings

   These are mainly mechanical changes performed at the Hess Oil and Martin Marietta plants on St. Croix to reduce their energy use and overall operating costs. Many of these modifications are trade secrets and VIEO only monitors the resulting savings.

UTILITY ASSESSMENT

There are substantial energy-saving opportunities in the operation of the publicly owned Water and Power Authority (WAPA) of the Virgin Islands. WAPA accounts for nearly one-third of all non-industrial energy consumption in the Virgin Islands and is a prime target for application of commercial-size solar technologies. Although some industries produce their own power and water (notably Hess, Martin-Marietta and Frenchman's Reef Hotel), WAPA is the only producer and distributor for electric power and water for the remainder of the domestic, commercial, industrial, and governmental users. Utility-Interface experimentation with wind machines for example must all be coordinated with this organization.

Although more than sufficient standby capacity is physically available at the plant site, these units are often in a state of disrepair and not available to permit a systematic program for removing major units from service for extended periods. This would be necessary in order to perform the periodic maintenance necessary to achieve peak operating efficiency. Units are often run continuously to the point of failure or fatigue and removed from service only in crisis situations. Having a mixture of diesel, steam and gas generators results in the need for excessive inventory, different operating and maintenance procedures and operator training methods.

Alternative available energy options must be considered if we are to reduce our high electricity costs, import less fuel, and lower consumption. There are only three alternatives which can be applied to WAPA, namely, oil-mixtures, coal or renewable energy. Use of oil-coal mixtures, low grade diesel fuels, or

Table 3 Estimated Savings in Btu for 1981
Virgin Islands Energy Program

Program Measure	Estimated Savings (in Btu's)
Thermal Efficiency Standard	0.08×10^9
Solar Hot Water Heaters	1.4×10^9
Installation of Window Films	3.0×10^9
Insulation	0.75×10^9
Procurement	2.3×10^5
Carpooling/Vanpooling	288×10^9
Left Turn on Red	3.99×10^9
Emergency Building Temperature Restriction Program	38×10^9
Industrial	$44,667 \times 10^9$

burner-modification to burn 100% coal, need to be considered, however these options will save money, not BTU's.

Energy alternatives such as solar and wind are being commercialized on a large scale and can offer near-term solutions to WAPA. However, these technologies can offer immediate economic relief to the homeowner and small businessman for they are very effective in small applications and if installed in large quantities can serve to reduce the peak demand of our utility and allow them to operate more efficiently.

Once WAPA's actual generating system is completely rehabilitated, the next step is to plan for the generation additions that will be required in the years to follow.

The main objective of generation planning is to determine the generating capacity required to satisfy the electrical load in a reliable manner during a given period of time. One of the most up to date approaches for fulfilling this objective is to rely on probability analysis to calculate the risk of not being able to meet the forecasted peak demands.

In any electrical system, its generating capacity can be divided into two parts; one part is used to supply the demand for energy, and the other is maintained as a reserve. This reserve is required to:

1. Provide maintenance to the generating units.
2. Account for the forced outage of units.
3. Account for the partial outages (units on limitation).
4. Provide an additional reserve for absorbing variations in any of the above items.

To accurately assess the need for new generating capacity using this approach, it is necessary to add the reserve requirements and the peak demand figures and compare this total to the installed generating capacity when it is really needed without over-building the system. This minimizes the economic burden on WAPA in that it avoids the extremely high cost of installing too much capacity. However, there is a disadvantage and it is that an underestimated load forecast may force WAPA to install short load time generating units such as gas turbines or diesel units.

One of the cornerstones of any generation expansion evaluation is a forecast of the electrical loads to be expected throughout the period of time to be analyzed. Also important are the expected costs of the fuels to be considered. As examples of the latter, there are the capital investment costs, operation and maintenance costs (O&M), forced outage rates, and unit heat rates.

The physical separation between St. Thomas and St. Croix, and the depth of intervening water, make interconnection of an electric grid near impossible. As a result, each of the two islands must have its own power and water systems. St. John's modest power needs are provided by underwater electric power cable from St. Thomas as well as 1.5 MW of standby capacity as a result of a diesel generator on that island. The diversified composition of each of the two grids is shown in Tables 4 and 5 below.

Gross electrical consumption in the Virgin Islands remained relatively constant between 1971 and 1976. There was an increase in consumption patterns between 1976 and subsequent years; however, the change was not very significant (3%). Peak demand in St. Thomas was constant from 1971 to 1977 when a slight increase occurred. St. Croix's peak demand pattern was constant throughout the 10-year period.

Electrical consumption on St. Croix remained lower (up to 25%) than St. Thomas throughout the 10-year period.

Below is 8-year fuel consumption data for WAPA that was helpful in the analysis of a generation profile. We currently spend the equivalent of 20% of the total budget of the Virgin Islands government (or $38M) for the purchase of fuel for our utility. As was mentioned earlier, plant efficiency is poor, therefore our fuel consumption is high and needs to be reduced through improved operations and renewables. Figures are collected July 1 through June 30 of the following year. The consumption figures appear to be around 1.15M bbls/yr until July 1980 when there was a sizeable increase. If fuel consumption continues at the present rate, the 1980-81 year will be 2.5M barrels, almost double the 1974-79 average. This is due to the fact that gas turbines have been operating more frequently than Unit 13 and they burn more fuel and are less efficient.

UTILITY CONSUMPTION DATA

*Fiscal Year	Fuel Consumption (x1000 bbls)
1974	1,102
1975	1,114
1976	1,076
1977	1,112
1978	1,095
1979	1,274
1980	1,273
July 1980-Feb 1981	1,847

*July to June

Table 4 St. Thomas-St. John Electric Grid†

Generating Unit	Year Installed	Design Capacity (MW)	**Current Capacity
No. 7 - Diesel*	1966	2.0	1.7
No. 9 - Diesel	1960	3.0	-
No. 10- Steam	1966	7.5	6.5
No. 11- Steam	1968	18.0	14.0
No. 12 - Gas	1970	15.0	13.0
No. 13- Steam	1974	3.0	26.0
No. 14 - Gas	1971	15.0	12.5
No. 15 - Gas	1981	20.0	21.0

*Standby Only.

**As of April 1, 1981.

†Currently there is a total of approximately 116 MW design capacity available, seventy-four (74) MW of which is available on a day-to-day basis to meet a peak demand of 42 MW.

Table 5 St. Croix Electric Grid†

Generating Unit	Year Installed	Design Capacity (MW)	*Current Capacity
No. 6 - Diesel*	1969	4.5	4.0
No. 7 - Diesel	1962	2.2	-
No. 10 - Steam	1967	7.5	7.5
No. 11 - Steam	1970	18.0	18.0
No. 12 - Diesel	1968	4.5	4.0
No. 13 - Gas	1971	15.0	-
No. 14 - Gas	1972	15.0	-
No. 16 - Gas	1981	2.0	21.0

*As of April 1, 1982.

†The St. Croix grid has a total of 67 MW to meet a daily peak demand of 32 MW. The power generating capacity currently available is only 34 MW, and actual operating capacity is just 33 MW. Small losses in power generating efficiency often result in power rotation or complete outages.

Table 6 10-Year Power Generation Profile of Virgin Islands Utility

Year	Gross Elec. STT-SJ	Gen (10^3MW) St. Croix	Total (10^3MW) Consumption	Avg. Peak Demand (MW) STT-SJ	Avg. Peak Demand (MW) St. Croix
1971	177	152	329	27	24
1972	193	174	367	29	28
1973	211	184	395	33	28
1974	206	185	391	32	29
1975	213	186	399	32	29
1976	215	184	399	33	28
1977	226	189	415	34	30
1978	240	199	439	37	30
1979	254	191	445	40	31
1980	261	192	443	40	20

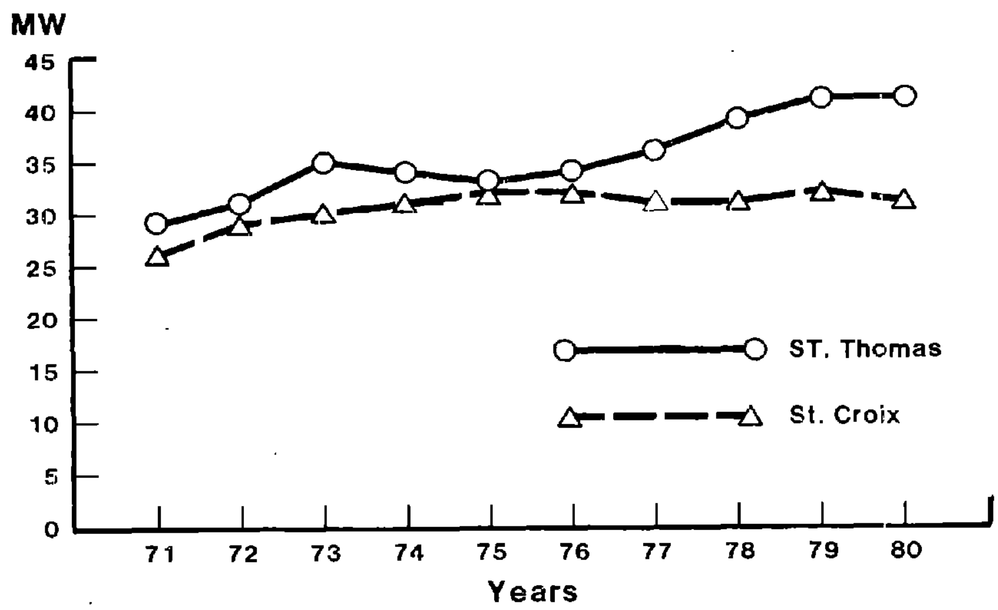

Fig. 3 WAPA Peak Load by Year (1971-1980)

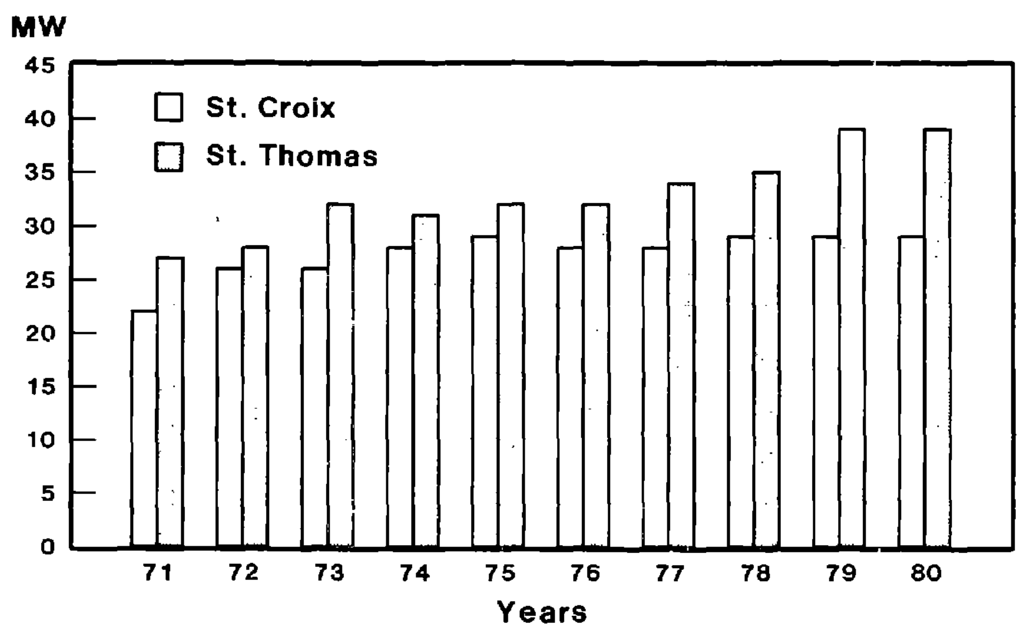

Fig. 4 WAPA Average Peak Loads (1971-1980)

PART II: SUPPLEMENTAL ANALYSIS OF ENERGY IN PUERTO RICO AND THE UNITED STATES VIRGIN ISLANDS

CONTENTS

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CONTENTS (Cont'd)

1 INTRODUCTION

This report presents additional data and analyses of the contributions of current and potential future energy resources to meeting the energy demands in Puerto Rico and the Virgin Islands, and is intended to supplement the reports (Section I) prepared by the Puerto Rico Office of Energy[1] and the Virgin Islands Energy Office[2] in support of the second phase of the Territorial Energy Assessments (TEA). The additional information presented here was developed from the reports of the first phase of the TEA[3] and from documents referenced herein.

This section also attempts to distill all the available information into a concise picture of the energy situation in the islands and suggests certain specific actions which should be considered in implementing a comprehensive energy plan. Because information has been drawn from studies done at different times by different organizations, it has been necessary to deal with the problem of inconsistent and sometimes conflicting data. To the extent possible, these inconsistencies have been either resolved or presented side by side for comparison. Nevertheless, the specific actions suggested are based on best technical judgments after weighing all available data and information.

2.1 DESCRIPTION OF THE ISLAND

The Commonwealth of Puerto Rico is a hilly, tropical island lying between the Atlantic Ocean to the north and the Caribbean Sea to the south (see Fig. 2.1). It is the easternmost of the West Indies group called the Greater Antilles. Puerto Rico consists of numerous small islands, including Vieques, Culehbra, and Mona, and the main island, which measures 35 miles wide and 105 miles long.

The population of Puerto Rico is 3,186,076 (1980 census). Four cities have populations over 100,000, including San Juan (the capital) with a population of slightly over 1,000,000; Ponce at 252,000, Caguas at 174,000; and Mayaguez with 133,000.

On July 3, 1950 the United States Congress adopted an Act (Public Law No. 600) that was to allow "the people of Puerto Rico to organize a government pursuant to a constitution of their own adoption." This Act was submitted to the voters of Puerto Rico and accepted in the summer of 1951. A new constitution was drafted in which Puerto Rico was styled as a commonwealth, or Estado Libre Asociado, "a state which is free of superior authority in the management of its own affairs" though it remained in association with the United States. This constitution was ratified by the people of Puerto Rico in 1952, and following approval by the Congress of the United States, the Commonwealth of Puerto Rico was established on July 25, 1952.

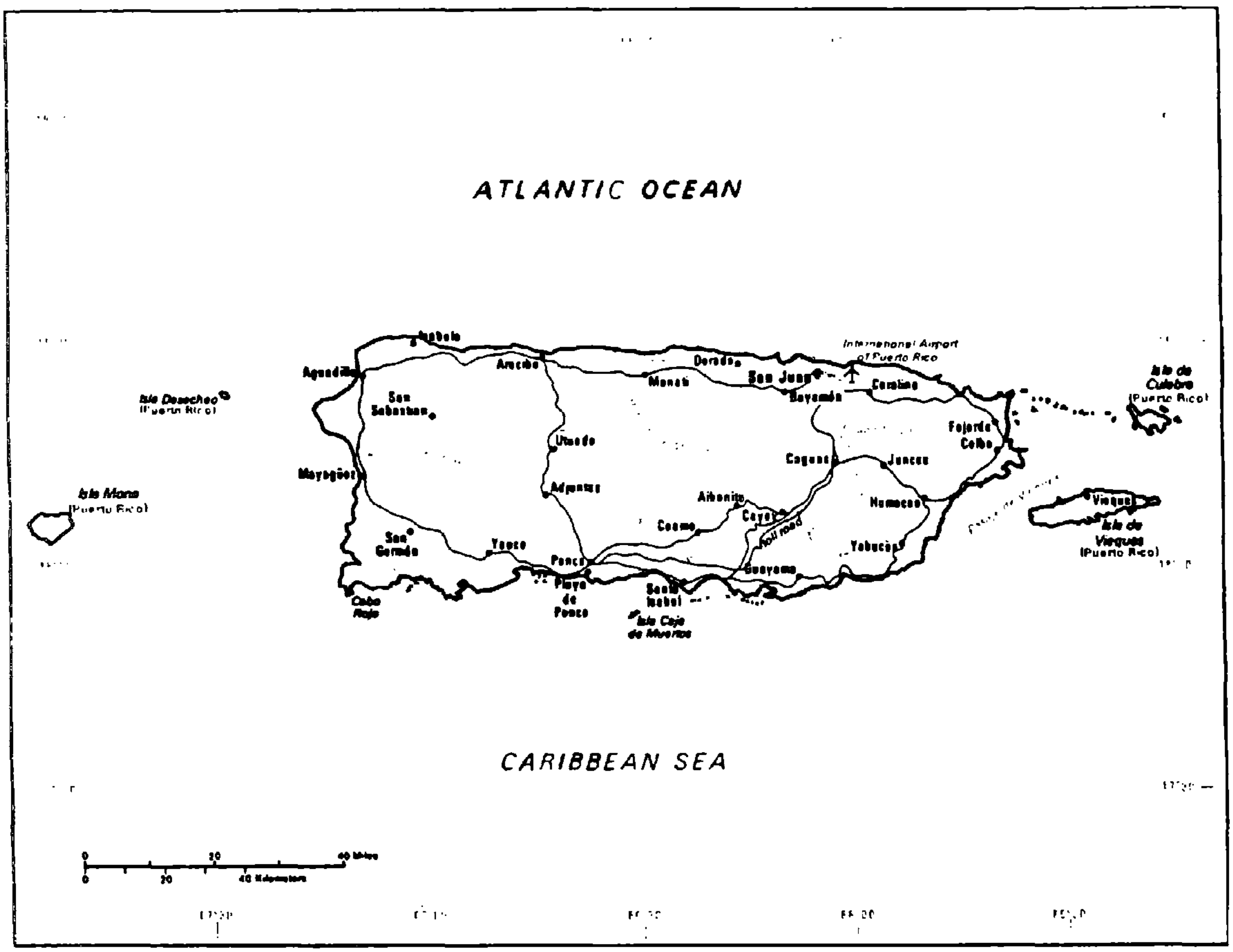


Fig. 2.1 Commonwealth of Puerto Rico

Under the terms of political and economic union between the United States and Puerto Rico, U.S. citizens in Puerto Rico enjoy the same privileges and immunities they would if Puerto Rico were a member state of the Union. Puerto Ricans are citizens of the United States and may freely enter and leave the mainland.

Puerto Ricans elect their own governor, legislature, mayors, and municipal assembly representatives. They have no vote in national elections and no voting representation in Congress. However, Puerto Rico participates in the House of Representatives through a Resident Commissioner, who has a vote in House Committees and caucuses of which he is a member but has no floor vote. Puerto Rico has a bicameral legislature consisting of a Senate of 27 members and a House of Representatives of 51 members who are elected to four-year terms concurrent with the Governor.

Puerto Rico is exempted from the tax laws of the United States. The U.S. social security system is extended to Puerto Rico except for unemployment insurance provisions. The laws providing for economic cooperation between the Federal Government and the states of the Union for the construction of roads, schools, etc., apply to Puerto Rico and are administered by the Commonwealth Government. Puerto Ricans do not pay federal income tax but are subject to most federal laws. The Puerto Rican government imposes its own personal and corporate income taxes.

2.2 THE ECONOMY

The following sections will describe the current economy of Puerto Rico, the perspective on growth and the current and possible future energy demands of the economy.

2.2.1 Current Situation

Puerto Rico, with its per capita personal income of $3,724 in 1981 (all economic data are for fiscal year ending June 30) qualifies as an industrial and modern economy.[1] The structure of the economy has been transformed from its agriculture orientation to manufacturing over the years. A brief overview of the economic development pattern is provided below.

Until the 1940s the economy was dominated by the agriculture sector and its related industries. In 1940 the agriculture sector accounted for 45% of the total employment in the economy.[2] Realizing the urgency of industrialization, the Puerto Rico Government initiated a program known as "Operation Bootstrap" in 1948.[3] Under this program outside investment was sought through financial incentive schemes that included exemption from Puerto Rico corporate income and property taxes. Together with the benefits of federal tax exemption and lower wages in Puerto Rico, a remarkable growth in the economy was achieved between 1950 and 1970. Figs. 2.2.1-1 to 2.2.1-4 and Table 2.2.1-1 show changes in key macro economic indicators over the last thirty years.

Real Gross Product

The real gross product grew 6.2% annually between fiscal 1950 and 1970. The high growth era continued from 1970 to 1973 as real gross product increased at an average annual growth rate of 5.9%. This dramatic growth rate was slowed down as a result of sharply higher prices of OPEC crude oil, and the slowdown in the U.S. economy. The real gross product increased only by 1.3% in fiscal 1974. As recession worsened in the U.S. economy, Puerto Rico experienced its first reversal in modern history as the real gross product declined by 2% in fiscal 1975. As shown in Fig. 2.2.1-1, the economy never captured its pre-recession growth rate of 7.3% in fiscal 1973. Along with the U.S. economy, Puerto Rico's economy grew 2.1% in fiscal 1976, 4.5% in 1977, 4.8% in 1978 and 5.9% in 1979. As a result of another OPEC shock in the 1979-80 period and the 1980 recession in the U.S. economy, Puerto Rico's economy also faltered. The gain in real gross product was 2.3% in fiscal 1980 and 0.7% in 1981. According to preliminary statistics of the Puerto Rico Planning Board, the island's economy suffered a drop in real growth of 3.9% in fiscal 1982.[4] At present, Puerto Rico's economy seems to mirror the current recession in the U.S. economy.

In spite of the setbacks in the economic growth rates during the last ten years (including two unprecedented recessions), Puerto Rico's economy has made major strides between 1950 and 1980. The island's real gross product increased 4.7 times during this period. The average standard of living has been boosted significantly as characterized by more than three-fold increase in the per capita real gross product between 1950 and 1980 (Fig. 2.2.1-2). In fiscal 1980, Puerto Rico gross product stood at $11.0 billion (equivalent to per capita gross product of $3475).

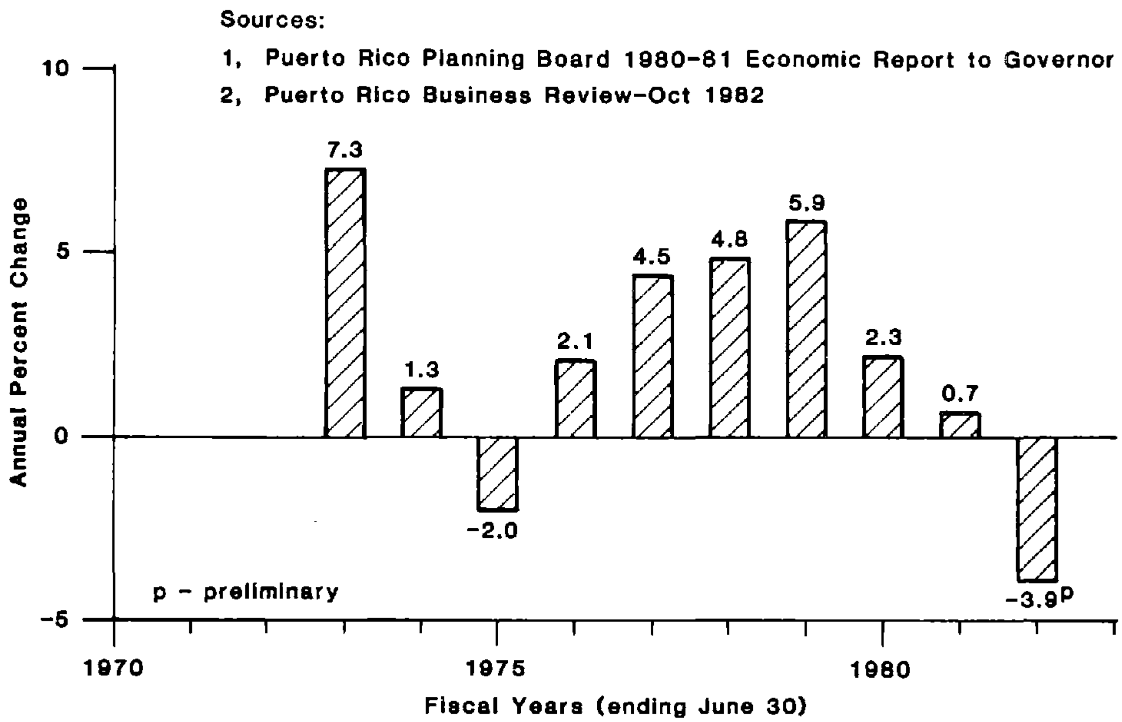


Fig. 2.2.1-1 Economic Growth of Puerto Rico - Real Gross Product

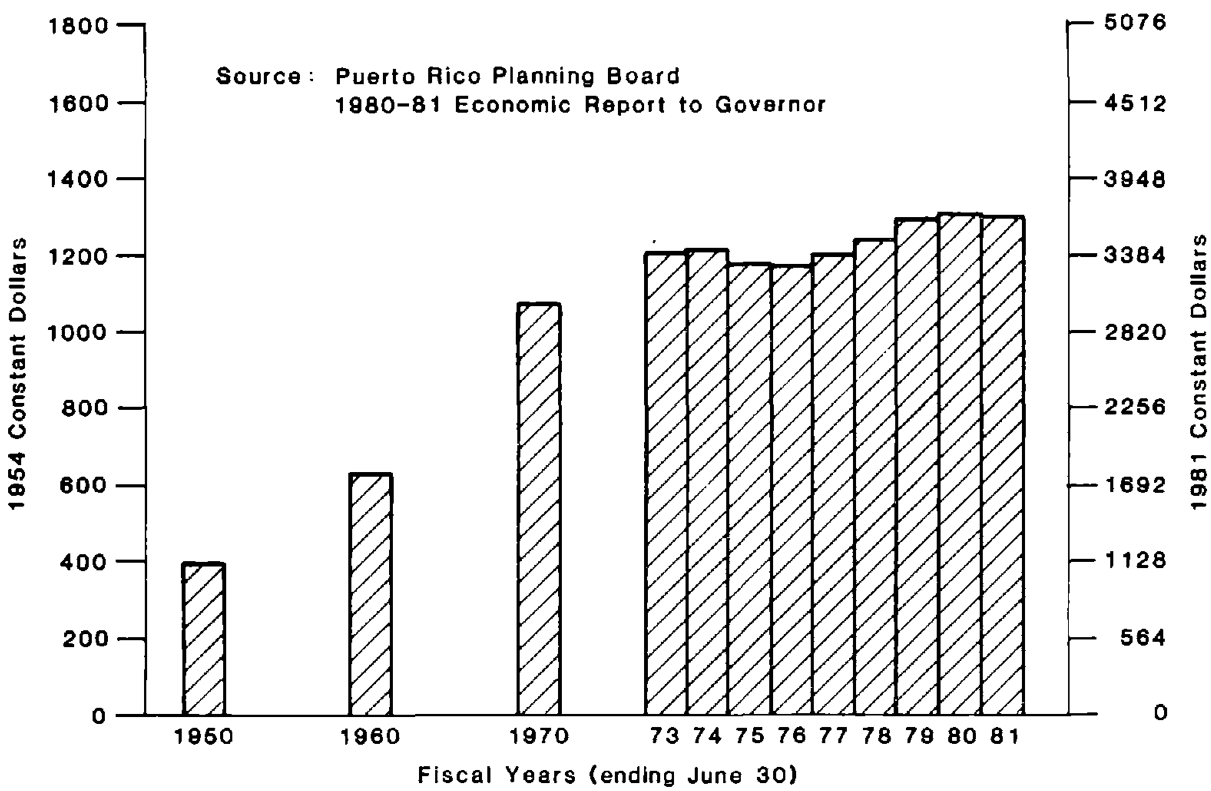


Fig. 2.2.1-2 Per Capita Gross Product of Puerto Rico

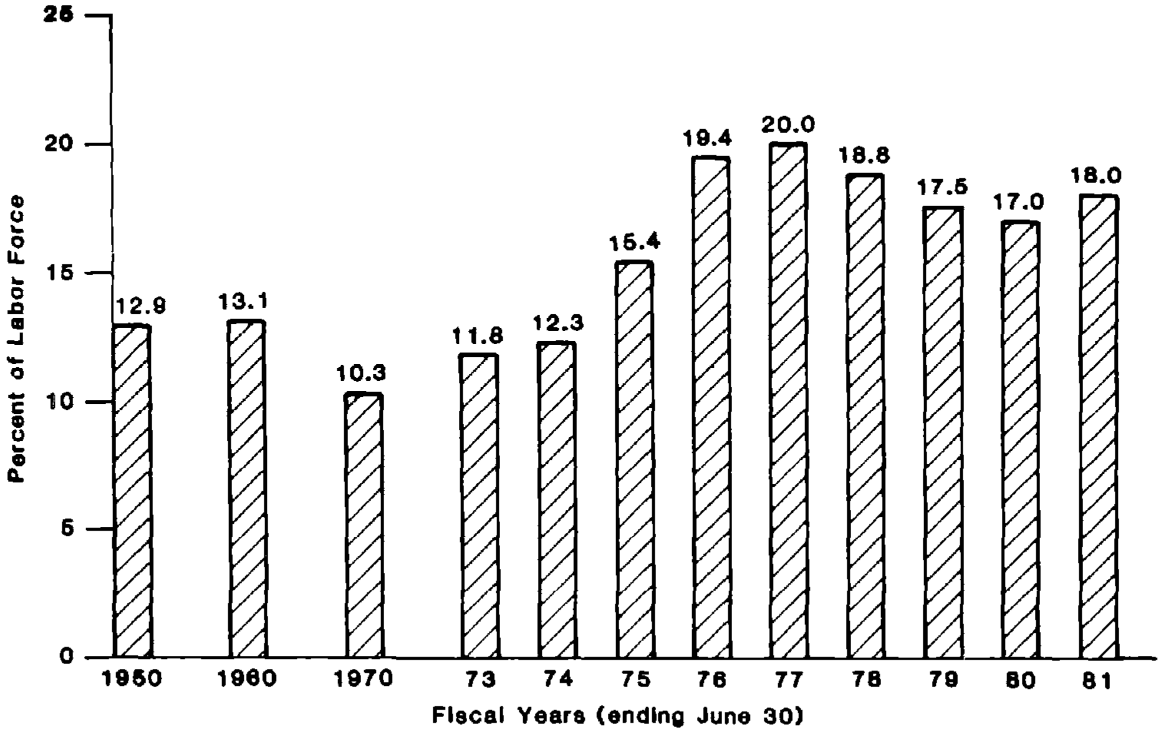


Fig. 2.2.1-3 Unemployment Rate of Puerto Rico

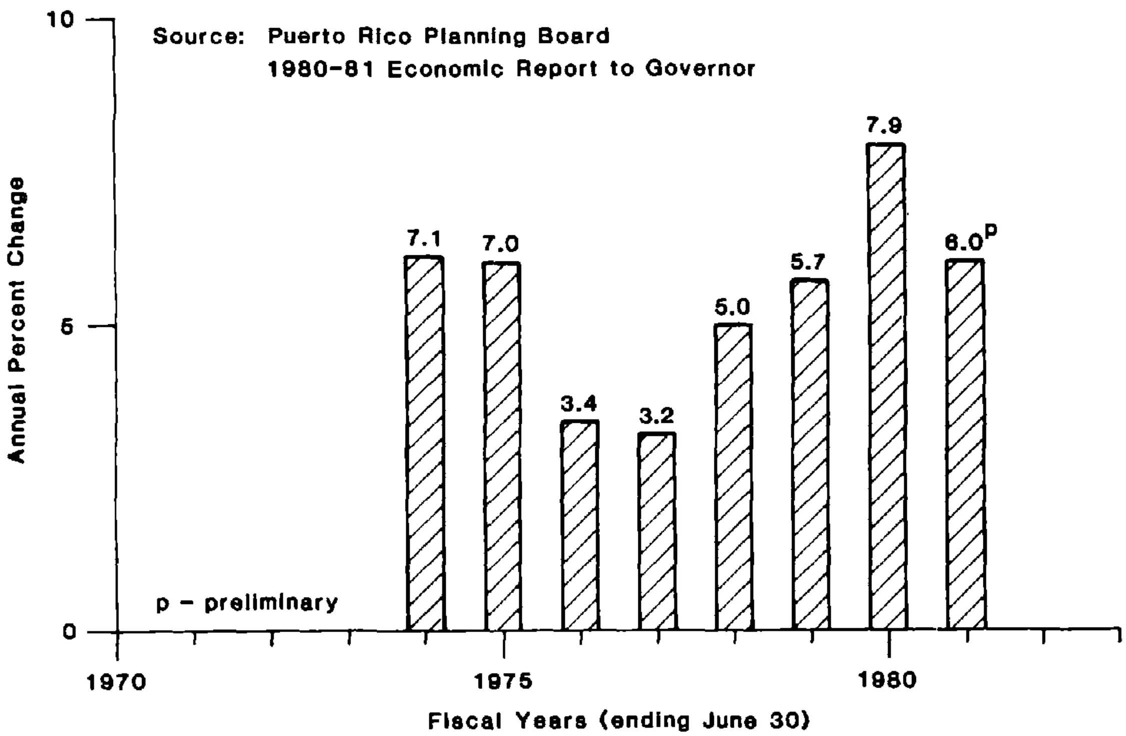


Fig. 2.2.1-4 Inflation in Puerto Rico - Implicit Price Deflator of Gross Product

Table 2.2.1-1 Historical Overview of Puerto Rico's Economy – Key Macro Economic Indicators[a]

	(Fiscal Years Ending June 30)											
	1950	1960	1970	1973	1974	1975	1976	1977	1978	1979	1980	1981
Personal Consumption	662	1,398	3,746	5,222	5,690	6,390	7,361	8,167	9,043	9,843	10,929	12,155
Government Consumption	86	218	765	1,231	1,326	1,612	1,616	1,728	1,877	2,025	2,245	2,513
Gross Fixed Investment[b]	111	355	1,402	1,603	1,677	1,907	1,784	1,536	1,735	1,865	2,030	2,121
Inventory Investment	1	42	50	188	148	336	386	176	175	151	408	327
Net Exports	-105	-336	-1,276	-1,975	-2,044	-3,116	-3,620	-3,490	-3,897	-3,891	-4,580	-5,345
Gross Product	755	1,676	4,687	6,270	6,798	7,129	7,527	8,116	8,932	9,993	11,031	11,771
Real Gross Product (1954 $)	879	1,473	2,901	3,450	3,494	3,422	3,494	3,652	3,827	4,052	4,146	4,174
Personal Income	653	1,374	3,753	5,336	5,894	6,843	7,644	8,134	8,947	9,894	10,934	11,984
Disposable Personal Income	638	1,333	3,564	5,040	5,564	6,446	7,182	7,601	8,461	9,336	10,314	11,271
Implicit Price Deflator of Gross Product (1954=100.0)	85.9	113.9	161.6	181.7	194.6	208.3	215.4	222.2	233.4	246.6	266.0	282.0
Unemployment Rate (%)	12.9	13.1	10.3	11.8	12.3	15.4	19.4	20.0	18.8	17.5	17.0	18.0
Total Employment (1,000)	596	543	686	757	775	738	718	735	780	807	826	833
Population (1,000)	2,206	2,342	2,711	2,866	2,878	2,911	2,974	3,040	3,091	3,133	3,174	3,218
Number of Visitors (1,000)	--	347	1,088	1,322	1,441	1,339	1,299	1,326	1,474	1,662	1,679	1,517
Net Receipts From Federal Government, State Governments and Non-residents (Million Dollars)	63	50	80	199	223	599	1,036	1,121	1,359	1,465	1,617	1,815
Per Capita Gross Product – (dollars)	342	716	1,729	2,188	2,362	2,449	2,530	2,670	2,890	3,190	3,475	3,658
– (constant 1954 $)	399	630	1,070	1,204	1,214	1,176	1,174	1,201	1,238	1,293	1,306	1,297

[a]Source: "Economic Report to the Governor: 1980-81", Area of Economic Research and Evaluation, Puerto Rico Planning Board, Puerto Rico.

[b]Addition of Gross Fixed Domestic investment and Maritime Shipping Authority investment.

Employment and Unemployment Rate

As the economic development came about, the number of employed persons increased from 596,000 in fiscal 1950 to 826,000 in 1980.[5] However, the labor force increased much more rapidly in the same period. This resulted in a much higher unemployment rate. As shown in Fig. 2.2.1-3, the unemployment rate was 12.9% in fiscal 1950, 13.1% in 1960 and 10.3% in 1970. This high unemployment rate became even worse after the economy experienced its first recession in 1975. During the period of 1975-81, the average annual unemployment rate remained in the range of 15.4 to 20.0%.

Inflation

The inflation in the economy (as measured by the implicit price deflator of gross product) has remained in quite an acceptable range. During the high growth period of fiscal 1950-73, the average annual price increase was 3.3%. However, the average annual price increase was 5.5% in the subsequent period of fiscal 1973-80. The annual price changes were relatively higher in fiscal 1974-75 and 1980-81 periods which also included large OPEC crude oil price increases (Fig. 2.2.1-4). Puerto Rico's economy is heavily dependent on the imported crude oil that provides almost all primary energy needs of the Island.[6]

Composition of Gross Product

Based on the data from the Puerto Rico Planning Board 1980-81 Economic Report to the Governor, Table 2.2.1-2 provides the distribution of Puerto Rico gross product by major industrial sectors.[7] The shift in the structure of the economy is captured by the facts that the agriculture share of gross product declined from 17.5% in fiscal 1950 to only 3.4% in 1980, and the manufacturing share of gross product rose from 15.9% in 1950 to 44.2% in 1980. This increase in the manufacturing sector has made Puerto Rico's economy more capital intensive over the years.

The other sectors that had above average growth included transportation and other public utilities (8.1% share of gross product in fiscal 1950 vs 11.4% share in fiscal 1980), trade (19.1% share in 1950 vs 20.2% share in 1980); finance, insurance and real estate (9.9% share in 1950 vs 13.9% share in 1980),

Table 2.2.1-2 Puerto Rico Gross Product by Major Industrial Sector[a]

	Percentage for Fiscal Year (ending June 30)				
	1950	1960	1970	1980	1981
Gross Product	100.0	100.0	100.0	100.0	100.0
Agriculture	17.5	9.8	3.4	3.4	3.2
Manufacturing	15.9	21.9	25.4	44.2	42.9
Contract Construction and Mining	4.0	6.0	8.1	3.4	3.2
Transportation and Other Public Utilities	8.1	9.3	9.4	11.4	11.5
Trade	19.1	19.0	19.2	20.2	20.3
Finance, Insurance and Real Estate	9.9	11.8	13.1	13.9	13.5
Services	5.9	8.4	10.9	12.3	12.5
Local Governments (Commonwealth, Municipalities)	10.0	11.2	13.0	17.2	17.3
Federal Government[b]	6.1	4.7	3.4	2.3	2.5
Other Nonresidents[c]	-2.0	-5.6	-10.8	-28.6	-26.9
Statistical Discrepancy	5.5	3.5	4.9	0.2	0.0

[a]Based on data from Puerto Rico Planning Board 1980-81 Economic Report to the Governor, p. A-5.

[b]Wages, salaries, and supplements paid by Federal Government.

[c](Factor income received from the rest of the world) - (Factor income paid to the rest of the world).

services (5.9% share in 1950 vs 12.3% in 1980), and local Commonwealth and municipalities governments (10% share in 1950 vs 17.2% in 1980.

The sectors that had below average growth included agriculture (17.5% share of gross product in fiscal 1950 vs 3.4% share in 1980) and Federal Government payments of wages, salaries and supplements (6.1% share in 1950 vs 2.3% share in 1980).

Miscellaneous

Puerto Rico attracted a greater number of tourists after the Cuban crisis in the early 1960s. The number of tourists increased from 347,000 in fiscal 1960 to 1,088,000 in 1970.[8] The visitors spent $615.4 million in fiscal 1980.[8] This amounted to a very significant share (5.6%) of gross product in fiscal 1980.

Total net balance (total receipts-total payment) of transfers between Puerto Rico and the Federal Government, state governments, and other non-residents have also seen an increase from $49.6 million in fiscal 1960 to $1,815 million in 1981. This net balance corresponded to a 3.0% share of gross product in fiscal 1960 to a 16.5% share in 1980, showing a greater influence of these transfer payments on the Puerto Rican economy.

2.2.2 Prospects for Growth

Having established Puerto Rico's economic past trends, the projections of future economic growth and the related energy implications must be developed. This section addresses the issues of economic growth scenarios for Puerto Rico.

Development Policy and Goals

Puerto Rico does not have any formal economic development plan providing specific projections or targets for individual sectoral growth rates or for the island as a whole. The Puerto Rico Planning Board has the jurisdiction on this issue and it provides economic guidelines to various government agencies from time to time. In fact, the Government of Puerto Rico has played a critical role in the development of the economy. The most important of all initiatives was the 1948 enactment of the highly successful program known as "Operation Boot Strap." The private sector development has been aided by local financial incentives to encourage investment, primarily by mainland corporations. Over the years, Puerto Rican development has come about as a result of the free market process, government guidelines and supportive legislation, and other financial incentives. It is reasonable to expect that the cooperative approach, which has made Puerto Rico's economy modern over the last thirty years, will continue in the future.

Macroeconomic Development Scenarios

As with any long-range forecasting, there is uncertainty as to how Puerto Rico's economy will develop in the next four decades. For the purpose of this report, two alternative scenarios have been derived from the report "Energy in Puerto Rico's Future" prepared by the National Academy of Sciences (NAS) in 1980.[1] This study provided certain economic projections to the year 2000. Economic data for the period 2000-2020 have been extrapolated from this information. The NAS assumptions and economic projections to year 2000 are:

A. Basic Assumptions - The economic projections were developed through the analysis of past economic trends. Several key assumptions were made:[2]

   1. The partial tax exemption for attracting outside investment will continue to be in force to the year 2000.

   2. The projections recognize that Puerto Rico is basically a region within the U.S. economy. As such, the forecast of the U.S. economy was derived by the National Academy of Sciences from the well-known Wharton Annual Model. The projected U.S. economy growth rates were 2.6% in 1979-85 period, 2.8% in 1985-90, and 2.9% in 1990-2000. (The actual average annual growth rate of U.S. economy was 3.2% in 1979, -0.2% in 1980 and 1.9% in 1981.[3])

3. In spite of the mainland minimum wage rate being applicable to Puerto Rico, the existing difference between the average U.S. wage rate and the average Puerto Rico wage rate will continue to prevail, except for the extremely labor-intensive industries (such as apparel and textiles.)

4. No major revision will take place in the present tax system.

5. Transfer payments from the Federal Government will grow but at a lower rate than in the past.

B1. "High Growth" Economic Projections: 1978-2000 - The study documented that Puerto Rico's economy has grown more rapidly than that of the United States mainland. For example, the Puerto Rican gross domestic product growth averaged 3.6% annually compared to 2.9% in the mainland gross national product between 1970 and 1978. On the basis of this relatively higher growth rate in Puerto Rico and the assumptions discussed above, the study estimated that growth rates for Puerto Rican gross domestic product would be 4.0% for 1979-85, 3.8% for 1985-90, and 5.7% for 1990-2000.[4] The projections of gross product by major sectors for 1985-2000 are shown on Table 2.2.2-1, which is the same as "Case A" of the NAS study report[5]. The corresponding growth rates are shown on Table 2.2.2-2.

The projections are based on the expectations that capital-intensive industries will experience a significant increase in employment as well as in real output. Pharmaceuticals is expected to be a leading

Table 2.2.2-1 Projections for Gross Product by Major Sectors - (High Growth Scenario)

Sector	Amount (millions of 1978 dollars)				
	1978	1985	1990	2000	2020
Agriculture	303[a]	365[a]	407[a]	505[a]	780
Manufacturing	3,785[a]	5,370[a]	6,673[a]	10,092[a]	22,979
Construction	339[a]	381[a]	425[a]	528[a]	816
Transportation and other public utilities	969[a]	1,261[a]	1,520[a]	2,160[a]	4,382
Trade	1,810[a]	2,319[a]	2,742[a]	3,768[a]	7,075
Finance, insurance, and real estate	1,110[a]	1,361[a]	1,583[a]	2,169[a]	4,072
Services	1,141[a]	1,623[a]	2,043[a]	3,190[a]	7,842
Government	1,558[a]	1,814[a]	2,073[a]	2,705[a]	4,609
Subtotal (Gross Domestic Product)	11,014[a]	14,494[a]	17,465[a]	25,117[a]	52,555
Rest of the World	-2,026[b]	-2,666	-3,213	-4,621	-9,557
Total (Gross Product)	8,988	11,828	14,252	20,496	42,998

[a]Source: Energy in Puerto Rico's Future, National Academy of Science (1980). Table 10 (Case A).

[b]Source: Economic Report to the Governor: 1980-81, Puerto Rico Planning Board.

Notes: (1) Fiscal 1978 date is actual. May have been revised by Puerto Rico Planning Board.
(2) Projections based on average annual growth rates in Table 2.2.2-2.
(3) See footnote on "Rest of the World" category in Table 2.2.2-1.
(4) 100 constant 1978 dollar = 42.8 constant 1954 dollars = 120.8 constant 1981 dollars.

Table 2.2.2-2 Projections of Annual Growth Rate of Real Gross Product - High Growth Scenario

Sector	Growth Rate, %			
	1978-1985	1985-1990	1990-2000	2000-2020[b]
Agriculture	2.7[a]	2.2[a]	2.2[a]	2.2[b]
Manufacturing	5.1[a]	4.4[a]	4.2[a]	4.2[b]
Contract, construction and mining	1.7[a]	2.2[a]	2.2[a]	2.2[b]
Transportation and other public utilities	3.8[a]	3.8[a]	3.6[a]	3.6[a]
Trade	3.6[a]	3.4[a]	3.2[a]	3.2[b]
Finance, insurance and real estate	3.0[a]	3.1[a]	3.2[a]	3.2[b]
Services	5.2[a]	4.7[a]	4.6[a]	4.6[b]
Government	2.2[a]	2.7[a]	2.7[a]	2.7[b]
Subtotal (Gross Domestic Product)	4.0[a]	3.8[a]	3.7[a]	3.7
Rest of the World[c]	4.0	3.8	3.7	3.7[b]
Total (Gross Product)	4.0	3.8	3.7	3.7

[a]Source: Energy in Puerto Rico's Future, National Academy of Science (1980). Table 11 (Case A).

[b]The sectoral gross product to grow at the 1990-2000 average annual rate.

[c]This "Rest of the World" category consists of three sectors: (1) Wages, salaries and supplements paid by Federal Government, (2) Other factor income received from the rest of the world, and (3) less factor income paid to rest of the world. Assumed to grow at the rate of gross domestic product.

industry followed by nonelectrical machinery. However, the construction activity is to be below average, thereby dimming the outlook for stone, clay, glass and concrete products. On an overall basis, the manufacturing sector will show an average annual increase of 4.6% compared to 3.8% for gross domestic product in the forecasting period of 1978-2000. The Services sector also shows an above average annual growth rate (4.8% between 1978 and 2000), creating new job opportunities.

The performance of trade and other key private sectors is expected to be at par with the growth rate of overall economy. Below average performance is expected for the agriculture sector with its average growth rate of 2.3% in the planning period 1978-2000 (compared to 3.8% for gross domestic product).

The labor-intensive industries are expected to show declines as Puerto Rico's economy becomes more modern and industrialized. According to the projections, real output and employment will continue to decline in the tobacco, textile, apparel, furniture and leather industries.

In order to estimate the real gross product, the real gross domestic product ($11,014 million in fiscal 1978) is added to the gross product under the category of "Rest of the World".[6] This "Rest of the World" value was obtained by adding the wages, salaries and supplements paid by Federal Government (as an example, $248 million in fiscal 1978) to the factor income received from the rest of the world ($262 million in fiscal 1978) and subtracting the factor income paid to the rest of the world ($2536 million in fiscal 1978).[7] A Puerto Rico real gross product of $8,988 was thus estimated for fiscal 1978. Furthermore, it was assumed that this "Rest of the World" category would grow at the overall growth rate of the gross domestic product. The real gross product in 1978 constant dollars was, therefore, $14,252 million by 1990 and $20,496 million by 2000. This is equivalent to real gross product growth rates of 4.0% for 1979-85, 3.8% for 1985-1990, and 3.7% for 1990-2000.

B2. "High Growth" Economic Projections: 2000-2020 - Beyond 2000, the various sectors of Puerto Rico's economy are assumed to continue to grow at the rates established during

1990-2000 period (NAS Report, Case A). Table 2.2.2-2 provided these sectoral growth rates. Based on these projections, the real gross product of Puerto Rico reaches $42,998 millions in 1978 constant dollars by 2020. The average growth rate of gross product is estimated to be 3.7% between 2000 and 2020.

C1. "Low Growth" Economic Projections: 1978-2000 - In order to have a range of plausible economic outlooks, an alternative scenario was derived from the NAS report (Case B).[8] This scenario shown in Tables 2.2.2-3 and 2.2.2-4 and is based on a more pessimistic view for Puerto Rico. The manufacturing sector growth is lower because of expected higher energy, transportation and labor costs. The agriculture and construction sectors hardly grow in the period of 1978-2000. Because of the weaker economy, emigration to the mainland picks up, thereby reducing the population growth. The study estimated that Puerto Rico's gross domestic product will grow only at 2.8% for 1978-85 (compared to 4.0% under High Growth Case), 2.6% for 1985-90 (compared to 3.7% under High Growth Case). By following the same methodology as for the "High Growth" scenarios, the Puerto Rico gross product is projected for 1978-2000 (by adding "Rest of the World" category gross product to gross domestic product). The Puerto Rico gross product increases from $8,988 million in fiscal 1978 to $10,880 million (constant 1978 dollars) in 1985 to $12,385 million in 1990 and $15,806 million in 2000.

C2. "Low Growth" Economic Projections: 2000-2020 - Similar to the "High Growth" scenario, the sectors of Puerto Rican economy are assumed to continue to grow at the rates established during the 1990-2000 period into the 2000-2020 period. Table 2.2.2-4 shows these sectoral projections. Accordingly, the real gross product of Puerto Rico reaches

Table 2.2.2-3 Projections for Gross Product by Major Sectors - Low Growth Scenario

Sector	Amount (millions of 1978 dollars)				
	1978	1985	1990	2000	2020
Agriculture	303[a]	334	353	394	481
Manufacturing	3,785[a]	4,848	5,702	7,663	13,840
Construction	339[a]	361	381	429	545
Transportation and other public utilities	969[a]	1,176	1,337	1,695	2,724
Trade	1,810[a]	2,137	2,383	2,905	4,317
Finance, insurance, and real estate	1,110[a]	1,266	1,391	1,679	2,446
Services	1,141[a]	1,522	1,808	2,501	4,788
Government	1,558[a]	1,694	1,825	2,118	2,853
Subtotal (Gross Domestic Product)	11,014[a]	13,338	15,180	19,384	31,994
Rest of the World	-2,026[b]	-2,458	-2,795	-3,578	-5,863
Total (Gross Product)	8,988	10,880	12,385	15,806	26,131

[a]Source: Energy in Puerto Rico's Future, National Academy of Science (1980), Table 12 (Case B).

[b]Source: Economic Report to the Governor: 1980-81, Puerto Rico Planning Board.

Notes: (1) Fiscal 1978 date is actual. May have been revised by Puerto Rico Planning Board subsequent to the National Academy report published in 1980.
(2) Projections based on average annual growth rates in Table 2.2.2-4.
(3) See Footnote on "Rest of the World", category in Table 2.2.2-4.
(4) 100 constant 1978 dollar = 42.8 constant 1954 dollars = 120.8 constant 1981 dollars.

Table 2.2.2-4 Projections of Annual Growth Rates of Real Gross Product - Low Growth Scenario

Sector	Growth Rate, %			
	1978-1985	1985-1990	1990-2000	2000-2020[b]
Agriculture	1.4[a]	1.1[a]	1.1[a]	1.1
Manufacturing	3.6[a]	3.3[a]	3.0[a]	3.0
Construction	0.9[a]	1.1[a]	1.2[a]	1.2
Transportation and other public utilities	2.8[a]	2.6[a]	2.4[a]	2.4
Trade	2.5[a]	2.2[a]	2.0[a]	2.0
Finance, insurance, and real estate	1.9[a]	1.9[a]	1.9[a]	1.9
Services	4.2[a]	3.5[a]	3.3[a]	3.3
Government	0.9[a]	1.5[a]	1.5[a]	1.5
Subtotal (Gross Domestic Product)	2.8[a]	2.6[a]	2.5[a]	2.5
Rest of the World[c]	2.8	2.6	2.5	2.5
Total (Gross Product)	2.8	2.6	2.5	2.5

[a]Source: Energy in Puerto Rico's Future, National Academy of Science (1980), Table 13 (Case B).

[b]The sectoral gross product is assumed to grow at the 1990-2000 average annual rate.

[c]This "Rest of the World" category consist of three sectors: (1) Wages, salaries and supplements paid by Federal Government, (2) other factor income received from the rest of the world, and (3) less factor income paid to the rest of the world. Assumed to grow at the rate of gross domestic product.

$26,131 million in constant 1978 dollars in 2020 (compared to $42,998 millions under "High Growth" scenario). The alternative projections of real gross product are plotted in Fig. 2.2.2-1.

2.2.3 Energy Demands of the Economy

The industrialization and rapid development of the Puerto Rican economy since 1950 has brought with it increases in GDP and per capita income as well as sharp increases in overall energy consumption. Improvements in the standard of living and expansion of the industrial base have served to contribute to a rapid increase in the intensity of energy in relation to GDP (until the mid-1970s) with the ratio of energy to GDP for Puerto Rico keeping pace with that of the mainland.[1] More recently these ratios have been declining (78,3000 Btu/$GDP in 1979 and 68,600 Btu/$GDP in 1981). The implications of this trend for Puerto Rico's energy future are significant. The form that increases in future energy demand take (electricity for air conditioning in households, fuel oil for industrial boilers, gasoline for automobiles) will affect Puerto Rico's ability to meet that demand and also determine what alternatives to imported oil should be developed.

At the present time, the primary sectors of the Puerto Rican economy (residential, commercial, transportation, agriculture, and industry) rely either directly or indirectly on imported oil for almost 100% of energy requirements. The energy consumed is either in the form of petroleum products or electric power, 98% of which is provided by oil-fired generating units. The preponderance of energy is consumed in industry (45%), transportation (27%), and residential/commercial (22%).[2]

The energy consumption patterns characteristic of each of the sectors are varied. Energy consumption in the residential sector is primarily electricity (accounting for nearly 33% of sales in 1980 and 1981)[3] to meet the basic household needs of cooking, lighting, domestic water heating and use of appliances. There are limited demands for direct petroleum use in the form of LPG and kerosene for cooking. In contrast, the

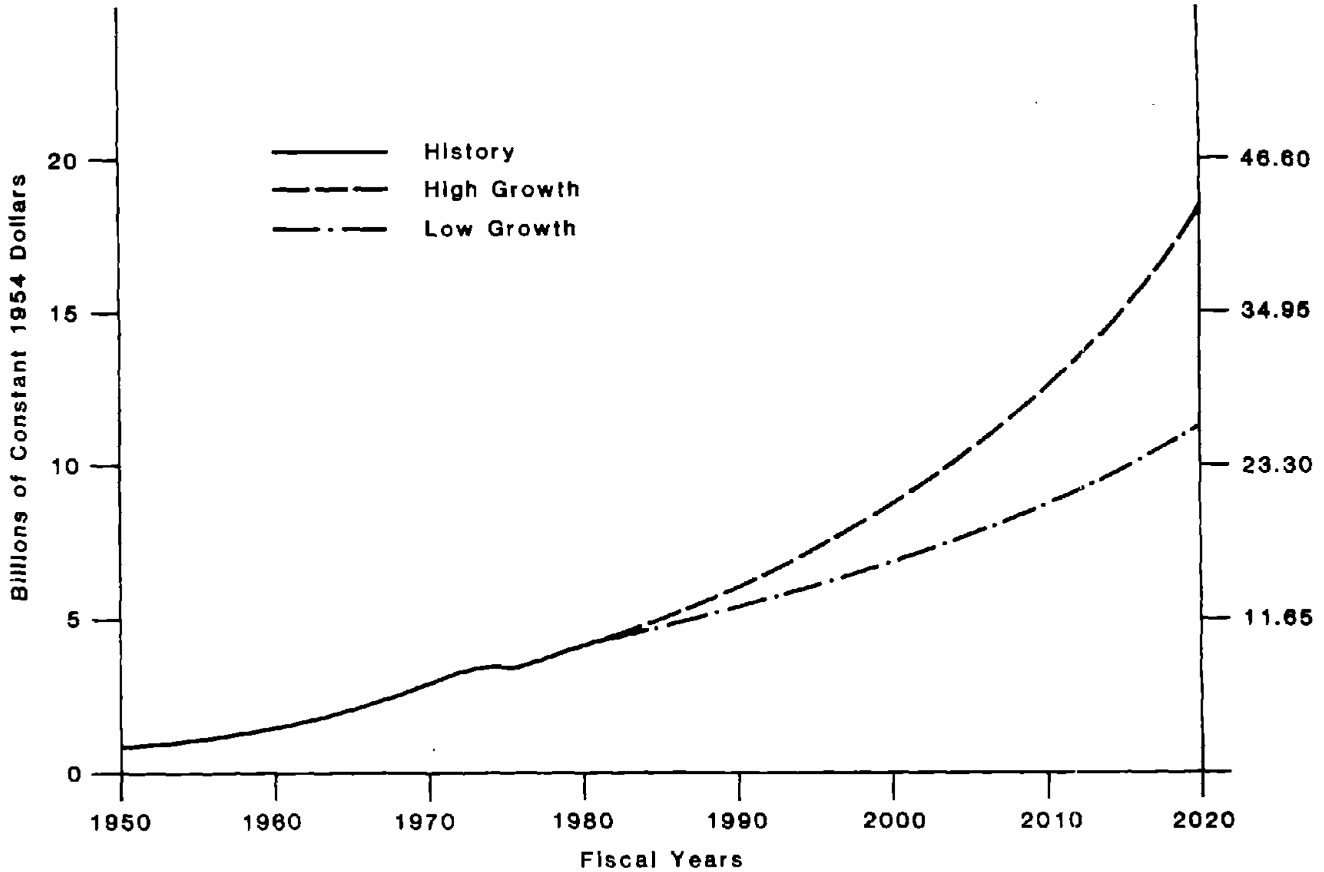


Fig. 2.2.2-1 Projections of Economic Growth of Puerto Rico - Real Gross Product

transportation sector consumes petroleum products, almost exclusively, in the form of gasoline, diesel, kerosene, and aviation fuels. Private automobiles are the major consumers, responsible for nearly 66% of transportation energy demand. In 1977, of the total petroleum fuels consumed in the economy, transportation accounted for 32%.[4] This dominance continues to the present.

The industrial sector, because of its size and diversity, accounts for consumption of significant quantities of both electricity and petroleum products. The source from which data could be drawn for total energy consumption combines commerce and agriculture as subsectors of industry in terms of petroleum product consumption. Industrial demand was 30% of total petroleum product consumption in 1977, in the form of residual fuel oil, distillate, gasoline and LPG. Direct industry/agriculture electricity consumption accounted for 42.8% of sales and commercial 26.3% in 1977.[5] Industry/agriculture consumption declined to 36.4% of sales in 1981 and commercial consumption increased to 30.1% of sales.

Table 2.2.3-1 summarizes the consumption of electricity by major class of customer for the years 1976 through 1981. Table 2.2.3-2 indicates levels of internal consumption of petroleum products by type for 1976 through 1981. Table 2.2.3-3 provides an overview of Puerto Rican energy demands disaggregated by sector. The important feature of this information is the relative contribution of each sector to the demand levels.

The following sector-by-sector discussions provide details regarding the composition of each sector, the major energy-consuming activities, and the sectoral issues that bear on Puerto Rico's energy future. For the most part, the latest data available on the distribution of energy consumption within each sector are for 1977. The level of consumption has changed since then but not necessarily the distribution.

Residential

The residential sector includes single and multifamily residences and small commercial establishments that are classified as residential customers under the Puerto Rico Electric Power Authority (PREPA) rate structure. Residential energy uses include space conditioning, domestic water heating, cooking and

Table 2.2.3-1 Consumption of Electricity by Major Classes of Customers: 1976-81

Fiscal Year	Residential Millions of kWh	Residential Percentage of Total	Industrial[a] Millions of kWh	Industrial[a] Percentage of Total	Commercial[b] Millions of kWh	Commercial[b] Percentage Total	Total (millions of kWh)
1976	3,277	31.0	4,558	43.1	2,740	25.9	10,575
1977	3,462	30.8	4,812	42.8	2,956	26.3	11,230
1978	3,630	31.4	4,874	42.1	3,062	26.5	11,566
1979	3,661	31.6	4,738	40.9	3,172	27.4	11,572
1980	3,657	32.9	4,214	37.9	3,250	29.2	11,121
1981	3,666	33.4	4,004	36.5	3,306	30.1	10,977

[a]Includes consumption by agricultural firms. The consumption of electricity by the agricultural sector was segregated for the first time in fiscal year 1978, and amounted to only 33.9 million kWh.

[b]Includes electricity consumed by government agencies and instrumentalities, and public lighting.

Source: Estadisticas Energeticas Anuales, Puerto Rico Office of Energy, 1981.

appliances (most of which require electricity -- lighting, televisions, fans, irons, toasters, dishwashers, stereos, vacuum cleaners and freezers). With the exception of cooking, a significant portion of which uses LPG and some kerosene, all residential energy use is in the form of electricity. Consumption amounted to 3.7 million kWh in 1981, for a 33% share of total electricity sales. This represents an increase in residential electricity consumption of 0.2 million kWh over 1977 and a 3% increase in share of electricity sales. Table 2.2.3-4, Residential Energy Use, summarizes the levels of demand by use and fuel for 1977.

With increasing standards of living, there is a broader saturation of appliances that meet basic household needs (cooking, lighting) and a more rapid increase in demands for such items as dryers and air conditioners, which increase energy consumption for households. In a survey of low-income families, it was found that the majority owned stoves, refrigerators, electric irons and clothes washers. Less than 30% owned electric fans and water heaters, while fewer than 7% owned air conditioners and clothes dryers.[6] Further development of the Puerto Rican economy will find increasing demands by low- and middle-income groups for the higher-energy-consuming convenience appliances. Table 2.2.3-5 provides a breakdown of appliance ownership in the San Juan Metropolitan Area and indicates the average consumption of electricity by appliance.

Commercial

The commercial sector includes such public and private facilities as schools, hospitals, shops, hotels, restaurants and offices. Energy consumed in the commercial sector is primarily electricity — 2.9 million kWh in 1977 — accounting for 26.0% of total sales and 3.3 million kWh in 1981, for 30% of sales. Limited amounts of LPG are used in cooking and laundries. End uses of electricity in the commercial sector closely resemble those in the residential sector; namely, space conditioning, lighting, television, water heaters, water pumps, stoves, ovens, refrigerators, motors and compressors. Detailed data on energy use by device is not available.

Transportation

Transportation is a major energy-consuming sector in Puerto Rico and is dominated by the automobile. The growth in automobile use is reflected in the 10% average annual growth rate in gasoline sales experienced in the years 1968-72 and the 3.5% rate since 1973.[7] As of mid-1977, the fleet of vehicles on the island was estimated at 830,373 for a person-vehicle ratio of 4 to 1. This is a significant increase over the 1965 rate of 10 to 1.[8] Between 1977 and 1981 the average annual new registrations were 103,000, 81% of which were new cars. This is a significant change over 1976 when new (as opposed to used) cars constituted 53% of new registrations. Nearly 60% of the households in San Juan own cars. Table 2.2.3-6 details the composition of the vehicle fleet in Puerto Rico.

Table 2.2.3-2 Energy Consumption in Puerto Rico Fiscal Years 1976-81

Item	1976	1977	1978	1979	1980	1981
Quantity (Trillions of Btu)						
Total Consumption	320.1	335.5	344.6	357.8	337.6	315.0
Fuels	177.5	182.1	188.4	204.3	188.3	169.2
Refinery Gas	21.1	21.2	19.2	21.1	20.8	18.1
Middle Distillates	24.0	25.2	16.0	19.5	17.1	10.6
Residual Fuel Oils	45.9	43.0	50.9	56.8	49.2	43.0
Motor Gasoline	77.2	82.1	86.6	90.1	87.2	84.0
Aviation Fuel	9.3	10.6	15.7	16.9	14.1	13.4
Electric Energy	125.2	138.1	142.4	142.3	138.3	135.8
Thermoelectric	123.7	137.2	141.3	141.1	136.2	134.5
Hydroelectric	1.5	0.9	1.1	1.1	2.1	1.3
Bagasse	17.5	15.3	13.8	11.1	11.0	10.0
Percent Distribution (%):						
Total Consumption	100.0	100.0	100.0	100.0	100.0	100.0
Fuels	55.4	54.3	54.7	57.1	55.8	53.7
Refinery Gas	6.6	6.3	5.6	5.9	6.2	5.7
Middle Distillates	7.5	7.5	4.7	5.5	5.1	3.4
Residual Fuel Oils	14.4	12.8	14.8	15.9	14.6	13.7
Motor Gasoline	24.1	24.5	25.1	25.2	25.8	26.7
Aviation Fuel	2.9	3.2	4.6	4.7	4.2	4.3
Electric Energy	39.1	41.2	41.3	39.8	41.0	43.1
Thermoelectric	38.6	40.9	41.0	49.5	40.3	42.7
Hydroelectric	0.5	0.3	0.3	0.3	0.6	0.4
Bagasse	5.5	4.6	4.0	3.1	3.3	3.2

Source: Alternative Energy Resource Assessment for Puerto Rico. Puerto Rico Office of Energy, Office of the Governor, 1982.

In 1977, 55% of personal vehicles were in the standard category (3,000-4,000 lbs), 34% light (2,000-2,500 lbs) and 10.5% heavy (greater than 4,000 lbs).[9] Almost 23% of cars imported at that time were used cars, the majority being large, poor-fuel-economy models. New, fuel-efficient cars represented about 10% of the whole fleet. More recently, however, 70% of new registrations have consisted of more fuel-efficient Japanese models.

Trips in private cars grew from 64% of the daily total in 1970 to 78% of the total in 1977, with the majority taking place within the San Juan metropolitan area.[10] The trips are, therefore, relatively short in distance, leading to higher fuel consumption. For the mainland, trips shorter than 5 miles accounted for 15% of all auto mileage and 30% of fuel consumption -- 50% more fuel than that consumed by automobile trips 40 miles or longer.[11] It is assumed that similar performance holds true for Puerto Rico.

The rapid increase in the number and use of personal vehicles, primarily automobiles, has been matched by a decline in demand for public transportation. Bus ridership peaked at 66 million in 1966 and by 1977 had experienced a 47% decline to 35 million.[12] At the same time, fuel consumption has increased primarily because of declining efficiencies and load factors. The average speed of buses in 1977 was 7 mph and average passenger trips per mile for buses capable of carrying 50 passengers was 2.6 persons. Energy efficiency for buses averaged 3.98 mpg between 1975 and 1977. Exclusive bus lanes have been designated, but by 1977 average speed of traffic in them was below 10 mph, bringing the average speed of the whole bus system to 7.2 mph -- equal to that in congested U.S. cities. Bus system service varies with respect to reliability and adherence to schedule.[13]

Table 2.2.3-3 Summary of Energy Demands by End-Use Sector

	Percent Distribution
Oil Use Distribution[a]	
To Electricity	41.0
To Residential	1.0
To Transportation	32.0
To Industrial and Commercial	26.0
Total	100.0
Electricity Distribution[b]	
Industry/Agriculture	36.5
Commercial	30.1
Residential	33.4
Total	100.0

[a]Based on 1977 data. Energy in Puerto Rico's Future. Energy Engineering Board, National Academy of Sciences, 1980, p. 68.

[b]Based on 1981 data. Estadisticas Energeticas Anuals. Oficina de Energia, Oficina del Gobernadar, Puerto Rico, 1981, p. 20.

Table 2.2.3-4 Residential Energy Use, 1977

	Electricity		LPG		Kerosene	
End Use	10^{12}Btu	%	10^{12}Btu	%	10^{12}Btu	%
Cooking[a]	1.37	12	2.02	100	1.44	100
Water heating	3.93	33				
Air conditioning	1.23	10				
Television, refrigerator	3.37	29				
Lighting and miscellaneous appliances	1.90	16				
Total	11.80	100	2.02	100	1.44	100

[a]Conversion efficiences: electricity; LPG 0.60; kerosene 0.40.

Source: Energy in Puerto Rico's Future, National Academy of Sciences, 1980.

Public transportation demand is served primarily by "publicos" (cars and vans serving as taxis with fixed routes and multiple riders) and is relatively the most energy efficient component of the collective transportation system in Puerto Rico. Publicos total nearly 13,000, a quarter of which are privately owned.[14] Taxis account for a minor share of passenger transportation. Table 2.2.3-7 indicates the relative use of energy in passenger transportation and shows that the majority of consumption is by private vehicles.

Freight transportation in Puerto Rico is by light (pickups, panels etc.) and heavy (2-axle, 6 wheels, and multi-axle) trucks. In 1975, 2.6% of vehicle population was classified as heavy trucks. Use of these is primarily linked with the service and manufacturing sectors of the economy -- agricultural and food distribution, construction, trade and utilities. Freight transportation accounts for 11% of total petroleum consumption.

Table 2.2.3-5 Percent of Puerto Rico Electric Power Authority Customers Owning Various Appliances--San Juan Metropolitan Area[a]

Usage in Kilowatt hours per month	Percent of Customers Owning Appliances									
	Regrig-erator	Electric range	Gas range	Clothes washer	Tele-vision	Electric water heater	Solar water heater	Dish-washer	Air condi-tioner	Central air condi-tioner
1-425[b]	100.00	35.85	59.19	73.70	92.93	56.16	0.00	0.60	14.15	0.00
426-1,000	99.27	75.46	21.24	93.41	98.80	88.28	0.00	4.40	58.24	0.37
Over 1,000	100.00	90.42	8.98	99.40	98.20	93.41	1.20	28.14	96.41	3.59
Average consumption by appliance (kilowatt-hours per month)	90	100	0	15	50	200	0	30	340	850

[a]Gas rate customers (regular residential rate). Low rent public housing customers are not included.

[b]For computing subtotals and total percentages, the data for each individual strata were weighted to account for its population relative to the other intervals (frequency distribution of population (percent) in San Juan metropolitan area by kilowatt-hour intervals of October 1976).

Source: Energy in Puerto Rico's Future p.130. Correspondence from Jose Marina, Puerto Rico Water Resources Authority, to F. Castellon, Director, Puerto Rico Office of Energy, April 24, 1978. Results derived from a survey conducted from December 1977 to February 1978.

The preponderance of air travel is by Puerto Rico residents to and from the United States, with most of the jet fuel consumed in Puerto Rico used by flights leaving Puerto Rico. Air freight is a relatively small component, accounting for only .4% of total cargo passing through Puerto Rican ports in 1977.[15]

Table 2.2.3-8 summarizes energy use for the various transportation modes for Puerto Rico in 1977.

Industry

The industrial sector in Puerto Rico is highly diversified and includes manufacturing, construction and mining activities. It is the major contributor to GDP and, as such, is the largest consumer of energy, both electricity and direct use of petroleum products. The development of Puerto Rico's industrial infrastructure over the past several decades has seen a dramatic change in the patterns of output. Agriculture has declined in its contribution to GDP while manufacturing has increased substantially.[16]

The extraordinary growth in the manufacturing subsector has been accompanied by a process of structural change. The most significant change has been the disappearance or decline of labor-intensive industries, which has to a great degree been offset by the creation and rapid development of capital-intensive industries. In terms of output and employment measures, the major industrial groups in Puerto Rico in 1949 were sugar, apparel, tobacco, food and stone, glass and clay. By 1977, apparel, electrical machinery, food products, pharmaceuticals, professional and scientific instruments, stone, glass, and clay and petrochemicals accounted for 65% of employment and 71.7% of output.[17]

The energy requirements to support the growing manufacturing sector are varied and depend on the level of activity and particular processes or technologies used. As such, structural changes have a direct effect on energy consumption patterns. It is also important to note that industries that are not major contributors to GDP, income and employment can be of great significance in terms of the energy situation. Puerto Rico's petroleum refining industry is a case in point. It contributed only about 1% to GDP in 1977 and less than 0.5% of employment. However, as shown in Table 2.2.3-9, it is a major energy-consuming

Table 2.2.3-6 Puerto Rican Vehicle Fleet, Fiscal Year 1977

Mode	Number of vehicles (thousands)
Personal vehicles	
Privately owned autos	660
Light trucks	93
Subtotal	753
Public vehicles	
Buses	2
For-hire autos and vans (publicos)	13
Taxis	2
Subtotal	17
Freight vehicles	
Heavy trucks and tractors	25
Trailers	19
Subtotal	44
Cycles	7
Government vehicles	9
Total	830

Source: R. Shackson. August 1979. Assessment of Opportunities for Conservation in the Transportation Sector and Strategies for Implementation. Report prepared for the Committee on Future Energy Alternatives for Puerto Rico, Energy Engineering Board, Assembly of Engineering, National Research Council. Arlington, Va.: Mellon Institute-Energy Productivity Center.

Table 2.2.3-7 Relative Use of Energy in Passenger Transportation

Mode	Percentage of Total Passenger Transport Energy	Percentage of Total Passenger Miles
Private		
Urban	72	53
Intercity	20	28
Public		
Urban	3	6
Intercity	5	13

Source: Energy in Puerto Rico's Routine Energy Engineering Board, National Academy of Science 1980.

Table 2.2.3-8 Transportation Energy Use, 1977

AUTOMOBILE ENERGY USE

Year	Gasoline consumption (trillions of Btu)	Miles per gallon	Btu per vehicle-mile	Vehicle miles (billions)	Number of automobiles	Yearly miles per automobile
1977	67.7	14.5	8,621	7.85	660	11,900

ENERGY USE BY TRUCKS

Year	Energy Consumption (trillions of Btu)				
	Freight				
	Heavy Trucks	Light Trucks	Total Truck Freight	Light Trucks Passenger Mode	Total Energy Consumption by Trucks
1977	5.8	4.2	10.0	4.2	14.2

AVIATION FUEL USE

Year	Aviation fuels (trillions of Btu)
1977	14.2

FUEL USE FOR BUSES, "PUBLICOS," AND TAXIS

Year	Fuel (trillions of Btu)			
	Gasoline	Diesel (bus)	Kerosene (bus)	Total
1977	5.8	0.3	0.4	6.5

Source: Energy in Puerto Rico's Future. National Academy of Sciences (1980)

industry in Puerto Rico. The industrial groups with the highest energy intensities in terms of direct fuel use in Puerto Rico are petroleum refining, petrochemicals, stone, clay, glass and concrete, paper products, printing and publishing, metal products and electrical machinery. Nearly 60% of total industrial electricity consumption is in pharmaceuticals, oil refining and petrochemicals, and cement (see Table 2.2.3-10).

The leading growth industries in Puerto Rico are pharmaceuticals, professional and scientific instruments, and petrochemicals. Of these, petrochemicals is a major consumer of both petroleum products and electricity. Pharmaceuticals is a significant user of electricity. The traditional industries that continue to account for major shares of GDP and are low in energy intensity are textiles and food products. Little growth is expected in this group. Petroleum refining and stone, glass, clay and cement are industries high in energy intensity, both petroleum product and electricity use. They face uncertain futures.

The future of Puerto Rico's industries will largely depend on their competitiveness with those on the U.S. mainland. This is particularly important for the petroleum refining and petrochemical industries. The

Table 2.2.3-9 Direct Fuel Use by Industry, 1977

Standard Industrial Classification		A Fuel consumed (thousands of barrels)[a]	B GDP (millions of dollars)[b]	A/B Energy Intensity (bbls/10^3 $)
22, 23	Textiles, apparel and related products	48.2	325.4	0.15
21	Tobacco products	5.2	121.3	0.04
20	Food and related products	749.9	521.1	1.44
38	Professional and scientific instruments	4.8	165.3	0.03
36	Electrical machinery	779.4	381.7	2.09
32	Stone, clay, glass and concrete products	1,839.9	89.6	20.53
33, 34	Metal products	208.1	94.4	2.20
26, 27	Paper products, printing and publishing	369.7	64.9	5.70
283	Drug products	1,137.2	866.1	1.31
281, 282, 286	Petrochemical products	1,140.7	253.5	4.50
29	Petroleum refining and related products	4,828[c]	117.8	40.98
	Other	57.9	317.9	0.18
	Total	11,189.0	3,319.0	3.37

[a]Preliminary Results, Puerto Rico Office of Energy, Survey of manufacturing energy use. October 1977.

[b]Jorge F. Freyra. July 1979. Long Term Projections of the Pureto Rican Economy. Report to the Committee on Future Energy Alternatives for Puerto Rico, Energy Engineering Board, Assembly of Engineering, National Research Council. See also Table 31.

[c]Estimated from refinery throughput.

Table 2.2.3-10 Industrial and Commercial Electricity Consumption

Subsector	1978[a] (trillions of Btu)
Pharmaceuticals	1.7
Oil Refining and Petrochemicals[b]	7.97
Cement	0.68
Other Industry	6.37
Total	16.75

[a]Jorge F. Freyre. July 1979. Long Term Projections of the Puerto Rican Economy. Report to the Committee on Future Energy Alternatives for Puerto Rico, Energy Engineering Board, Assembly of Engineering, National Research Council. Table 60.

refining industry was founded on the basis of the availability of low-cost, foreign oil that could be processed and sold at higher domestic prices on the island and the mainland. As long as world crude prices remained below U.S. domestic prices, the high transportation costs resulting from the Jones Act (goods transported by water between U.S. ports must be in U.S.-registered ships) did not affect the market competitiveness and profitability of products from Puerto Rico's refineries. The dramatic rise in world oil prices in 1973 and 1978-79 ended the cost advantage of Puerto Rico.

The petrochemical industry has undergone similar experience, with low-price, foreign-origin feedstocks and a system of local tax incentives fueling the rapid growth of large, efficient, world-scale petrochemical units. The upheaval of oil prices and overcapacity, worldwide, of downstream facilities has had a severe effect on Puerto Rico's petrochemical industry.

To counteract this market penalty, Puerto Rico has been included in the entitlements program (which equalizes crude oil costs among all mainland U.S. refiners). Imports of naphtha feedstocks are also included in the program, though it only partially offsets the cost differential.[18]

Construction and mining are major components of industrial activity. Data regarding energy consumption directly attributable to the subsectors are lacking. Construction activity has declined significantly over the past decade and remains in a depressed state. The rapid increase in manufacturing contributed to an earlier increase in total construction activity. Housing is also a major element of total construction activity, and the current depressed state of construction can largely be attributed to a fall off in new housing starts. Highway and public works projects are a third component of construction.

Agriculture

Puerto Rico has been transformed from a traditional agricultural economy into an industrial-oriented economy. Agriculture is now the smallest sector as measured by contribution to GDP. In 1976, it provided employment for only 6% of the work force and received only 5% of the total net income.[19]

The energy-consuming activities in agriculture are: crops, dairy products, livestock, fishing and lumber. The latter two are not significant in terms of energy consumption. Detailed data are not available for the agriculture sector though a few general observations can be made. Electricity consumption is primarily for irrigation pumps in crop production and for refrigeration and milking machines in the dairy industry. Petroleum use is for farm machinery, fishing vessels and crop drying.

2.2.4 Possible Future Energy Demands

The estimation of future energy consumption for an economy as complex and modern as that of Puerto Rico needs a comprehensive assessment. The future energy demand will be affected by several critical factors some of which are the changes in the economic structure over the planning period, the availability of different fuels at different prices, and the extent of the improvement in the efficiency of the energy end-use devices. The estimated energy demand becomes even more uncertain as the forecasting period is extended. Some of the energy assessment methodologies have included the development of economy-energy analysis systems involving complex macro econometric models for the economy and the energy sectors, and the development of complex energy demand/supply equilibrium models (usually having a great deal of end-use detail). In the absence of such a methodology, a very simplistic approach is followed for this report for estimating the total energy consumption in Puerto Rico to the year 2020.

2.2.4.1 Methodology

Projections of the energy demand are derived from the National Academy of Science (NAS) report "Energy in Puerto Rico's Future up to 2000".[1] This study provides the projections of energy demands to 2000 under the high and low growth economic scenarios (see Section 2.2.2). The methodology, assumptions and results are highlighted below.

The total consumption of energy in Puerto Rico was projected to 2020 based on the energy elasticity in the earlier period of 1985-2000. The energy elasticity is defined as the ratio of the average annual percentage change in energy consumption to the average annual percentage change in gross product of the economy. In the first step, the energy elasticity is estimated for the period 1985-2000 based on the NAS projections of the gross product and the total energy consumption. Next, an assumption was made that the energy elasticity for the period 1985-2000 would prevail in the subsequent period of 2000-2020. There will be two compensating factors influencing the energy intensity in Puerto Rico's economy: (a) the economy is expected to become even more dominated by the manufacturing sector, which is relatively more energy intensive, and (b) the trends in energy conservation as observed in most of the developed economies worldwide (U.S., Japan, etc.) will continue in Puerto Rico. Finally, knowing the growth rates of gross product between 2000-2020, and the energy elasticity, one can estimate the total energy consumption in 2020. However, the caveats of this type of highly simplified analysis cannot be over-emphasized.

2.2.4.2 Energy Demand Projections

A1. "High Growth" Energy Demand Projections: 1977-2000

Under the "High Growth" economic scenario, the energy demand projections for the residential sector were based on the demand of energy services such as cooking, lighting, domestic hot water, and household appliances. To estimate the future energy demand, the number of households in Puerto Rico was projected. The unit energy demands were mostly unchanged. For selected large appliances, such as air conditioning units, the federally mandated efficiency improvements were incorporated. The demand for lighting and miscellaneous small appliances was increased at the assumed rates of increases in personal income under the scenario, with an adjustment to account for price-induced conservation. Another factor considered in the analysis was the level of saturation of the appliances. For example, the electric water heater penetration increases from 65 to 80 percent of all households in the "High Growth" scenario[3].

The fuel consumption in the transportation sector was estimated for automobiles, trucks, public transportation and aviation categories. Per capita ownership of automobiles is very high for Puerto Rico relative to its per capita gross product. For this important category, the gasoline requirements were linked to the projected number of vehicles in the fleet, personal income, and the annual sales of more energy-efficient cars. The projected gasoline consumption reflected the impact of higher gasoline prices on its use, the higher fraction of the second cars in the automobile fleet, and the federally mandated gasoline efficiency for new cars. These factors resulted in a complete break with pre-1977 historical trends of gasoline use. For estimating energy use in trucks, the growth in freight transportation was linked to the growth in manufacturing and service sectors. The projections of the energy demand for aviation category was linked to the number of visitors to the island as most of the jet fuel consumed in Puerto Rico is used by flights leaving the island. Finally, the public transportation demand was estimated for the categories of "publicos and taxis" and buses. In the absence of in-depth historical data, certain simplistic assumptions were made for the increase in the number of passenger miles for publicos and taxis, and the energy use intensity.

The industrial and commercial sector includes energy used in manufacturing, agriculture, construction, trade, finance, and government and other services. The consumption of fuels and electricity in this sector were linked to the level of the activity of the subsectors. The energy projections were adjusted for any anticipated change in overall energy efficiency. In general, the energy consumption will grow more slowly than output. The direct fuel demand by the industrial and commercial sector was projected using one overall growth rate because no detailed breakdown of the data was available. In contrast, the future demand for electricity was estimated on the basis of assumed separate growth rates for manufacturing industries, refining and petrochemicals, pharmaceuticals, and cement. For other industries and for the commercial sector, one overall growth rate was used. The commercial sector is comprised of trade, financial services, insurance, real estate, and government categories.

Table 2.2.4-1 summarizes the primary energy consumption under "High Growth" scenario. The total energy consumption grows from 341.8 trillion Btu in 1977 to 393.6 trillion Btu in 1985, and 588.1 trillion Btu in 2000. These Puerto Rican energy demands correspond to an average annual growth of 1.8% between 1977 and 1985, and 2.7% between 1985 and 2000.

A2. "High Growth" Energy Demand Projections: 2000-2020 - The total energy consumption in Puerto Rico is projected to 2020 on the basis of the projected overall energy elasticity in the period of 2000-2020, and the estimated growth rates of the gross product during 2000-2020. As shown in Table 2.2.4-2, the real gross product rises at an averal annual growth rate of 3.73% between 1985 and 2000 compared to 2.71% annual increase in the island's total energy consumption in the same period. This implies that Puerto Rico's energy elasticity was 0.73 in the period of 1985-2000.

Table 2.2.4-1 Projections of Puerto Rican Energy Demands Under Alternative Scenarios (1977-2000), Trillion Btu

		High Growth Case		Low Growth Case	
	1977	1985	2000	1985	2000
		Primary Energy Consumption			
Total Consumption:	341.8	393.6	588.1	364.8	469.8
Oil to electricity	134.7	154.8	257.3	142.2	200.5
Oil to residual	3.5	3.6	4.6	3.5	4.2
Oil to transportation	102.6	111.1	140.9	105.8	122.9
Oil to industrial and commercial	84.6	107.2	159.9	97.6	122.0
Petroleum for non-energy products	16.4	16.9	25.4	15.7	20.2
		Fuel Consumption			
Residential:					
Electricity	11.80	15.88	26.75	14.90	21.14
Cooking	1.37	1.64	2.26	1.59	2.06
Water heating	3.93	5.09	8.04	4.77	6.19
Air conditioning	1.23	1.92	3.81	1.75	2.60
Television, refrigerator	3.37	4.40	6.99	4.28	6.35
Lighting and miscellaneous	1.90	2.83	5.65	2.51	3.94
Petroleum:					
Cooking (LPG)	2.02	2.73	4.61	2.65	4.19
Cooking (Kerosene)	1.44	0.91	0.0	0.88	0.0
Transportation:					
Automobile	67.7	64.9	73.0	61.1	61.0
Trucks	14.2	19.1	27.7	17.6	21.7
Public Transportation	6.5	8.8	13.6	8.8	13.6
Aviation	14.2	18.3	26.6	18.3	26.6
Industrial & Commercial:					
Electricity	25.1	30.56	50.43	27.75	39.01
Petroleum	84.6	107.2	159.9	97.6	122.0

Source: "Energy in Puerto Rico's Future," Energy Engineering Board, National Academy of Sciences, Washington, D.C. (1980). Table 15, Table 20, Table 29, Table 35.

As was discussed earlier, Puerto Rico's gross product is projected to rise at an average growth rate of 3,77% between 2000 and 2020. Assuming the same energy elasticity of 0.73 for the period of 2000-2020, the implied rate of increase of energy consumption is estimated to be 2.75% (.73 x 3.77%). As shown in Table 2.2.4-3, this translates into Puerto Rico's total energy demand of 1,012 trillion Btu in 2020.

B1. "Low Growth" Energy Demand Projections: 1977-2000 - In order to have a range of plausible energy demands, an alternative scenario was derived from the National Academy of Sciences report (Case B[4]). The energy demands are estimated under the pessimistic outlook of Puerto Rico's economic growth rates discussed earlier. The alternative energy demands are estimated in a fashion similar to the "High Growth" energy projections discussed above. The technical assumptions and parameters remain the same between these two scenarios.

The number of households are lower under "Low Growth" case compared to the "High Growth" case (1,115,000 vs 1,226,000 in 2000[5]). Because of lower economic growth, the penetration of electric water

Table 2.2.4-2 Estimated Puerto Rico Energy Consumption Elasticity Under Alternative Scenarios

	High Growth Scenario			Low Growth Scenario		
	1985	2000	Annual % Change 1985–2000	1985	2000	Annual % Change 1985–2000
Real Gross Product[b] (Millions of 1978$)	11,828[a]	20,496[a]	3.73[b]	10,880[d]	15,806[d]	2.52[b]
Total Energy Consumption[c] (Trillions of Btu)	393.6	588.1	2.71	364.8	469.8	1.70
Estimated Energy Use Elasticity[e]			.73			.68

[a]Source: Table 2.2.2-1.

[b]Real gross product growth rate is equal to real gross domestic product growth rate which are sourced from the report: "Energy in Puerto Rico's Future", National Academy of Sciences (1980), Table 10 (Case A and Case B)

[c]Source: "Energy in Puerto Rico's Future", National Academy of Sciences (1980), Table 35 (Case A)

[d]Source: Table 2.2.2-3.

[e]Energy use elasticity = (Annual percent change in energy use)/(Annual percent change change in real gross product).

Table 2.2.4-3 Projection for Puerto Rico's Energy Demand Under Alternative Scenarios

	High Growth Scenario			Low Growth Scenario		
	2000[a]	2020	Annual % Change 2000-2020	2000[a]	2020	Annual % Change 2000-2020
Real Gross Product (Millions of 1978$)	20,496	42,998[b]	3.77	15,806	26,131[c]	2.55
Energy Consumption Elasticity			0.73[d]			0.68[f]
Total Energy Consumption (Trillions of Btu)	588.1	1,011.8[e]	2.75	469.8	662.0[e]	1.73

[a]Source: Table 2.2.2-4

[b]Source: Table 2.2.2-1

[c]Source: Table 2.2.2-3

[d]Based on the assumption that energy consumption elasticity remains same as 0.73 of period 1985-2000 (Table 2.2.4-2).

[e]Estimated

[f]Based on the assumption that energy consumption elasticity remains same as 0.68 of period 1985-2000 (Table 2.2.4-2).

heaters is less under the "Low Growth" case compared to the "High Growth" case (75% vs 80% in 2000[6]). Furthermore, personal income is lower under the "Low Growth" case reducing the residential electricity demand. Because of these factors, the residential electricity demand reaches only 14.90 trillion Btu compared to 21.14 trillion Btu under the "High Growth" case.

The efficiency of automobiles through 2000 almost offsets the lower growth in the automobile fleet. The transportation energy demand growth rate declines to 1.0% between 1985 and 2000 compared to 1.6% under the alternative "High Growth" case.

The reduced activity in manufacturing and service sectors under this "Low Growth" scenario also results in lower industrial energy demand.

The projected energy demands in residential, industrial and commercial, and transportation sectors are shown on Table 2.2.4-1 and increase from 341.8 trillion Btu in 1977 to 364.8 trillion Btu in 1985, and 469.8 trillion Btu in 2000. This increase in total energy use corresponds to a growth rate of 0.85% between 1977 and 1985 and 1.7% between 1985 and 2000.

B2. "Low Growth" Energy Demand Projections: 2000-2020 - Similar to the "High Growth" scenario, Puerto Rico's energy demand is projected to 2020 under this pessimistic scenario. In the first step, the energy elasticity for the period 1985-2000 was estimated to be 0.68 (as average annual increase of gross product in this period is 2.52% vs 1.70% for total energy use). Using this elasticity for the period of 2000-2020, the average annual growth rate of energy demand was estimated to be 1.73% as gross product grows at the rate of 2.55%. This results in total energy demand of 662.0 trillion Btu in 2020. Tables 2.2.4-2 and 2.2.4-3 provide the details of the derivation of the energy demand projections.

Figure 2.2.4-1 shows the total energy demand of Puerto Rico under the alternative scenarios and is estimated to be in the range of 0.662 to 1.102 quads in 2020. As discussed earlier, these projections must be considered only as an indication of the future Puerto Rican energy demand. Only a detailed total energy/economy assessment of the island as discussed earlier can provide reliable projections of energy demands for planning purposes.

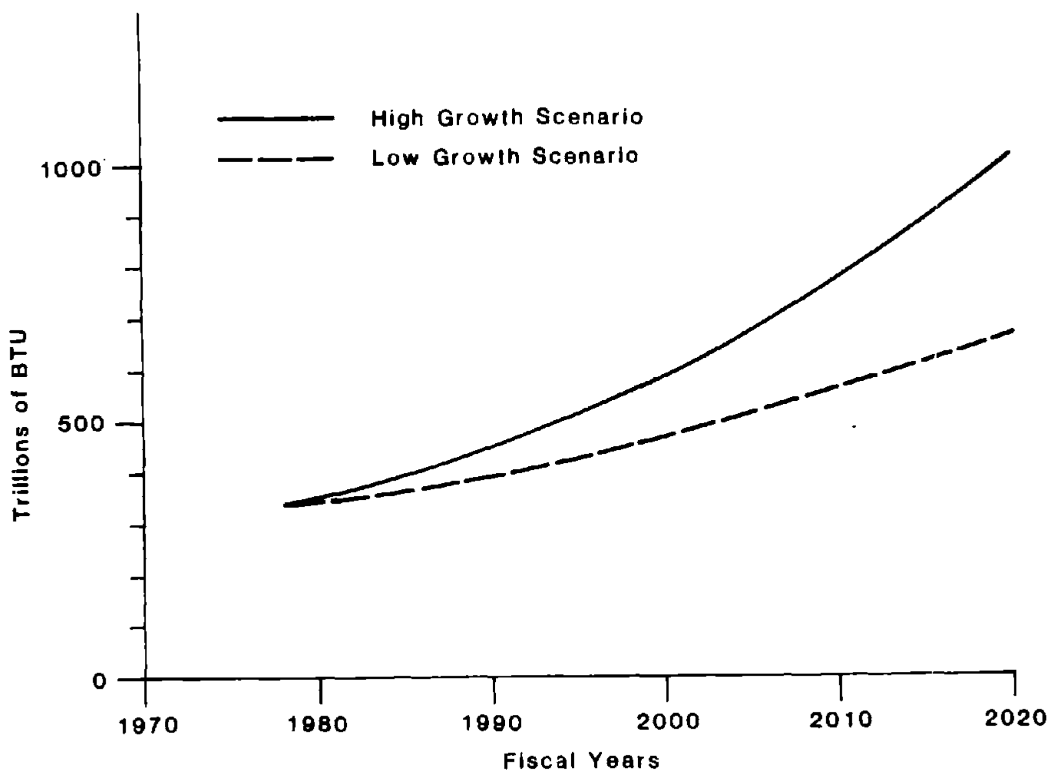


Fig. 2.2.4-1 Projections of Energy Demand of Puerto Rico

2.2.5 Energy Conservation Possibilities

The opportunities open to Puerto Rico to conserve energy are numerous. The specific conservation projects identified by government[1] and private sector[2] sources focus on the high energy-consuming transportation and industrial sectors, emphasizing improved efficiencies in existing systems as well as performance goals for future activities. Consideration is also given to conservation in buildings and in electricity generation by utilities.

Transportation. Transportation energy conservation focuses primarily on reducing gasoline consumption with a secondary benefit of improved traffic flows and increased use of public transportation. The specific measures are:

(a) Rationalized Public Transport System

The bus system in Puerto Rico has 47 routes, many overlapping, which have been laid out to serve every neighborhood from every other without a transfer. A more energy efficient system would consist of a trunk line with true express buses operating as much as possible on priority lanes in the corridor linking San Juan, Rio Piedras, and Carolina, with a westward spur to Bayamon. This trunk system would be supported by a series of feeder lines. Although many trips would then require transfers, the total elapsed time for most trips would be significantly reduced and the system would become a more attractive alternative to the automobile. Such a system also should be capable of operating with fewer vehicle miles for a given capacity and level of service. Also if public transportation is to operate as a true system, the publicos need to be integrated into the network to serve as feeders in neighborhoods where full-size buses are not warranted. The problem of limited off-peak service must be addressed if publicos are to be thus integrated into a revised system.

(b) Park and Ride Lots

Under the park-and-ride lots measure, commuters would leave their cars in parking facilities at suburban locations and board vans or buses for the commute to work. The schedule for operation of the vehicles would be fixed during rush hours. Routes would run from the parking facilities to specific employment centers in the heart of the city. This use of public transportation not only saves gasoline but also reduces traffic congestion.

(c) Revised Taxi Fare System

The present rate structure for taxis prohibits the collection of multiple fares for the same trip. A revision of this structure with the implementation of a shared ride system (allowing multiple fares for long trips) would save fuel.

(d) Fuel-Economy-Based Excise Taxes and Registration Fees

Under present law, new and used passenger cars imported into Puerto Rico are subject to an excise tax ranging from 14% to 85% of their values, depending on weight and horespower. This tax does not correlate precisely with fuel economy, nor is it perceived as an efficiency tax. The Office of Energy has prepared a bill, supported by the Govenor, that would substitute a tax shedule based on the U.S. Environmental Protection Agency estimates of vehicle efficiency. The bill would substitute a tax varying from 7% (for a car achieving 30 miles per gallon) to 85% (for a 13-miles-per-gallon car). If adopted, the PROE estimated it would reduce fuel consumption by about 400,000 barrels per year.

(e) Parking Charges and Enforcement

The price of parking in the San Juan metropolitan area is generally less than $15 per month, significantly below that in comparable metropolitan areas on the mainland. These low prices encourage the use of automobiles for trips that might otherwise have been made by public transportation. A study of these rates might reveal the possibility of large gasoline savings from relatively modest rises in rates. If this hypothesis is correct, a gradual removal of controls, or at least a rise in the controlled price, should be considered.

(f) Traffic Engineering Improvements

The traffic engineering improvements measure would save fuel by improving traffic flow through physical improvements to public roads. Improved traffic flow would, in turn, reduce travel time, idling time, and the number of stop-go cycles. The provisions of such a measure include widening roadways at critical locations, adding and improving exits on major roadways, and installing traffic-actuated traffic lights at intersections.

(g) Right Turn on Red

Right-turn-on-red has been in effect in Puerto Rico since 1977. As an energy conservation measure, it improves traffic flow and thus vehicle efficiency. Fuel savings are realized as a result of reduced traffic congestion and idling time. As of 1980, right-turn-on red was permitted at 80 percent of intersections controlled by traffic signals.

(h) Coordination of Government Transportation Activities

Puerto Rico's transportation system is controlled by a number of government agencies. The Department of Transportation and Public Works is responsible for constructing and maintaining highways and other public facilities and for administering federal highway and transit funds. The Metropolitan Bus Authority owns and operates the public transportation system of the San Juan metropolitan area, except for the publicos. The Public Service Commission regulates publico routes and fares. The Department of Consumer Affairs controls the rates charged for parking. The Office of Energy is responsible for developing energy policy, including conservation programs, and for administrating federal and Puerto Rican energy funds. To provide focus on an energy-efficient system, the Director of the Office of Energy recently was asked by the Governor to organize a task force of senior representatives of each of the involved agencies, charged with developing a plan for transportation. This appears to be a necessary first step in implementing many of the conservation measures for transportation.

Buildings. Energy consumption in buildings in Puerto Rico is not high by mainland standards. As a result, conservation efforts may not have a large net effect for the island as a whole but the individual consumer will realize a measurable gain. The conservation measures include:

(a) Lighting Efficiency Standards

Efficiency standards for lighting are designed to reduce the use of electricity for lighting in both new and existing buildings. The incorporation of standards as a supplement to the existing building code makes compliance mandatory for all new construction. The plan would make conformity to lighting standards in existing buildings mandatory for public buildings in excess of 10,000 sq. feet. It would be voluntary for all other existing buildings.

(b) Thermal Efficiency Standards

Thermal efficiency standards are directed towards minimizing energy consumption for air conditioning, primarily in new buildings. In existing buildings a number of measures can be taken to save energy including installing awnings, interior and exterior shading devices, and insulating roofs.

(c) Energy Audits

Energy audits help to pinpoint sources of energy waste and identify appropriate methods or equipment to improve efficiency. Audits on government, industrial and commercial establishments have the potential to save significant amounts of energy.

Industry. The opportunities to conserve energy in industry are broad and can be identified through energy audits. The most far-reaching effort is cogeneration, an arrangement that produces both electricity and useful heat from the same primary energy source.

Much of the potential for cogeneration is found in industrial operations that consume large quantities of steam generated in boilers on-site. Detailed studies of candidate sites are required to determine the applicability, since the economic feasilibility of cogeneration is so heavily dependent on individual circumstances. Petrochemical plants, refineries and sugar mills appear to be likely candidates.

In 1981, an assessment of the cogeneration potential of Puerto Rico was conducted under the auspices of the Puerto Rico Office of Energy. Three hundred forty-seven (347) individual PREPA customers were identified as having cogeneration potential, totalling 473 MW considered to be technically attainable.[3] The itemized cogeneration potential is summarized as:

1. 183 classical cogenerators (184 MW)

2. 56 chiller candidates (cogeneration potential based on driving chillers to provide air conditioning (139 MW)

3. 6 process industries for which PROE gathered process characterization data (22 MW)

4. 102 candidates analyzed with estimated data (128 MW)

The purpose of the study was to provide order of magnitude cogeneration potential for the Commonwealth as a whole rather than site or sector-specific potential. The review does however, provide a sound source of information on which to base decisions regarding the most likely candidate sites for detailed evaluation and consideration for cogeneration. Cogeneration is also applicable to large resort hotels.

Further opportunities exist for industrial cogeneration by supplying process steam to industry directly from a utility power station. The location of the industrial facility must be close to that of the power station. For practical purposes, this alternative applies to future plans and requires coordination between PREPA and industry.

Education and Information. The success of conservation rests with the consuming public's willingness to adhere to plans and standards. As such, an information program that explains how conservation benefits the individual as well as the island as a whole is a necessary first step. Several approaches can be taken to effect such a program. The alternatives appropriate for Puerto Rico include a public awareness campaign that relies on the use of multimedia advertising; a public information system made up of a hotline, a resource center and a series of conferences; and a formal educational program for students in Puerto Rico's schools. All of them look to instilling an awareness of conservation's value in the public conscience.

Electricity Rate Reform. Electricity rate reform as a means of conserving energy is grounded in the principle that rates should reflect the costs of producing and distributing electricity. The possible rate structure changes are discussed later.

Government. The measures identified to conserve energy in government operations are directed towards two areas -- current use and future efficiency. Actions that can be taken immediately to reduce the use of energy in government facilities and buildings include: delamping government buildings, converting street lighting to use less energy intensive bulbs, and controlling electricity use at off-hours in government offices, public parks and recreational facilities. Energy efficiency in the future can be supported by government standards that require the consideration of energy-efficiency of products in making a purchasing decision. As the government purchases such equipment or automobiles, motorcycles, air conditioners, etc., these measures offer the opportunity for significant energy savings.

2.3 THE ENERGY SUPPLY SYSTEM

The discussion of Puerto Rico's energy supply system is divided into two parts. The first deals with the existing system and identifies the major issues. The second deals with the future system, both what is currently planned and what might be considered as possibilities.

2.3.1 The Current Energy System

The current system includes fossil fuel use, the electric system, and renewable resource technologies.

2.3.1.1 Fossil Fuels

There appears to be no evidence that any extensive fossil fuel (coal, oil, natural gas) deposits exist in Puerto Rico.[1,2,3] Based on a reconnaisance survey[21] by the U.S. Geological Survey, some mangrove peat deposits may exist in the upland region along the north shore. The potential for the existance of petroleum in Puerto Rico was summarized in Ref. 4, which forms the basis for the following.

Oil Potential

Oil and gas generally form in sedimentary deposits resulting from the accumulation and burial of large quantities of organic matter under suitable geologic conditions, which include:

- A suitable source rock containing the necessary organic matter for the generation of hydrocarbons.

- A suitable porous reservoir rock.
- A suitable naturally sealed entrapment feature to collect and confine the oil and/or gas.

To be economically attractive, a particular hydrocarbon prospect must be accessible and of sufficient size and volume to offset exploration and production costs.

To date, only two confirmed reports of natural petroleum are known in Puerto Rico. Petroliferous limestone concentrations in shale beds near the town of Coamo in the south-central part of the island were reported by Glover.[5] A seep from oil-impregnated sediments beneath a lake about 8 km northeast of Ponce in the south-central part of Puerto Rico was reported by Monroe.[6] Both of these occurrences involved Eocene age or older rocks and most authorities agree that any petroleum that may have been formed could not have survived the history of extensive deformation, intrusion and metamorphism of the rocks. Therefore, substantial quantities of oil and gas are unlikely in the older rocks that occur in the Island's core and lie beneath its northeast sedimentary deposits. These petroleum occurences, however, confirm the existence of formative conditions for petroleum in the geologic history of Puerto Rico.

The relatively thick mid-tertiary marine sedimentary sequence of the north flank of Puerto Rico is stratigraphically, structurally, and historically more favorable for the accumulation of hydrocarbons.

In 1944, the Puerto Rico Development Company asked the U.S. Geological Survey to investigate the oil and gas possibilities of the island. As the coastal plains of Puerto Rico offer the best possibilities, a team composed of C.R. Thomas, A.D. Zapp, and H.R. Bergquist spent 4 months during the fall and winter 1944-45 making stratigraphic studies and preparing an overall geologic map of the belts of the middle Tertiary rocks on both the north and south coasts of Puerto Rico. From aerial and structural mapping studies and reconnaisance geophysical surveys in the north-coast mid-tertiary sedimentary belt, a variety of prospective sedimentary sections and structures have been identified.[6,7,8,9] Interfingering limestones and clastic strata as well as anti-clines, burried hills and ridges, and fault traps both onshore and offshore may provide favorable conduits for the accumulation of hydrocarbons. In general, subsurface conditions on the north coast are more favorable for stratigraphic traps, while abundant faults on the south coast are favorable for structural traps. The reconnaisance survey was performed on the north coast between San Juan and Aguadilla by United Geophysical Company, Inc., for both onshore and offshore areas.

The first exploratory wells for petroleum were drilled by Kewanee Interamerican Oil Co. in 1959 and 1960. The wells (CPR 1-3) were drilled on the south-central coast between Ponce and Santa Isabel. A fourth well (CPR 4) was drilled on the north-central coast at Islate. No positive evidence of petroleum hydrocarbons was encountered at any of the four well locations. Information gained from well CPR 4 indicated the presence of a variety of limestones, sandstones, and conglomerates with porosities and permeabilities considered suitable for source rocks, reservoir rocks, and continuing layers. However, Briggs[11] reported that low-grade coal (lignite) was encountered in the San Sebastian formation in test well CPR 4 and in the outcrop.

Between 1968 and 1971 exploration permits for much of the coastal area were granted to P.R. Petroleum Exploration Co. (July 14,1968), Weaver Oil and Gas Co. (Aug. 20, 1968), Caribe Sun Oil Co. (September 11,1969) and Oceanic Exploration Co. (September 24, 1971). All of these permits have since expired. In 1969, a number of continuous seismic profiles were made offshore on the south coast Muertos shelf using a 13,000-joule sparker. Although some interesting structures were identified, the detail was insufficient to identify particular areas.

The most promising prospects for oil and gas were identified as a result of extensive geophysical surveys in 1973 and 1974 by the Western Geophysical Company and Furgo, Inc.[12] for the purpose of site selection for nuclear power plants. Offshore surveying included the use of magnetometer and nonexplosive seismic techniques, with the deep penetrating aqua pulse system and a shallow-sparker profiling system. Coverage was provided for the areas from San Juan west around the island to the southwestern shelf area and for the area off the southeastern corner of the island. Onshore seismic surveys included the use of the nonexplosive Vibroseis system on selected roads between Dorado and Islote on the north-central coast and explosive surveys in the vicinity of Islote. From these surveys, potentially large offshore prospects involving a previously undetected, discontinuous, deep unit designated as formation "R" was identified. Based on seismic-velocity information, DeGolyer and McNaughton[13] postulated that formation "R" may be upper cretaceous to Eocene limestones or dolomite that accumulated on the flanks of acoustical basement highs in the vicinity of Manati, Dorado, and San Juan. Reefal limestones of this age are known to produce petroleum elsewhere in the Caribbean-Gulf of Mexico region. However, according to DeJong[9] formation "R" could also represent less favorable volcanic rocks.

Although the nature of the formation "R" prospects is currently speculative, their size is of sufficient magnitude to make them economically attractive. The total extent of the prospects is unknown, especially in the vicinity of and east of San Juan.

The extent of any further drilling or exploration activities within the last 2-3 years is unknown. An exhaustive search of activities in this field of endeavor was not undertaken.

Gas Potential

Natural gas can be classified as conventional or unconventional. Conventional natural gas is found with petroleum (associated, free or dissolved gas) or separately (non-associated). Unconventional gas sources as defined in Ref. 14 includes gas from Devonian shale, geopressured brines, coal seams, and tight-gas reservoirs. This definition excluded sewage gas, synthetic natural gas and gas from landfills. Devonian shale gas is found in deposits of black or gray shale horizons. The black shales have a higher gas content than the gray shales and are generally believed to be the predominant source beds of the natural gas found in the shales. Some geopressured brine reservoirs, which are underground reservoirs that contain hot salt water at a pressure gradient greater than 0.465 psi per foot of depth, are known to contain methane dissolved in the brine. Tight gas is defined as natural gas in either blanket or lenticular formations that have in-situ effective permeability of less than 1 millidarcy. Historically, most of these formations have been uneconomical to produce at prior gas prices due to the low natural flow rates of the gas. Coal-bed gas is a natural byproduct of coal formation and can be found in varying quantities in coal seams lying below drainage. Although a large portion of the gas thus formed has escaped to the atmosphere, a portion may have been trapped and remains in place. Coal-bed gas molecules exhibit a high affinity for their parent material, which enables larger volumes of the gas to be stored in coal than in porous media (sandstones, etc.) at the same conditions. The coal-gas resource is intimately related to the coal resource base itself.

A limited search of accessible literature has failed to find any information related to the existence of coal fields, Devonian shale, tight gas formations or geopressured brines in Puerto Rico. Hence, it is assumed that unconventional gas sources do not exist on the Island.

Coal Potential

Whereas there is no evidence of extensive coal deposits in Puerto Rico, Monroe[15] states that near Lares, the upper middle part of the San Sebastian formation contains several thin beds of lignite. In the section exposed along Highway 111 in the northern part of Lares, five beds of lignite each about 10-cm thick, are exposed in a sequence of silty carbonaceous clay and fine sand, whose top is 21 m below the base at the Lares limestone. Lignite has also been reported in the San Sebastian formation by Briggs[11] from the drilling of the test well CPR 4 on the Atlantic coast east of Arecibo.

Federal Energy Incentives and Policies

Due to the lack of any developable indigenous fossil resources, Puerto Rico has been an importer of petroleum and its products. Governmental incentives led to the development of petroleum refining and petrochemical industries between 1955 and 1971.[2] Hence, Puerto Rico has become an exporter of refined petroleum products whose quantities about equal 35% of its total petroleum import volume.

A brief survey of some of the Federal energy policies that impacted the Puerto Rican petroleum and petrochemical industry follows. Additional details can be found in Ref. 16. Federal energy involvement in Puerto Rico began in 1959 with the establishment of crude oil import quotas by the Oil Import Administration of the Interior Department. This mandatory oil-import program (MOIP) was established by Presidential Proclamation 3279 (March 10, 1959), and amended in its entirety by Presidential Proclamation 4210 (April 18, 1979). These MOIP regulations protected high domestic crude oil prices by imposing quotas on the amount of cheap foreign oil that could be imported into the U.S. It also provided to island refiners, a long-term allocation (usually 10 years) that permitted specified volumes of crude or unfinished oils to be imported under a fee-exempt license. On May 1, 1973, the quotas were converted to a fee system of imports, some of which were fee-exempt and others were fee-paid. Puerto Rican refiners benefited from the long-term allocation of fee-free licenses and when these licenses expired, they obtained additional exceptions to the payment of license fees. Consequently the refiners experienced no disadvantage from the license fee program or any impact from the exemptions.

In order to stimulate the local economy and to provide vital employment opportunities in Puerto Rico, Presidential Proclamation 3693 (December 19, 1965) was adopted. This proclamation authorized the import of cheaper foreign oil and naptha by firms establishing in Puerto Rico. It also granted valuable preferential treatment to those companies by excluding their shipments of oil and oil-derived products to the continental U.S. from import quotas. These incentives gave the companies a competitive advantage of $1.35 to $1.45 per barrel over mainland firms. Also, cheaper electricity rates were available from the use of the lower-cost foreign oil for electricity generation. In return for these incentives, the industrial firms had to commit to making certain investments. Such provisions were originally advantageous to both the Island and U.S. industries. They provided the U.S. firms with inexpensive petrochemical feedstocks, tax exemptions and relatively cheap labor; Puerto Rico gained economic advantages in new industries, increased investments and earnings and employment opportunities for its population.

The price advantage of foreign oil disappeared in the fall of 1973 when the oil embargo and subsequent sharp increases in oil prices from OPEC countries occured. These actions led to the Emergency Petroleum Allocation Act (EPAA) in November 1973. This act established ceiling prices on domestic crude oil and petroleum products to prevent domestic producers from increasing their prices to foreign levels. It resulted in the average price of domestic crude oil becoming considerably lower than the average price of foreign oil. These circumstances led to the establishment of the crude oil entitlements program in November 1974. Under the program, refiners utilizing more than the national average amount of price-controlled domestic crude are required to buy entitlements for each barrel processed above this average from refiners who use less than average amounts of price-controlled crude. This program, essentially functions as an income transfer program between refineries so that their average acquisition costs for crude oil are equivalent. Puerto Rican refiners are included in the entitlements program.

Naphtha, the primary feedstock imported by the Island for use in its petrochemical facilities, was decontrolled in July 1976, although the price continues to be affected by the entitlements program. In the continental United States, naphtha is an intermediate product in the refining process, and meets domestic requirements. The costs of production of domestic naphtha are substantially lower than the prices for naphtha in the world market. A program which provides entitlements for naphtha feedstock imports for use in island petrochemical plants was adopted and became effective July 1976. The naphtha entitlements program was designed to subsidize refiners in Puerto Rico who have no access to lower priced domestic naphtha but must rely on higher priced imports. While this program has neither completely remedied the cost problems associated with imported naphtha feedstock nor the competitive position of Puerto Rican firms versus domestic manufacturers, it has assisted in improving the situation experienced by importers on the island prior to implementation of the program. Currently, mainland firms do not have a naphtha entitlements deduction for volumes of petrochemicals exported from the U.S. However, Puerto Rican firms have a naphtha entitlement deduction for exported petrochemicals and thus are limited in the participation in the export market. DOE has recognized this inequity and has granted exceptions in the form of additional entitlements to Puerto Rican refining and petrochemical firms on a case-by-case basis.

To add to the problems experienced by Puerto Rican firms, all exports by water to the U.S. must travel by U.S. registered ships as required by the Merchant Marine Act of 1920 (Jones Act 46 U.S.C. 883). These ships typically have relatively high freight charges, which adds another cost disadvantage to the Island.

Imports of Crude Oil and Refined Products

A unique feature of the Puerto Rican refining and petrochemical industry is its total dependence upon imported crude oil and naphtha for its feedstocks. Imported quantities of crude oil and refined products by refiners and wholesalers for the calendar years 1976-1980 as obtained from Ref. 17 are shown in Table 2.3.1.1-1. Imports by wholesalers consisted of all of the aviation fuel and in recent years all of the gasoline. The average price per barrel for these imports is shown in Table 2.3.1.1-2. The country of origin for these imports is given in Table 2.3.1.1-3. In the early seventies, over 70% of imported oil came from Venezuela. In 1974 this percentage dropped to about 40% and has steadily declined since that time. Also evident is the drop in the total quantity of imports in recent years. This decline is a result of poor world economic conditions and the effects of conservation efforts.

Refining

Puerto Rico has three petroleum refineries with a total capacity of 284,000 barrels per day (b/d) as of January 1, 1982. Capacity figures vary somewhat with the year and reference cited and the data

Table 2.3.1.1-1 Volume of Imports of Crude Oil and Refined Products by Refiners and Wholesalers of Puerto Rico

Product	Volume (10^6 Barrels)					
	1976	1977	1978	1979	1980	1981[a]
Crude Oil	83.1	77.7	77.3	69.2	59.0	52.5
Naphtha	36.6	42.4	38.4	34.2	32.6	30.1
Motor Gasoline	0.8	0.2	0.3	2.0	2.5	2.3
Aviation Fuel	1.1	1.4	2.1	2.2	1.6	1.6
Other Products	0.4	0.7	0.4	1.6	1.6	10.8
Total	122.0	122.4	118.5	109.2	97.3	97.3

[a]1981 data is for fiscal year 1981, Source: Ref. 20.

Source: Ref. 17.

Table 2.3.1.1-2 Average Price of Imports of Crude Oil and Refined Products by Refiners and Wholesalers of Puerto Rico

Product	Price ($ Per Barrel)					
	1976	1977	1978	1979	1980	1981[a]
Crude Oil	12.48	13.86	13.69	20.28	29.45	32.02
Naphtha	14.21	14.75	15.42	30.80	36.44	37.19
Motor Gasoline	16.53	19.66	19.53	36.13	47.77	47.85
Aviation Fuel	16.95	18.43	19.01	29.29	41.66	42.07

[a]1981 data is for fiscal year 1981, Source: Ref. 20.

Source: Ref. 17.

presented in this report is from Ref. 18 and is based on calendar days. (Calendar-day figures are the average volume a refinery unit processes each day including down time used for turnarounds. This is the actual volume for the year divided by 365. Stream-day figures represent the amount a unit can process when running full capacity for short periods.) The three refineries are: Commonwealth Oil Refining Co. (CORCO), located on the south coast at Penuelas, Yabucoa Sun Oil Co., located on the south coast at Yabucoa, and Caribbean Gulf Refining Corp. located on the north coast at Bayamon (San Juan metropolitan area). In addition, there is an aromatics plant owned by Phillips Puerto Rico Corp., Inc. which is located on the south coast at Guayama and converts naphtha into gasoline and aromatics (benzene, toluene, xylene, etc.). There is also a small operation by Peerless Petrochemicals for which no information is currently available. Table 2.3.1.1-4 contains information on charge and production capacity of the three refineries.

Details on these refineries are limited. CORCO is the largest refinery with 57% of the total refining capacity in Puerto Rico. Its principal products are liquefied petroleum gas (LPG), aviation fuel, kerosene, motor gasoline, naphtha, residual fuels and intermediate distillates. Yabucoa Sun Oil, owned by Sun Oil Co. of the U.S. has 30% of the Island refining capacity. It is basically a lubricating oil facility but also produces naphtha, distillate and residual fuel oils. Essentially, all lubes and about half of the other products are shipped to the east coast of the U.S. The remaining products from the Sun Oil Co. are consumed on the Island. The residual fuel oil is sold to the authority's Aquirre station on the south coast and also as boiler fuel for ships. Caribbean Gulf Refining Corp., owned by Gulf Oil Corp. of the U.S., with the remaining 13% of the refining capacity produces about 25% gasoline, 25% middle distillates, and 50% residual oil. All of these products are consumed on the Island, except for small amounts of distillates shipped to the east coast of the U.S.

Table 2.3.1.1-3 Country of Origin of Imported Crude Oil by Puerto Rican Refiners

	1976		1977		1978		1979		1980		1981[a]	
Country	10^6 Barrels	%	10^6 Barrels	%	10^6 Barrels	%	10^6 Barrels	%	10^6 Barrels	%	10^6 Barrels	%
United States	1.9	2.3	0.5	0.7	13.1	16.9	21.0	30.4	25.7	43.6	23.5	44.6
Venezuela	35.1	42.2	31.4	40.4	26.2	33.9	25.6	37.0	12.9	21.8	14.1	26.9
Middle East	15.4	18.5	22.7	29.2	11.3	14.6	5.8	8.0	8.8	15.0	6.0	11.5
Other Countries	30.7	37.0	23.0	29.6	26.7	34.6	16.8	24.3	11.5	19.6	8.9	16.9
Total	83.1	100.0	77.7	100.0	77.3	100.0	69.2	100.0	59.0	100.0	52.5	100.0

Source: Ref. 17.

[a]1981 data is for fiscal year 1981. Source: Ref. 20.

Table 2.3.1.1-4 Puerto Rico Refining Capacities

		Charge Capacity (b/cd)						Production capacity (b/cd)			
Company and Refinery Location	Crude	Vacuum Distillation	Thermal Operations	Catalytic Cracking	Cat Reforming	Cat hydro-Cracking	Cat hydro-treating	Alky. Poly.	Aromatics/ Isomerization	Lubes	Hydrogen MMcfd
Caribbean Gulf Refining Corp-Bayamon	38,000	20,000	---	12,000	6,000	---	6,000	1,000	---	---	---
Commonwealth Oil Refining CI-Penuelas	161,000	65,000	20,000	40,000	70,000	---	70,000 16,000	4,500 2,400	44,000 6,400 3,400	---	---
Yabucoa Sun Oil Co.-Yabucoa	85,000	42,500				15,600				6,500	18.0
Total	284,000	127,500	20,000	52,000	76,000	15,600	103,000	7,900	53,800	6,500	18.0

Source: Ref. 18.

CORCO is a privately owned firm that filed for bankruptcy in March, 1978, as a result of losses from some fixed-price contracts and the escalation of oil prices after 1973. In 1979, an agreement in principle between CORCO and Arabian Sea Oil Corp. for investments and crude oil supply was arranged. At that time, the agreement would form the basis of a plan for CORCO's emerging from bankruptcy. CORCO supplies about 69% of the Island's petroleum products; 30% of their products were shipped to the U.S. and the remainder to foreign markets. The major recipients of the internal sales were other major oil companies, the Puerto Rico Water Resources Authority for electricity generation, and CORCO's petrochemical operations.

CORCO has transported significant amounts of the crude oil and naphtha feedstocks it purchases in its chartered oil tankers. The company also transports significant amounts of its refined petroleum products and its petrochemical products in ships or barges that it either owns or charters. Due to a significant decrease in cargo rates resulting from worldwide excess capacity and a reduction in the level of utilization of vessels by the company as a result of a decline in business activity, CORCO has been incurring significant losses from its tanker operation.

The production[17] of petroleum products by Puerto Rican refiners is given in Table 2.3.1.1-5 for the calendar years 1976-1980 and fiscal year 1981. For the same time span, the amount of products sold locally and exported by the refiners are listed in Table 2.3.1.1-6. Over 90% of the exported products go to the U.S.

As of June, 1981, Puerto Rico had 177 storage tanks[19] for petroleum feedstock and refined products for a total design capacity (capacity of tanks if completely filled; working capacity is about 81% less than design capacity) of 17,200,700 barrels. A breakdown of this capacity is given in Ref. 19.

Table 2.3.1.1-5 Refinery Production of Petroleum Products in Puerto Rico

Product	Volume (10^6 Barrels) 1976	1977	1978	1979	1980	1981[a]
Naphtha	4.7	5.6	4.8	5.1	4.3	3.4
Refined Gas	5.3	5.1	4.7	4.7	4.4	4.1
Middle Distillates	23.9	20.8	20.3	17.7	18.1	15.0
Residual Fuel Oil	30.1	30.4	30.4	27.6	22.4	19.4
Motor Gasoline	27.4	32.0	30.2	28.2	25.2	24.8
Aviation Fuel	1.1	1.2	1.0	1.2	1.1	0.9
Lubricants	1.3	1.9	1.6	2.0	2.0	1.9
Aromatics	9.2	8.8	8.6	7.6	7.5	7.0
Other Products	0.9	0.7	1.1	0.7	1.0	0.8
Total	103.8	106.5	102.9	95.0	85.9	77.2

[a]1981 data is for fiscal year 1981. Source: Ref. 20.

Source: Ref. 17.

Table 2.3.1.1-6 Quantity of Petroleum Products Sold Locally and Exported by Puerto Rican Refiners

	Volume (10^6 barrels)											
	1976		1977		1978		1979		1980		1981	
Product	Local	Export	Local	Export	Local	Export	Local	Export	Local	Export	Local	Export
Naphtha	16.7	—	16.4	—	15.5	—	15.8	—	14.3	—	13.2	—
Motor Gasoline	13.8	14.0	13.8	18.2	15.0	16.1	12.2	16.0	10.6	14.1	26.2	14.3
Aviation Fuel	1.1	—	1.1	—	0.9	—	0.8	—	0.8	—	3.0	—
Middle Distillates	6.6	12.4	6.3	13.6	7.8	12.2	5.5	12.1	6.3	11.	7.8	35.5
Refined Gas	2.2	—	2.2	—	1.8	—	1.9	—	1.9	—	3.9	—
Residual Fuel Oils	22.7	6.8	25.8	3.4	25.4	2.7	25.0	3.2	18.9	3.2	18.7	2.5
Aromatics	1.8	6.4	2.9	5.4	4.2	4.5	3.6	4.2	3.8	3.4	3.8	3.1
Pitch and Asphalt	0.3	—	0.1	—	0.2	—	0.2	—	0.3	—	0.3	—
Other	—	3.1	—	6.4	—	4.6	—	3.1	—	3.7	0.3	2.8
Total	65.2	42.7	68.6	47.0	70.7	40.0	65.1	38.5	56.9	35.6	77.3	30.9

[a]1981 data are for fiscal year 1981. Source: Ref. 20.

Source: Ref. 17.

Petrochemical Industry

The petrochemical industry in Puerto Rico was founded upon the basis of the ready availability of low-cost, foreign-origin feedstocks and a system of local incentives with emphasis on industrial tax exemption. However, the worldwide upheaval of oil prices during 1974-1977 eliminated many of the economic advantages of producing petrochemicals in Puerto Rico. These feedstock price changes occured before the Island's petrochemical complex had attained an optimum structure, and coincided with the 1974-1975 worldwide recession which caused a slump in demand for petrochemicals. In addition, the cost of electricity escalated well above that of the mainland. These events discouraged further investment in downstream petrochemical facilities and caused a number of the plants to close.

Naphtha is the basic feedstock for all petrochemical production on the Island. It is either imported or produced in local refineries from imported crude oil. There are no published statistical data on petrochemical production, consumption, and exports on a weight basis because this information would reveal individual company operations. The petrochemical products are classified as basic or intermediate, and are almost totally shipped to the mainland for further processing into finished goods. Figures 2.3.1.1-1 and 2.3.1.1-2 are schematic diagrams of the Island's refinery and petrochemical industries as initially structured.

The major petrochemical core facilities are owned by Union Carbide, Inc., CORCO, Phillips Petroleum Co., and PPG Industries. The Puerto Rico petroleum refineries and petrochemical plants are highly interdependent, and in a few cases, operations are vertically integrated. In general, the refineries provide naphtha, gas oil, process fuels, and residual fuels for the petrochemical units. The latter in turn supply fuel-producing operating with aromatics, fuel gases, raffinate and raw materials for alkylate.

CORCO represents the largest industrial complex in Puerto Rico. It has joint ventures with the Herco Chemical Corp., Puerto Rico Olefins Corp., and Oxchem Enterprises. Herco Chemical Corp. is jointly owned by CORCO and Hercofina (a joint venture 75% owned by Hercules and the remainder by American Petrofina, Inc.) and produces paraxylene, which is a vital component in the manufacture of polyester fibers and polyester film. Xylene feedstocks are purchased from CORCO's aromatics and ethylbenzene plants and the paraxylene is sold to Hercofina. Due to a new and more efficient catalyst, certain plant facilities of Herco have been shut down since January, 1977.

Puerto Rico Olefins Corp. (PRO) is a joint venture by CORCO and PPG Industries, Inc. to produce ethylene, propylene, and butadiene. The ethylene was sold to PPG and Union Carbide for further downtream processing in Puerto Rico. The propylene is sold to Oxochem Enterprise as a feedstock for manufacturing oxoalcohols for use in plastic products. The butadiene is sold mainly to Firestone Rubber Co., as a raw market for making synthetic rubber. PRO operated at a loss since it began operations in mid-1972. It had numerous shutdowns and technical difficulties and never operated at full capacity because of a lack of market for its ethylene. PRO terminated operations in November 1978.

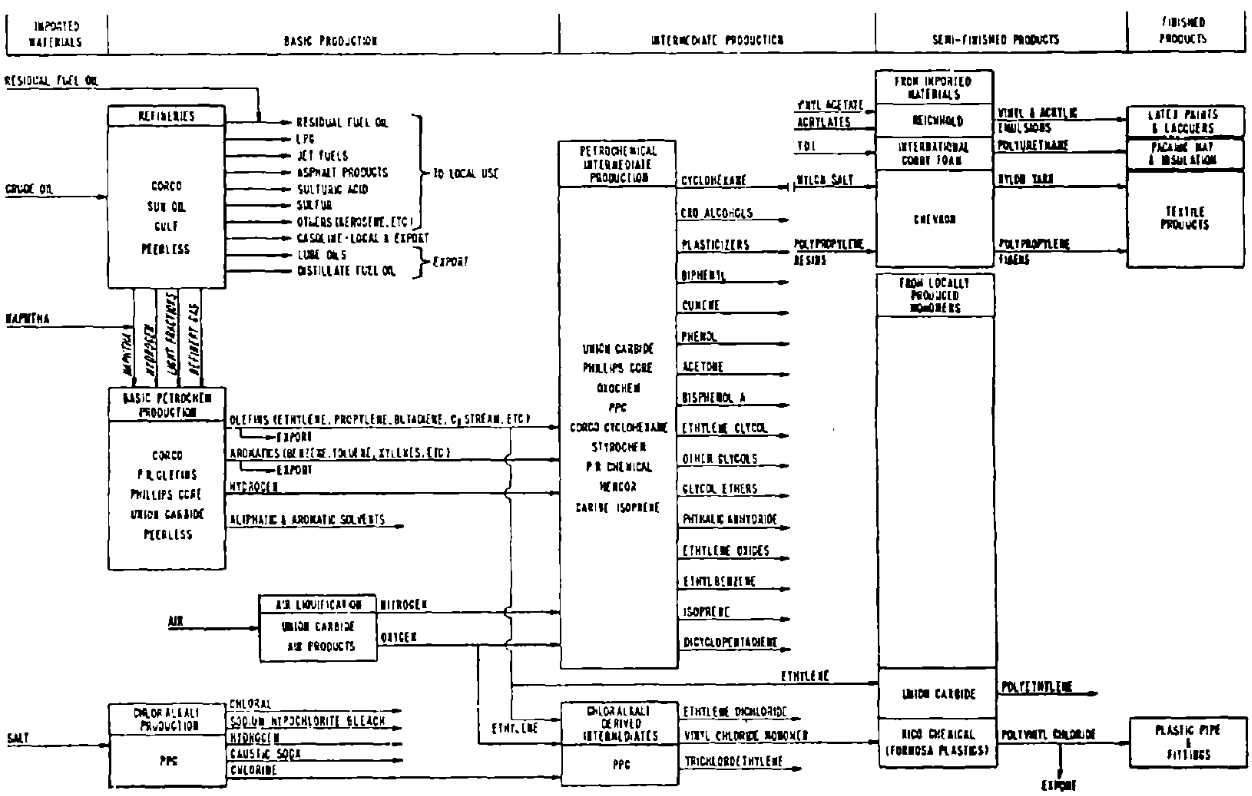


Fig. 2.3.1.1-1 Puerto Rico Refining and Petrochemical Industry:
Imported Materials to Finished Products

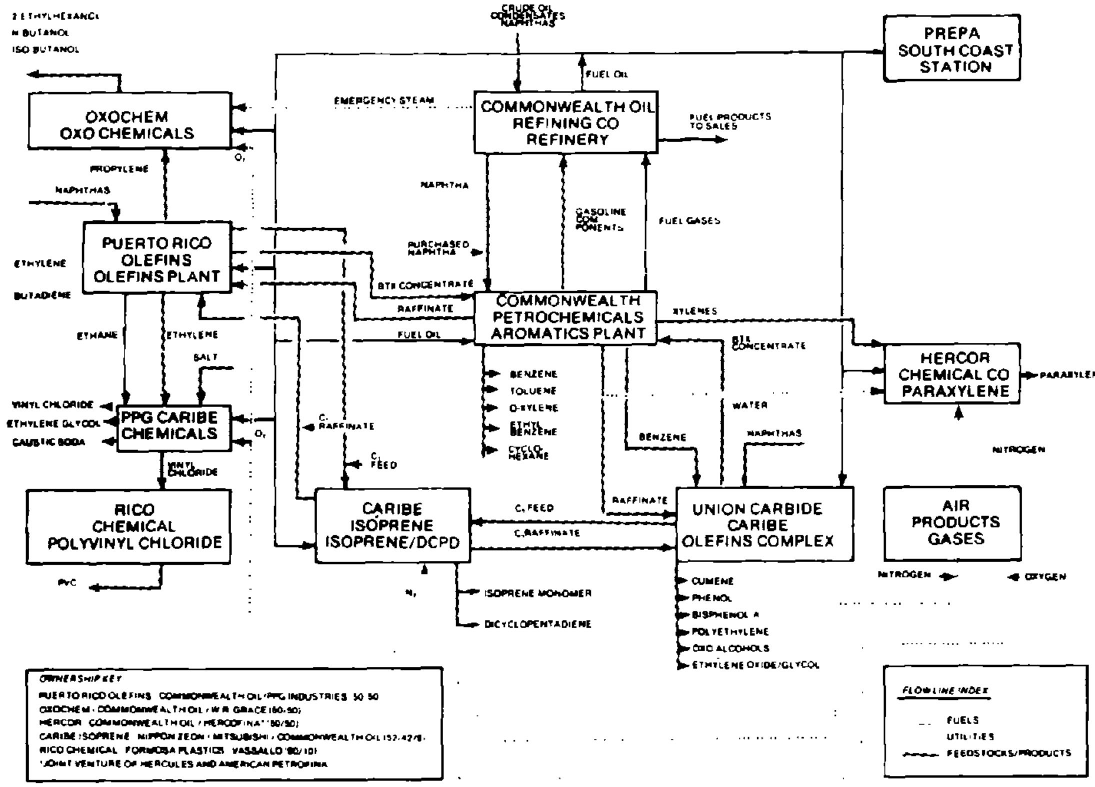


Fig. 2.3.1.1-2 Puerto Rican Petrochemical Complex: Fuels, Utilities, Feedstocks, and Products

Oxochem Enterprise is a joint venture between CORCO and W.R. Grace and Co. to produce oxoalcohols. The principal product is 2-ethyl-hexanol, which was purchased by the Hatco Division of Grace. CORCO sold the propylene feedstock to Oxochem under a long-term contract significantly below its cost, and as a result incurred substantial losses. When PPG terminated operation of PRO in November, 1978, Oxochem's primary source of feedstock was eliminated and Oxochem also suspended operations in early December 1978.

Union Carbide Caribe, Inc. has 13 plants in Puerto Rico and can produce the following selected products annually: butadiene (185 million lbs), ethylene (1 billion lbs), ethylene-glycol (700 million lbs), ethylene oxide (650 million lbs), phenol (200 million lbs), low-density polyethylene (310 million lbs) and propylene (500 million lbs).

The annual production capacity of the Phillips Puerto Rico Corp., Inc. petrochemical complex is: benzene (126 million gallons), cyclohexene (98 million gallons), toluene (110 million gallons), mixed xylenes (108 million gallons), orthoxylene (250 million lbs), and paraxylene (470 million lbs).

In addition to Puerto Rico Olefins and Oxochem, other plants that are currently shut down are the PPG Industries Caribe, Caribe Isoprene, and Air Products. The PPG Industries Caribe chloronali plant produced chlorine and caustic soda and its viability was based on low-cost electric power that existed prior to 1974.

The petrochemicals manufactured in Puerto Rico have become an important component of the total U.S. refining and petrochemical industry during the past two decades as evidenced by the data in Table 2.3.1.1-7 from Ref. 16. CORCO is the largest benzene plant. CORCO's petrochemical operations produce more aromatic chemicals than any other facility in the world.

2.3.1.2 Electric Sector

The Puerto Rican Electric Power Authority (PREPA), formerly known as the Puerto Rican Water Resources Authority is responsible for over 99% of the production, transmission, and distribution of electricity on the island of Puerto Rico. The remaining electric power is generated by certain industries for their own use and by the town of Cayey. PREPA is a public corporation and an instrumentality of the Commonwealth of Puerto Rico.

Table 2.3.1.1-7 Production Capacity for Selected Petrochemicals Manufactured in Puerto Rico in 1978

Product	Annual Capacity 10^6 lbs	Percentage of U.S. Capacity
Benzene	355[a]	15.7
Cyclohexane	137	28.4
Paraxylene	1170	20.4
Orthoxylene	437	32.2
Ethylene	1800	5.1
Ethylene Glycol	1075	15.8
Vinyl Chloride Monomer	500	6.0

[a]Millions of gallons per year.

The PREPA system is almost totally dependent upon oil for generation of electricity. Oil-fired steam units, combustion turbines, and diesel units account for 98% (4104 MW) of the generating capacity with hydroelectric power comprising most of the rest (95.4 MW). An experimental 200 kW wind turbine, built with U.S. DOE assistance, was put in service in July 1978 on the offshore island of Culebra.

Load Profile

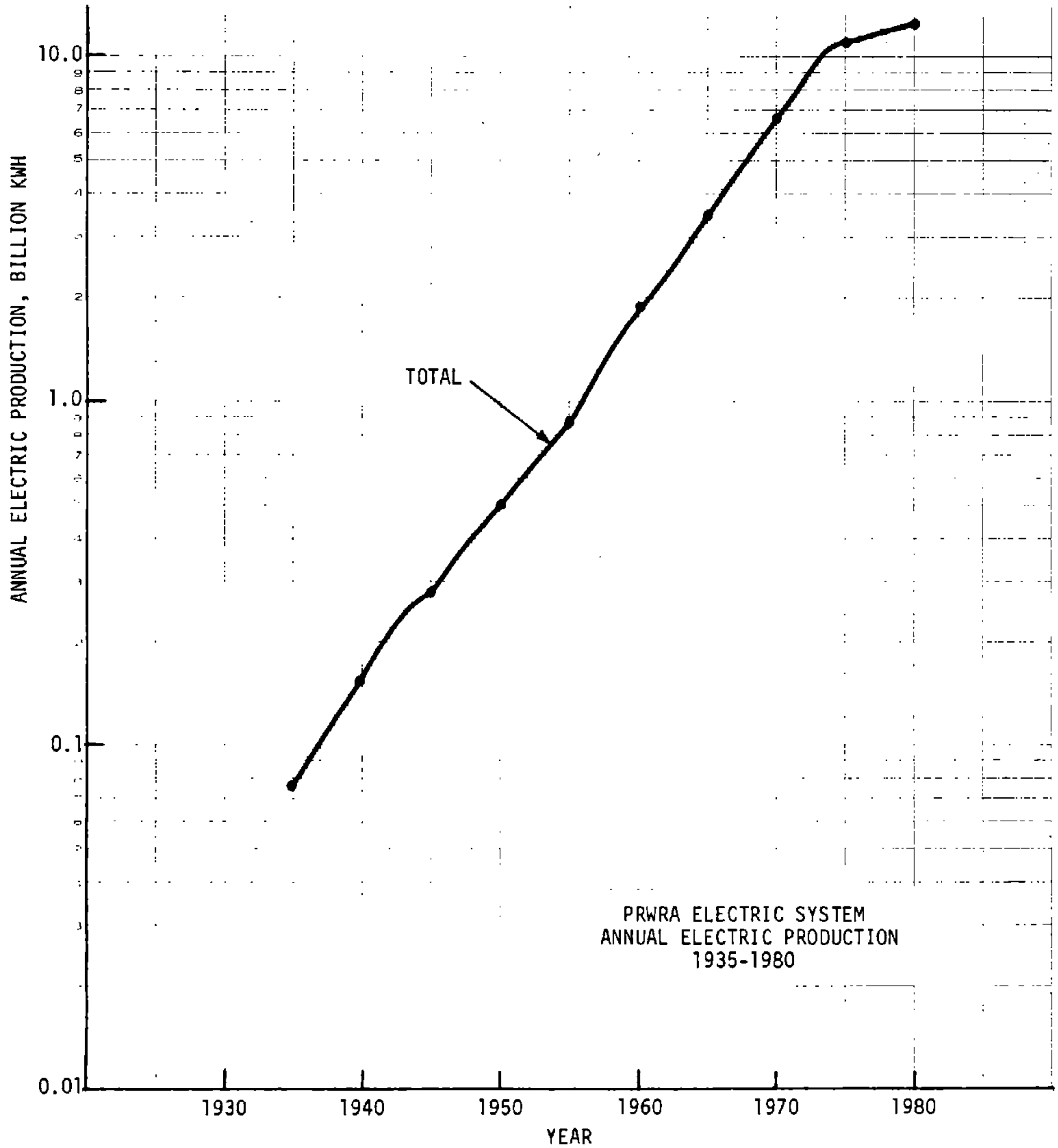
Puerto Rico has experienced a tremendous growth rate in electrical demand for most of the last 47 years. Figure 2.3.1.2-1 illustrates this trend. From 1935-1973, annual electric production in Puerto Rico grew almost 14%/yr. However, since the first oil embargo, load demand growth has dropped sharply to just 3%/yr. The all-time peak demand of 2057 MW occurred in 1978. This sluggish growth rate is expected to continue over at least the next few years. The average annual load factor is 76%, with the daily load factor during the average weekday going as high as 89%. This unusually high load factor is due mainly to the use of air conditioners at night.[2] There is also little seasonal variation since monthly peak loads vary by no more than 13% during the year. Figure 2.3.1.2-2 shows the hourly load variations for several days during the week. Two peaks occur during the average weekday; one at noon and a second, slightly higher one, at 8 p.m. The nighttime "valleys" in the daily load demand are smaller than in typical systems on the U.S. mainland.[2] This, coupled with the uniformity in weekly and yearly load variations, results in problems peculiar to the PREPA system regarding reserve capacity requirements, maintenance schedules, etc. The lower nighttime "valleys" may also affect pumped storage capacity requirements if this technology is considered as a future option.

System Configuration

Table 2.3.1.2-1 shows the plant composition of the PREPA system. The large units in the system consist of two 300 MW combined cycle units, two 410 MW steam turbines, and two 450 MW steam turbines. All of these plants came on line within the last 10 years in anticipation of the 14%/yr growth rate of the 1960s and early 1970s continuing. Because peak demand is around 2000 MW, PREPA's reserve margin is approximately 100%. A large reserve margin for an isolated system such as Puerto Rico is not uncommon, but the system still encounters problems and customers experience recurring service interruptions. There are several reasons for these service problems. First, six of PREPA's steam turbines are between 300 - 450 MW. When one of these units fails, about 20% of the peak demand is out of service and hence system reliability is difficult to maintain. Second, maintenance of existing units has been difficult to keep up. PREPA is in the position of having to use a "component overhaul." The result is that every large unit is shut down for some time each year as work is done on individual portions of the unit. Hence, units spend more time in maintenance under this schedule than if each was overhauled completely every few years. Finally, the large system load factors present a special problem for maintenace scheduling.

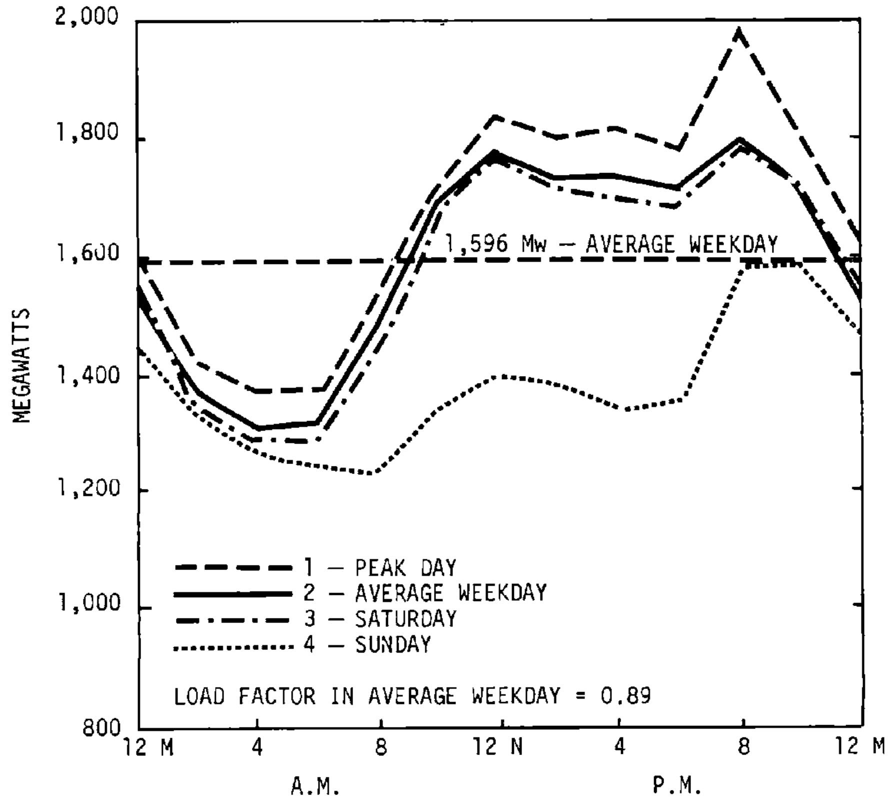
The combination of large load factor and relatively constant monthly peak loads does not permit PREPA to perform preventative maintenance during periods of low demand, which is common practice on the U.S. mainland. Although PREPA has a large reserve, scheduling maintenance can be quite difficult.

PREPA's transmission system consists of 230/114 kV primary and 38 kV secondary transmission voltages. Primary distribution is 13 kV and secondary voltage is 4.16 kV. Transmission and distribution losses



SOURCE: REF 2

Fig. 2.3.1.2-1 Annual Electricity Production (1935-1980)



SOURCE: REF 2

Fig. 2.3.1.2-2 Projected Hourly Load Variations (week in June 1977)

Table 2.3.1.2-1 Plant Composition by Type for the PREPA Electrical System (December 1978)

Plant Type	Capacity (MW)	Percent of Total System
Oil-Fired Steam Plants	3858	92
Gas Turbines	243	6
Hydroelectric	95.4	2
Diesel Units	2.9	-
Wind Turbine	0.2	-
Total	4199.5	100

Source: Economic Study of Puerto Rico, Vol II. U.S. Dept of Commerce. Washington, D.C. December 1979.

from 1972-1978 have amounted to 9-11% of the power transmitted, which is about the same as that which U.S. mainland utilities experience.[3] PREPA has also recently begun building a power control center. The minicomputer-equipped center will alert officials of problems that arise so that repair crews can be dispatched immediately. The in-service date of this center has not been set.[4]

Rural electrification is being carried out under a program called Guaranteed Minimum Consumption. When a customer agrees to a guaranteed minimum consumption, PREPA covers all installation costs and grants the customer five years to amortize the materials and cost of the installation.[4]

Since the 1973 oil embargo, electric energy sold to residential customers increased from 2.6¢/kWh in 1972 to 10.43¢/kWh in 1985.[5] In the commercial and industrial sectors electric rates also increased dramatically. Presently, most of PREPA's customers are charged on declining block structures. That is, each increment of electricity to a given consumer is charged at a lower rate than the last. Also, about 70% of residential customers receive the benefits of the subsidized electric rate for consumers who use less than 425 kWh of electricity per month.

Short Term Steps

Several short-term remedies have been advanced in order to increase the reliability of the present system and also decrease overall operating costs through savings on fuel. First, improved system maintenance can be achieved by altering current maintenance practices. The practice of "component overhaul" can be replaced by "unit overhaul." Units will not be on maintenance as much if a complete overhaul is done every few years rather than servicing a part of a unit every year.[1] If continued, the "component overhaul" maintenance approach may impair system reliability as reserve margins are reduced in the future.[1] It has also been suggested that PREPA consider doing disassembly work on a schedule of three shifts per day, seven days a week, whenever a unit is shut down for overhaul, so that the size of the overhaul job can be assessed quickly. Disassembly work done in this manner can reduce opening time for a steam turbine generator from 3-4 weeks on a straight-time basis to within seven days.

Second, changing the system operation so that more quick-response capability is available could improve the reliability by lessening the impact of forced outages on the system. This can be achieved by operating nearly all steam units at below full capacity. This would allow them to respond quickly to emergency demands and should reduce their maintenance requirements. No major capital expenditure would be needed since most steam units are equipped with load frequency controls that automatically maintain constant generator speed under varying load conditions. Also, refurbishing some of the fast-starting gas-turbine generating units can help assure that lost capacity could be more smoothly and rapidly replaced.[1] Furthermore, the installation of fast-acting under-frequency relays throughout the system would permit shedding selected loads immediately in case of generation losses. Noncritical customer loads could be dropped almost instantly, so that priority service could be given to users for whom a loss of load would have severe economic or safety consequences. Most U.S. mainland utilities protect vital services such as hospitals and certain industrial processes that require very reliable service in this manner.[1]

Third, changing the electic rate structure may cause customers to conserve or transfer peak time usage to off-peak hours. Inverted rates, that charge customers more for each incremental block of electricity used rather than the present practice of charging less, are one possibility. Also, time-of-day rates may help provide signals to consumers to shift their usage of electricity to off-peak hours.[1] Finally, opportunities for cogeneration of electricity with industrial steam producers can be explored.[1]

It should be noted that construction of the next gnerating units means PREPA will have to borrow about $300 million each year for several years in the early 1980s. To do this at a reasonable cost means PREPA will have to raise its revenues substantially, primarily by raising rates.[1]

2.3.1.3 Renewable Energy Resources

Although Puerto Rico is endowed with several indigenous renewable energy resources, as far as the composition of current energy supply system is concerned, renewable forms of energy contribute a very small share of the total energy supply. Puerto Rico is in the process of determining the quantity and quality of the energy available for each resource; evaluating the commercial technologies available for harnessing energy from each form of renewable resource, their costs, engineering details, and performance characteristics; estimating the economic viability of each renewable resource when compared to the economics of energy from conventional sources; and evaluating demonstration units operating in Puerto Rico to provide field data on the operation, maintenance and problems associated with each conversion device. Reference 1 is a compilation of available information. The following is a summary of the demonstration efforts.

Wind. A pilot 200 kW wind-electric system was installed on Culebra Island and began operation as part of the PREPA system in February 1979.[2] Modified blades were installed after 600 hours and the unit was back in service in February 1980. Operating results through the end of 1980 showed some weeks with capacity factors as high as 54%. If the weeks with extensive down time are excluded, the average weekly capacity factor was 22%. The installed cost of the demonstration unit was $1 million, representing a cost of $5000/kW, which is very high. It must be remembered, however, that this is a demonstration unit, not a commercial system. It is expected that the cost of wind electric system will decrease with increased production of these units. Presently, the wind electric system can satisfy roughly one-fourth of Culebra's electric demand.

Multipurpose and Small Scale Hydroelectric System. Since the available catchment area for collecting and channeling rainwater in Puerto Rico is small, the number of sites for developing hydroelectric power is limited. Puerto Rico has 17 reservoirs, 13 of which are used to feed the various hydroelectric stations. Energy from hydroelectric stations provides roughly 1% of the national electric demand. Since the individual outputs of the hydroelectric situations is less than 5 MW, the hydroelectric sites available in Puerto Rico might be termed small-scale rather than large-scale, multipurpose systems.

Of the 13 reservoirs that supply water to the hydroelectric stations, several reservoirs are non-productive due to silting that has resulted in a reduction of their reservoir capacity. PREPA has initiated a study on the feasibility of reactivating and rehabilitating the reservoirs. Findings of the study will be useful to increasing the energy generation capability from hydropower sites in Puerto Rico. A recently completed study on the redevelopment potential at 13 existing sites conducted by the Puerto Rico Office of Energy indicates favorable cost benefits for development.[1]

Biomass. Puerto Rico's climate facilitates year-round agricultural activity. Agriculture was, at one time, the major economic activity on the island. Industrialization has since received the major emphasis and agriculture has declined as a component of the economy. The result is that biomass, in its various forms including agricultural material (plant and animal), industrial waste, and urban waste, currently is not utilized extensively in Puerto Rico. Table 2.3.1.3-1, from Reference 1, shows an estimate of current biomass production and its energy potential.

The PROE is in the process of funding several small projects to assess and quantify specific biomass sources. Plans are being formulated for an islandwide systems analysis to evaluate the bioenergy potential and to identify steps that can be taken.

Solar Hot Water Systems. It is estimated that about 17,000 residential solar water heating systems have been installed in Puerto Rico. Manufacture and installation of solar hot water systems started in 1976 in response to local demand for these units. Considerable incentives to potential buyers of solar hot water systems, such as a deduction of up to 30% of the cost from taxable income and exemption from the 5% excise tax, provided the necessary boost for switching to solar hot water systems.

Several industries have installed flat plate collectors to provide low temperature hot water for industrial applications. The largest of these is at Johnson and Johnson Co. in Las Piedras. The India beer brewery at Mayaguez also has an operational solar water heating system.

Other Systems. Apart from the wind, hydro, biomass, and solar water heating systems mentioned above, there is currently no other renewable resource use in Puerto Rico.

2.3.2 The Future Energy System

The nature of the future energy supply system in Puerto Rico is dependent on a wide variety of variables. Economic growth patterns, technology developments, oil prices, and a number of other parameters will have an influence on the structure of the supply system. Instead of making predictions of what will happen out to the year 2020, the following section deals with what could conceivably happen under a particular set of conditions. Where possible, a range of outcomes for the supply system is described. The discussion is again divided into the fossil fuel system, the electric sector, and renewable resources.

Table 2.3.1.3-1 Estimated Potential of Currently Available Biomass

	Resource	Amount of Waste	Potential Energy (Heat Value)		Methodology
Municipal Solid Waste[1]	Residential & Commercial at Landfills	1,510 Thousand ton/yr for 1980	6,000 Btu/lb of dry solids		Direct Combustion; methane generation
Sewage Sludge[2]	Waste water treatment	47.82 dry TPD (tons per day)	Digested Primary Sludge	Digested Primary & Secondary Sludge	Methane generation
			7,600 Btu/lb dry solids	8,500 Btu/lb dry solids	
Slaughterhouse Waste[3]	Cattle & Hog	8,741 ton/yr for 1980	3.85×10^{10} Btu/yr		Methane generation
Agricultural Waste[4-5]	Animal Waste	4,350 ton/day (liq. waste)	3.01×10^{10} Btu/yr of liq. waste		Agriculture Methane generation
		760 ton/day (dry waste) for 1980 Animal Waste	5.27×10^{9} Btu/yr of dry waste		
	Biomass	83-110 ton/acre/year	4.5×10^{8} Btu/acre/year		Direct combustion

References:

1. Solid Waste Management Authority, Islandwide Resource Recovery Plan, Brown & Caldwell Assoc. - April 1982 - Preliminary copy.
2. Ibid.
3. Ibid.
4. Environmental Quality Board, Data on Agricultural Waste, 1980.
5. Alexander, Alex C., UPR/CEER, Rio Piedras, The Energy Cane Alternative, UPADI 1982.

Source: Ref. 1.

2.3.2.1 Future Fossil Fuel System Configuration

As previously described, Pureto Rico already has a sizable fossil fuel supply system and major petrochemicals facilities. In addressing future configurations of this supply system several items must be considered. First, the existing facilities represent a major capital investment that cannot be discarded without economic consequences. Second, in any transition to alternative energy sources, petroleum will continue to play a significant role in the energy system for an extended period of time. It is important to recognize that adequate attention must be paid to the need to provide fossil fuels in an efficient and cost-effective manner for the forseeable future. Third, petroleum imports will be a continuing issue for Puerto Rico. The procuring of secure supplies at reasonable costs must be a major area of emphasis. All of these factors will influence the future direction of the fossil energy supply system. Some of these considerations are discussed in References 1-5.

Sources of Petroleum

There are several sources of petroleum for the future in Puerto Rico. The existence of indigeneous reserves has never been completely established. As only limited exploratory drilling has been done to date, the extent of any reserves is unknown. Future efforts in this area will need to focus on the most promising areas and will need to expand the amount of drilling information available.

In a normal supply/demand situation, Puerto Rico should be able to secure its imported oil requirements on the world market with no difficulty. With diminishing oil production, the Island may find itself competing with the mainland U.S. or other oil-importing countries elsewhere in the world. Almost all countries that export crude oil are promoting downstream integration into refining and petrochemical production. In the future, many of these countries may refuse to export crude alone. Oil production in the Caribbean Basin and Mexico is insufficient to supply the existing refinery capacity of the region. For example, in 1977, crude oil production was about 3.6 million barrels per day while refining capacity was about 6 million barrels per day.[4] The situation has further deteriorated today. Hence, the dependence of the region on oil supplies from Eastern Hemisphere sources is extensive. Another factor is that production from traditional sources for Puerto Rico, such as Venezuela, has been declining. Also, production is more frequently in the form of heavier crudes with high sulfur contents. These will require modifications to the existing refinery equipment.

Coal Use Potential

Considering the cost and supply problems of petroleum, an alternative fossil fuel for use in large industrial or utility boilers is coal. The fuel is readily available from the U.S. and possibly from large reserves in Columbia. The Columbian reserves are high in quality and well suited for export markets. Coal preparation, handling and combustion is a well-developed technology, but Puerto Rico currently has no infrastructure for coal use. The necessary coal ports, handling equipment, and transportation facilities represent a major capital investment. An integrated coal feasibility study, considering utility and industrial use as well as infrastructure requirements is needed to define the economic viability of coal.

The utilization of coal-water slurries is being developed and could potentially be adaptable to the existing oil-fired boilers on the Island. The coal-water slurry could be prepared in the coal-producing country and shipped to Puerto Rico in tankers as oil is. It could be handled and stored with modified oil equipment. If feasible, such a fuel would eliminate some of the problems associated with coal usage. Developments in this technology need to be watched and an assessment of the use of this fuel needs to be made.

Gas Use Potential

There is no gas use in Puerto Rico apart from bottled LPG delivered for cooking purposes. The existence of any natural gas reserves, either conventional or unconventional, might make this a viable fuel alternative.

Lacking any indigenous gas reserves the only other alternative for the future is liquified natural gas (LNG) imports. There are very large gas-handling facility requirements that would make this a very capital-intensive alternative. It is not clear that the market for LNG in Puerto Rico is large enough to justify this type of investment.

Another consideration affecting both possible indigenous gas use and LNG is the required gas distribution system. Since no such system is currently in place there would need to be a very large investment in infrastructure to support such fuel use.

Petroleum Products

The Puerto Rican refiners must remain competive as foreign refiners can compete in both the Island and U.S. mainland markets. A list, adapted from Ref. 7, of refineries and their capacity in the Caribbean Basin and Mexico is given in Table 2.3.2.1-1. Note that Puerto Rico's capacity is only about 5% of the total. If the Island refineries can secure crude oil at prices equivalent to their competition and maintain comparable processing efficiencies, then they will continue to be a viable supplier of refined products to the mainland. The effect of higher transport costs imposed by the Jones Act requirements has been addressed in References 1, 3, and 9 and has been somewhat offset by a differential tariff on refined products. The National Academy of Science Study[4] states that the best way to solve the transport cost problem would be to exempt transportation of oil products refined in Puerto Rico from the Jones Act.

One encouraging factor in the future of CORCO is that it is one of the largest producers of aromatics that are used in the production of unleaded gasoline. The demand for unleaded gas is growing, so a favorable market for CORCO should result.

With the diminishing availability of light sweet crudes, the refineries of Puerto Rico need to consider equipment modifications to process the heavier crudes and those with high sulfur contents. Refinery expansion and modification plans need to consider a number of issues. Reference 4 states that the Island has no cost advantages that would warrant expansion of refining capacity for the purpose of increasing exports to the mainland. They expect that any growth in demand for refined products on the Island will absorb some of the present export flow, and possibly use more of the existing capacity, but it will not support major increases in refining capacity.

Petrochemicals

As mentioned previously, the petrochemical industry in Puerto Rico never developed to an optimum or balanced system and part of it has actually been shut down. One major problem is that there are not enough users in Puerto Rico for all the ethylene their facilities were designed to produce. A recent petrochemical

Table 2.3.2.1-1 Refining Capacity in the Caribbean Basin as of January 1, 1982

Country	No. Plants	Crude, b/cd	Vacuum Distillation	Charge Capacity, b/sd: Thermal Operations	Catalytic Cracking	Catalytic Reforming	Cat Hydro-Cracking	Cat Hydro-Refining	Cat Hydro-Treating	Production Capacity, b/sd: Alkylation	Aromatics-Isomerization	Lubes	Asphalt	Hydrogen (MMcfd)	Coke (t/d)
Bahamas	1	500,000	94,000	--	--	--	--	--	--	--	--	--	--	--	--
Barbados	1	3,000	--	--	--	--	--	--	--	--	--	--	400	--	--
Colombia	6	198,500	110,000	41,000	77,000	6,000	--	--	33,700	5,230	4,860	2,000	2,100	17.5	--
Costa Rica	1	15,000	700	--	--	1,500	--	--	3,800	--	--	--	66	--	--
Dominican Republic	2	48,000	--	--	--	9,500	--	--	22,213	--	--	--	--	0.4	--
El Salvador	1	16,300	1,900	--	--	2,800	--	12,100	--	--	--	--	--	--	--
Guatemala	1	16,000	--	--	--	3,000	--	--	5,000	--	--	--	--	--	--
Honduras	1	14,000	--	--	--	1,800	--	--	4,800	--	--	--	--	--	--
Jamaica	1	22,000	1,800	--	--	3,500	--	--	20,00	--	--	--	900	--	--
Martinique	1	11,000	--	--	--	2,500	--	3,500	4,400	--	--	--	--	--	--
Mexico	10	1,470,000	594,200	82,00	297,000	141,000	18,000	--	561,600	6,600	--	--	9,000	70.0	300
Netherlands Antillies	2	782,000	230,000	260,000	42,000	15,000	--	196,000	95,000	1,500	--	--	--	75.0	--
Nicaragua	1	14,400	1,900	--	--	2,850	--	--	11,130	--	--	300	750	--	--
Panama	1	100,000	14,000	--	--	7,500	--	--	30,000	--	--	--	5,000	--.	--
Puerto Rico	3	284,000	127,500	20,000	52,000	76,000	15,600	--	103,000	7,900	53,800	6,500	--	18.0	--
Venezuela	8	1,323,060	525,810	74,520	114,200	6,500	--	304,800	--	28,250	--	6,200	--	336.1	--
Virgin Islands	1	640,000	140,000	--	--	70,000	--	150,000	--	--	--	--	--	--	--
Total	42	5,457,260	1,841,010	491,320	593,600	350,250	33,600	666,400	894,643	49,480	58,660	15,000	18,810	517.0	300

Source: Ref. 7.

report[8] by the Oil and Gas Journal stated that during the first quarter of 1982, an estimated 25% of the U.S. ethylene capacity was not operating. On-stream units were running at reduced rates in an attempt to work off inventories. Polyethylene and styrene production appear to be the best technical possibilities for downstream expansion to absorb ethylene. However Reference 8 reports that serious differences exist among predictions on the future of polyethylene in both the U.S. and worldwide. There is a consensus that U.S. exports will decline significantly during the 1980s, but domestic growth is expected to be vigorous. As of October 1981, there were 77 polyethylene and 50 ethylene plants planned, proposed or under construction worldwide.

The PPG Industries Caribe chloralkali and vinyl chloride plants in Puerto Rico depended upon low cost electricity. The cost of electrical power meant that such an operation could not become viable under forseeable circumstances. The closing of the chloralkali plant eliminated the vinyl chloride feedstock to the Rico chemicals plant for the production of polyvinyl chloride. No current information is available on the operational status of this plant or its alternate feedstock source.

The principal market for petrochemicals produced in Puerto Rico is the mainland U.S. Their main competition is from the plants located on the Gulf Coast and in the eastern states. The U.S. market may not be immune to foreign competition. There is an excess petrochemical capacity worldwide as a result of the building boom that was prompted by high growth-rate predictions of the early 1970s. Petrochemical producers are struggling to regain or improve profitability through feedstock flexibility, better process efficiency, plant closings, or conversion of existing facilities to other uses. Looming in the future are new facilities in the Asia Pacific area, the Middle East, Africa and Mexico. Saudi Arabia in particular has a multi-billion-dollar petrochemical plan now being implemented that the Saudis expect will lend to the capture of 4 to 5% of the worldwide petrochemical market in the late 1980s. Mexico expects to be turning out about 9 million tons/year of petrochemicals when its La Congrejera complex is fully on-stream. Four more market production centers are scheduled in order to establish the country's petrochemical self-sufficiency. On the other hand, in Western Europe petrochemical overcapacity is severe.

Overall, the petrochemical industry's outlook is still cloudy, but according to Reference 8, the majority of producers think the future will be better. Reduced new plant construction, coupled with significant rationalization of existing capacity, should bring supply and demand more into balance. Hence, Puerto Rico should share in an improved market provided they maintain sufficient process efficiencies and are able to secure competively priced feedstocks. Many olefin producers are giving light-feed flexibility to plants that were originally designed only for heavier feedstocks such as naphtha or gas oil. Union Carbide completed a $28 million feedstock flexibility project at Ponce, Puerto Rico, early in 1982, that will allow its oflefin unit to use either LPG or naphtha. In addition, major new investments in downstream operations can be sought to ensure a market for existing excess products.

2.3.2.2 Future Electric Sector Configuration

For Puerto Rico, a low cost, reliable future electric system is necessary in order to attract new industry, stimulate the economy, and maintain or raise the standard of living. Because of its large reserve margin, the present PREPA system should be able to handle the short-term load growth if several modifications are made. As noted in Sec. 2.3.1.2, these modifications included improving maintenance operations and changing the system operation so that more quick-response capability is available. However, a comprehensive long-term plan is needed to reduce PREPA's dependence upon oil, increase overall system reliability, and lower the costs of electricity generation. Currently PREPA does short-term planning, typically less than 10 years. Long-term plans are needed because lead times for the construction of new generating plants alone are on the order of 7 to 10 years. Consequently, the remainder of this section will detail the considerations in performing generation planning studies, compare the results of a generation planning study performed by the Center for Energy and Environmental Research (CEER) with PREPA's own plans, and briefly discuss both the conventional and alternative technologies for electric power generation and how these may apply to the Puerto Rico situation.

Long Range Generation Planning

Because of ever increasing fuel prices and the long lead times required for constructing new electric power plants, generation planning has become especially important. System planners must also deal with many uncertainties among which are future load growth, load management, cost and availability of fuels, construction time, and costs plus utility rate sturctures. If careful studies have not been made, the constraints of time may require costly gas turbine and diesel peaking units to be constructed in order to satisfy a projected load demand even though base load capacity may have actually been called for. In a situation like Puerto Rico's where fuel costs are already very high because of almost total dependence upon oil, this type of short term solution is very costly.

The heart of any system planning effort is the load forecast. This is an estimate of the total energy that must be generated and the peak demands that must be served reliably during the study period. Many diverse factors can influence load growth. Among them are population growth, economic growth, tourist activity, projected energy-intensive industrial growth, etc. Consequently, communication among officials from PREPA, the Puerto Rico Energy Office, and other governmental and industrial representatives involved in planning is necessary so that input from all sectors can be taken into account. Also, several scenarios should be decided upon in order to test the sensitivity of the future system to changes in sectoral growth assumptions.

In a recent PREPA generation planning study[2], system peak loads are forecasted to grow at a compound annual rate of 3.5% through fiscal year 2000. This projection was based partly on estimated socio-economic indicators for Puerto Rico prepared by the Planning Board of Puerto Rico. The indicators included government and personal consumption expenditures, gross national product, population, exports, and personal disposable income. It also takes into consideration the current reduction in industrial demand in Puerto Rico (due mainly to the closing of PPG Industries, Inc.), federal and local energy conservation measures, and expected reductions in the previously projected growth rates of the U.S. mainland and Puerto Rican economies.[3] Based on this projected load growth, PREPA believes that 900 MW of additional capacity would be required through 1990, with 300 MW plants coming on line in fiscal 1986, fiscal 1987, and fiscal 1989. A final decision on construction of these facilities or the financing thereof has not yet been reached. Since minimum lead times for the construction of new generating facilities is six to seven years, these in-service dates may be delayed.

More recent discussions with PREPA planning authorities have indicated that a growth rate of 3.5%/year may be too high. Expectations now are that a growth rate of less than 2%/year may be more likely for the next 10 years. These new load projections can be input to the system planning model PREPA uses to study the effect this new load projection has on the planned capacity additions to the electric system. Projections beyond 1990 can also be made and analyzed.

Another generation planning study of the PREPA system was performed by CEER. In this study,[4] load projections were made by statistically analyzing historical data. It was discovered that a power correlation with GNP was the variable that fit the historical data quite well. Based upon this correlation, it was found that the average electric growth rate for 1985 to 2000 was 4%/year and for 2000 to 2020 the average growth rate fell slightly to 3.7%/year. This growth rate is about twice the more recent rate projected by PREPA out to the year 2000. It appears that the CEER forecast may be somewhat optimistic as to the continued growth of the GNP. To satisfy the future electric demand, it was felt in the CEER study that a strategy that maximized the use of renewable resources was the best program to follow. The renewable resource technologies that could make the greatest contribution to the generation of electric power were biomass, OTEC, photovoltaics and wind turbines. Appropriate R&D programs and funding requirements would need to be developed in order to achieve the following goals as expressed in the CEER study:

1) the operation of the first biomass power plant (300-450 MW) by 1986;

2) the operation of a pilot OTEC power plant (40 MW) by 1985 and a commercial plant (250 MW) by 1991;

3) the operation of a demonstration photovoltaic plant by 1993;

4) the operation of a wind power turbine farm (12.5 MW total) by 1988.

Table 2.3.2.2-1 shows the projected in-service dates and capacities of electric power plants out to 2000 for this scenario from the study.

Regardless of the electric generation expansion option chosen, there are several considerations unique to the PREPA system that must be taken into account. The first is the high annual load factor, which is currently 76% and expected to remain the same in the future. This means that a greater share of the generating capacity be devoted to base load generation than is normally done in a U.S. mainland utility. Second, because Puerto Rico is an isolated system, a much larger reserve margin is needed than for a utility system that has interconnections. Currently, PREPA has a 100% reserve margin, but this is necessary because four of the plants have a capacity in excess of 400 MW, each of which is more than 20% of the system peak

Table 2.3.2.2-1 Schedule of Operation Dates and Capacities of Electric Power Plants (CEER Study)

Year	Biomass	OTEC	Photovoltaic	Wind	Coal
1985	--	1-40MW	--	--	1-300MW
1986	1-300MW	--	--	--	--
1987	1-300MW	--	--	--	--
1988	--	--	--	12.5MW	--
1989	--	--	--	--	1-400MW
1990	--	--	--	--	1-400MW
1991	--	1-250MW	--	--	--
1992	--	1-250MW	--	--	--
1993	--	--	1-250MW	--	--
1994	--	1-250MW	--	--	--
1995	--	--	1-250MW	--	--
1996	--	--	--	--	--
1997	--	--	--	--	--
1998	--	1-500MW	--	--	--
1999	--	1-500MW	--	--	--
2000	--	--	--	--	--

Source: Ref. 4.

load. More capacity is needed in order to have enough reserve when one of this units is out of service. When the system loads grow enough to acommodate these units, a reserve margin of 50-60% will be required. Finally, the specified loss-of-load probability (LOLP) planning criteria should be reevaluated. The current LOLP used by PREPA is 1.5 days in 10 years. This figure was chosen based upon the 1 day in 10 years LOLP used by most U.S. mainland utilities. However, these planning guidelines are too demanding economically and the LOLP may need to be readjusted to a more cost effective figure.[5]

Future Conventional Technologies

In order to reduce Puerto Rico's dependence upon oil-fired generating capacity, several conventional technologies have been advanced as alternatives. Among them are coal, hydro and pumped storage, and nuclear. This section will briefly describe how each of these technologies may fit into the Puerto Rican electric sector.

Coal. Coal-fired plants can be an attractive, low risk alternative to oil. PREPA's next large addition to base load generating capacity might best be fired with coal. Competition among coal suppliers on the U.S. mainland and in several foreign countries could make the price of coal very attractive. It has been suggested that PREPA convert some of the existing oil-fired capacity to coal; however, none of the oil-fired plants were designed for coal burning. Neither their boilers nor plant layouts are currently adaptable to the use of coal.[6] Special coal handling and ash disposal facilities are required. New operating and maintenance skills are needed also in order to handle the relative complexity of coal plants. Furthermore, the environmental impact of coal-fired plants needs to be studied. The possibility of using coal/water mixtures has also been discussed.

Hydro and Pumped Hydro-Storage. Puerto Rico has potential for further development of hydroelectric power, but the possibilities are limited. A recent study by the U.S. Army Corps of Engineers estimates that about 106 MW are available from the 19 existing and potential sites evaluated.[7] Low head hydro installations were not included in this study, but their potential will be discussed in Sec. 2.3.2.3. Pumped hydro-storage is currently not attractive because all of the base-load plants are oil-fired and hence there is no cost advantage. When a switch is made to coal or other less expensive fuels for base-load generation, this situation may change. Also, because the load during the night does not drop as much as on the U.S. mainland, the effect this has on the pumped storage capacity requirements needs to be studied.[3]

Nuclear. Nuclear power is also a low cost possibility for future generation. However, because of the large size of the reactors currently being installed (about 800-1000 MWe), it would take about 20 years before the electric sector could accommodate a reactor of this size comfortably.[6] Small reactors (200 MWe) are currently under development by several European and Japanese corporations and, depending on the economies of these plants, could provide Puerto Rico with low cost reliable electric power. Other technical and economic questions need to be addressed, though, before making a commitment to nuclear power. These issues include providing for a regulatory framework for siting and licensing plants, ensuring safety, and providing for spent fuel management and waste disposal.

Future Alternative Technologies. Because of the high cost of electricity in Puerto Rico and the tropical climate, renewable resources have a good oportunity to provide significant amounts of electric power to the grid. The potential for solar, wind, OTEC, biomass, urban waste, and small scale hydro contributing to the electric sector will be discussed in the following sections.

2.3.2.3 Future Renewable Resource Use

As renewable resources are not now a major component of the energy supply system in Puerto Rico, there is a great deal of potential that can be tapped. Each of the possibilities is addressed in terms of resource base, the technology system available, the system performance, costs, potential users, potential oil use reduction, and implementation factors.

SOLAR

The use of direct solar energy to provide heat or to generate electricity is one of the most promising renewable resource systems for Puerto Rico.

Resource Base. Data collected thus far indicate that the level of solar insolation in Puerto Rico, on the average, is one of the highest in the world, year around.[1,2,3] The geographical and temporal distribution of insolation has been measured at six sites[1]. Figure 2.3.2.3-1 shows the cities where the measurements were made. Table 2.3.2.3-1 shows average daily insolation at each measuring station. Figures 2.3.2.3-2 and 2.3.2.3-3, respectively, show average daily insolation on a horizontal plane for each month of the year. Significant differences of insolation among sites have been found; however, the insolation remains fairly constant throughout the year at a given site. Annual rainfall varies from 80 cm to 400 cm in Puerto Rico and the level of solar insolation decreases as the annual amount of rainfall increases.

The average daily insolation (for years 1952-1975)[2] at San Juan was measured to be 18.6 mJ/m^2. This is very close in value to that measured in Reference 1 for Catano. Insolation measured by Lof and others[3] showed average insolation values between 16.2 mJ/m^2 and 25 mJ/m^2 for Caribbean Islands during the years. These measurements are consistent with those reported in Reference 1 and are among the highest in the world.

Technologies. Direct solar energy has been utilized two ways: to produce heat and to produce electricity.

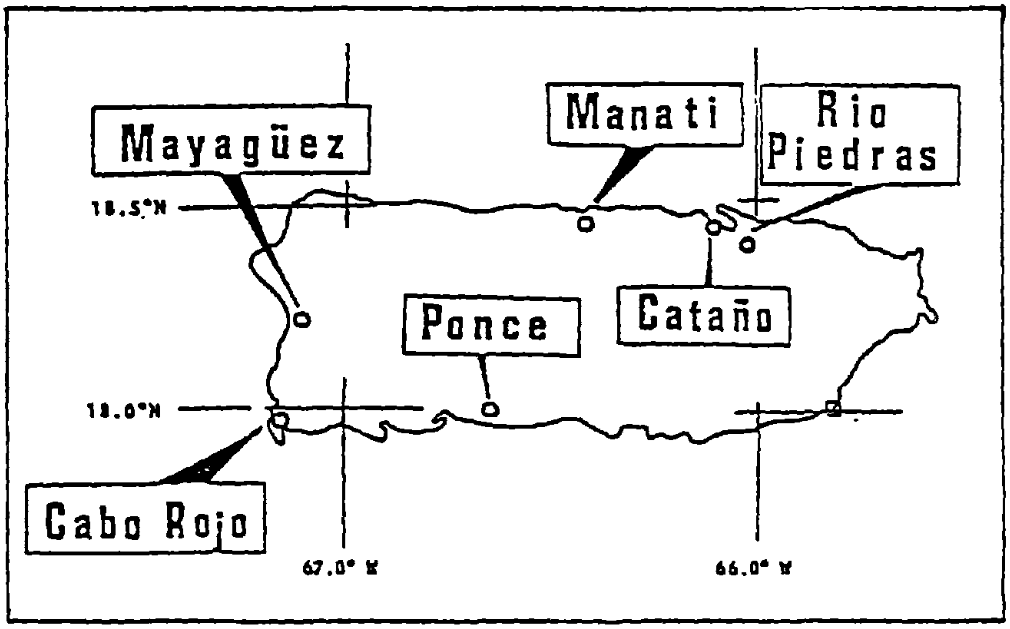


Fig. 2.3.2.3-1 CEER Stations in Puerto Rico

Table 2.3.2.3-1 Average Daily Insolation on a Horizontal Plane

Station	Component	Dates	Insolation (mJ/m^3)
Mayaguez	Global	Jan 1976-Present	16.0
	Diffuse	June 1977-Present	6.9
Rio Piedras	Global	June 1978-Present	16.6
	Diffuse	July 1978-Present	7.7
Ponce	Global	Mar 1978-Present	19.3
Catano	Global	July 1978-June 1979	18.1
	Diffuse	July 1978-June 1979	7.9
Manati	Global	Sept 1979-Feb 1981	18.6
Cabo Rojo	Global	Apr 1980-Present	19.9

Source: Dr. A Lopez and Dr. K. Soderstrom, CEER, 1982.

Some of the major technologies[4] developed to produce heat include single and double glazed flat plate collectors (using either liquid or gases as heat transfer media), low-cost or innovative flat plate collectors, shallow and salt-gradient solar ponds, evacuated collectors, stationary concentrating collectors, north-south, east-west and polar axis parabolic troughs, parabolic dishes and point focus central receivers. The technologies mentioned above are at various stages of development. Flat plate collectors have reached the highest level of commercialization around the world; nevertheless their experience in mass production remains limited.

Both the heat-producing and electricity-producing technologies are candidates for application in Puerto Rico. Studies must be made to determine the best alternatives for implementation.

Converting solar radiation directly to electricity by photovoltaics relies on the solid-state properties of the semiconductor used. Photovoltaic modules are connected electrically to form an array to

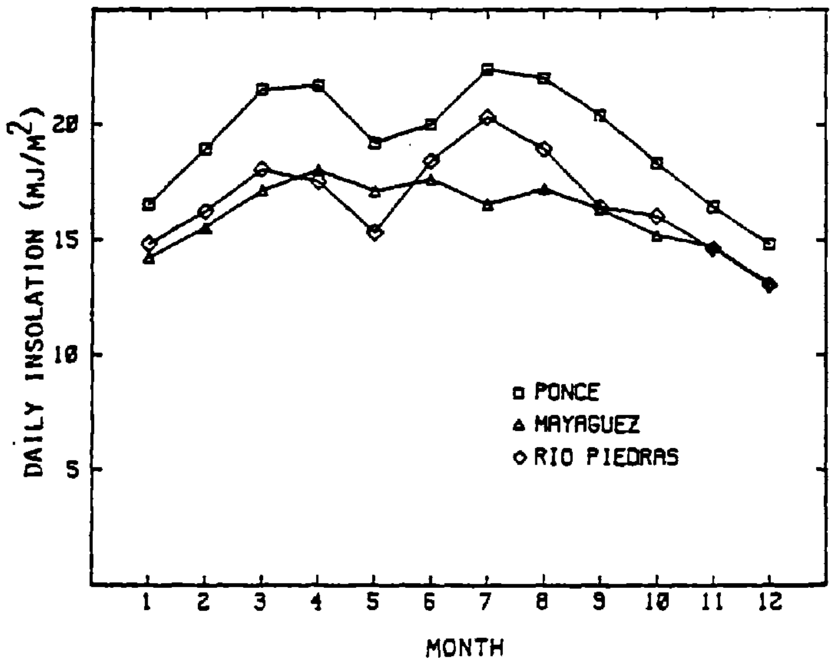


Fig. 2.3.2.3-2 Average Daily Insolation on a Horizontal Plane vs. Month

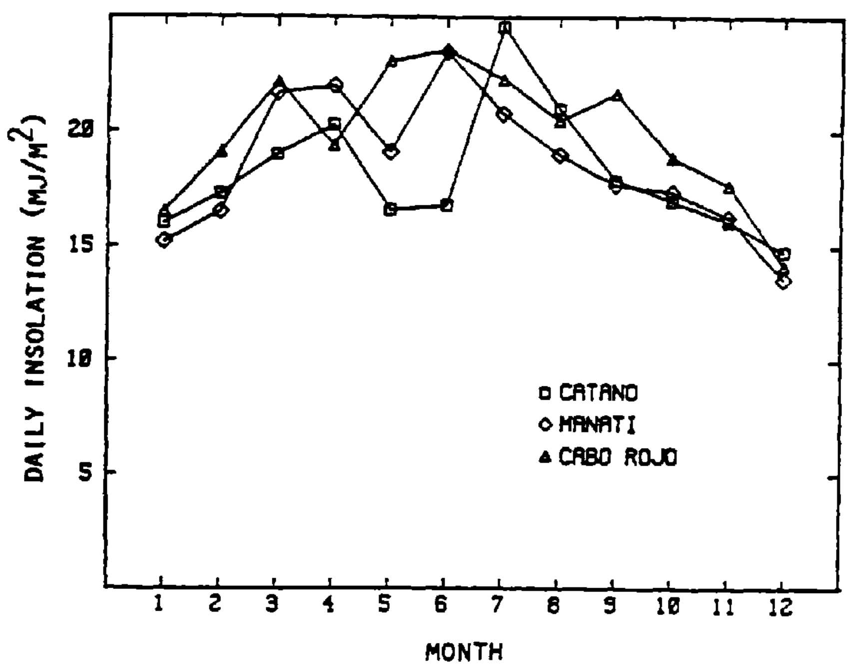


Fig. 2.3.2.3-3 Average Daily Insolation on a Horizontal Plane vs. Month

provide large quantities of power. This technology is not yet cost competitive with electricity from conventional generating sources. However, much is being done to improve the efficiency and reduce the cost[6]. A detailed discussion of photovoltaic technology is found in Ref. 4.

Performance. For simplicity and clarity, the technologies converting solar energy directly to heat have been divided into five areas. Photovoltaics are treated separately.

Flat plate collector technology has reached maturity. Typically, a reliable, high performance collector is capable of delivering working fluid temperatures up to 100°C, weighs approximately 40 kg/m^2 and costs about \$350 m^2 to install. Reference 7 summarizes the performance of some 22 flat plate collectors tested at the Florida Solar Energy Center.

Evacuated collectors (concentrating) are still in various stages of development. Often, the evacuated tubes are used with the assistance of a reflector that provides some concentration of radiation without tracking the sun. Performance, measured by the Florida Solar Energy Center, of the evacuated tubes manufactured by three companies are given in Reference 7. In the present state of development, a typical evacuated collector is capable of delivering working fluid temperatures of 150°C, weighs less than 40 kg/m^2 and costs about \$400/m^2 to install. Improved fluid temperatures up to 300°C have been achieved in the laboratory.

Parabolic troughs (line focus technology), both tracking and non-tracking, are essential technologies to meet the demand for higher working fluid temperatures. Typically, a temperature of 300°C is produced. A tracking collector (north-south, east-west or polar axis) is more efficient than the non-tracking types because it always faces the sun. Although not widely used, collectors based on this technology are being marketed by several commercial concerns. A series of tests have been conducted in 1980 on these collectors. Results were reported in a set of reports[8] and are summarized in Reference 5. The efficiency of the tracking parabolic trough is one of the highest among all collectors. Maintenance requirements are also higher for these collectors.

Central receivers, including parabolic dishes and point focus control receivers, are technologies used for large scale systems. Seven control receivers are operating[5] ranging from a small unit consisting of 85 heliostats for a small power system of 2.38 MWt, to a large unit consisting of 7505 heliostats for a large central power system of 195 MWt. Field efficiencies for the small system range as high as 74% for the small unit and 68% for the large unit.

Solar ponds are of the shallow type or salt gradient type. The shallow pond is technically simpler to construct and less capital intensive. A typical shallow pond uses a blackened plastic envelope filled with a few centimeters of water. The water, after heating, would be drained and stored. This principle is simple and easy to implement; however, the temperatures reached are generally below 100°C depending on insulation between the envelope and the earth as well as the re-radiation of the heated envelope. A salt gradient solar pond is a body of water with a salt gradient in the upper part of the pond. As salinity increases with depth, the density of water will increase with depth and will prevent convection in the pond and reduce heat loss. The highest temperature ever recorded in a solar pond is 227°F, set in the summer of 1980 at the University of New Mexico, Albuquerque. Depending on location, water clarity, and temperature, the solar pond can capture 10 to 20% of the solar radiation hitting its surface; hence, each square meter of pond surface can supply one-half to two gigajoules of thermal energy per year at temperatures from 100°F to 200°F[9]. Several good reviews on solar pond have been written[10,11]. Experience indicates that solar ponds are most suitable in areas where salt and land cost are low, low-salinity water supply is available (sea water is acceptable) and there is no moving ground water. At Ein Bokek, Israel, a large salt gradient pond provides the national power grid with an average of 35 kW of electricity in summer, 15 kW in winter, enough to power a large residential complex or office building.

Photovoltaic electrical power has been demonstrated to be reliable in space applications and in some rural water pumping applications. Sponsored research by U.S. DOE has concentrated on low cost production processes. Typically a single crystal silicon cell of 12% efficiency[4] would generate a DC power of 12 mW/cm^2 of cell area at an insolation of 100 mW/cm^2 and a cell temperature of 28°C. Solar cells are interconnected to form a cell panel bonded to supporting substrates and encapsulated with transparent materials to provide environmental protection. Solar cells are arranged in flat-panel arrays or at the receiving end of a concentrator. The latter arrangement intensifies the incoming light incident on a relatively small cell target with increased efficiency. Until the cost becomes competetive, its use in Puerto Rico may be limited.

Cost

The cost of a solar system is a function of many factors. Figure 2.3.2.3-4 from Reference 13 shows collector costs through distributor mark-up in 1980 $\$/ft^2$ ($10\ ft^2/m^2$) as a function of annual collector production starting at a 20,000 unit annual rate. Table 2.3.2.3-2 from Reference 5 shows preliminary capital cost estimates for flat plate collectors, evacuated collectors, parabolic trough collectors and central receivers.

Costs of $\$35/m^2$ have been quoted for the Miamisburg salt gradient solar pond and $\$73/m^2$ for Argonne pond[9]. These estimates must be used carefully because R&D costs are included and difficult to separate. The cost of the pond varies and depends on the cost of salt and the need for water pipe lines. For large solar pond systems on an average site, Reference 9 estimates a cost of $6.22/gigajoule for thermal energy and $26/gigajoule for electricity generation. For thermal energy application, solar ponds seem competitive. For electricity, solar ponds maybe competitive only for off-grid applications.

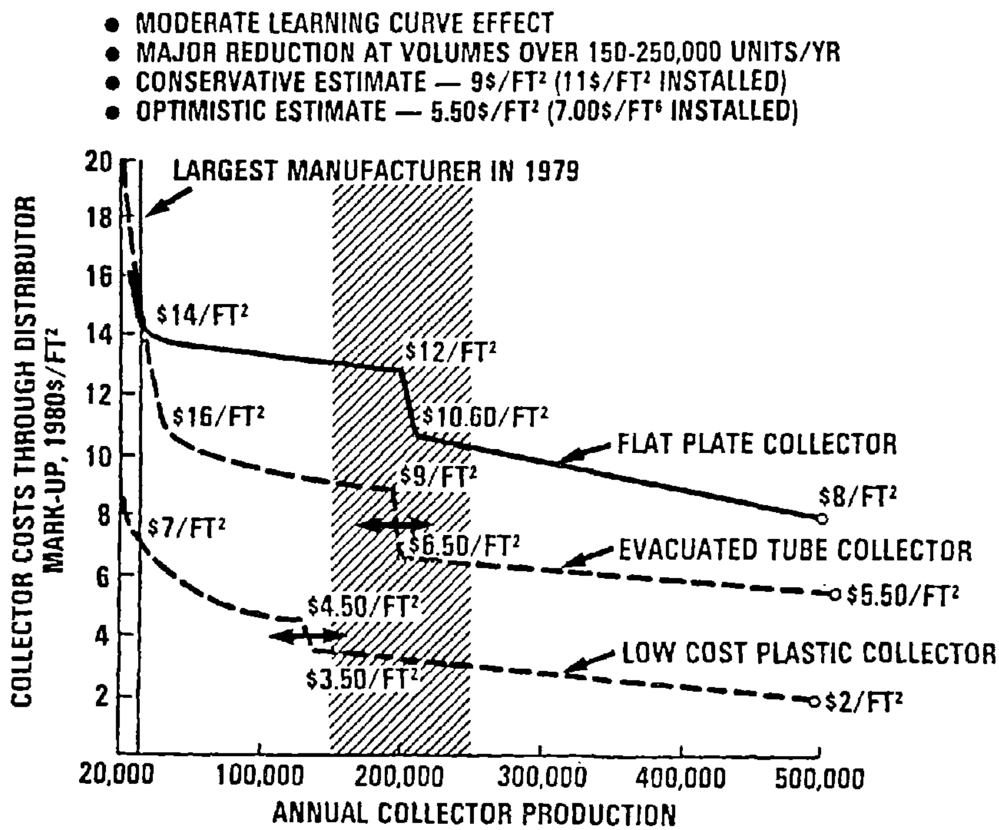


Fig. 2.3.2.3-4 Estimated Cost of Three Types of Collectors

Table 2.3.2.3-2 Cost Estimates for Various Solar Collectors

	1981 $\$/m^2$		
	1981 Base	1990-2000 Projected Cost	1985 Estimate
Flat Plate Collectors	270-304	172-202	270-279
Evacuated Collectors	334-538	172-262	219-405
Parabolic Trough Collectors	468-615	117-195	300-615
Central Receiver	473	71-174	276-473

Source: Ref. 5.

U.S. DOE has made substantial progress in reducing the cost of the photovoltaic solar collectors[6]. Collector research and development is dealing with the development of materials, processes, and manufacturing techniques for flat-plate and concentrator collectors that have the potential for achievement of less than 70¢ per peak watt (1980 dollars) and long life expectancy (20 years or greater). Technology feasibility of $2.80/per peak watt has been achieved. Table 2.3.2.3-3 shows the cost targets for photovoltaic systems.

Potential Users. The use of direct solar energy for heating water is one of the most promising near term renewable sources of energy for Puerto Rico. This use could apply to all sections of Puerto Rico's economy.

Market penetration of residential solar hot water is well documented.[16,17,18,19] A survey by PREPA[19] indicates that the average residential consumption of the electrical energy for water heating in the San Juan metropolitan area amounts to 200 kWh per month. PREPA also estimated that between 365,000 to 479,000 electric water heating systems were installed. This is the approximate market for solar systems. Reference 24 estimates that at the current rate of installation, approximately 188,000 solar hot water systems will be installed by 2000. Industrial and commercial uses are another potential market for solar systems, especially the more sophisticated units, in Puerto Rico. Levels of penetration depend in the long run on the cost and the reliability of the solar equipment. Reference 24 gives some penetration estimates for solar ponds and photovoltaics in Puerto Rico.

Potential Oil Use Reduction. Solar water heating systems now used in commercial and institutional buildings are estimated to displace about 4 million kWh of electricity per year[16]. Reference 16 also suggests that solar water heating can displace perhaps 1% of the Island's projected electricity production by the year 2000, and about 2% of the projected industrial and commercial fuel use. This would amount to annual oil savings of about 1 million barrels or $30 million with oil at $30/barrel.

Reference 24 estimates oil savings in the year 2000 of 630,000 barrels for solar water heaters, 1,150,000 barrels for solar ponds and industrial process heat, and 1,550,000 barrels for photovoltaics.

Implementation. The biggest factor influencing the implementation of solar systems is cost. If the costs can be brought down then there will be ample incentive to use these systems.

Table 2.3.2.3-3 Photovoltaic Technology Feasibility Cost Targets

Application and Year	Collector Cost (FOB) ($/Wp)	System Cost[a] ($/Wp)	Production Scale (MWp/year)
Remote Stand-Alone 1982	$\leq$2.80[b]	6.13	--
Residential 1986	$\leq$0.70	1.60-2.20	100-1000
Intermediate Load Center 1986	$\leq$0.70	1.60-2.60	100-1000
Central Station	0.15-0.40	1.10-1.80	500-2500

[a]System cost correlates with production scale

[b]All figures are quoted in 1980 dollars.

Source: Ref. 6.

A positive aspect of the implementation issue is that extensive use of solar technologies can create a new industry in Puerto Rico. Even the more sophisticated systems are well within the manufacturing expertise of the highly developed Puerto Rican industry.

WIND

Studies carried out to date indicate wind power has the potential to make a contribution to the energy supply of Puerto Rico. This section reviews major issues facing wind energy applications in Puerto Rico.

Resource Base. Puerto Rico is exposed to relatively consistent trade winds out of the northeast. These prevailing trade winds are significantly affected by the mountainous interior of Puerto Rico and by the sea breeze created by the land-sea interface[1]. Estimates of the potential wind resources for Puerto Rico have been carried out with limited data from only a few sites in the coastal plains ringing the perimeter of the main island.[1-7,16]

The most complete description of he wind conditions and data in Puerto Rico is contained in the Wind Energy Resource Atlas for Puerto Rico.[1] This report indicates that only a few of the limited recording stations in Puerto Rico are well-exposed to the prevailing trade winds. Furthermore, the interior has no recording stations at favorable mountain locations and is virtually void of data. The most favorable sites typically would be expected at exposed coastal sites and at crests of ridges. The authors of the wind atlas have used the available data and generally accepted extrapolation methods to estimate the wind speed and power density profiles for Puerto Rico.

The distribution of wind power in power density classes is given in Table 2.3.2.3-4 and is shown geographically in Fig. 2.3.2.3-5. Most of the promising areas for wind energy are indicated by a class 3 or greater wind power on the annual power map. The exposed coastal locations near Cape San Juan, on the northeastern corner of Puerto Rico, are the primary locations estimated to have class 4 annual average wind power. Good exposure to the trade winds and reinforcement by the sea breeze tend to result in persistent moderate winds. There may be other sites along the northern and eastern coasts where good exposure and terrain enhancement combine to produce class 4 conditions. Most of the northern and eastern coastal regions are class 3, as are exposed mountain peaks and ridge summits in the interior. The blocking effects and the interference of the sea breeze tend to make poor wind conditions in the west and south.[1]

The Puerto Rico Office of Energy[16] has several activities underway to help in wind resource assesment including an anemometer loan program for individuals interested in measuring wind characteristics at particular sites, and the design and implementation of the Wind Resource Assessment Program. The Wind Resource

Table 2.3.2.3-4 Distribution of Wind Power Classes in Puerto Rico

Wind Power Class	Wind Power Density (Watts/M^2)	Wind Speed Corresponding To Upper Limit Of Power Density M/S (mph)	Land Area Equal Or Exceeding Power Class (km^2)	Percentage Land Area Equal Or Exceeding Power Class
1	0-100	4.4 (9.8)	8,764	100.0
2	100-150	5.1 (11.5)	2,193	25.1
3	150-200	5.6 (12.5)	373	4.3
4	200-250	6.0 (13.4)	11	0.1
5	250-300	6.4 (14.3)	5	0.1

Source: Ref. 1

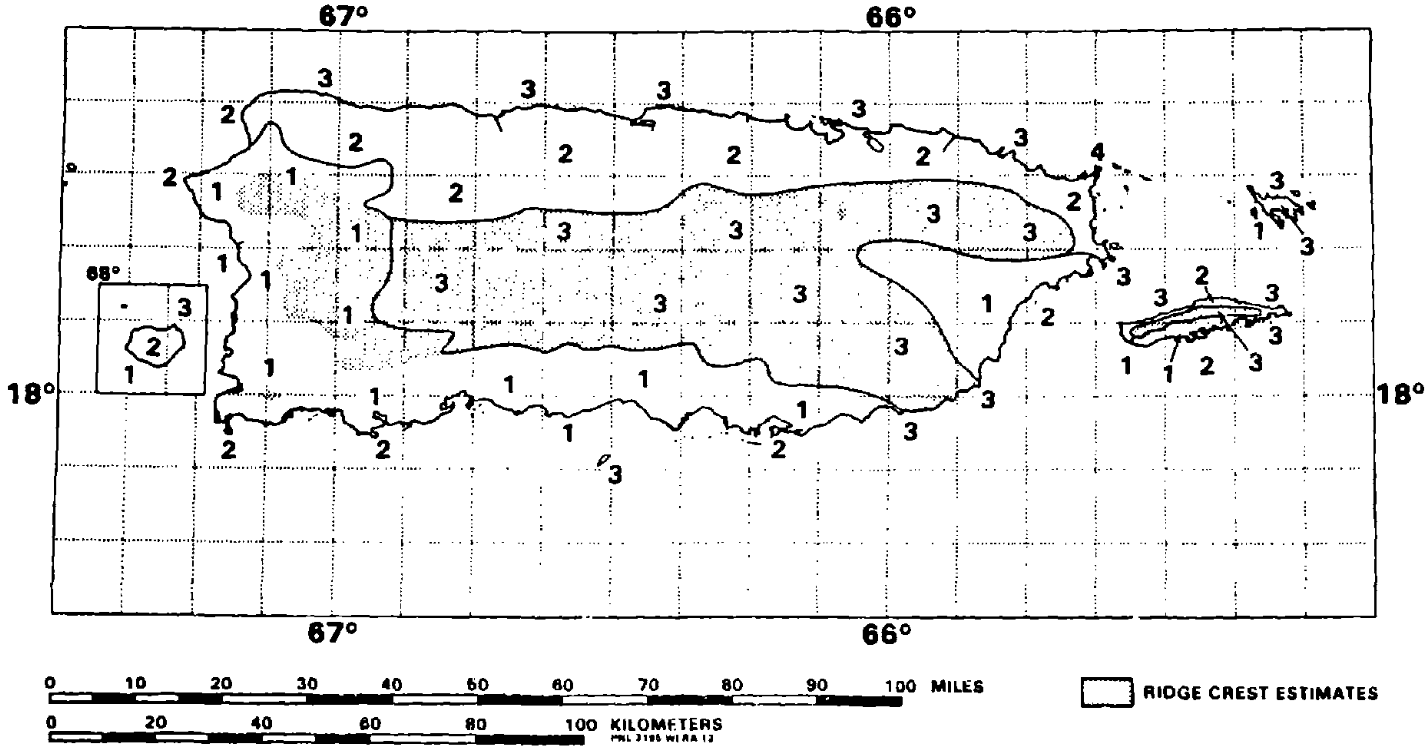


Fig. 2.3.2.3-5 Annual Average Wind Power in Puerto Rico
(See Table 2.3.2.3-4 for explanation of density classes)

Assessment Program is a joint effort between Meridian Corporation and the Office of Energy to augment the data in the Wind Energy Resource Atlas[1], to provide data on wind characteristics from the mountainous interior and to provide a basic guide to siting and sizing all potential applications of wind turbines. As part of this program two sets of instruments will be deployed to measure wind characteristics: four fixed meteorological towers and two mobile towers. Additional details on this program are in Reference 16.

There is seasonal variation in wind availability, with summer being the season of maximum wind availability and autumn the season of least availability. This characteristic will not help the economic competitiveness of wind for electric utility applications, as current monthly peak loads do not vary by more than 13% during the year.

A significant diurnal variation in wind has been reported at most recording stations. Wind speeds reach a maximum during the late morning and early afternoon and reach a minimum in the early morning hours in all the seasons. This characteristic matches reasonably well with variations in electric load although daily loads currently do not exhibit large fluctuations. Wind speeds at some sites reach levels greater than 6 m/s (seasonally averaged) at the peak hours, while early morning wind speeds may be as low as 2 m/s. Since wind power varies as the cube of the wind speed, the power obtainable at times when the electric utility has the greatest need is relatively high. Of course, the actual power obtainable also depends on the characeristics of the wind turbine (e.g., cut-in speed and rated speed).

The General Electric study[6] also identified potentially favorable wind sites along the northern coast and on inland peaks or ridges with clear access to the prevailing trade winds. A subsequent study[2] indicated that perhaps half of the mountain sites were inaccessible without special road construction.

Technologies. The wind turbines considered to date are primarily of the large variety (greater than 100 kWe) for electric power generation. There is some potential for small wind turbines (1-45 kWe) for the residential and agricultural market and it is possible some of the 100-200 kWe machines could be used for irrigation and crop processing on large farms.[2,8] However, the greatest potential in terms of total energy use appears to be electrical generation from machines rated from 500 to 2500 kWe.

The typical wind turbine for electrical generation has a horizontal axis and has two large blades.[9-13] The 200 kWe machine (DOE MOD-OA) already installed and feeding into the grid on Culebra Island has a blade diameter of 125 feet. The cut-in speed at which power generation begins is only 6.9 mph measured at a height of 30 feet (approximately 10 meters). The wind speed at which this machine reaches full power (200 kWe) is 18.3 mph. At wind speeds higher than 34.2 mph the wind turbine automatically turns out of the wind to avoid damage. In contrast to the 200 kWe wind turbine, a promising 2,500 kWe design (DOE MOD-2) is being tested in the state of Washington. This machine has a blade diameter of 300 feet and higher cut-in (8.6 mph) and rated (20.1 mph) speeds than MOD-OA (and therefore lower expected capacity factor), but it also is expected to have a capital cost that is significantly less than MOD-OA if both machines reached the mature industry level.[13] The basic tradeoff is capital cost and maintenance cost per unit capacity (highest for the smaller machines) versus energy produced per unit of capacity (also highest for the smaller machines). These issues are yet to be resolved, but the large machines appear to be favored at this time.

Small machines have similar general characteristics, often with relatively low cut-in speeds. Vertical axis systems and horizontal axis designs with more than two blades are also available. Dedicated energy storage systems are generally not considered as part of the wind system because they usually result in a large economic penalty. If the machines are connected to the grid then storage is provided only in light of overall grid economic considerations.

A special technical issue for Puerto Rico is the difficulty that may be experienced in obtaining land for the sites, especially in the coastal areas. If land availability becomes a problem, the larger machines have an advantage. Typically, minimum spacing to avoid interference is assumed to be in the range of 10 to 20 blade diameters. Therefore, since the MOD-2 offers 12.5 times as much rated power as MOD-OA with a blade diameter that is only 2.4 times as large, the MOD-2 can produce significantly more energy per unit of land area.

System Performance. The performance of wind turbines within an electrical generating system is a complex problem to analyze.[7,13,14] The characteristics of the wind turbines themselves, such as mechanical forced outage rate, are not yet well known. One study estimated that a 2,500 kWe wind turbine located at favorable sites in Puerto Rico would have an average capacity factor of 20%.[2]

Wind turbines are usually justified strictly on the basis of their fuel (oil) saving capability. That is, the cost savings from displaced oil is the only cost savings used to compare with the cost of energy from the wind turbine. Basically, this operational mode means that PREPA would have no reduction in new capacity needs as a result of installation of wind turbines. However, in recent years some studies have pointed out that wind turbines may also have some capacity value in addition to the fuel saving value.[13,14] Generally, if the system loss-of-load probability is improved by installation of wind turbines, some capacity "credit" may be in order. Such considerations can help in the analysis of cost competitiveness for wind turbines. Wind turbines of smaller size, in the range of 200-500 kWe, may be competitive with the larger wind turbines because of their ability to produce more power at low wind speeds and therefore to contribute more to the reliability of the generating system. However, given Puerto Rico's current large reserve margin, the capacity credits would be small in the near future. In the long term they may be more significant economic factors.

Costs. Wind turbine costs for a mature industry are highly uncertain. Costs for a research unit such as the Culebra system are known but are generally considered substantially higher than for the same unit produced by a mature industry. The associated reduction in unit capital cost with increased production is analyzed by estimating different rates of reduction, or learning. Another large uncertainty for wind turbines is the economy of scale over the size range of interest. Finally, an important additional consideration may be the fixed operation and maintenance (O&M) costs. The fixed O&M costs in 1978$ have been estimated to be 60-90 $/kWe-yr for a 100 kWe machine, 20-30 $/kWe-yr for a 500 kWe machine, and approximately 12 $/kWe-yr for a 2,500 kWe machine.[10,13] Thus, economy of scale in maintenance cost could be a hindrance to implementation of the smaller wind turbines.

An energy analysis by CEER[3] found electricity generated by wind to be cheaper than oil-fired generation but to be more expensive than coal-fired generation. The study concluded that wind was therefore suitable for fuel oil displacement but not for the base-load energy system. However, this study did not consider the system reliability effects of wind turbines or the possible effect of limited wind turbine installation on the optimum expansion pattern for the system. That is, wind installations could reduce the required additions of coal capacity somewhat. Wind and coal, however, may not be direct competitors when performing a system optimization. The CEER study estimated 1979 capital costs for a 500 kWe machine to be

2840 $/kWe and for a 1,500 kWe machine to be 1265 $/kWe. Land costs amounted to an additional 1200 $/kWe for the 500 kWe unit and an additional 400 $/kWe for the 1,500 kWe unit. Levelized costs (5%/yr inflation) were estimated to be approximately 200 mills/kWh in 1985, significantly less than the estimated 300 mills/kWh for the oil-fired generation fuel cost.

The Electric Power Research Institute estimates the capital cost (Dec. 1980$) for 25 of the 2,500 kWe wind turbines would be 970 $/kWe.[15] The fixed O&M cost is also estimated to be 9 $/kWe-yr.

Potential Users. As mentioned earlier, electrical generation appears to have the greatest potential for wind to make a significant contribution to Puerto Rico's energy supply. However, the possibility of using smaller wind turbines for agricultural purposes and pumping water does exist. If the latter represents the major application of wind in Puerto Rico, the overall contribution of wind will be small.

Several studies have made estimates of potential market penetration. In spite of the conclusion that wind was not competitive with coal or some other less developed renewable energy sources, CEER estimated that a wind farm totaling 12,500 kWe (25 wind turbines rated at 500 kWe each) would be installed by 1988. If some of the assumptions concerning biomass, OTEC, and photovoltaic costs proved to be optimistic, this study could be used to consider additional wind installations after 1988.

The Committee on Future Energy Alternatives for Puerto Rico[2] estimated nearly 300 MWe of wind capacity as the ultimate contribution based on complete development of highly favorable sites (maximum technical market). Of the 300 MWe potential, the installation of large (2,500 kWe) machines account for 95% of the total capacity. Approximately 200 MWe would be located at 75 favorable sites on peaks or ridges exposed to the northeasterly winds. Additional large machines were assumed to be located along the northern coast at sites with access to the trade winds. In addition, 50 of the 200 kWe machines were assumed to be installed on large farms for irrigation and crop processing. If Puerto Rico were to pursue an aggressive development program by installing a limited number of test machines to gain construction and operation experience, it might be possible under the most favorable circumstances to install one-third of the total potential capacity (approximately 100 MWe that would produce about 170 million kWh per year) by 1990. Continuing the assumption of most favorable circumstances would allow the additional 200 MWe (80 wind turbines of 2,500 kWe each) to be installed by 2000. The electrical production from the 300 MWe would be approximately 500 million kWh per year. Such an optimistic installation schedule requires a strong economic incentive that has not yet been shown with any certainty to exist. A more likely implementation rate would reach the 300 MWe level well after the turn of the century. A brief discussion of a few practical problems facing a rapid implementation program is presented later in this section.

The Office of Energy also prepared estimates of potential implementation for both small and large wind machines.[16] The small machines (2-50kWe) are considered marginally cost-effective at this time; however, tax incentives and anticipated rate increases will help commercialization. The Office of Energy[12] estimated the potential implementation at 7500 units by the year 2000 for an annual savings of 1.35×10^{12} Btu/yr (Table 2.3.2.3-5).

The implementation rate for the large machines was assumed to be in blocks of 40 MWe, starting in 1988. The second 40 MWe block was assumed to become operational in 1991, and 80 MWe more was assumed for 1995. The total installed capacity by 1995 is 160 MWe. The associated energy savings is approximately 3.8×10^{12} Btu/yr by 1995 (Table 2.3.2.3-5).

Potential Oil Use Reduction. The potential displacement of oil depends on the capacity installed and the expected average capacity factor for the wind turbines. The capacity factor depends on the wind turbine characteristics and the wind availability at the site. However, assuming one barrel of oil produces approximately 600 kWh, the estimate for the year 2000 of 300 MWe installed wind capacity at 19% capacity factor would displace nearly 850,000 barrels of oil per year, or $25.5 million with oil at $30/barrel. If 100 MWe could be installed by 1990, the savings would amount to approximately 280,000 barrels in that year. The Office of Energy projection also results in a savings of 850,000 barrels in the year 2000, although only 75% is from the large wind machines.[16]

Implementation. Land use appears to be a potential barrier to significant implementation of wind turbines along the coastal areas. Other potential concerns include noise, interference with television, radio, and other communications, and aesthetics.[12]

Table 2.3.2.3-5 Office of Energy Estimates of Wind Turbine Implementation

Fiscal Year	Energy Savings[a] (10^{12}Btu/yr) Small Machines	Large Machines	Total Oil Savings (10^6Bbl/yr)
1980	0	0[b]	0
1984	0.1	0	0.02
1988	0.7	0.9	0.27
1992	0.9	1.9	0.47
1996	1.1	3.8	0.82
2000	1.3	3.8	0.85

[a]Fossil-fuel equivalent.

[b]Small savings occurred from the 200 kWe MOD-OA on Cirlebra Island

Source: Energy savings, Ref. 16.

In order for wind to make a contribution as large as 160-300 MWe by the year 2000, a number of favorable events must occur. These include successful demonstrations (reliability, construction, and cost) with the early commercial machines on the mainland U.S. and in Puerto Rico, detailed wind survey work in Puerto Rico, studies by PREPA that indicate the overall value of wind power to the utility is great, land must be made available at not too great a cost, the public must be in favor of such an aggressive program, the markets for small wind machines must be developed, utility interface policies must be developed, conventional fuel prices must increase in real terms, other renewable sources must not provide too much competition, and, perhaps most importantly, financing of a large capital intensive program must be possible (wind turbines have no fuel cost and relatively low maintenance cost, especially for the very large machines, but have higher capital costs). Therefore, if wind continues to look promising and most of the above conditions hold, a likely approach would be to install small groups of machines of different sizes at a relatively slow rate in order to benefit from the operating experience that is being accrued. This could result in a total installed capacity in the year 2000 as low as 20 to 30 MWe[2], or only 7-10% of the 300 MWe estimated to be the maximum potential.

Installation of 300 MWe would result in annual generation of about 500 million kWh. This represents only a few percent of current generation. Therefore, by the year 2000 it is unlikely that wind will be able to provide more than a very small part of total generation. However, for the longer term, the technologies may improve and conditions may be such that additional wind resources can be tapped at other less favorable sites. From a utility system perspective, the maximum desirable contribution from wind power in a system having no storage depends on wind resource availability and wind turbine characteristics but is probably less than 15% of total capacity.[13]

BIOMASS

Biomass is both a direct (combustion) and an indirect (synthetic fuel manufacturing) source of fuel. Biomass resources include crop and forest residues, specially grown energy crops, and animal and urban wastes.

Puerto Rico is ideally suited for biomass technology development[1] since out of the 10 soil orders in the world's tropics, nine are found in Puerto Rico.[1] There are 27 suborders, 37 great groups, 54 families and 63 soil series. There are seven discrete ecological life zones superimposed over these resources. Principal candidates for cultivation as energy crops evaluated by CEER include napier grass, sorghum, sundangrass hybrids and sugarcane (referred to as energy cane when managed for energy production). Research with energy cane indicates that the 70,000 acres set aside for sugarcane by the government of the Commonwealth of Puerto Rico could provide as much as 17% of the Island's energy needs (358 Trillion Btu's in 1979) and 100% of its molasses needs. Eucalyptus robusta, albizia and lecalha and water hyacinth are also being studied.[5]

Biomass technologies are classified into three basic categories: direct combustion, thermochemical conversion and biochemical conversion. Table 2.3.2.3-6 from Reference 3 presents a good summary of the uses of different types of biomass and the conversion process involved. A detailed discussion is presented in Reference 8.

Direct combustion or burning of biomass for heat had been the only use of biomass until the beginning of this century. In 1981 10 x 10^{12} Btu's were generated in Puerto Rico from the combustion of bagasse.[2] Crop residues and some municipal solid waste can also be burned directly. Much work has been done to improve the efficiency of biomass combustion and to reduce its environmental impacts.

Thermochemical conversion processes are either gasification (including pyrolysis) or direct and indirect liquefaction. Biomass gasifiers are available in several forms depending on the heat input form (air, oxygen, or pyrolytic); gas-solid contact method (up-draft, downdraft, fluidized bed or suspended flow); feedstock form (residues, pellets, providers); gasification temperature (dry ash or slagging); product (low or medium energy gas, char, or pyrolysis oil); heating rate; and residence time (slow and fast pyrolysis). An excellent description of the principle and current technology and research has been given in Reference 4. Direct liquefaction is not well understood and commercialization in the near future is unlikely. However indirect thermochemical liquefaction has achieved some success. Indirect liquefaction is accomplished by using two steps -- gasification to produce synthesis gas (CO and H_2) followed by a catalytic conversion route to produce liquid products such as methanol or hydrocarbon mixtures. The products do not require extensive upgrading, and their characteristics are independent of feedstock. Yields and compositions are predictable and controllable.

Biochemical conversion processes consist of either fermentation (includes acid, hydrolysis) or anaerobic digestion. Fermentation processes to produce ethanol from sugar and starch-rich biomass have been used in many countries.[8] The current challenge is to reduce the cost of production. The production of fuel ethanol from fermentation of sugar cane or food stock (i.e., corn) is in progress in several countries including Brazil and the U.S. Accelerated production of ethanol raises environmental concerns.[6] Suggestions on the use of sugar cane for ethanol production in Puerto Rico have been documented.[7] Although questions of the net energy balance of ethanol production produced much debate in early 1979, computations[12,13] indicated that the output to input energy ratio is 2 to 1. Sponsored research on alternative feedstocks to produce ethanol has been in progress in many universities (i.e. Purdue, MIT), but commercialization has not yet been achieved. Biogas production using anaerobic digesters on animal or urban waste has been used all over the world. Presently, the Peoples Republic of China is attempting to use digesters to produce methane as well as reduce waste.[9] A good discussion on biogas and alcohol fuel production is presented in Ref. 10.

Cost for biomass systems are extremely difficult to project since the cost of the feed is highly variable and is a major component of the total cost. CEER reported[5] production costs of energy cane in Puerto Rico at $25.46/oven-dry ton or $1.70/million Btu as an oil substitute. This includes delivery charge. SRI International had performed an up-to-date economics study[11] on biomass feedstock as well as biomass conversion technologies in the mainland U.S.

Reference 7 assumed that 20,000 acres could be converted to energy crops by the year 1990 in Puerto Rico. The energy produced would contribute about 600 million kWh or 3% of the electricity demand and 17 million gallons of ethanol. If 90,000 acres could be used, the 3% would grow to 10% and 17 million to 78 million gallons of ethanol.[7] Reference 2 estimated biomass displacement of oil to be 541 million barrels from bagasse combustion and 1.24 million barrels from the use of municipal solid waste.

Land availability is the biggest issue affecting biomass use. Energy crops would compete with food crops for the land. Experiences of similar projects in countries facing similar land use problems need to be explored. Reference 3 gives a good account of some these experiences.

OCEAN THERMAL ENERGY CONVERSION

Ocean Thermal Energy Conversion (OTEC) is a concept for utilizing the temperature difference between the warm surface waters of tropical oceans and the deep cold waters in a thermodynamic cycle to produce electrical energy. In the open-cycle concept, the warm waters are flashed at low pressure, expanded through a turbine, and then condensed against cold water; this cycle can produce fresh water as a byproduct. In the closed-cycle concept, a working fluid such as ammonia is used in the traditional Rankine cycle. The open cycle was tested by Georges Claude in Cuba in 1930: it produced electricity, but not enough to run the equipment.[1] The closed cycle, using ammonia as the working fluid, was successfully tested off Hawaii in

Table 2.3.2.3-6 Classification and Uses of Biomass Energy

Fuel Type	Source	Conversion Process	Energy Content (Btu/lb)	Region Primarily Used	Primary Uses	Development Related Issues	Status of Technology
<u>Solid Fuels</u>							
Charcoal	wood	destructive distillation	11,500	global	cooking/heating		
Fuelwood	eucalyptus	direct combustion	5,700[a]	tropical/sub-tropical	cooking/heating/steam	erosion	well developed, practical for cooking and heating
	koa haole (<u>Leucaena</u>)	direct combustion	5,700[a]	Pacific/SE Asia	process heat/steam		
	hardwoods	direct combustion	5,780[a]	global	process heat/steam	deforestation	
	conifers	direct combustion	5,400[a]	temperate to global	process heat/steam	use of mill waste	
Bagasse	sugarcane	direct combustion	6,600[a]	tropical	produce steam/electricity	water quality, alternative by-products	increasingly practical for electricity
<u>Liquid Fuels</u>							
Methanol	wood	pyrolysis	8,600	U.S./Europe	transportation fuel, industrial raw materials	high impact on environment	
	solid waste	pyrolysis					
	methane	catalytic oxidation					
Ethanol	wood cellulose	acid hydrolysis[b]/fermentation	12,000	U.S./Brazil/N.Z./Australia/etc.	transportation fuel	food vs. fuel	available, increasingly practical
	sugar crops	fermentation			transportation fuel		low impact on environment
	starch crops	enzymatic saccharification/fermentation			transportation fuel		
Organic acids	solid wastes	flash pyrolysis	10,500	U.S. (not common)	fuel oil	MSW control	
<u>Gaseous Fuels</u>							
"Biogas" (primarily methane)	organic residues	anaerobic digestion	12,900	India/China/Korea/Germany/U.S.	direct burning heating/cooking	waste/pollution control, convenience factor	well developed, low impact on environment, practical
	organic residues	pyrolysis/hydrogasification	8,000-9,2000		electrical generation form vehicle fuel	residue as fertilizer, MSW control	
Wood gas	wood	destructive distillation	7,000-8,000	global	replace natural gas		
Producer (synthesis) gas	wood/cellulose	hydropyrolitic conversion	5,000-6,000	Europe/U.S.	replace natural gas		well developed, practical

[a]Energy values for fuelwood and bagasse based on 20% H_2O.

[b]Acid hydrolysis is a pretreatment.

Source: Ref. 3. Figures taken from U.S.D.A., "Fuel Value of Wood," <u>Technical Note 98</u> (Madison, Wis.: Forest Products Lab, 1956); James L. Brubaker, "Leucaena Biomass Productivity Studies," paper presented at 20th Annual Hawaii Forestry Conference, Kona, Hawaii, Sept. 22, 1978; John R. Benemann, <u>Biofuels: A Survey</u> (Palo Alto, Ca.: Electric Power Research Institute, 1978); Richard Merrill and Thomas Gage, <u>Energy Primer</u> (New York: Dell Publishing Co., 1978); and G.M. Fair and E.W. Moore, "Heat and Energy Relations in the Digestion of Sewage Solids I. The Fuel Value of Sewage Solids," Sewage Works Journal, (1980).

1979 by the Mini-OTEC project, producing net electrical power for the first time in an OTEC plant and demonstrating the feasibility of the concept.[2]

Resource Base. An ideal OTEC site would meet the following criteria: (a) high thermal differences between the surface and deep water (generally taken to mean a difference of 20°C to a depth of 1000 meters); (b) nearness to the market for the OTEC product; (c) absence of storms; and (d) low-velocity ocean currents.[1] Puerto Rico is acknowledged to meet the first two conditions off the southeast coast where deep water can be found within a few miles of shore.[1,6,7,8] The other two criteria are more important for floating OTEC platforms moored in deep water than for shore-based or tower-mounted OTEC plants that could be built in Puerto Rico. For example, the suitability of the Punta Tuna site is evidenced by the fact that two of eight proposals for OTEC pilot plants submitted to DOE[3,4,5] were based upon tower-mounted facilities at this location.[9,10]

Technologies. A considerable technology base for OTEC exists because of the work done in the past decade in the United States and elsewhere. Although this technology base is not now adequate to justify the construction of the large plants (250 to 400 MW) that are believed to necessary to be competitive in most markets at today's energy prices,[11] it may well be adequate for small plants in the range of 10 to 40 MW.[12] This is especially true for locations (such as at Punta Tuna) where the plant can be placed on shore or put on a shelf-mounted tower platform.

Historically, major emphasis in OTEC research and development has been placed on heat-exchanger design and on the means for prevention of biofouling and corrosion. Because of the research done to date, several promising heat-exchanger concepts have been developed, and effective biofouling control techniques have been selected for long-term testing at the Seacoast Test Facility in Hawaii. At the present time, the major technical uncertainties are believed to be (in order) in the designs of the riser power cable, the cold-water pipe, and the ocean platform.[13] However, these are mainly problems for floating OTEC platforms moored in deep water, and can be largely avoided by a shore- or shelf-based plant.[14] It is probably significant that most of the pilot-plant proposals were shore or tower installations; although probably less efficient than floating plants, they entail substantially less technical risk.

System Performance. The efficiency of an OTEC plant is inherently low because of the small difference between the temperatures of the heat source and the heat sink. For seawater temperatures of 40°F and 80°F (figures commonly used in OTEC examples), the ideal Carnot cycle efficiency is only 7.4%. For large OTEC plants, overall efficiencies of the order of 2.5% are expected; this compares with efficiencies approaching 40% for large fossil-fueled plants. Efficiencies of shore-based plants would be lower because of the longer pipe runs and (probably) lower temperature differences.[12] Although these low efficiencies do not impact on energy cost (the energy source, of course, is free), they do have a major bearing on capital cost and require that parasitic losses (e.g., the power required to pump the large quantities of water) be kept to a minimum.

OTEC has an important advantage over other solar energy systems in that it is essentially uninterruptible. The energy-storage capacity of the oceans is so great that there is no difference between day and night operation, and only a slight variation over the year. Therefore, OTEC is suited for base-load operation, an important consideration in a system with high capital costs and low operating costs.

Maintainability and durability of OTEC systems have not been demonstrated. For the shelf-mounted plants proposed for Puerto Rico, the main uncertainties would appear to be in the lifetimes of the cold-water pipe and heat exchangers, and in the clean-ability of the latter. Major risk elements for heat exchangers have been minimized by some designers through choice of materials (e.g., titanium) and geometries (e.g., configurations that can be easily cleaned). The cold-water pipe presents a more difficult problem, at least in the larger sizes. For a shore-based 10 MW plant, however, fabrication and deployment of cold-water pipes with an expected lifetime of 30 years are believed to be within the state of the art.[12]

Reliability of a fully-operational OTEC plant should be as good or better than for a conventional power plant. Heat exchangers would be modular (for fabrication reasons), permitting serial shutdown for cleaning or other maintenance. The other mechanical equipment is typical of that found in conventional power plants. There is no reason to believe that operations would necessarily by interrupted by adverse weather (e.g., hurricanes). In this regard there is encouragement from the experience of the OTEC-1 ocean-going test platform, which continued operations during a Pacific storm of a magnitude which the designers had expected to require the jettisoning of the cold-water pipe.[4] Moreover, tower platforms are commonly used in the Caribbean for oil exploration.

Costs. OTEC, like all solar-energy concepts, is capital intensive because it requires large amounts of equipment to take advantage of the low-intensity energy source. Since the energy source is free (and assuming other operating costs are comparable to those for conventional plants), the economics of OTEC is reduced to comparing the savings in fuel costs against the cost of amortizing the construction expense over the lifetime of the plant.

Cost estimates for OTEC plants are site-specific and design-specific, and depend to a large extent upon the size of the plant assumed. A wide range of estimates can be found in the literature.[8,11,12,14,15,16,17] For the purpose of this report, it is sufficient to note that the cost of a 40 MW OTEC plant is of the order of $5000/kW, with larger and smaller plants being less or more expensive, respectively. This compares to generally quoted figures of $1000/kW for oil-fired plants and $2000/kW for coal and nuclear plants.[8] Using a plant amortization charge of 18%/yr and a plant availability factor of 80% (both figures are typical of those found in OTEC studies), the incremental cost of the OTEC plant over the oil-fired plant represents a busbar power cost of about 10¢/kWh. By comparison, the current fuel cost for electricity generation in Puerto Rico is about 8¢/kWh and the average price charged consumers is 11-13¢/kWh. Clearly, small OTEC plants are not competitive with oil at current interest rates and current world prices for petroleum. Conversely, OTEC becomes relatively more attractive as interest rates come down and the price of imported petroleum goes up. For all practical purposes, therefore, a commitment to OTEC is a hedge against the prospect that the world price of oil will increase at a rate which exceeds the long-term interest rate. This certainly has been the case during most of the past decade; it is not true at present and may not be true for the next several years.[18] In any event, predictions of this sort are difficult to make and have proved to be unreliable in the past.

Potential Users. The OTEC plants that have been proposed for Puerto Rico would be used exclusively for the production of electrical power. OTEC can be used to produce power-intensive products or fresh water, but neither of these applications have appeared attractive for Puerto Rican locations.

Potential Oil Use Reduction. Since OTEC would be used for generation of base-load power, it would be a direct substitute for power produced in oil-fired plants. Using the figures presented above, and assuming a heat rate of about 10,000 Btu/kWh for an oil-fired plant, substitution of OTEC for oil would result in a yearly savings (in the cost of purchased oil) of about $400 per year per installed kilowatt of OTEC capacity. Thus, for the 40 MW plant, the savings in avoided oil purchases would pay the incremental cost of the OTEC plant (over that of the oil-fired plant) in ten years. Although this in itself does not provide economic justification for constructing an OTEC plant, it can be an important consideration if it is desired to reduce dependence upon imported energy resources, or if it is desired to preserve foreign-exchange currency that would otherwise be spent on petroleum imports.

Reference 21 indicates that 40 MW of OTEC may be on-line by 1994 with an additional 80 MW added in 1998. The savings in imported oil were estimated to be 1.86 million barrels in 2000.

Implementation. The major barriers to the implementation of an OTEC strategy for Puerto Rico are those related to technology and financing. Environmental impacts and land-usage issues should not be major problems. Although the United States OTEC program has been directed at the technology required to build very large plants, there has been recent recognition of the possibility that initial commercialization of OTEC may occur in island markets dependent on imported oil, and where smaller plants in the range of 5 to 40 MW may be more appropriate.[8,19] A 10 MW OTEC plant can be built with existing technology but may not be economically viable except as a hedge against an oil embargo or a rapid escalation in the price of petroleum. A 40 MW OTEC plant is potentially attractive for economic conditions that may exist within this decade, but requires some extrapolations of existing technologies. The large plants (250 to 400 MW) that are believed to be competitive under today's conditions require major technological extrapolations that will take years to achieve.

Financing of OTEC plants will be a major problem because of the large amounts of capital required in comparison with conventional power plants. Financing must come from either private sources or from various government agencies.

Land use is not an issue because little land is required for an OTEC installation. OTEC plants are either located on floating platforms far out to sea, or on shelf-mounted towers as proposed for a few favored locations such as Punta Tuna. Shore-based plants have been proposed, but these would be little larger than a conventional power plant.

Environmental impacts from OTEC plants are not expected to be a hindrance to their use. There is some mixing of deep water and surface water, but this can be controlled so as not to produce undesirable effects. The most promising anti-biofouling system requires intermittent chlorination, but at levels that do not exceed EPA standards. Some working fluids (e.g., ammonia) impose environmental risks if accidentally released in large quantities, but the risks can be minimized by careful design and operation. Overall, the environmental impacts from OTEC-produced power are probably less harmful than those associated with conventional sources.

COMBINATION SOLAR POND/OTEC ALTERNATIVE

A scoping study has recently been completed for a 5 MWe power plant combining two developmental technologies - solar ponds (SP) and ocean thermal energy conversion (OTEC) - into a hybrid system that offers potential advantages over either pure SP or pure OTEC systems for production of electrical power.[19] Although this study was based upon a Hawaiian location, the concept is applicable to any tropical location with a near-shore source of deep ocean water and an on-shore topography suitable for construction of solar ponds. Puerto Rico fits into this category.

In the SP/OTEC combination, a salt-gradient solar pond replaces the warm surface water of the ocean for the collection and storage of solar energy. Solar radiation is absorbed and stored in the water at the lower levels of the pond. The water temperature at the lower levels can be scalding hot while the surface temperature remains very close to the ambient air temperature. Convection is prevented by the presence of a salt gradient that develops naturally in the pond causing the salt concentration to vary from near seawater concentration at the surface to over 20% at the bottom. Because of this salt gradient, the fluid density at the lower levels is higher than that at the surface, thus preventing the hotter fluid at the lower levels of the pond from moving upward. The concept of collecting and storing solar energy by means of salt-gradient solar ponds was derived from studies of various natural lakes that have salt concentration gradients. A salt gradient solar pond normally consists of three zones: a thin convective zone at the surface, a non-convective gradient zone in the middle that provides thermal insulation, and a convective storage zone at the bottom. A typical pond would be about 10 feet deep and require 30 or more acres per megawatt of net power production.

The resource-base requirements for the SP/OTEC combination are more restrictive than for a pure OTEC or a pure solar-pond system. As with OTEC, a tropical location is required: the Hawaiian study was based upon a mean annual solar insolation value of 280 W/m^2, with a lower practical limit of perhaps $200W/m^2$. The source of deep, cold water must be very near the shore. The on-shore topography must be suitable for the construction of the large pond complex. Finally, there must be available an inexpensive source of salt, or at least the means of producing the salt from seawater. The Punta Tuna site meets the first two requirements. There is no record of studies covering the second two requirements.

Although small solar-pond and OTEC plants have been built, the combination has never been tried. In locations where the requirements of both systems are met, the SP/OTEC hybrid is potentially superior to either. Using deep, cold ocean water in combination with a tropically located solar pond results in a substantial increase in the thermal efficiency of a pure solar pond power plant and a significant decrease in the size of the pond required. Conversely, using a solar pond as a source of warm water for an OTEC plant provides a many-fold increase in efficiency over that of a pure OTEC system. In the 5 MW SP/OTEC plant, for example, the Carnot efficiency would be about 21.5% and the net realizable cycle efficiency about 11.7% (compared to 7.4% and 2.5%, respectively, for OTEC alone.). In addition, using a solar pond in conjunction with OTEC eliminates the need for the warm-water and mixed-discharge pipes, and permits a many-fold decrease in the size of the cold-water pipe and heat exchangers. For example, the cold-water pipe - a major risk item in a pure OTEC installation - would have a diameter of only 5 feet in a 5MW SP/OTEC combination (compared to 12.5 feet for a 5 MW pure OTEC plant) and would entail significantly fewer uncertainties in its deployment and expected useful life. The other side of the trade-off is, of course, the solar pond itself, which becomes the major cost item and which has uncertainties of its own.

As the result of theoretical and experimental work done in the United States and Israel, the thermal and hydrodynamic behavior of solar ponds are sufficiently well understood for conceptual design purposes. Major technical unknowns remain in the areas of wave formation and suppression (believed to be site-specific problems requiring site-specific solutions), and in the design and installation of a suitable pond liner to prevent leakage of water. Other areas requiring careful attention are the construction of the ponds themselves and the accumulation of the extensive salt inventory; the costs for these items are high and very site-specific. Moreover, because large solar ponds have not yet been built and tested, the first SP/OTEC plants would probably consist of many ponds of a few acres each rather than a few large ponds. On balance, however, the risks due to uncertainties may be less for the hybrid than for a pure OTEC plant of the same capacity.

The cost of the 5 MW Hawaiian SP/OTEC plant was estimated to be about $5000/kW, which makes it competitive with the 40 MW pure OTEC plant discussed above. This makes it potentially attractive within this decade, and because of its smaller size, much more affordable in terms of initial capital outlays. The primary use would be for the production of electrical power. A major difference from pure OTEC is that the SP/OTEC combination is also suitable for peaking operations; the energy-storage capacity of the ponds - unlike that of the oceans - is not unlimited. In addition, the hot water from the ponds could also be used in flash evaporators for the desalination of seawater, an application that could be important in water-short locations. The savings in oil use would be the same as for OTEC: about $400 per year per installed kW of baseload capacity.

A major barrier to implementation could be in finding enough suitable land. The 5 MW plant discussed here would require about 160 acres of contiguous, relatively flat land at a shore location near a source of cold water, with a 40 MW plant requiring about two square miles. An initial step would be to survey potential sites to see if these criteria can be met. Another potential problem could be the environmental effect of leakage of brine through the pond liner into the soil. Factors tending to encourage implementation are the smaller size, the smaller capital investment, and the fact that the technology for the OTEC portion is sufficiently advanced to justify plants of this size.

HYDROPOWER

As stated in Ref. 1, the potential for hydropower in Puerto Rico has not been fully evaluated. Recent estimates by the U.S. Corps of Engineers suggest that at least a total capacity of 106 MW are available from 19 existing and potential sites that were evaluated. This potential, which does not include all possibilities, almost doubles the existing installed hydroelectric capacity for the island.

A recent reconnaissance study[2] focussing on the possibility of rehabilitating existing dams and hydroelectric power plants that are in disrepair evaluated thirteen dams and hydroelectric sites. Brief reports were prepared on 10 of the 13: three did not have sufficient information. All but one of the 10 sites showed that the development of hydropower was financially feasible. A summary of the evaluations is contained in Ref. 1.

The economic analysis for the rehabilitation was based on critera that considered that PREPA has excess generating capacity and additional capacity is not needed in the near future. The value of additional power from hydroelectric was compared to the savings in operation and maintenance to the utility (i.e., comparable to roughly 8¢/kWh and not the 11-13¢/kWh that is the price to consumers).[3] An alternative analysis based on the cost of delivered electricity might further enhance the financial viability of the rehabilitation program.

With respect to new hydroelectric sites, the Corps of Engineers developed an extensive body of information on the potential for additional base-load capacity using hydroelectric facilities.[4] The study concluded that it does not appear many hydroelectric sites or systems can be economically developed to provide new base-load. By restricting the study to base load generation, opportunities for identifying intermediate and peak load hydroelectric generating capability were not evaluated.

The Puerto Rico Office of Energy estimated that hydroelectric stations could provide 200 MW of power by the mid- to late-1990s. Oil savings are estimated to be 3.28×10^6 bbls per year in 2000.[5]

2.4 THE ENERGY PROGRAM

The energy program for Puerto Rico focuses on five major areas. These are:

1. Fossil Fuels,

2. Electricity,

3. Energy Conservation,

4. Renewable Resource Use, and

5. Energy Planning

In each of these areas three components of the program can be identified:

a. Issues - these are the major factors in each area. The previous discussions have provided the basis for the identification of these issues.

b. Approach - the fundamental premise that can guide the development of specific actions.

c. Specific Actions - based on the premises above, the steps that can be taken to address the issues. These actions include both policy measures (e.g. regulations, incentives, etc.) and projects (studies as well as hardware installations).

The energy program in each of the five areas will be described in terms of the three components.

2.4.1 Fossil Fuels

The fossil fuels area covers the use of petroleum products, the refining and petrochemical industries, and the potential for alternative fossil fuel use.

Issues. The issues involving fossil fuels in Puerto Rico can be summarized as the following:

1. Puerto Rico is almost totally dependent on imported petroleum for all of its energy supply. The demand sectors (industry, agriculture, residential, commercial, and transportation) and the domestic supply system (refineries, electricity generation) trace virtually all of their needs to imported oil. The economic growth and development of the island, therefore, is highly vulnerable to the uncertainties of the oil market.

2. The refining and petrochemical industries, major components of the Puerto Rican economy, are suffering from poor competitive positions in their major market, the mainland U.S. These disadvantages include higher costs for imported crude than mainland operations, higher product transportation costs due to the requirement to use U.S. flag shipping, higher prices for naphtha feedstock than mainland operations, and competition from other Caribbean refining operations.

3. Puerto Rico has difficulties with regard to its sources of crude oil. Venezuelan crude is decreasing both in absolute and relative quantities as a component of imports. U.S. crude is increasing measurably in relative terms but only slightly in absolute terms. Puerto Rico is competing with other countries, including the mainland U.S., for international oil supplies.

4. Puerto Rico is in a complex position with regard to oil entitlements, quotas, and price controls. Various federal regulations and controls worked to Puerto Rico's advantage in the pre-1973 period. The rapid rise in the price of foreign oil has changed this.

5. Alternative fossil fuels (coal and natural gas) are not now in use in Puerto Rico. To utilize these fuels would require extensive investment in infrastructure (e.g., coal ports, LNG facilities, etc.) and careful evaluation of environmental and safety issues.

6. A definitive evaluation of the potential for oil and/or gas reserves in Puerto Rico (including off-shore) is not available. Preliminary indications have been negative but no extensive evaluation has been done.

Approach. The following is a synopsis of some of the key premises on the basis of which specific actions are suggested:

1. It is important to determine as soon as possible the existence of oil and/or natural gas in Puerto Rico.

2. Steps should be taken to identify, evaluate, and implement technologies that can serve as substitutes for petroleum. These steps include (a) providing adequate legal and

institutional frameworks, (b) encouraging industry participation, (c) continuing interaction with the Federal Government, (d) considering the provision of matching funds, (e) establishing priorities and criteria for new technologies, and (f) using scientific resources available in Puerto Rico to study issues.

3. The refining and petrochemical industries continue to represent a major component of the economy. The corollary industries that can use the raw petrochemicals and produce finished consumer products can be a significant feature of growth and development for Puerto Rico. Efforts should be made to improve the crude oil supply situation, to improve the competitive position of the refining and petrochemical industries, and to secure appropriate consideration under various federal oil entitlements, quotas, and price controls.

Specific Actions. The specific actions suggested for the fossil fuels area include the following:

1. Evaluate the need for additional exploratory drilling for oil and/or gas. The available geological information needs to be reviewed in detail to determine if an extensive exploratory drilling program is warranted. The existing geological reports, drilling logs, soundings, and other evidence needs to be compiled into a complete documentation and evaluated on a consistent basis. A follow-up exploration program, if warranted, should then be prepared.

   Schedule: The review can probably be completed over a 6-month period.

   Resources: The review and program preparation, if necessary, should cost in the range of $40,000-$60,000.

2. Conduct a comprehensive feasibility study on the potential for coal use. The potential for coal use in electricity generation and for industrial applications needs to be evaluated in a comprehensive fashion. The possible uses should be identifed (e.g., utility boilers, industrial boilers, furnaces, etc.), the infrastructure requirements should be identified (e.g., coal ports, inland transportation, handling equipment, ash disposal, etc.), alternative configurations should be identified (e.g., coal/water mixtures, coal/oil mixtures, etc.), and a cost estimate should be made for each portion of the coal fuel cycle. Estimates should be made of the potential penetration of coal into the market and comparisons should be made to continued oil use.

   Schedule: Approximately 12-18 months

   Resources: Approximately $250,000-$400,000

3. Identify policy measures to deal with the existing refining and petrochemical industries. The steps that can be taken to improve the position of the existing industries need to be identified, evaluated, and implemented. Puerto Rico government, federal government, and private sector groups need to work together to outline specific steps (including investment incentives, entitlement options, crude oil supply agreements, etc.) that can be taken. The existing industry and the potential for new downstream operations need to be addressed and appropriate measures need to be recommended.

   Schedule: This activity should be completed in 6-9 months.

   Resources: Effort for this should come from the various Puerto Rico, federal, and private sector organizations involved.

2.4.2 Electricity

The electricity area includes all aspects of the generatión, transmission, and distribution of electricity.

Issues. The major issues involving the electrical system in Puerto Rico can be enumerated as follows:

1. The electrical generation system is almost exclusively dependent on petroleum. Small amounts of hydropower are the only non-petroleum generation source.

2. The electrical system experiences significant reliability problems based on its isolation (and inability to connect to a supporting grid), the large size of several units relative to total system size (4 units with capacity in excess of 400 MW each in a system of peak load in the range of 2000 MW), limited quick response capability (e.g., spinning reserves, quick-start units, selective load shedding capability, etc.) and maintenance problems (maintenance scheduling, repair work).

3. Electricity costs are high. Since the generation is almost exclusively from oil, fuel costs are high and must be passed on to consumers. Also, the rate structure favors large block users with the result that residential customers are bearing a larger portion of the cost of system operation. Substantial financing will be required to meet system expansion plans.

4. New generating capacity will be needed by PREPA despite the current existence of a large reserve margin. Load growth and increased system reliability requirements will dictate the new capacity required. Puerto Rico faces unusual and complex problems in planning for new capacity. The isolation of the system, the cost of alternative base load units (e.g., oil vs coal), the current sluggish economic growth, the difficult financing environment, and other factors contribute a great deal of uncertainty and risk to the timing, size, and type of new units to be purchased.

Approach. The approach with respect to electricity consists of the following premises:

1. Improving the system reliability through appropriate operation and maintenance procedures is a high priority.

2. Efforts need to be made to improve the system efficiency through operational procedures, conservation measures, and the consideration of cogeneration systems.

3. Rate structures need to be continually evaluated and revised as necessary. New rate mechanisms, such as peak load pricing, can be considered.

4. Generating units that offer an alternative to oil need to be given special consideration including conventional (coal, gas, nuclear) and renewable (wind, solar, OTEC, etc.) systems.

5. As oil will be a major part of the electrical system for some time to come, enhancement of Puerto Rico's position in the market for petroleum fuels would be economically advantageous.

Specific Actions. The specific actions in the electric sector include the following:

1. Expand training for PREPA personnel in operation and maintenance techniques. On a continuing basis PREPA staff need to have expanded and advanced training in the latest techniques for operation and maintenance of the system. The training should include current employees (i.e., on a continuing education basis) as well as new employees. Training can be via formal courses or on-the-job training (e.g., by attaching staff to mainland electric utilities to observe practices).

   Schedule: Intensive training should be for 2-4 weeks per year.

   Resources: About 5-7 people per year should receive training. A training budget of $20,000-$30,000 per year is estimated.

2. Implement repair and overhaul program. Numerous recommendations have been made regarding the needed maintenance of the current system. A prioritization scheme is needed to determine the highest priority projects. The overhauls then need to be performed.

   Schedule: The priorities can be established within a 3-6 month period.

   Resources: The cost of the overhaul program depends on the maintenance to be done.

3. Perform rate structure study. A detailed analysis of the rate structure needs to be carried out to determine the potential benefits of changing the existing structure. Alternative structures need to be identified (e.g., inverted block, time-of-day, etc.), the potential impact on reducing load needs to be computed, the mechanisms for implementing the changes need to be evaluated, and the selected scheme needs to be implemented.

   Schedule: The study should be completed in 9-12 months. Recommended changes can be implemented thereafter.

   Resources: The study is estimated to cost $75,000-$125,000.

4. Peform long-range generation planning study. A long-term (20-30 year) analysis of the generation system needs to be conducted. This would include the development of a long-term load forecast and the application of state-of-the-art planning tools to determine the optimum system expansion plan.

   Schedule: The planning can be done in a 9-12 month period.

   Resources: Approximately $100,000-$150,000 would be required.

2.4.3 Energy Conservation

The energy conservation areas cover efforts to improve the efficiency of energy use by the various end use demand sectors. Efficiency improvements in the supply sectors (petroleum refining and electricity) are covered elsewhere.

Issues. The energy conservation issues include both general considerations affecting all sectors and specific considerations for individual sectors:

1. With the exception of electricity, virtually all of the energy consumed by the demand sectors is in the form of petroleum products. Since electric generation is almost all oil-fired, the dependence on oil is total.

2. Puerto Rico has a high rate of energy consumption per unit of personal income. It ranks 11th among the U.S. states.[1] Energy use per unit of GDP is also high.

3. The transportation system is a major energy consumer with private automobiles accounting for most of the consumption. Incentives are needed to enhance the penetration of more fuel-efficient automobiles into the fleet.

4. The residential sector constitutes a small component of energy demand because of the lack of space heating requirements and the limited market penetration of appliances compared to the mainland. Nevertheless, the high cost of electricity has a significant impact on the individual consumers.

5. The commercial sector (including offices, hotels, public buildings, government installations) has a large stock of buildings that were not designed with energy considerations in mind. Lighting and air conditioning systems designed to minimize electricity requirements have not been installed to any great degree. Other energy conservation measures (e.g., site design, thermal insulation, reflective window glazing, etc.) have not been implemented to any great extent.

6. The industrial sector is the largest energy consumer. Reductions in industrial energy consumption are primarily the responsibility of individual industrial firms to evaluate in light of their special circumstances.

Approach. The approach to an energy conservation program is necessarily complex because of the multi-faceted aspects of the problem:

1. Energy conservation measures to be implemented in Puerto Rico should consider economic development impacts and should be designed to complement growth programs. For each measure considered, emphasis should be placed on reviewing the capital cost requirements, employment effects, environmental impacts, use of local resources, and the oil savings potential.

2. Energy conservation measures require the involvement and cooperation of all elements of society and the economy. Emphasis should be placed on programs to inform and educate industrial operators, farmers, building owners, and the general public on the need for conservation.

3. In the transportation sector two basic strategies must be used in concert: improvement in the public transportation system and incentives to reduce the inefficient use of private automobiles. Both of these could be carried out through a combination of regulatory measures and capital improvement projects.

4. For buildings, both residential and commercial, energy conservation can be effected by retrofit of existing buildings and improved energy performance of new buildings. As this sector is not a major energy consumer, changes will be driven more by energy cost considerations than by concerted regulatory action. There is, nevertheless, a role for a program to improve the awareness of what can be done to conserve energy and to make energy efficiency improvements more attractive.

5. In the industrial sector, the private sector is the primary implementer of energy conservation efforts. Programs can be developed to educate industrial plant personnel as to what conservation measures are available, to promote consideration of new approaches (e.g., cogeneration), to provide incentives to industry to implement energy conserving systems and to remove any unnecessary barriers to the use of more efficient equipment and processes.

6. Government operations could serve as a model for energy efficiency. For the facilities that are operated by the government (buildings, vehicles, etc.), cost-effective energy conservation measures can be applied to demonstrate the energy and cost savings potential.

Specific Actions. The specific actions that can be part of an energy conservation program include the following:

1. Revise the island's energy conservation plan. Puerto Rico's energy conservation program needs continued review. A methodology needs to be established to monitor the effectiveness of the various measures that are implemented. A continuing identification of new measures needs to be carried out.

   Schedule: The energy conservation program should be reviewed and updated approximately every two years.

   Resources: The review will cost approximately \$100,000-\$150,000 each time it is done.

2. Implement the conservation measures. There are a variety of energy conservation measures in Puerto Rico's energy conservation plan. These measures should be prioritized and implemented as resource become available.

2.4.4 Renewable Resources

Renewable resources include a variety of technologies including solar, wind, biomass, urban waste, ocean systems, and hydropower.

Issues. The issues regarding renewable resources include considerations that affect all renewable resource uses and considerations regarding individual technologies:

1. Apart from some hydroelectric facilities and some small demonstration and pilot plant units, there is currently almost no use of renewable resources in Puerto Rico.

2. Being in a tropical region, the renewable resource potential is large for Puerto Rico. There are many different technologies that can be considered for implementation. With a large number of alternatives available, a major concern is the allocation of limited financial and manpower resources. It will not be possible to develop all renewable resources systems simultaneously. Priorities should be established and choices made.

3. Cost is a major factor affecting the implementation of renewable resource technologies. The higher initial capital cost of most systems acts as a barrier to implementation. For these technologies to make any significant market penetration a series of incentives will have to be developed.

4. Many of the renewable resource technologies being considered for Puerto Rico are designed to generate electricity. As there is limited operating experience with many of these systems, there is a degree of risk involved in incorporating them into the integrated grid system.

5. Some of the renewable resource technologies (particularly biomass, large centralized solar installations, and solar ponds) will compete with other activities for limited land area. Of special concern is potential competition for agricultural land.

Approach. The general approach to be taken in dealing with renewable resources can be summarized as follows:

1. The choice of which renewable resource technologies to pursue should be made in light of the impacts on overall economic development goals. Those systems that are complementary to these goals can be the target of various incentive programs.

2. Efforts should continue to investigate the potential for all renewable resource technologies. These efforts should include estimation of the resource base, evaluation of the performance of the various technologies, evaluation of the economics of the systems, and review of the implementation issues. No technology should be eliminated from consideration until it has been clearly determined to be inappropriate. Priorities for the continued development and implementation of specific technologies and systems should be developed.

3. Appropriate procedures for comparing the economic performance of renewable resource technologies to conventional systems should be developed and applied.

4. Where appropriate, incentive programs (e.g., tax credits, pilot plant financing, loan guarantees, price supports, etc.) should be developed to assist renewable resource technologies to penetrate the market.

Specific Actions. Since some renewable resource technologies involve the long range research and development activities, it is not possible to specify a definitive set of long term actions. Instead, the emphasis is on what is most needed at this point in time.

1. Expand the evaluation of the renewable resource base. The data available on the extent of renewable resources needs to be expanded. Field data collection needs to be done for solar insolation, wind potential, biomass generation, ocean thermal profiles, and

hydropower potential. The data presented here are limited and need to be reinforced. The Wind Assessment Program is an example of the type of expanded effort needed in all areas. An integrated program plan outlining the information requirements needs to be prepared and implemented.

Schedule: Data collection for most renewables needs to be assembled over an annual cycle and preferably should be collected continuously.

Resources: The cost of the program will depend on the extent of the data gathering effort decided upon.

2. Establish a renewable resource technology data base. A complete set of current information on various renewable resource technologies needs to be assembled. The data should include technology configurations available, performance, and costs. The information can be in the form of a report library or a computerized data retrieval system. The data should be made available to energy planners, researchers, private industry and the general public as a means of increasing the awareness of renewable technology potential.

Schedule: The first set of information should be compiled for use in a 6-9 month period.

Resources: A budget of approximately $25,000 would be necessary.

3. Conduct a study on the integration of renewable resource technologies into the PREPA system. An integrated study to determine the role that renewable resource electricity systems can play needs to be carried out. The perspective needs to be that of the electric system planner and should consider issues such as capital and operating costs, effects on system reliability, rate structures for renewable technologies, etc.

Schedule: The study can be completed in approximately 12-18 months.

Resources: The study cost is estimated at $75,000 to $150,000.

4. Implement pilot scale demonstrations. The most attractive renewable technologies need to have field demonstrations to gain experience on their operation. An integrated program plan should be prepared that outlines which technologies should be given priority. The plan should then be implemented as sufficient resources are available.

Schedule: The plan can be prepared in a 6-9 month period.

Resources: The costs depend on the demonstrations to be carried out.

5. Evaluate institutional structures influencing renewable resources. The institutional issues affecting the use of renewable resources need to be evaluated. Energy pricing, tax incentives, permit requirements, financing opportunities, and other items need to be addressed. Appropriate policy measures to deal with potential barriers to renewable resource use need to be identified and evaluated.

Schedule: The review can be done in approximately one year.

Resources: The costs are estimated at $75,000-$100,000.

2.4.5 Energy Planning

This area covers overall energy planning and its integration with economic planning and analysis.

Issues. The major issues in the planning area are as follows:

1. There has been no comprehensive, integrated analysis of the energy/economy system in Puerto Rico. There have been some attempts at dealing with portions of the problem but no complete analysis has been conducted.

2. The data for carrying out a detailed energy/economy analysis are not complete. In some areas there is insufficient information for all but a cursory analysis. In other areas the data are quite good and complete.

3. The available analytical tools to carry out integrated energy studies have not been applied. Economic models for Puerto Rico exist but have not been used to drive a detailed energy system analysis. Energy sector models exist but have not been coupled into a consistent framework.

Approach. The approach toward energy planning is a recognition that there is a need for this type of integrated effort in order to make more informed energy decisions. The necessary resources (funds, effort, time) will have to be made available to implement an energy planning program. It is also recognized that the planning activity is an ongoing iterative process that must be updated periodically.

Specific Actions. The specific energy planning activities include:

1. Develop an integrated energy planning system

   For continuing energy planning efforts, a comprehensive energy planning system needs to be developed. The system should consist of a complete energy data base and a set of analytical tools that can be used to develop decision-making information. The data base should build on existing PROE systems used to compile energy statistics. The data base should be extended to include detailed information on useful energy demand pattern in each sector. It should be based on regular surveys and samples in each sector and should be updated at least annually. The data base should also include information about the energy supply system (e.g. outputs, efficiency, cost of production, etc.). New energy technologies should be included as well as existing systems.

   The analytical tools needed for energy planning include a macroeconomic model (for economic analyses), a complete energy sector model that deals with the entire energy system in an integrated fashion to construct supply/demand balances, and a set of specialized energy sector models to deal with individual elements of the energy system (e.g., electric sector, refinery sector, etc.). A battery of tools is needed rather than a single tool in order to address different aspects of the process. Some of these tools exist already in PROE and CEER.

   Schedule: The data base can be compiled over approximately a 1-1/2 year period. The analytical tools can be designed and implemented concurrently.

   Resources: The cost of the data base assembly is dependent on the level of detail desired. For planning purposes, an estimate of $150,000 to $300,000 is reasonable. The development of the analytical tools would cost about $100,000 to $200,000 depending on what existing procedures could be used.

2. Conduct Updated Energy Planning Effect

   An effort to improve and update the results of this work should be carried out as a step toward a regular energy planning exercise. New data and improved analytical procedures should be applied. Revisions to the energy program should be made in light of new information.

   Schedule: The energy planning effort should be updated at least every two to three years.

   Resources: With new data collected as part of a routine information gathering program, the update activity would cost approximately $100,000-150,000 each time it is carried out.

3 UNITED STATES VIRGIN ISLANDS

3.1 DESCRIPTION OF THE ISLANDS

The United States Virgin Islands are situated at the eastern end of the Lesser Antilles, about 40 miles east of Puerto Rico in the Caribbean Sea. The Virgin Islands consist of three main islands (St. Thomas, St. John, and St. Croix) and about 50 smaller islands (mostly uninhabited) (see Fig. 3-1).

The Islands have a population of about 95,000 (1980 census) and a land area of 136 square miles. The populations and land areas for each of the main islands are: St. Thomas - 44,500 people on 32 square miles; St. John - 2,500 people on 20 square miles; and St. Croix - 49,000 people on 84 square miles.

The Government of the U.S. Virgin Islands is organized under the provisions of the Organic Act of the Virgin Islands, passed by the Congress of the United States in 1936 and revised in 1954. Subsequent amendments provided for the election of a non-voting Virgin Islands delegate to the U.S. House of Representatives, and the popular election of a Governor of the Virgin Islands in 1970. Executive power is vested in the Governor who appoints, with the advice and consent of the Legislature, the heads of the executive departments, and may also appoint administrative assistants as his representatives on St. John and St. Croix. Legislative power is vested in the Legislature of the Virgin Islands, a unicameral body composed of fifteen Senators elected by popular vote. Legislation is subject to the approval of the Governor. All residents of the Islands who are citizens of the United States and aged over 18 have the right to vote in local elections, but not in national elections. In 1976, the Virgin Islands were granted the right to draft their own constitution, subject to the approval of the U.S. President and Congress. A constitution permitting greater autonomy was drafted in 1978 and gained the necessary approval, but was rejected by the people of the Virgin Islands in a referendum in March 1979. The Virgin Islands Fourth Constitutional Convention completed a revised draft constitution in July 1980.

3.2 THE ECONOMY

The following sections discuss the economy of the Virgin Islands and the energy requirements of the economic structure.

3.2.1 Current Situation

The economy of the United States Virgin Islands is a mixed economy dominated by tourism, raw material processing and government services. The relative strength of the Virgin Islands' economy can be measured by its per capita income[1] which stood at $4,743 in 1977, which was 68% of the U.S. mainland value of $7,019.

The economy of the Virgin Islands has gone through several growth phases. In 1950, the economic activity was equally dominated by agriculture, tourism and government activities as each sector utilized approximately 20% of the labor force.[2] The slow economic growth pattern observed after World War II continued in the early 1950s. In 1954 a revised Organic Act was passed by the U.S. Congress. Under this act the U.S. internal revenue taxes collected on Virgin Island products were to be paid to the Virgin Islands Government. The Organic Act also modified the internal revenue code so that the taxpayers in the Virgin Islands could satisfy their federal tax obligation by paying their income taxes to the Virgin Islands Government. The revised Organic Act marked the beginning of a rapid development of the Virgin Islands economy. Table 3.2.1-1 shows the key economic indicators depicting the growth rate over the last 20 years. The growth was concentrated primarily in three sectors: tourism, manufacturing and government services.

3.2.1.1 Employment and Unemployment Rate

There is a general lack of economic data for analyzing the macro-economic changes in the Virgin Islands. No official figures are available on such key indicators as gross product and its compositions, prices such as consumer price index, personal income, industrial production, etc. Faced with this difficult situation, employment statistics along with sectoral indicators are used as surrogate for describing and analyzing the economic growth. The changes in employment usually do not parallel the changes in the real output because of such factors as productivity, sectoral shifts, etc. Nevertheless, it remains a critical indicator to measure the overall economic performance.

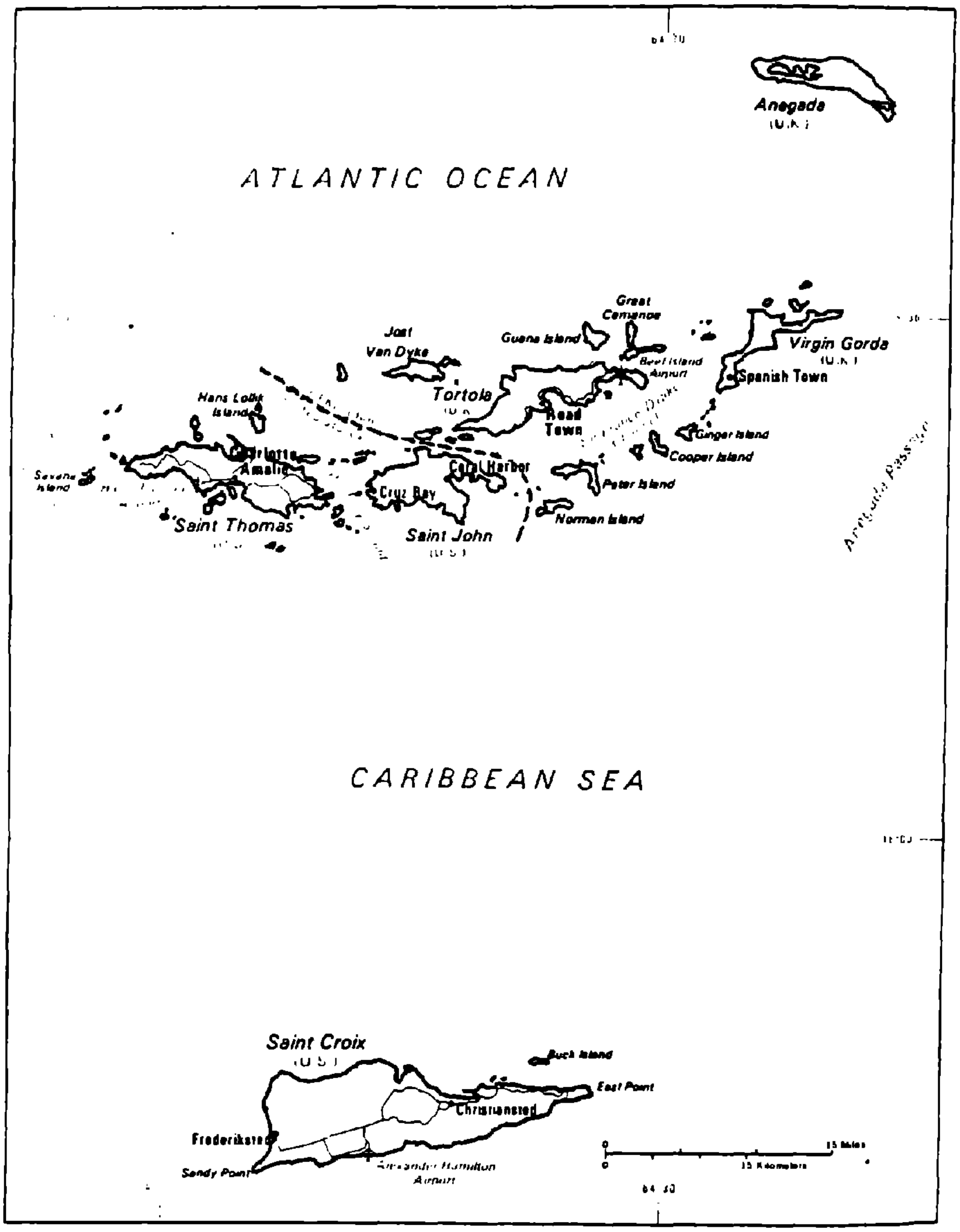


Fig. 3-1 The United States Virgin Islands

Table 3.2.1-1 shows the demographic, employment and earnings data beginning in 1960. The total employment (nonagriculture wage and salary employees) increased from 10,846 jobs in 1960 to 30,446 in 1970. This sharp threefold increase in the employment came as a result of: (1) a dramatic increase in the number of tourists from 210,000 in 1960 to 1,100,000 in 1970, (2) an increase in government spending from $7.1 million (current dollars) in 1960 to $64.9 million in 1970, and (3) a boost in exports from $8.3 million in 1960 to $262.0 million in 1970, primarily of petroleum products. After the Cuban crisis in the early 1960s, the Virgin Islands attracted many more tourists, resulting in an average annual growth rate of 18.0% between 1960 and 1970.

In the decade of the 1970s the total employment fell to a growth rate of 2.1% annually compared to its 10.9% growth rate in the 1960s. The total employment in the economy stood at 37,320 in 1980. The latest data from the Virgin Islands Department of Commerce[3] indicate that 1981 was a stagnant year as the

Table 3.2.1-1 Key Economic Growth Indicators of the Virgin Islands[a]

						% Change		
	1960	1970	1975	1980	1981	1960-70	1970-80	1980-81
Demographics and Employment								
Population	32,099	75,151	85,830	96,569	98,307	8.9	2.5	1.8
Total Labor Force	11,228	35,580	36,142	43,130	43,210	12.2	1.9	0.2
Nonagriculture Wage & Salary Employment	10,846	30,446	33,070	37,320	37,340	10.9	2.1	0.1
Unemployment Rate (%)	3.4	1.3	8.0	6.0	6.5	NA	NA	NA
Prices and Wages								
Nonagriculture Wage & Salary Empoyment - Annual Average Gross Pay	NA	NA	NA	$11,285	$12,639	-	-	12.0
United States GNP Price Deflator[b] (1972 = 100.0)	68.7	91.4	125.6	177.4	193.6	2.9	6.9	9.1
Trade								
Total Exports ($ million)	8.3	262.0	1,934.5	4,315.1	5,068.2	12.2	32.3	17.5
Petroleum Products	NA	1,846	1,819.7	4,123.1	4,830.4	-	36.4	17.2
Total Imports ($ million)	42.2	400.6	2,196.3	4,919.5	5,013.6	25.2	28.5	1.9
Petroleum Products	NA	159.6	1,823.0	4,134.9	4,110.2	-	38.5	-0.6
Tourism								
Total Visitor Expenditure ($ million)	24.8	129.6	165.7	304.3	317.5	18.0	8.9	4.3
No. of Tourists (1,000)	210[d]	1,100[d]	1,025[d]	1,306[e]	-	18.0	1.7	-
Other Key Measures								
Total Government Operating Budget ($ million)	7.1	64.9	122.1	174.1	223.8	24.8	10.3	28.6
Per Capita Income[c] ($)	NA	2,584	4,458	-	-	-	-	-

[a]Source: "U.S. Virgin islands Growth Statistics", U. S. V.I. Dept. of Commerce.

[b]Source: "U.S. Long-Term Review: Winter 1981-82", Data Resources, Inc.

[c]Source: "The Economy of the U.S. Virgin Island", Office of Territorial Affairs, U.S. Dept of the Interior, p. 53 June 1979).

[d]Source: Virgin Islands Trade Study, Federal Maritime Commission (October 1979), p. II-4.

eSource: Office of Policy, Planning and Research, VI Department of Commerce.

employment increased only by 0.1% over 1980. This performance has resulted from the decline in tourist activity (as characterized by the drop in visitor air arrivals from 526,000 in 1980 to 475,000 in 1981[3]), and the continued weak performance of the U.S. economy. The U.S. GNP declined by -0.4% in 1980 and had a weak rebound of 1.9% in 1981.[4] With yet another recession in the U.S. economy, the short-run problems in the Virgin Islands' economy are expected to prevail.

Table 3.2.1-2 shows the historical unemployment rate of the Virgin Islands. There was hardly any unemployment in the Virgin Islands by 1970 as employment increased threefold along with the labor force. The unemployment rate dropped from 3.4% in 1960 to 1.3% in 1970. However, the situation worsened in the early 1970s when the U.S. economy went into a recession in the 1974-75 period. (The visitor air arrivals fell from 573,000 in 1970 to 456,000 in 1975.) With the continued increase in population and labor force shown in Table 3.2.1-1, the unemployment rate increased to 8.0% in 1975. Subsequently, it has remained in the range of 5.6 to 10.8% between 1975 and 1981. In 1981 the unemployment rate stood at 6.5%. Even though not very high compared to other places, the unemployment is high compared to the past standards.

3.2.1.2 Inflation

As noted earlier, the official figures on any price index are not available. However, in an earlier study done by the U.S. Department of the Interior,[1] a partial consumer price index (including 56% of the typical consumer market basket as defined by the U.S. Bureau of Labor Index) is provided. This Virgin Island Consumer Price Index (1972 = 100) was 170.9 in 1977 compared to the U.S. Consumer Price Index (1972 = 100) of 156.1. It points out that the price escalation in Virgin Islands over the long run has not been too far from the rate in the United States even though year to year changes have been quite different. Table 3.2.1-3 provides this annual comparison.

3.2.1.3 Composition of the Economy

Based on data from the Virgin Islands Department of Commerce, Table 3.2.1-4 provides the distribution of the total employment by major sectors.[3] The total employment breakdown prior to 1970 was not available to identify the shifts in the economy. However, as mentioned earlier, the increase in tourism, government expenditure, and the processing of petroleum products were responsible for the upsurge in total employment from 10,846 in 1960 to 30,446 in 1970. The 1970 employment share was 28.4% for territorial government; 18.2% for wholesale and retail trade; 16.8% for construction; 9.2% for hotel and other lodging places; 8.5% for manufacturing; 6.6% for other services; 6.5% for transportation; 4.6% for financial, real estate and insurance; and 1.2% for Federal Government.

The structural shifts have not been dramatic in the decade of the 70s. Between 1970 and 1980, compared to a growth rate of 2.1% annually in total employment, the growth was higher in the sectors of wholesale and retail trade (3.0%), other services (4.3%), Federal Government (6.1%), and territorial

Table 3.2.1-2 Unemployment Rate in the Virgin Islands

Year	% Unemployment
1960	3.4
1970	1.3
1975	8.0
1976	10.8
1977	7.9
1978	6.4
1979	5.6
1980	6.0
1981	6.5

Source: U.S. Virgin Islands Growth Statistics, U.S.V.I. Dept. of Commerce.

Table 3.2.1-3 Inflation in the Virgin Islands

	Consumer Price Index (CPI)		CPI Annual Charge, %	
Year	Virgin Islands	Mainland U.S.	Virgin Islands	Mainland U.S.
1970	100.0	100.0	-	5.9
1971	106.5	104.3	6.5	4.3
1972	118.8	107.7	11.5	3.3
1973	132.2	114.4	11.3	6.2
1974	148.7	127.0	12.5	11.0
1975	160.9	138.6	8.1	9.1
1976	163.0	146.6	1.3	5.8
1977	170.9	156.1	4.8	6.5

Source: "The Economy of the U.S. Virgin Islands", U. S. Department of the Interior, p. 53.

Table 3.2.1-4 U.S. Virgin Islands Employment by Major Industry Sector

Industry	1970	1975	1980	1981	% Change 1970-80	% Change 1980-81
Manufacturing	2,585	3,060	3,190	3,050	2.1	-4.4
Construction & Mining	5,128	4,480	3,480	3,580	-3.8	2.9
Transportation and Public Utility	1,965	1,740	2,060	2,070	.5	0.5
Wholesale and Retail Trade	5,528	6,290	7,460	7,550	3.0	1.2
Finance, Insurance, Real Estate	1,403	1,340	1,580	1,630	1.2	3.2
Hotels & Other Lodging Places	2,816	2,060	3,040	2,710	.8	-10.9
Other Services	2,013	2,400	3,070	3,090	4.3	0.7
Federal Government	359	500	650	650	6.1	0.0
Territorial Government	8,649	11,200	12,790	13,010	4.0	1.7
Total Employment	30,446	33,070	37,320	37,340	2.1	0.1

Source: "U.S. Virgin Islands Growth Statistics", Office of Policy, Planning and Research, U.S. Virgin Islands Department of Commerce, St. Thomas, U.S. Virgin Islands.

government (4.0%). In contrast, the growth in employment was below total employment average rate of 2.1% annually in the sectors of construction and mining (-3.8%); transportation and public utility (0.5%); finance, insurance and real estate (1.2%); and hotels and other lodging places (0.8%). For manufacturing employment, the growth rate was 2.1% annually in this period of 1970-80.

Total employment changed very little between 1980 and 1981 (37,320 vs 37,340). Some minor shifts in sectoral employment occurred. The significant shifts have occurred in the sectors of territorial government (34.3% share of employment in 1981 vs 28.4% in 1970) and construction (9.6% in 1981 vs 16.8% in 1970).

3.2.1.4 Miscellaneous

Besides the importance of government services and tourism to the islands' economy, the importance of two companies which are located on the islands cannot be ignored. First, Amerada Hess Company operates one of the world's largest oil refineries. The company provides about 1,900 jobs[5] or about 5% of the total labor force of 40,000 persons. Furthermore, as most of the refinery output is exported, the local economy earns much needed export dollars. For example, the petroleum products exports were $4.83 billion in 1981 as compared to imports of petroleum products of $4.11 billion. These export dollars were largely responsible for a favorable balance of trade ($5.07 billion total exports vs $5.01 billion total imports). The local economy must import food and manufactured goods to sustain its improved standard of living.

The other important company contributing to the local economy is Martin Marietta which processes bauxite into alumina. According to a Federal Maritime Commission report,[6] Martin Marietta is the second largest employer in the Virgin Islands and provided employment to 700 people in 1978 or about 1.8% of the total labor work force.

The other industries that are important include (1) the rum industry, providing $24.5 million as excise tax return from the Federal Government in 1978;[7] (2) the watch industry providing jobs to 715 persons in 1978;[8] and (3) the textile industry exporting $7 million in 1978.[9]

3.2.2 Prospects for Growth

Having established the Virgin Islands' long-run economic trends, the projections of future economic growth must be developed in order to estimate the energy demand in the future period. This section describes the economic growth scenarios.

3.2.2.1 Development Policy and Goals

Over the years, the Virgin Islands' development has come about as a result of a combination of the free market process, tax incentives, and other inducements offered by the local government. During the last twenty years, economic planning seems to have been focused on the job opportunities. In 1979, the Virgin Islands Department of Commerce prepared economic development policy guidelines providing goals, objectives and recommendations.[1]

The cooperative approach between the government and the private sector is expected to continue in the future as tremendous progress has been made in the development of the economy over the last 30 years. In 1981, the unemployment rate was only 6.5% and the average annual gross pay of an employee was $12,639[2].

3.2.2.2 Macroeconomic Development Scenarios

As with any long-range projections, there is uncertainty as to how the Virgin Islands economy will develop between now and 2020. For the purpose of this report, a scenario prepared by James Pobicki, Director of the Office of Policy, Planning and Research of the Virgin Islands Department of Commerce provides the basis of projections to year 1990.[3] The economic data has been extended for the period 1990-2020.

U.S. Virgin Islands Outlook for 1980s. Employment projections by industry are shown in Table 3.2.2-1. These projections show the increase in employment by industry that would meet the basic needs of the economy for growth and diversification. These projections recognized the presence of highly cyclical tourism sector, the lack of broad economic diversification, and the difficulties of the economy in keeping up with the increase in the labor work force. In the 1970s, most of the new jobs (95%) were created in the public sector. The private sector must grow and diversify to meet these needs. Based on these goals, the projections estimated that about 1,100 jobs per year will be needed to meet the need of the emerging labor force in the 1980s. These projections reflect the assumptions that the private sector provides seven new jobs for each new job in the public sector.

The total employment needs to increase from 39,770 in 1980 to 51,000 in 1990. This is equivalent to an average annual growth rate of 2.5% in the period 1980-1990. All sectors of the economy grow in this period. The above-average growth comes in tourism (2.7%), manufacturing (5.7%), construction (3.6%), local trade (3.1%), local services (3.5%), and total private (3.2%). The below-average growth is seen for the sectors of local transportation and utilities (1.3%), and the government (1.0%) during this period of 1980-1990.

"High Growth" Economic Projections: 1980-2020. In the recent history of the Virgin Islands, the total employment increased at an average annual rate of 1.3% between 1970 and 1980 (Table 3.2.2-1). If the

Table 3.2.2-1 Projections of Virgin Islands Employment by Industry, 1980-1990[a]

Industry	1980 No.	1980 %	1990[b] No.	1990[b] %	Average Annual Change 1980/1990[c] No.	Average Annual Change 1980/1990[c] %
Tourism	10,210	25.7	13,150	25.8	2940	+2.7
Manufacturing	3,240	8.1	5,650	11.1	2410	+5.7
Construction	3,160	8.0	4,520	9.8	1360	+3.6
Local Trade	3,670	9.2	4,980	8.6	1310	+3.1
Local Services	3,130	7.9	4,400	8.6	1270	+3.5
Local Trans. & Utilities	1,400	3.5	1,600	3.1	200	+1.3
Fin. Ins., Real Estate	1,520	3.8	1,850	3.6	330	+2.0
Total Private	26,330	66.2	36,150	70.9	9820	+3.2
Government	13,440	33.8	14,850	29.1	1410	+1.0
Total Employment	39,770	100.0	51,000	100.0	1,123	+2.5

[a]Source: "Poblicki, J., Director of the Office of Policy, Planning and Research, U.S. Virgin Islands Department of Commerce[3].

[b]1990 projections are an illustration depicting minimum growth necessary to absorb potential increases in the resident labor force.

[c]Average annual compound growth rates.

outlook of the Virgin Islands Department of Commerce (including 2.7% annual growth rate in employment) were to be realized, this would be an extremely satisfactory performance. The economy in the 1980s would have to grow twice as fast as that of the 1970s as characterized by the growth rate in the employment. Keeping in view the poor performance during 1981 (when nonagriculture payroll employment increased by only 0.1%[2]), and the current severe recession in the U.S. economy, this performance of the Virgin Islands economy would be quite optimistic. Therefore, these projections can serve as the high growth scenario.

Beyond 1990, there is very little information and analysis available. For the purpose of this report, it is assumed that the Virgin Islands economy would grow at an average annual rate of 2.5% between 1990 and 2020. As shown in Table 3.2.2-2, the total employment in the economy will increase from 39,770 in 1980 to 51,000 in 1990, 65,280 in 2000, 83,570 in 2010, and 107,000 in 2020.

"Low Growth" Economic Projections: 1980-2020. Under this alternative outlook for the Virgin Islands economy, it is assumed that the actions outlined under the high growth scenario will not take place. The effort to diversify the economy and new investment in the private sector is assumed not to materialize. The economy continues to have the kind of growth as achieved in the 1970s. The total employment grew at an average annual rate of 1.3% between 1970 and 1980.[4] The economy of the Virgin Islands is assumed to continue to be affected by the conditions in the mainland and to remain cyclical. For the low growth scenario it is assumed that the Virgin Islands economy will only grow at a 1.3% average annual increase in total employment. Thereby the total employment increases from 39,770 in 1980 to 47,100 in 1990, 55,700 in 2000, 675,900 in 2010 and 78,000 in 2020 as shown in Table 3.2.2-2.

These economic projections are very simplistic as they are not based on a detailed economic analysis. However, they give an indication of the possible size of the Virgin Islands economy that could provide employment for 78,000-107,000 people by 2020.

Table 3.2.2-2 Projections of Total Employment in the Virgin Islands

	1970	1975	1980	1990	2020	Annual % Change 1970-80	Annual % Change 1980-90	Annual % Change 1990-2020
High Growth Scenario	35,118	33,250	39,770	51,000	107,000	1.3	2.5	2.5
Low Growth Scenario	35,118	33,250	39,770	47,000	78,000	1.3	1.3	1.3

3.2.3 Energy Demands of the Economy

The economy of the Virgin Islands experienced a rapid, expansive growth in the 1960s, which leveled off during the 1970s and remains at lower levels in the 1980s. This growth occurred primarily in three sectors -- government, tourism and manufacturing -- and they continue to be the most significant activities in terms of income, labor and output. Concomitant to this sectoral development has been a rapid increase in population (much a result of migration from outer islands) from 32,000 in 1960 to 92,000 in 1975.[1]

Increased demands for energy are linked directly to the growth in the number of households, industrial establishments, government and public services and tourist facilities. The Virgin Islands uses less energy per capita than the U.S. mainland as a whole because it has little heavy (energy-intensive) industry and no space heating (an end-use that accounts for nearly 15% of demand in the United States as a whole). The form that increases in future energy demand takes (electricity for air conditioning in hotels, gasoline for automobiles, fuel oil for industrial boilers) will determine the Virgin Island's ability to meet that demand and also define what alternatives to imported oil are available.

Currently, the primary sectors of the economy (residential, tourism/commercial, industry, agriculture, and transportation) rely either directly or indirectly on imported oil for nearly 100% of their energy requirements. Energy consumed in the Virgin Islands is either in the form of petroleum products or electric power, which is produced almost exclusively by oil-fired generators. Industry accounts for the major share of energy consumption, electricity and petroleum products alike, with residential, and tourism/commercial being a distant second and third in terms of total energy consumption. It is important to note that the major energy-consumers in the Virgin Islands are Hess Oil Virgin Islands Corporation (HOVIC) and Martin Marietta Alumina. Combined they account for over 90% of consumption. However, as self-sufficient entities with their own power-generating and water supply facilities, they do not draw on the services of the Water and Power Authority. Therefore, statistics regarding energy consumption measured by sales of electricity to certain classes of customers do not include the significant amounts of electricity generated by and consumed in these two plants.

The major form of energy consumed in the Virgin Islands is electrical energy -- 65% of the total.[2] The remaining 35% is almost entirely direct use of petroleum products. Solar water heating is used to a very limited extent, but detailed data have not been collected to present even a rough estimate of its contribution.

The energy consumption patterns characteristic of each of the sectors are varied. Energy consumption in the residential sector is primarily electricity (accounting for 40% of sales in FY 80).[3] Of this amount, 35% went to heat water, 2% for refrigeration and 10% for cooking, with lighting and appliance use accounting for the remaining percentage.[4] There are limited demands for direct petroleum use in the form of LPG for cooking. The tourism/commercial sector is also highly dependent on electricity to meet energy demands (15% of electricity sales in FY 80)[5] for air conditioning, cooking, refrigeration, laundry, water heating, lighting and appliance and equipment use. In contrast, the transportation sector consumes petroleum products, almost exclusively, in the form of gasoline, jet fuel, aviation gas and limited amounts of diesel fuel. Private automobiles and freight transport account for the major consumption.

The industrial sector accounts for consumption of significant amounts of electricity and petroleum products. The energy intensity of industry in the Virgin Islands (excluding HOVIC and Martin Marietta Alumina) is relatively low since there is primarily light industry. Industry is credited with 42% of electricity sales in FY 80[6] and also accounts for consumption of relatively large shares of diesel fuel.

Table 3.2.3-1 presents statistics in energy consumption for 1978-80 for the Virgin Islands by fuel type. Since electricity (with a 65% share of total energy consumption) is petroleum-derived, the reliance of the Virgin Islands on oil is total.

The following sector-by-sector discussions provide details regarding the composition of each economic sector, the major energy-consuming activities, and the sectoral issues that bear on the Virgin Island's energy future.

Residential. In the Virgin Islands, nearly all residential energy consumpion is in the form of electricity. A small amount of LPG is used in cooking and water heating and as a fuel for small electric generators. LPG is supplied by Antelles, Protane and Caribe Gas Companies.

Major end-uses in the residential sector include water heating, cooking, refrigeration, lighting and appliances. Virtually all households have stoves (gas and electric), water heaters, lights, and such basic appliances such as refrigerators and radios. There are no requirements for space heating due to the temperate climate, and few, if any, private residences are air conditioned. Increased standards of living may lead to additions to the electrical appliance stock, thereby adding to the demand for electricity in the residential sector.

Tourism/Commercial. The Tourism/Commerical sector is extremely diverse and one of vital importance to the Virgin Islands economy. It includes such public facilities as schools, hospitals and communication services as well as private hotels, shops, restaurants, and other service establishments. The diversity of the sector is reflected in the diversity of energy-consuming end uses, including space conditioning, cooking, water heating, nonsubstitutable electric, stationary motors, pumps and backup electrical generation. Detailed data are not available regarding energy consumption, but several observations can be made using information known regarding energy use patterns in hotels in other islands. The major form of energy used to meet demand is electricity (63% of total) with fuel and diesel oil accounting for approximately 28% and LPG making up the difference.[7] The end uses to which each of the direct fuel sources are put are as follows: LPG -- water heating, cooking and laundry drying; and diesel and fuel oil -- majority of water heating, steam generation (for water heating, central air conditioning systems, emergency backup generators, emergency lighting, elevators).[8]

Table 3.2.3-1 Energy Consumption Statistics for the United States Virgin Islands

	Consumption Total (In Gals. Except kWh for Electricity)								
	1978			1979			1980		
Energy Source	Amt. ($x10^6$)	Btu ($x10^{12}$)	%	Amt. ($x10^6$)	Btu ($x10^{12}$)	%	Amt. ($x10^5$)	Btu ($x10^{12}$)	%
Diesel Fuel	110	13.8	20.	141	17.6	24	17.3	21.6	28
Gasoline	25.4	3.3	4.8	25.6	3.3	4.5	25.9	3.4	4.4
Propane Gas	3.22	0.3	0.4	3.59	0.3	0.4	4.0	0.37	0.5
Jet Fuel	13.0	1.7	2.5	14.2	1.9	2.6	11.1	1.4	1.8
Aviation Gas	2.40	0.3	0.4	2.38	0.3	0.4	2.2	0.3	0.4
Electricity[a]	539	49	72	445	49.6	68	443	49.4	65
Total	-	68.4	100	-	73	100	-	76.5	100

Conversion Factors: Diesel - 125,000 Btu/Gal, Gasoline - 130,000 Btu/Gal, Propane - 92,000 Btu/Gal., Jet Fuel - 130,000 Btu/Gal, Aviation Gas - 130,500 Btu Gal., Electricity - 11,150 Btu/kWh.

[a]Does not include figures from Hess Oil and Martin Marietta who generate their own electricity.

Source: Ref. 2

Transportation. The transportation sector is entirely dependent on petroleum fuels. Most of the fuels are purchased through local distributors who are supplied by the Hess Oil refinery or imported products. Gasoline consumption for transportation accounts for approximately 5 percent of total energy consumption in the Virgin Islands[9] and has remained relatively constant despite increases in population and the number of private automobiles. The major end-uses of energy in the transportation sector include: passenger transport via automobile, taxi, bus, ferry and airplane; freight transport via truck, ship, barge and airplane; and service vehicles operated by such agencies as the Department of Public Works, Public Safety, and Property and Procurement, the PAT Authority, WAPA and VITELCO. The large number of cruise ships that stop in the Virgin Islands do not refuel, consequently they do not affect energy consumption in the transportation sector. The short distances for on-island and inter-island trips make them particularly energy-intensive.[10]

Agriculture/Fishing. Current activity in food and lumber production in the Virgin Islands is not significant relative to other energy-consuming sectors, with approximately 90% of current food-stuff consumed in the Virgin Islands being imported. The three major activities in the sector are agriculture, fishing and lumber. Agriculture includes vegetable crops, feed crops (such as sorghum) and feedstock (primarily for cattle). Production is geared for local consumption, but is very limited. A relatively small amount of land is currently zoned for agriculture -- approximately 465 acres (0.73 sq. mi.) in St. Thomas and 12,000 acres (18.75 sq. mi.) on St. Croix for crops and cattle grazing. The government leases an additional 120 acres in 5-acre tracks for agriculture. No detailed energy consumption data for the agricultural sector are available. However, it can be assumed that petroleum products are used for farm machinery (primarily tractors) and crop drying and electricity for irrigation pumps and refrigeration. Fishing vessels (both commercial and sport) are of relatively small tonnage. Energy consumption is in the form of gasoline and diesel fuels. Lumber production in the Virgin Islands is fairly small. There are approximately 2,000 acres of land in St. Croix dedicated to the forestry program. Current lumber production is primarily as a raw material for charcoal. The lumber and fishing activities are not significant in terms of their total energy consumption.

Industry. Aside from the Hess Oil and Martin Marietta industrial activities, industry in the Virgin Islands is currently geared towards fairly small operations classified as light industry, producing products for local consumption. The notable exceptions are the rum and watch industries that do rely on export markets. Currently the Virgin Islands imports, on the average, 98 percent of finished goods demand.

Table 3.2.3-2 presents a breakdown of industries in the Virgin Islands by SIC code. The most significant to the economy and to the energy situation are Food and Kindred Products (Rum Industry), Instruments and Related Products (Watch Assembly), Chemicals and Allied Products (includes Martin Marietta) and Petroleum and Coal Products (Hess Oil Virgin Islands Corporation). In addition, the construction industry is a significant energy-consuming subsector.

Energy-consuming end-uses in the Food and Kindred Products industries include boilers for steam production, bakery ovens, blending or mixing operations and refrigeration units for cold storage -- the latter two using primarily electricity. The rum industry is of particular importance within this subsector, both because of its level of energy and potable water consumption and its significance as a product export activity. Though fuel and electricity costs are not major components of the total materials costs within the industry (assuming a similarity between Virgin Islands and Puerto Rican industries, fuels and electricity accounted for 1.7 percent of total costs[11]), the portion of industrial electricity consumption is significant.

The major industrial activity within the Instruments and Related Products group is watch assembly, totaling 15 of the 17 establishments in the 1981 survey. Energy consumption is primarily electricity for electric-motor-driven devices, lighting and possibly air conditioning. Limited amounts of gasoline are also used for transportation of raw materials and finished products. In terms of energy intensity, this industrial group is quite low; an expansion of activity would not significantly increase energy demands in the Virgin Islands.

Energy-consuming activities in construction are primarily in the form of trucks for material hauling, front-end loaders, cranes, etc. Construction materials such as asphalt are an important petroleum item used for non-energy purposes. The production of gravel, asphalt, cement and concrete blocks are energy-intensive activities demanding direct use of petroleum products and electricity. Consequently, the level of construction activity and domestic production of construction materials has a direct and significant effect on the energy demands of the economy.

Table 3.2.3-2 Manufacturing Establishments in the U.S. Virgin Islands, 1981

SIC Classification	Number of Establishments
Food and Kindred Products	15
Rum Distilleries	
Textile Mill Products	6
Apparel and Other Textile Products	8
Lumber and Wood Products	1
Furniture and Fixtures	2
Printing and Publishing	14
Chemicals and Allied Products	12
Petroleum and Coal Products	1
Rubber and Plastics Products	3
Leather and Leather Products	2
Stone, Clay and Glass Products	6
Fabricated Metals Products	3
Transportation Equipment	1
Instruments and Related Products	17
Miscellaneous	5
Total	96

Source: Directory of U.S. Virgin Islands Manufacturing Establishments, Office of Policy, Planning and Research, Virgin Islands Department of Commerce, 1981.

Crude oil supplies and energy consumption in the Virgin Islands are completely dominated by the fuel requirements of the Hess Oil Virgin Islands Corporation (HOVIC) and Martin Marietta Alumina plants in St. Croix. Both plants are, however, completely self sufficient units as far as energy and water needs are concerned. HOVIC has a 125 MW electric generation capacity and desalination plants supplying two million gallons of water per day. Martin Marietta has 18 MW capacity and desalination plants supplying all its water needs.[12] Since the two industries are self-sufficient, their energy demands do not currently affect the overall energy situation in the Islands. The existence of the refinery on St. Croix provides a locally available supply of petroleum products, primarily gasoline and diesel fuel. However, the majority of refinery output is exported to the mainland.

3.2.4 Possible Future Demands

The estimation of energy consumption over the next four decades needs a comprehensive assessment. The energy demand will be affected by several critical factors, some of which are the changes in the economic structure, the availability of different fuels at different prices, and the extent of the improvement in the efficiency of the energy use devices. The estimation of energy demand becomes even more uncertain as the forecasting period is extended to 2020. In the absence of a comprehensive methodology, a simplistic approach is used to estimate the future energy demands of the Virgin Islands.

3.2.4.1 Methodology

As the data on gross product of the Virgin Islands is not available from official sources, it is not possible to use the energy-elasticity-based methodology. Therefore, an even simpler approach must be utilized. Under this methodology, the total energy demands are projected on the basis of growth rates in total employment under alternative scenarios.

3.2.4.2 Energy Demand Projections

Two sets of projections are made corresponding to the high growth and low growth economic scenarios.

"High Growth" Energy Demand Projections: 1980-2020. The future course of the economy is assumed to be characterized by the high growth economic scenario discussed in Section 3.2.2. As was shown in Table 3.2.2-2, the total employment increased at an average annual growth rate of 2.5% between 1980 and 2020. There will be compensating factors from the energy demand perspective. First, the economy is expected to become more energy-intensive as above-average growth occurs in manufacturing and construction sectors. Second, the trends in energy conservation as observed in most of the developed economies worldwide are assumed to continue. Some of the improvements in energy efficiency are envisioned in higher mileage from automobiles, higher energy efficiency in household appliances, and improved industrial equipment. To determine the extent of the improved usage of primary energy in the economy is a difficult and tedious task beyond the scope of this report. Therefore, a simple assumption was made that the two above compensating factors will tend to offset each other. In summary, the needs of greater energy demand for the growth in energy-intensive industries will be compensated for by the improved utilization of primary energy resources throughout the economy.

It was, therefore, assumed that the energy demand in the Virgin Islands will grow at the rate of growth (of employment) of the economy. Consequently, the Virgin Island total energy consumption grows at the projected rate of 2.5% annually between 1980 and 2020. This translates into Virgin Island total energy demand increasing from 76.5 trillion Btu in 1980[1] to 97.9 trillion Btu in 1990, 125.3 trillion Btu in 2000, 160.5 trillion Btu in 2010, and 205.4 trillion Btu in 2020 as shown in Table 3.2.4-1.

"Low Growth" Energy Demand Projections: 1980-2000. In order to have a range of possible energy demands, an alternative scenario including the low growth economic projection was used. This is a pessimistic view of the Virgin Islands economy over the next four decades. The energy demands under this scenario are estimated in a fashion similar to the High Growth Case. The sectoral shift towards more manufacturing and construction industries are assumed not to occur under this outlook. The composition of employment is assumed to remain more or less as it was in 1980 (see Table 3.2.2-1). The energy intensity of the economy will decrease moderately as some conservation trends continue. However, as new investments are limited (because the economy is growing only at 1.3% rate annually), the extent of this improvement will be limited. In the absence of data, no detailed analysis is possible. It is again assumed that the total energy consumption will grow at the pace of the economy (characterized by the employment growth). Consequently, the total energy demand grows from 76.5 trillion Btu in 1980 to 87.0 trillion Btu in 2020 (Table 3.2.4-1).

As discussed earlier, these projections (128.2 to 205.4 trillion Btu in 2020) must be considered as only a rough indication of the future Virgin Islands energy demand. Only a detailed total energy assessment of the economy can provide reliable projections of energy demands.

Table 3.2.4-1 Energy Demand Projections for Virgin Islands

						Annual % Change	
	1978[a]	1979[a]	1980[a]	1990	2020	1978-80	1980-2020
High Growth Scenario	68.4	73.0	76.5	97.9	205.4	5.8	2.5
Low Growth Scenario	68.4	73.0	76.5	87.0	128.2	5.8	1.3

[a]Source: Territorial Assessment of the United States Virgin Islands
Virgin Islands Energy Office, p.9, 1982.

3.2.5 Energy Conservation Possibilities

In principle, the types of conservation projects that can be implemented in the Virgin Islands are similar to those appropriate to an island economy that enjoys a mild climate. There are, however, unique circumstances in the Virgin Islands. Two privately-owned, major industrial complexes combined account for more than 90% of energy inputs and consumption -- Hess Oil Virgin Islands Corporation and Martin Marietta Alumina plant. Energy savings in these facilities can be realized primarily through mechanical changes to processes -- many of which are considered trade secrets.[1] The effects of a conservation effort for these facilities must, therefore, be distinguished from conservation activities in other areas. It is in these other areas where conservation strategies need attention.

The Virgin Islands Energy Office has outlined a plan for energy conservation in the sectors under its purview.[2] The primary focus is on measures that reduce energy consumption without hindering future economic growth or reducing the standard of living. Conservation savings are directed towards reduced consumption of electricity and of petroleum products used for transportation. Both goals have the net effect of reducing reliance on imported oil. The estimated energy savings realized through the application of specific conservation measures are detailed in Table 3.2.5-1.

The sections that follow identify conservation measures currently in effect and proposed for the various energy demand sectors of the Virgin Islands' economy. They are drawn from the Virgin Islands Energy Conservation plan (Ref. 1) that was prepared in 1978. Some additional analysis on these measures was done and included in Ref. 2. These are noted as appropriate.

3.2.5.1 Residential/Commericial

Residential/commercial energy demand in the Virgin Islands is low by U.S. standards, primarily due to the absence of space heating and the limitation of air conditioning demand to commercial establishments. The conservation measures focus on new and renovated buildings and efficiency of new appliance acquisitions.

Thermal Efficiency Standard. Thermal efficiency standards for new and renovated building construction specify efficiency requirements for air conditioning and lighting. They are implemented by inclusion in the building code, thereby assuring compliance for new construction. It is proposed to emphasize the promotion of architectural designs and standards that take advantage of natural air ventilation and discourage the use of air conditioning and other energy-intensive building techniques. Modifications to older buildings through such methods as roof insulation and application of thermal window frames will help to reduce the air-conditioning load.

Lighting Efficiency Standards. Efficiency standards for lighting are designed to reduce the use of electricity for lighting in both new and existing buildings. The incorporation of such standards as a

Table 3.2.5-1 Estimated Savings for 1981 Virgin Islands Energy Program

Program Measure	Estimated Savings (in Btus)
Thermal Efficiency Standard	0.08×10^9
Installation of Window Films	3.0×10^9
Insulation	0.75×10^9
Procurement	$2.3 \times {}^5$
Carpooling/Vanpooling	288×10^9
Left Turn on Red	3.99×10^9
Emergency Building Temperature Restriction Program	38×10^9
Industrial	$44,667 \times 10^9$

Source: "Territorial Energy Assessment for the United States Virgin Islands", 1982 supplement to the existing building codes makes compliance mandatory for all new construction. The definition of standards appropriate to the Virgin Islands requires a survey of current use patterns, followed by an evaluation of the survey results to determine reasonable goals applicable to the particular circumstances prevailing on the Islands.

Energy Audits. The energy audit program consists of efforts to perform energy audits of office buildings, industrial plants and residential buildings throughout the Islands. Energy audits provide the detailed data on energy use and efficiency of use in buildings that pinpoint waste and opportunities for conservation. Energy conservation measures identified through an audit as applicable for a given building include, but are not limited to, weatherstripping and caulking; wall, ceiling and floor insulation; use of renewable resources; measures for ventilating, air conditioning, water heating, lighting and electrical systems. Energy audits in industry and large commerical buildings may well be carried out by government-hired auditors. A public education program that encourages households and small business owners to undertake their own audits using workbooks devised by the Government will have a twofold result: (1) it raises the public consciousness of the energy situation emphasizing both national and personal benefits; and (2) it contributes directly to reduced consumption of electricity through the implementation of actions identified as appropriate in the audit.

3.2.5.2 Transportation

As would be expected, transportation accounts for the major share of direct fuel use (gasoline) outside of the industrial sector. Faced with rising gasoline prices, consumers in the Virgin Islands have followed the obvious trends similar to their mainland counterparts -- such as purchase of energy-efficient, small cars. Transportation conservation efforts on which the Government has focused are directed towards reduced consumption of gasoline and improved traffic flows.

Shared Rides (Carpooling and Vanpooling). The Virgin Islands Energy Office reports that the private transportation system in the Islands is characterized by an informal, pervasive practice of "hitching a ride". In fact, several unofficial "stops" exist throughout the Virgin Islands, with most pedestrians being successful in obtaining the desired transportation. As a result, the Energy Office is of the opinion that such shared ride systems as vanpools and carpools as defined by mainland standards may not be directly applicable to the Virgin Islands social system.[2] Increased emphasis on the informal hitching practice as a modified form of carpooling and vanpooling will have the same net result as the formal systems that have proven successful on the mainland but will be more in tune with the social milieu of the Islands.

Improvement of Public Transportation. Little detail is available regarding the use and efficiency of the Virgin Islands bus system. The Energy Office has identified the development of maintenance regulations for bus companies and the expansion of bus routes as two of the means available to improve public transportation and thereby encourage increased use of the system, improve intensities and load factors. Further analysis is warranted and necesary to determine the real contribution that modification to the current system of public transportation can make to conservation of energy in the Virgin Islands.

Left-Turn on Red. The left-hand traffic patterns in the Virgin Islands call for the modification of standard mainland conservation efforts based on right-turn on red. In all, there are 15 intersections controlled by signals in St. Thomas, four in St. Croix and none in St. John. Therefore, the number of intersections is small, making the likely savings very limited. It is the intent of the Government to initiate left turns on red formally at all appropriate locations, a determination of which must be made following a review of traffic and pedestrian patterns at each intersection.

Car Care Clinics. Car Care Clinics are intended to demonstrate energy conservation techniques in automobile maintenance and to emphasize the relationship between good maintenance and driving practices and conservation. Motorists are encouraged towards these practices for the primary purpose of reducing total consumption of gasoline.

3.2.5.3 Agriculture

It is planned that seminars in energy management in agriculture be conducted for all of the Islands' farmers who work with mechanical equipment. It is expected that 70% of the farmers who attend will make changes in their farm eqipment and adopt practices that would result in greater energy efficiency on the farm. By using such techniques as proper maintenance of tires and carburetors and replacement of parts worn by friction, the farmer will be able to reduce fuel consumption and operational costs.

3.2.5.4 Industry

The predominance of the Hess Oil Virgin Islands Corporation and Martin-Marietta Alumina, Inc. in the industrial sector and the economy as a whole has been emphasized. A conservation effort of any consequence in the industrial sector demands the close cooperation of these industries with the Government. The tack taken by the Government in formulating and approach for industrial conservation is based on two premises: (1) the two companies are already very energy conscious and have to remain that way in order to be competitive; and (2) they have energy-efficient trade secrets that they need to protect. To accommodate these circumstances, the Virgin Islands Energy Office has decided to proceed with the following steps:

1. Employment of an industrial energy coordinator to establish a liaison with these companies and identify a mutually beneficial program for data collection and new program identification;

2. Participation of industrial employees in seminars and workshops sponsored by the Virgin Islands Energy Office;

3. Collection of regular fuel consumption data from the plants by the industrial coordinator;

4. Relate any changes in monthly fuel consumption levels to changes within the plants, drawing parallels between fuel reductions to documented energy savings measures and increases in fuel consumption to a need for a corrective plan; and

5. Description of benefits of energy conservation measures such as cogeneration, improved maintenance, heat recovery, improved boiler efficiency and add-on equipment.

This approach allows the Virgin Islands Energy Office to contribute significantly to the national energy program and not violate the companies operations or trade secrets.[3]

The savings that can be realized in other industries is primarily through efficiency of energy use in buildings and process improvements identifiable through energy audits conducted on a site-by-site basis.

3.2.5.5 Water Supply

The provision of potable water to the Islands is an energy-intensive activity. The merits and technical feasibility of interconnecting HOVIC and Martin Marietta Alumina with the Water and Power Authority is under investigation. The interconnection would be mutually beneficial as the St. Croix Division of the Department of Public Works has a critical need for surplus water from the two plants.

3.2.5.6 Public Education

Public Education measures are directed towards increasing public awareness as to the need for conservation, the substance of the Government program and the benefits that accrue to the individual as well as the public at large as a result of energy conservation. This is effected through use of the media (television, newspapers and radio), distribution of pamphlets, and the conduct of seminar courses.

3.2.5.7 Government Procurement

The intent of this measure is to institute procurement standards in Government offices that are supportive of energy conservation, specifically: buying less energy-intensive manufactured items, buying items that consume less energy in use for a given functional output, and buying fewer energy-consuming items. To complement this, specifications and guidelines for all energy-intensive equipment is required. Specification should cover (but not be limited to) equipment and supplies such as air-conditioners, cars and trucks, busses, refrigerators and freezers, electrical tooling machines, and high volume consumables (paper, gasoline and oils, detergents). The monitoring and review of current practices provides the basis for establishing the technical criteria to be used as procedural guidance in developing procurement requests. The responsibility for such a program should rest with a single coordinator, who transfers the information to all departments and monitors energy consumption reductions realized through the program's implementation.

3.3 THE ENERGY SUPPLY SYSTEM

The energy supply system in the Virign Islands is described in two following sections. The first addresses the current system and outlines the major issues. The second deals with prospects for the future.

3.3.1 The Current Energy System

The discussion of the current system is divided into considerations of the fossil fuel supply system, the electric sector (including water supply), and renewable resource use.

3.3.1.1 Fossil Fuels

The Virgin Islands has no known domestic reserves of oil, natural gas or coal.[1,2] No detailed geological surveys to determine the existence of any fossil fuel resources have been documented. Based on conditions in nearby Puerto Rico there has been some speculation on the existence of unconventional natural gas deposits in the Virgin Islands. Unconventional gas sources includes gas from Devonian shale, geopressured brines, coal seams, and tight-gas reservoirs. This definition excludes sewage gas, synthetic natural gas and gas from landfills. A search of accessible literature has failed to find any information related to the existance of any of the appropriate geological formations for unconventional gas deposits. It must therefore be assumed that unconventional gas sources do not exist on the Islands.

With no developable fossil resources, the Virgin Islands derives about 99% of its energy from imported oil, most of it from foreign sources. In the early 1960's the Virgin Islands Government sought to attract new industry in order to provide employment. Special incentives were offered to industries willing to locate on the St. Croix where unemployment was greatest and where level land was available for heavy industry. On Sept. 1, 1965, an agreement was made between the Virgin Islands Government and Hess Oil Virgin Islands Corp. (HOVIC) for the construction of a major refinery on St. Croix.[4] Hess was granted an exemption from all Virgin Island taxes for a period of 16 years from approval of the agreement. In addition Hess would receive a rebate (technically a subsidy) of import duties on raw materials and equipment during the same period. This rebate was equal to 75% of income taxes paid the V.I. Government by Hess or its resident stockholders for 16 years from the date of completion of the refinery. No land was provided to Hess by the government, although various permits and rights of way were assured in the agreement. In return, Hess made certain employment agreements. Information on these agreements and other favorable concessions to Hess in ensuing years is presented in Reference 4.

Capacity of the HOVIC refinery is given as about 700,000 barrels per day (b/d) in Ref. 4, as 730,000 b/d in Ref. 1, as the third largest oil refinery in the world with a capacity of approximately 750,000 b/d in Ref. 5, and in Ref. 6 for Jan. 1, 1982, as 640,000 barrels per calendar day or b/cd. (This is the total volume for the year divided by 365. It is the average volume a unit processes each day including downtime used for turnarounds. Capacity based on a stream day represents the volume a unit can process when running at full capacity for short periods.) Reference 6 also lists the following charge capacities: vacuum distillation (140,000 b/cd), catalytic reforming (70,000 b/cd) and catalytic hydro treating (150,000 b/cd). The HOVIC refinery began operation in 1967, and employs about 825 people. It states[2] that all operational data is privileged; therefore, its product slate, yearly production, efficiency, crude type, crude source and costs are not available. Most of the refined products are exported to the U.S. mainland (Ref. 1,5). Therefore, the only advantage derived from having a local refinery, apart from the jobs created, is that fuel is more readily available and transportation problems are eliminated.[5] The distributors of fuel on the islands are ESSO, Shell and Texaco, all of whom purchase products from HOVIC. The Hess refinery is also a major distributor of diesel fuel to various industries, e.g., the Cruzan and Brugal Rum Distilleries, construction companies, the V.I. Water and Power Authority, and Martin Marietta Alumina. HOVIC also supplies fuel to U.S. naval ships on annual fueling contracts and it may be assumed that visiting tankers are also refueled.

Reference 2 provides estimated data on the quantity of refined products for the years 1970-1976. These data are based on imports of crude oil and petroleum products as reported by the Customs Service of the U.S. Treasury Department and are presented in Table 3.3.1.1-1. Similar data from Ref. 7 for 1976-1981 are shown in Table 3.3.1.1-2.

The units of the two tables are different and in some cases conversions can only be approximate. For convenience, conversion factors are listed in Table 3.3.1.1-3. Some statistical data from the Virgin Islands Energy Office list imports of crude oil as 203,665,487 barrels in 1977 and 203,492,590 barrels in 1978.

Gross refinery output of products from Ref. 7 is presented in Table 3.3.1.1-4. From these data and the refining capacity data the refinery utilization factor is 75%, 73%, 69%, 64%, 64% and 55% for the years 1976-1981 respectively. The quantity of refined products exported (from Ref. 7) is given in Table 3.3.1.1-5. From these data and the total refinery product output from Table 3.3.1.1-4, the percentage of production being exported is 84%, 83%, 81%, 84%, 73%, and 70% for the years 1976-1981 respectively. The quantity of energy consumed by HOVIC is estimated[2] as 79.3% of the Islands' total consumption. However, the plant is completely self-sufficient with regard to water and energy.[1]

3.3.1.2 Electric Sector

The generation and distribution of electric power and the production of fresh water through desalination is handled by the Water and Power Authority (WAPA). Created in 1964, WAPA is an autonomous public corporation and an element of the Virgin Islands Government. Although some industries generate their own water and power, most notably the Hess Oil Virgin Islands Co., the Martin-Marietta Alumina plant, and the Frenchman's Reef Hotel, WAPA is the only producer and distributor of electric power and water for the remainder of the domestic, commercial, industrial, and governmental users. WAPA itself accounts for nearly one-third of all non-industrial energy consumption in the Virgin Islands, mostly through the operation of water desalination plants.[1] Water produced by these plants is then sold to the Department of Public Works (DPW) for distribution on the islands. Because fresh water is such a scarce commodity and is so intimately tied in with the production of electric power by WAPA, this section will be divided into a discussion on the current electric power production system and on the current fresh water production system.

Electric Power Production

Two separate electric systems provide power for the Virgin Islands. The physical separation and the depth of the water between St. Thomas and St. Croix make interconnection currently infeasible. An underwater electric power cable from St. Thomas provides power to St. John and a small diesel generator located on St. John provides backup power. The electric system is also totally depedent on imported oil for fuel; fuel oil #6 is used in the steam units and fuel oil #2 is used in the gas turbines and diesels. All the steam units have extraction turbines where steam is diverted for use in the desalination plants, thereby decreasing the overall efficiency of the steam plants.

The diffuse nature of the population and the very hilly terrain lead to high electric distribution costs. This, coupled with the total dependence upon imported oil results in consumer electric energy costs of 21¢/kWh which is 2-3 times the U.S. mainland average.[2]

Table 3.3.1.1-1 U.S. Virgin Islands Imports of Crude Oil and Petroleum Products from 1970-1976

Product	1970	1971	1972	1973	1974	1975	1976
Crude Oil, 10^6 barrels	103.32	130.21	136.92	185.41	180.77	172.69	167.53
Crude Oil, 10^{12} Btu	619.91	781.29	821.50	1,112.46	1,084.63	1,036.15	1,005.18
Distillate Fuel Oil, 10^{12} Btu	7.02	7.60	7.19	7.01	11.71	14.14	-
Jet Fuel, 10^{12} Btu	1.63	1.01	1.11	0.46	0.02	0.19	-
Kerosene, 10^{12} Btu	0.02	0.02	0.03	0.01	-	-	-
LPG, 10^{12} Btu	0.04	0.02	0.02	0.01	0.01	0.01	-

Source Ref. 2.

Table 3.3.1.1-2 U.S. Virgin Islands Imports of Crude Oil and Petroleum Products From 1976 - 1981

Product	10^3 tonnes					
	1976	1977	1978	1979	1980	1981
Crude Oil	27,302	28,261	29,624	26,949	25,500	21,300
Aviation Gasoline	15[a]	5[a]	5[a]	3[a]	2[a]	2[a]
Motor Gasoline	21	30	35	58	17	25[a]
Kerosene	0	0	0	0	2	5[a]
Gas-Diesel Oils	227[a]	50[a]	6	6[a]	6	10[a]
Residual Fuel Oil	0	0	46	150[a]	268[a]	200[a]
LPG	0	0	0	0	1	1[a]
Bitumen/Asphalt	8	4	4	0[a]	0[a]	0[a]
Lubricants	3	3	3	3[a]	4[a]	4[a]

[a]Estimated

Source: Ref. 7.

Table 3.3.1.1-3 Conversion Factors

Product	Weight lb/gal.	Gross Heating Value	
		Btu/lb	Btu/gal
Crude Oil (30° API)	7.3	19,590	143,000
#6 Fuel Oil (Residual)	8.0	18,126	153,120
Diesel	6.8	19,110	129,948
Kerosene	6.5	19,750	128,375
Motor Gasoline	6.1	20,190	123,361
LPG (Butane)	4.9[a]	21,190	108,047
LPG (Propane)	4.2[a]	21,554	91,044

[a]Liquid
1 barrel = 42 U.S. gallons
1 tonne = 2205 lb.

Table 3.3.1.2-1 is a list of the generating units for the St. Thomas and St. Croix systems. The table gives three different ratings for the units; the design gross rating, the design net rating after subtracting auxiliary loads, and the present operating net rating. The unit net rating is more widely used in the industry in order to make valid comparisons among systems having different auxiliary load requirements, such as coal- versus oil-fired units. Furthermore, the net rating reflects the capacity available to meet future customer loads; only future customer loads are forecasted and not auxiliary loads. The table also shows that on St. Thomas, Unit #13 is operating below its maximum design rating which is caused by superheater problems. Unit #10 has boiler control problems and has been inoperable for most of the last five years. Currently there are no plans to upgrade this unit. On St. Croix, Unit #11 is presently undergoing a major overhaul.[3] Units #13 and #7 are not operable at present and will require major repair work to restore their operability. No decision has been made to repair either of these units at this time.[3]

Like all isolated systems, WAPA has a rather large reserve margin. On St. Thomas for fiscal 1980/1981 the peak load (customer load plus line losses) was 39.5 MW while on St. Croix it was 29.0 MW. This amounts to a reserve margin of 180% (using the generator net design ratings) on St. Thomas and 202% on St. Croix. Even with this extremely large reserve margin, the system has reliability problems. Periods of 2-3 day rotating power outages have been experienced throughout the year.[4] The loss of load probability (LOLP), which is the number of days per year the system capacity will be insufficient to meet the daily peak

Table 3.3.1.1-4 HOVIC Refinery Capacity and Product Output for 1976-1981

Product	1976	1977	1978	1979	1980	1981
	10^3 tonne					
Refinery Capacity	36,400	39,100	40,800	41,250	39,750	38,925[a]
Motor Gasoline	3,350[a]	3,859[a]	3,882	3,478	3,125[a]	2,600[a]
Jet Fuel	500[a]	985[a]	1,075[a]	845[a]	915[a]	550[a]
Kerosene	417[a]	860[a]	581	517	550[a]	450[a]
Gas-Diesel Oils	4,670[a]	6,050[a]	6,568	5,806	6,000[a]	4,600[a]
Residual Fuel Oil	18,138[a]	15,572[a]	14,565	14,664	13,500[a]	12,000[a]
LPG	30[a]	30[a]	36[a]	40[a]	40[a]	35[a]
Other Petroleum Products	150[a]	1,339[a]	1,300[a]	1,200[a]	1,150[a]	1,100[a]
Total	27,255	28,695	28,007	26,550	25,280	21,335

[a]Estimated

Source: Ref. 7.

Table 3.3.1.1-5 HOVIC Refinery Exports For 1976-1981

Product	1976	1977	1978	1979	1980	1981
	10^3 tonne					
Aviation Gasoline	15[a]	5[a]	5[a]	3[a]	2[a]	2[a]
Motor Gasoline	3,256	3,752	3,734	3,401	3,038	2,500[a]
Jet Fuel	463	946	1,030	799	667	500[a]
Kerosene	395	794	449	301	423	350
Gas-Diesel Oil	4,212	5,322	5,245	4,948	4,800[a]	3,500[a]
Residual Fuel Oil	14,623[a]	12,850	12,132	12,790	9,600[a]	8,000[a]
Total	22,964	23,669	22,595	22,242	18,530	14,852

[a]Estimated

Source: Ref. 7

load, is 5.29 days/yr. for the present St. Thomas system and 6.96 days/yr. for the present St. Croix system.[3] This is to be compared to the U.S. mainland LOLP planning standard of 0.1 days/yr. Maintenance problems have been the main cause of the lack of system reliability. Table 3.3.1.2-1 shows that many units are derated or totally out of service. It has not been possible to institute a systematic maintenance program for removing major units from service for extended periods for repair and overhaul. The result is that units are often run continuously and removed from service only when absolutely necessary due to failure. WAPA has been repairing units as funds become available. A short term plan is needed that will identify the priority in which these units should be repaired, based on the savings realized from the repair work and improvements in system reliability.[3]

System dispatch is another area where improvements are being worked out. Average heat rates for each unit currently are determined based on monthly (or yearly) electric output and fuel consumption. Since heat rates are known only in a very general way, it is difficult to determine the optimum loading regimen. WAPA officials have estimated that 62% of total operating costs are represented by fuel costs. Another consideration is that the thermal efficiency of steam units is reduced because of the need to extract steam for use in the desalination plants. The needs of the desalination plants need to be taken into consideration when dispatching the steam units.

Table 3.3.1.2-1 Generating Units for St. Thomas and St. Croix Systems

Unit Number	Unit Type[a]	Year Installed	Original Design Ratings (MW) Gross	Original Design Ratings (MW) Net	Present Operating Net Rating (MW)
				St. Thomas	
13	Steam	1974	35.0	35.0	26
11	Steam	1968	18.0	14.0	14
10	Steam	1966	7.5	6.5	0[3]
15	Gas Turb.	1981	20.0	20.0	21
14	Gas Turb.	1971	15.0	15.0	12.5
12	Gas Turb.	1970	15.0	15.0	13
9	Diesel	1960	3.0	3.0	3
7	Diesel[b]	1966	2.0	2.0	1.7
			115.5	110.5	91.2
				St. Croix	
11	Steam	1970	18.0	18.0	18.0
10	Steam	1967	7.5	7.5	7.5
16	Gas Turb.	1981	21.0	21.0	21.0
14	Gas Turb.	1972	15.0	15.0	15.0
13	Gas Turb.	1971	15.0	15.0	0[c]
12	Diesel	1968	4.5	4.5	4.0
7	Diesel	1962	2.2	2.2	0[c]
6	Diesel	1969	4.5	4.5	4.0
			87.7	87.7	69.5

[a]All units are oil-fired.

[b]Installed on St. John as a standby unit, not included in daily unit dispatch.

[c]Inoperable - needs repair work.

Source: Adapted from Refs. 8 and 3.

Table 3.3.1.2-2 shows a list of historical gross peak loads and estimated customer peak loads for the St. Thomas and St. John systems. Customer peak loads were obtained by subtracting calculated auxiliary station loads from the gross peak load. Values of 3 MW and 1.5 MW were used for auxiliary station loads on St. Thomas and St. John, respectively. It is necessary to use past customer peak loads as a basis when making future load forecasts, since the use of gross peak loads would project the auxiliary system loads to grow at the same rate as customer loads. However, auxiliary system loads are a function of type and size of installed generation and not a function of customer load growth. Also, the system load factor is distorted when using gross peak loads. In fiscal year 1980/1981 the system load factors were 65% and 69% on St. Thomas and St. John, respectively. This is higher than the 59-60% load factors common to U.S. mainland utilities. Scheduling maintenance can be difficult because of the relatively little variability in daily system peak loads. Table 3.3.1.2-2 also shows that customer loads on St. Thomas grew an average of 8% per year between 1970 and 1973, leveled off or decreased slightly from 1973 to 1976 and then grew again an average of 5.5% per year from 1976 to 1980. On St. Croix customer peak loads grew an average of 11.6% per year from 1970-1973 before holding steady or decreasing slightly since then.

Several short-term remedies have been advanced in order to increase the reliability of the present system and also decrease overall operating costs through savings on fuel. The first is to identify the priority in which inoperable or derated units should be repaired based on the savings realized from the repair work and improvements in system reliability. EBASCO has recently done a study[3] for WAPA identifying possible repair scenarios and their effect upon system operating cost and reliability. On St. Thomas it was found that by dispatching diesel #9 in the daily schedule, overhauling unit #13 to increase its net rating to 33 MW, improving the availability of Unit #11 to 86%, and converting gas turbine #15 to fuel oil #6 would result in a production cost savings of over $2 million per year and a reduction in LOLP from 5.29 days per

Table 3.3.1.2-2 Historical Gross Peak Loads and Estimated Customer Peak Loads

	St. Thomas/St. John		St. Croix	
Fiscal Year[a]	Gross Peak[b] (MW)	Customer Peak[c] (MW)	Gross Peak[b] (MW)	Customer Peak[c] (MW)
1970	26.0	26.0	22.5	21.0
1971	28.3	28.3	25.8	24.3
1972	30.8	30.8	28.6	27.1
1973	35.2	32.2	30.7	29.2
1974	34.1	31.1	31.5	30.0
1975	33.2	30.2	30.6	29.6
1976	34.7	31.7	32.0	30.5
1977	36.2	33.2	30.6	29.1
1978	39.0	36.0	30.3	28.8
1979	40.6	37.6	31.2	29.7
1980	42.5	39.5	30.5	29.0

[a]The fiscal year starts July 1 of the year shown.

[b]For the years 1970 to 1978, the gross peak loads are taken from a study done by WAPA entitled "Ten Year Load Forecast for Water and Power Authority" prepared by Hatem Abdallah, May 1, 1979. The gross peak loads for 1979 and 1980 are taken from WAPA's Production Analysis Sheets.

[c]Customer peak loads are obtained by subtracting 3 MW and 1.5 MW from the gross peak loads shown for St. Thomas and St. Croix, respectively.

Source: Adapted from Ref. 3

year to 1.52 days per year. The cost, excluding the cost of improving the availability of unit #11, is about $2.5 million meaning these improvements will yield a payback in just over a year. Likewise, on St. Croix, converting gas turbine #16 to fuel oil #6, repairing diesel #7 and dispatching it daily, and repairing gas turbine #13, to be used as a reserve unit would result in a production cost savings of almost $1 million per year and a reduction in LOLP from 6.90 days per year to 1 day per year. Excluding the cost of repairing diesel #7 and gas turbine #13, the improvements would cost about $800,000 and be paid for in the first year's production cost savings.

Second, improved utilization of equipment through better maintenance planning, improved maintenance operations, and increased effectiveness of maintenance personnel through training would help keep the system in peak operating performance and thereby reduce costs and increase reliability.

Third, data on heat rates at various loading levels for each unit should be gathered so that the system can be dispatched optimally, consequently reducing system operating costs.

Transmission and distribution on the Virgin Islands consists of one substation on St. Thomas at Krum Bay and one on St. Croix at North Shore. At Krum Bay there are five 13.2kV and three 4.16kV overhead feeders. A 34.5 kW substation is partially constructed but no decision has been made to complete the substation at this time. Distribution line losses on St. Thomas were nearly 21% in fiscal 1978/1979 and 18% in fiscal 1979/1980. This is substantially greater than the 9-10% distribution losses for utilities on the U.S. mainland particularly in view of the relatively small area that is served. WAPA has conducted a study[5] of the Krum Bay substation and recommended several modifications. Long-term needs also need to be addressed before making any modifications.[3] In particular, information on distribution feeder parameters and loadings are currently unavailable. This information is needed so the adequacy of the system for future needs can be evaluated by calculating voltage drop and feeder losses and the costs and benefits of converting the existing radial system into a primary loop system.

At North Shore there are five 13.2kV and two 24.9kV feeders. Distribution line losses on St. Croix were nearly 19% in fiscal 1978/1979 but only 9.2% in fiscal 1979/1980. No explaination is available for the improvement in the efficiency of the distribution system. A WAPA internal study[6] of this substation indicates specific modifications. The remainder of the distribution system also needs to be addressed along with the impacts future load growth and new unit additions will have on the entire distribution system. As on St. Thomas, data on the distribution feeders should be collected in order to evaluate the adequacy of the system for future needs.

Water Supply

High cost and limited availability of potable water for domestic, industrial, and tourist-related activities are major problems. Since the Islands' catchment area is small and the rainfall seasonal, there are no perennial rivers or lakes to draw fresh water from. Of a yearly rainfall of 40", 35" is lost to evaporation and transpiration by vegetation, 3" becomes runoff or streamflow and 2" moves into the deep subsurface to replenish and recharge underground water reservoirs. Recharge is not possible over large areas because of the rocky terrain. Also, the terrains in St. Thomas and St. John are such that the rainfall quickly drains into the sea without replenishing underground reservoirs. There is a need to evaluate the potential yield of ground water as existing data are out of date. There are underground water reservoirs; however, their storage capacity, particularly in St. Thomas and St. John, is small. Diffusion of sea water into the existing underground reservoirs is a problem in St. Thomas. Subpotable ground water is used in some cases to carry out household chores that do not require potable water. For example, seawater is used for sanitary flushing and firefighting.

Through a network of cisterns in each household for collecting rainwater, many individual homes gather potable water for domestic use. Some water is pumped from existing aquifers and water is also transported in barges from Puerto Rico and distributed by trucks. The bulk of the potable water supply in St. Thomas and St. Croix is produced by desalination plants. Table 3.3.1.2-3 lists the desalination units of WAPA and their design capacity. In the past, the Baldwin-Lima Hamilton and Envirogenics units on St. Thomas have not been very reliable and have been out of service thereby creating water shortages. The desalination plants use steam from the electric power plants to produce potable water. Linking the desalination plants to the electricity generation plants promotes cogeneration and opportunities for the efficient utilization of energy. Unfortunately, it also introduces reliability problems. When the electric generation plants are down for repair or maintenance, water must be trucked to users, since the desalination units and the electric pumps in the water distribution network will not function.

Distribution of water is handled by the Department of Public Works (DPW). On St. Thomas the hilly terrain limits the distribution of water by pipelines and hence some water is distributed to customers by

Table 3.3.1.2-3 Desalination Units of WAPA

Unit	Year Installed	Design Capacity (MGPD)
		St. Thomas
Baldwin-Lima Hamilton	1968	2.50
Envirogenics	1975	2.25
IDE Number 1	1981	1.25
IDE Number 2	1981	1.25
		St. Croix
Stearns-Rogers	1967	1.0
Envirogenics	1975	2.25
IDE Number 1	1981	1.25

Source: Adapted from Ref. 2.

truck. Also, water for St. John is barged from St. Thomas and distributed to residents by truck. The two major towns on St. Croix, Christiansted and Frederiksted, and the mid-island area are served by a common pressurized distribution system. The pipeline distribution system is obsolete and needs substantial upgrading. More than 50% of the potable water that enters the public distribution system cannot be accounted for with much of the water lost because of leaks.[2] Furthermore, a few water storage tanks cannot be filled to capacity because of leaks.

The possibility of supplying St. Thomas with water via an undersea pipeline from Puerto Rico has been considered. A Puerto Rico to Vieques pipeline has been built demonstrating the feasibility of such a project from an engineering and construction standpoint. However, long term export arrangements between Puerto Rico and the Virgin Islands need to be worked out. Finally, since St. Croix has a large amount of flat land, it has been estimated that there is a tremendous potential for the development of an economical ground water program. More study and exploration is needed.

3.3.1.3 Renewable Energy Resources

Although the Virgin Islands are ideally located in the tropical belt where abundant quantities of solar-based renewable forms of energy are available, only very small amounts of energy are currently derived from these resources.

The only commercial solar energy cooling system installed and operating is at the 400-room Frenchman's Reef Hotel in St. Thomas. It is believed to be the largest of its kind in the world. The system incorporates 13,400 sq. ft. of evacuated tube solar collectors that produce a peak output of 2×10^6 Btu/hr. at 230°F for approximately 6 hrs/day to power a 200-ton absorption chiller. The chilled water is circulated through a central system to the restaurants, shops, halls and the lobby of the hotel. The solar system is capable of driving the chiller from 10:00 a.m. to 4:00 p.m. on an average day.

In 1979, the Ministry of Agriculture for the Virgin Islands ordered a wind-power-driven reciprocating pump to pump water from fresh water springs in St. Thomas to storage tanks located at higher elevations. The water was to be used for drinking and agricultural needs in the Island.[2]

The Ministry of Agriculture also reported that a forestry program exists in the Islands for producing charcoal for cooking purposes. The charcoal would be produced from a thorny tree ("Casia") that will be grown and harvested on a regular basis.[2]

Apart from these systems, there is little other use of renewable resource energy in the Virgin Islands.

3.3.2 The Future Energy System

The structure of the future energy supply system in the Virgin Islands will depend on a number of parameters. The following sections describe some of the options that are available. The section is again divided into discussions of the fossil energy system, the electric sector, and renewable resource use.

3.3.2.1 Future Fossil Fuel System Configuration

The Virgin Islands will have a continued reliance on petroleum in the foreseeable future, even as alternative energy sources begin to penetrate the market. In this light, continued efforts must be made to insure a reliable, cost-effective source of petroleum products.

The Hess Oil Virgin Island Company refinery is large enough to provide virtually all of the Island's need for products. The critical issue is competitiveness of the HOVIC operation in relation to mainland U.S. operations and other Caribbean refineries. In order for the refinery to continue as a profitable operation (and thereby continue to meet the needs of the Virgin Islands) it must secure adequate crude oil supplies at competitive prices, must operate at acceptable efficiency and productivity levels, and must compete effectively in the markets for its products.

An alternative fossil fuel for use in large industrial or utility boilers is coal. This fuel is available from the U.S. and potentially from large proved reserves in Columbia. The Columbian reserves are high in quality and well suited for export markets. Coal preparation handling and combustion is a well-developed technology, but the Virgin Islands currently has no infrastructure for coal usage. Reference 1 reports that coal-fired generation of electricity will be difficult for the Water and Power Authority (WAPA) in the Virgin Islands. The delivered price of coal has become volatile and capital investment in equipment by WAPA might be prohibitive. The use of coal-fired power plants might face some disapproval from the tourist industry. Compliance with air pollution emission standards might be difficult to achieve at acceptable costs, and the disposal of ash and sludge would be a particularly demanding problem to solve in view of the limited land area. In spite of the problems associated with coal usage, Martin Marietta Co. on St. Croix has begun construction of a 15 MW coal-fired plant[2]. Some of the bauxite handling facilities will be used for the coal. Martin Marietta, like HOVIC, is self-sufficient in their power and water requirements.

Both References 2 and 3 recommend that future electrical generating capacity in the islands have dual firing capabilities (i.e., oil and coal). Recommendations from Ref. 3 include the installation of a 55-MW generating plant on St. Thomas and a 44-MW plant for St. Croix. The Government of the Virgin Islands and Martin Marietta may be able to combine their power planning so that installations may be beneficial to both. No reference was found on the cost and requirements for developing an infrastructure for coal usage.

The technology for using coal-water slurries in existing oil-fired boilers is rapidly being developed. Such a slurry could be made in the coal-producing country and then shipped to the Virgin Islands where it would be handled and stored with modified oil equipment. If the use of this fuel is found to be feasible, then it would eliminate some of the problems associated with coal. Developments in this technology need to be watched and an assessment made on the potential for its usage.

3.3.2.2 Future Electric Sector Configuration

Because the production of electric power in the Virgin Islands is so closely tied in with production of potable water, future electric sector planning efforts must also address the fresh water needs of the islands. As mentioned previously, short-term electric and water needs can be handled by the present system after modifications are made. These modifications include repairing certain units that are currently out of service, overhauling units in order to increase their output capacity, and improving maintenance operations. However, in order to supply reliable electric power and fresh water for the least cost over the long term, a comprehensive generation planning effort should be initiated. At the present time, WAPA does not have any long-term generation plans for the Virgin Islands. Consequently, the remainder of this section will detail the considerations in performing generation planning studies as well as briefly discussing both the conventional and alternative technologies for electric power generation and fresh water production and how these may apply to the Virgin Islands situation.

Long Range Generation Planning

Because of ever increasing fuel price increases and the long lead times required for constructing new electric power plants, generation planning has become especially important. System planners must also deal with many uncertainties among which are future load growth, load management, cost and availability of fuels, construction time, and costs plus utility rate structures. If careful studies have not been made, the constraints of time may require that costly gas turbine and diesel peaking units be constructed in order to satisfy a projected load demand even though base load capacity may have actually been called for. In a situation like the Virgin Islands where a significant portion of the operation and maintenance costs go for the cost of fuel, this type of short term solution can be very costly.

The heart of any system planning effort is the load forecast. This is an estimate of the total energy that must be generated and the peak demands that must be served reliably during the study period. Many diverse factors can influence load growth. Among them are population growth, economic growth, tourist activity, projected energy-intensive industrial growth, etc. Consequently, officials from WAPA, the Virgin Islands Energy Office, the Office of Policy Planning and Research, and other representatives of the industrial and tourism sectors should meet to discuss the future development of the Virgin Islands and its effect upon the growth in electric energy. Also, several scenarios should be decided upon in order to test the sensitivity of the future system to changes in sectorial growth assumptions. A similar strategy should be used to forecast future fresh water needs.

A load growth study was performed recently for the St. Thomas/St. John system by EBASCO Services.[1] The load forecasting model developed was based upon the past load growth patterns in the Virgin Islands. The GNP of the U.S. and the Virgin Islands population were chosen as the parameters affecting customer peak load demand. The U.S. GNP was chosen because it was felt to be a good indicator of U.S. tourist activity in the Virgin Islands. The model forecasted that the St. Thomas/St. John system would grow at a rate of 3.24% from 1980 to 1990 and then drop to 1.6% from 1990 to 2000. The abrupt change in load growth was due largely to the forecasted drop in population growth. However, this is just one forecast of the expected load growth in the electric sector. More input from other government and private agencies is needed so that a range of possible forecasts can be studied.

It may also be beneficial for WAPA to study the extent to which rate structure changes can reduce system peak demands and thereby effect a change in load forecasts. Current WAPA rates for all customers are not structured to provide price signals that reflect the costs of serving the customer nor to encourage conservation during peak periods of the day. Possible changes to the rate structure include time-of-day (TOD) rates, interruptible rates, and inverted rates. TOD rates may help improve daily load factor and reduce system peak load by providing signals to customers to shift consumption from peak to off-peak periods.[2] Interruptible rates can provide similar benefits since the utility reserves the right to interrupt all or a portion of a customer's load a maximum number of times, with a maximum length of time per interruption, within a given time period.[2] Inverted rates establish lower rates for initial blocks of power to a customer, and higher rates for subsequent blocks which can lower system energy costs by reducing kilowatt-hour consumption and provide rate relief to small customers without eroding aggregate utility revenues.[2]

The second part of any system planning activity is to explore the options available for generating the required electricity. Conventional technologies, such as coal, oil, hydro, and nuclear need to be studied with respect to cost parameters, siting and environmental restrictions, and other socio-economic criteria to decide whether or not they are appropriate to the Virgin Islands. Likewise, alternative technologies such as solar, wind, OTEC, biomass, etc., should be studied to determine the extent each may penetrate the market and what the economic and environmental costs may be. All possible future technologies should also be evaluated as to their ability to be integrated into the potable water production system.

Several technologies for the production of fresh water in the future are available including the present method of distillation using steam. Other technologies include reverse osmosis, and OTEC. Reverse osmosis is the newest commercial desalination process and uses semipermiable membranes through which pure water is forced by extended application of pressure on saline water on the opposite side of the membrane. Membranes are expected to last between three to six years depending upon whether seawater or brackish water is used. The strategy using OTEC will be discussed later in this section.

Future Conventional Technologies

A number of conventional technologies are candidates for new generation units.

Oil - Although the Virgin Islands is at present totally dependent upon oil for all electric power generation, low-speed diesel engines should be considered for peak power generation. Low-speed diesel engines are extremely efficient, burn low-cost residual oil, and low temperature turbines can convert heat from exhaust gases into electricity or steam without burning additional fuel.[2]

Coal - Coal-fired plants can be an extremely attractive, low risk alternative to oil. Conventional coal handling and burner technology are well established and ample coal supplies are available through the U.S. and foreign sources. However, because WAPA is a small utility, coal-fired generation has several drawbacks. Coal prices are volatile and the investment in coal ports, handling facilities, ash removal systems, etc., may be prohibitive. Furthermore, coal would present problems in air and water pollution and solid waste disposal and would require additional training of maintenance personnel.[3] However, steam from the plant could easily be used to desalinate water. Hence, these questions concerning coal use need to be addressed before any committment is made.

Hydro and pumped hydro-storage - Because there are no natural rivers or large waterfalls on the Virgin Islands, hydroelectric power potential is virtually nonexistent. The few potential hydropower sites are old and undeveloped and the potential would vary with seasonal rainfall.[3] The high elevation regions and proximity of the ocean would appear to make St. Thomas an attractive site for pumped hydro-storage facilities. However, the use of salt water poses the potential problem of salt water intrusion into the fresh water system. Furthermore, because the system is already plagued by frequent power outages and has problems meeting peak demand, pumped hydro-storage is not expected to become a significant portion of the future electric system.

Nuclear - Nuclear power reactors pose special problems because of the social and technical issues involved. The current political, regulatory, and social climate is not condusive to the construction of nuclear power plants. Also, the lack of technical personnel on the islands presents a problem.[3] Finally, although several European and Japanese corporations have plans to develop small reactors for market to developing nations, the smallest proposed plant of 200 MWe[3] already exceeds all current and projected electric load demands until after the year 2010.

Future Alternative Technologies

Because of the high cost of electricity on the Virgin Islands and the tropical climate, renewable resources have a good opportunity to provide significant amounts of electric power to the grid. The potential for solar, wind, OTEC, biomass, and urban waste contributing power to the electric sector will be discussed in following sections.

Of all the renewable technologies listed above, only OTEC also produces fresh water as a byproduct of its normal operation and should therefore be examined carefully. A feasibility study done by Westinghouse[4] for the U.S. Maritime Administration analyzed the economics of two OTEC designs for use in the Virgin Islands. Although both strategies were for the production of water only (the power produced was used solely to power the plant equipment), it would not be difficult to enlarge the system and produce both fresh water and electric power. The open cycle OTEC design had a capacity of 15 MGPD and a deployment date of 2005. The hybrid OTEC system would have a capacity of 5 MGPD and a deployment date of 1990. Both systems were projected to be located about 1.1 nautical miles from the St. Croix coast and the fresh water would be pumped to shore via pipeline. The capital cost of the open cycle system would be $200 million (1979 dollars). The considerably lower cost and earlier deployment date of hybrid system would probably be attractive to a private investor considering the attractive selling price of water in the Virgin Islands. On the other hand, Federal government assistance and involvement in constructing the open cycle plant with private enterprise could bring the project to reality. Both projects would also help attract industry and therefore employment opportunities to the Virgin Islands by assuring a good supply of fresh water.

Finally, a program to utilize commercially available cold storage (ice) systems to reduce peak loads on the WAPA grid should be initiated. Storage systems for both residential and commercial applications should be considered. This will help shift electrical demand from peak to off-peak hours. Past studies have shown that payback periods are on the order of 2-5 years.[2]

3.3.2.3 Future Renewable Resource Use

Renewable resources offer a major opportunity for the Virgin Islands to enhance its energy supply system. The possible technologies are described in the following sections in terms of resource base, technological configurations that can be considered, performance of the systems, cost, potential users, oil use reductions, and implementation factors.

SOLAR

Solar energy is one of the promising alternative technologies that can be used in the Virgin Islands.

Resource Base. Solar insolation data for the Virgin Islands, from recording stations located in the Islands, are extremely limited. Also, there are noticeable variations in the data that are available. The level of solar radiation in the Caribbean region is on the order of 2000 kWh/m^2/year.[1] Martin Marietta at St. Croix has conducted some meteorological and solar insolation measurements. Unfortunately, the data were not gathered for a long enough period to determine if they are reproducible. The Martin Marietta study shows that approximately seven hours of direct sunshine above the threshold level of 65-70 watts/ft^2 are available in the islands.[2] A significant micro-meteorological factor that affects solar irradiance is the "spinal" cloud. The cloud develops almost daily between 3 to 6 p.m. and covers the land mass above an elevation of 800 ft with a thick layer of moisture.

One of the immediate needs for the islands is a set of solar data gathering stations appropriately located in the Islands with a central station for gathering, recording, and publishing the solar insolation, temperature, and wind data.

Technologies and Costs. Reference 5 has considered the following solar energy technologies as possible sources of alternate energy generation in the islands:

Solar Thermal Power Tower (electricity)
Photovoltaics (electricity and water pumping)
Solar Pond (electricity and heat)
Solar Hot Water Systems (thermal energy)

The solar thermal power tower technology to generate electricity requires considerable land area, roughly two square miles of reasonably flat land for every 100 MW capacity. Also, the capital cost of a 100 MW solar thermal power tower in 1982 dollars is estimated at $2200/kW.[3] This technology is not expected to be commercially available before the year 1997.

Because of the high production costs, photovoltaics may not be able to compete with conventional forms of electricity generation for the Islands. Without a breakthrough in the manufacture of solar cells, it is unlikely that photovoltaics can serve as an alternative to conventional forms of elctricity generation in the Virgin Islands except in the long term as indicated in Reference 5.

Solar pond technology provides another renewable resource opportunity to generate electricity or provide heat. However, Reference 5 considered and rejected this technology for application in the Virgin Islands since it requires a considerable area of sheltered flat land for the solar pond per MW of electric generating capacity and a sizeable quantity of fresh water to replenish water lost through evaporation. Availability of fresh water in the Virgin Islands is a serious limiting factor. The possibility of combining a solar pond with an OTEC system is discussed later.

Reference 5 estimates that 1.4×10^9 Btu of energy were saved in 1981 by hot water systems that used solar instead of electricity to heat the water for domestic use. Providing domestic hot water represents the largest share (35%) of electricity consumption in the residential sector followed by refrigeration (20%), and cooking (10%). Hence, it seems logical that solar hot water systems should penetrate the most among the renewable energy technologies in the Virgin Islands. This opportunity requires further analysis. As indicated in Fig. 3.3.2.3-1,[4] cash purchase (with a 40% tax credit) of a solar hot water system to provide 50% of the hot water needs in the Virgin Islands yields a return on the investment of 33.6%. It should be pointed out that cash purchases of solar hot water systems might be beyond the capability of many residents. Therefore, if solar hot water systems are to penetrate rapidly, substantial cost reductions and financing mechanisms will be necessary.

New housing in the Virgin Islands seems an attractive candidate for installing solar hot water systems. Unfortunately, the low level of annual housing starts (100/yr) in the Virgin Islands restricts this opportunity.

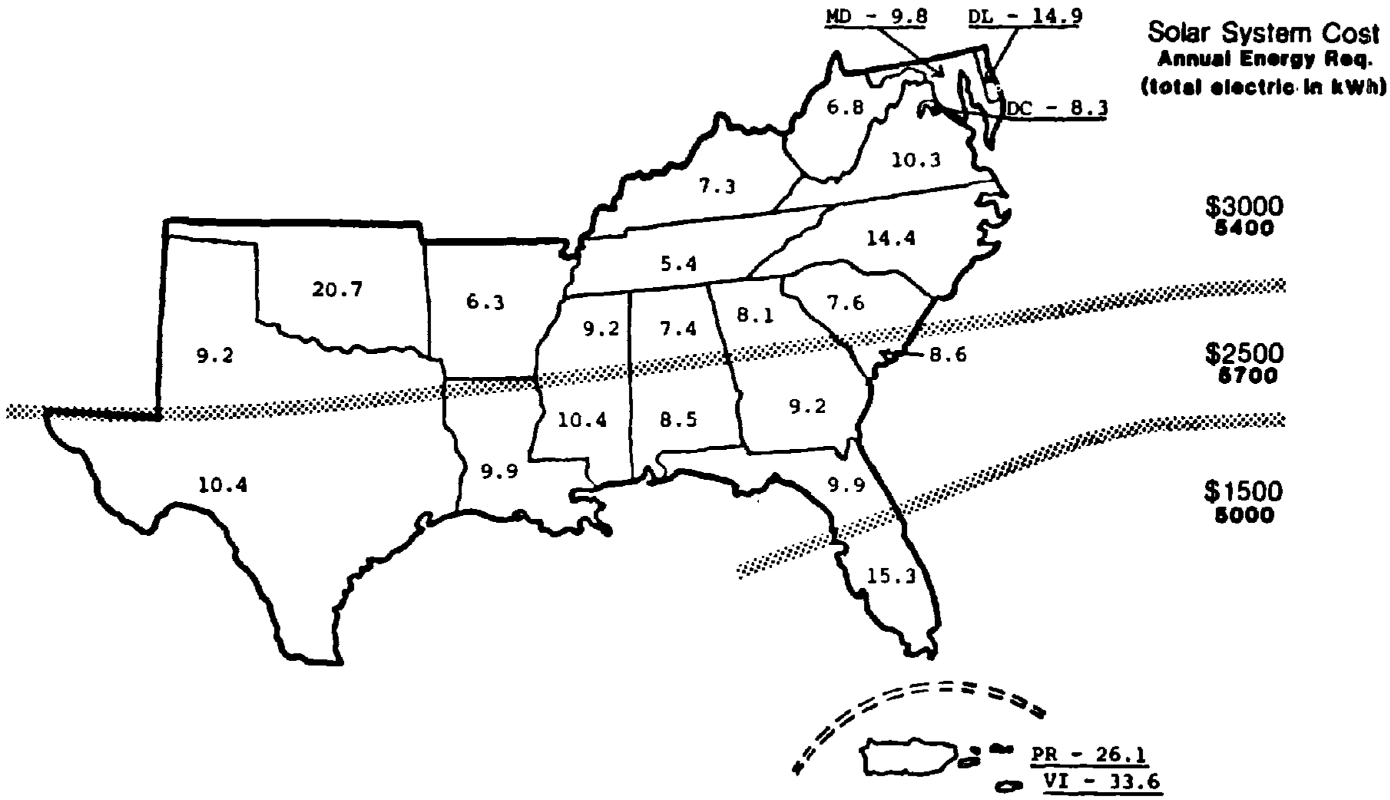
Implementation. The biggest factors influencing the implementation of solar technologies in the Virgin Islands are cost and land area. The cost of current systems, although competitive with the high electricity prices, is still too high to have a significant penetration level. Innovative schemes for financing solar systems are necessary.

The solar technologies requiring extensive land area face a major barrier. The limited flat land available may hinder extensive use of these systems.

WIND

Studies of potential wind use in the Virgin Islands have shown promise not only because wind resources are reasonably good but also because existing electricity costs are very high by U.S. mainland standards. This gives wind systems the opportunity to compete on a favorable basis. This section reviews the major issues facing wind energy applications in the Virgin Islands.

Resource Base. The Virgin Islands are exposed to relatively consistent trade winds out of the northeast. The wind characteristics are affected by the rugged topography of St. Thomas and St. John. St. Croix is the only one of the three islands having a large portion of flat land.[1] St. Thomas has steep slopes leading from the 470 m (1,550 ft) summit of Crown Mountain to the coasts. St. John's topography is similar to St. Thomas, but the highest peak, Bordeaux Mountain (400 m, 1,300 ft) as well as the other hilltops are somewhat lower than those on St. Thomas.



ASSUMPTIONS: Return on Investment = $\frac{\text{First Year Electricity Savings}}{\text{Solar System Cost, Less Tax Credits}}$

Solar System provides 50 percent of hot water requirements

Source: *Assessment of the Potential for Renewable Energy Sources in the Southern United States, Puerto Rico and the Virgin Islands* by Graves and Bonnet, Nov. 1980, p. 30.

Fig. 3.3.2.3-1 Solar Hot Water Return on Investment (%) (Source: Assessment of the Potential for Renewable Energy Sources in the Southern United States, Puerto Rico, and the Virgin Islands by Graves and Bonnet, Nov. 1980, p. 30)

Unfortunately, wind data for the Virgin Islands is sparse and mostly from relatively poor sites for wind turbines. The major source of data for St. Thomas is from the Harry S. Truman Airport, on the southwestern (leeward) coast.[1,2] A few months of data are also available from marine coastal surface weather observations.[2] No source of wind data are available for St. John. The only wind data for St. Croix, other than the sparse marine coastal surface weather observations, are from the Alexander Hamilton Airport on the south coast.

Using the limited data, generally accepted extrapolation methods, and knowledge of topographic features, two groups have characterized the wind resources for the islands.[1,2] The distribution of wind power in power density classes is given in Table 3.3.2.3-1 and is shown graphically on Fig. 3.3.2.3-2. Most of the promising areas are indicated by a class 3 or greater wind power on the annual power map. Only sites at exposed coastal locations, or at higher elevations, are expected to experience class 3 or greater wind power. Such locations include well-exposed sites on the central ridges, and all but the west coasts of the three islands.[1]

Vukovich, et al.,[2] have constructed isotachs (lines of constant wind speed) for the three islands in order to pinpoint areas of high wind energy potential. The results of that analysis included the identification of several potential sites for each of the main islands. The specific criteria used for selecting sites included the degree of windward exposure reasonably free of turbulence; the elevation of the site; the enhancement potential of the terrain; and the proximity of the site to a roadway which was assumed to have a commercial power line running along it. Generally, elevated sites near windward shorelines were chosen over locations further inland or on lee shores. Five sites were identified on both St. Croix and St. John, and six sites were selected for St. Thomas.

Table 3.3.2.3-1 Distribution of Wind Power Classes in the U.S. Virgin Islands

Wind Power Class	Wind Power Density (Watts/M^2)	Wind Speed Corresponding to Upper Limit of Power Density M/S (mph)	Land Area Equal or Exceeding Power Class Class (km^2)	Percentage Land Area Equal or Exceeding Power Class
1	0-100	4.4 (9.8)	344	100.0
2	100-150	5.1 (11.5)	115	33.4
3	150-200	5.6 (12.5)	2.5	7.3
4	200-250	6.0 (13.4)	0	0.0

Source: Ref. 1.

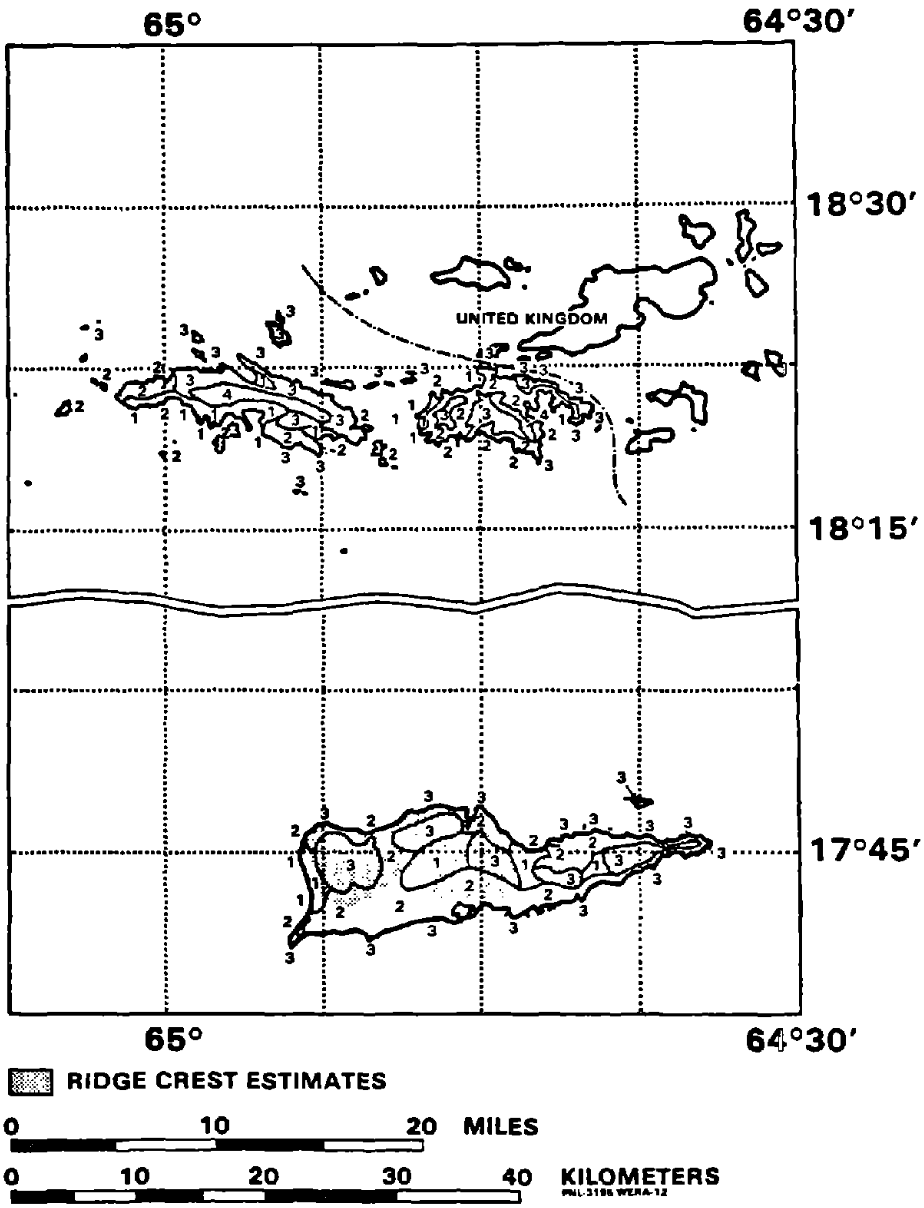


Fig. 3.3.2.3-2 Annual Average Wind Power in the U.S. Virgin Islands

The wind exhibits a seasonal variation on the Virgin Islands. Summer is the season of maximum wind power. Based on the exposed sites, winter has the next highest average wind, with spring being somewhat less. Autumn has significantly less wind power than the other seasons.[1]

The diurnal variations are quite regular on the islands, with the maximum wind speed generally occurring about 1:00 p.m. local time for all seasons. Minimum wind speeds typically occur in the early morning hours. Such predictable variation should be taken into account when analyzing wind power potential to match electrical generation loads.

Technologies. The wind turbines considered for electric utility operation have been primarily of the large variety with capacities greater than 100 kWe.[3-5] Some analyses of small wind turbines (1-25 kWe) have been carried out for residential and commercial applications.[2,6] Another option identified in one study was a system of wind turbines driving reciprocating pumps that raise water from potable water tanks at sea level to water distribution tanks located in nearby hills.[3]

The typical wind turbine for electrical generation has a horizontal axis and has two large blades.[5,7,9] A 200 kWe machine (DOE MOD-OA) already installed and operating in Puerto Rico has a blade diameter of 125 feet. The cut-in speed at which power generation begins is only 6.9 mph measured at a height of 30 feet (approximately 10 meters). The wind speed at which this machine reaches full power (200 kWe) is 18.3 mph. At wind speeds higher than 34.2 mph the wind turbine automatically turns out of the wind to avoid damage. In contrast to the 200 kWe wind turbine, a promising 2,500 kWe design (DOE MOD-2) is being tested in the state of Washington. This machine has a blade diameter of 300 feet and higher cut-in (8.6 mph) and rated (20.1 mph) speeds than MOD-OA (and therefore lower expected capacity factor), but it also is expected to have a capital cost that is significantly less than MOD-OA if both machines reached the mature industry level.[8] The basic tradeoff is capital cost and maintenance cost per unit capacity (also highest for the smaller machines). These issues are yet to be resolved, but the large machines appear to be favored at this time. Since peak loads are less than 50 MWe on each of the two grids on St. Thomas/St. John and St. Croix, the MOD-2 at 2.5 MWe may be too large for the early applications.

An additional possibility for electrical generation is the vertical axis, Darrieus machine. A 500 kWe vertical axis machine was used as the basis for an economic feasibility study for the Virgin Islands.[2] Some advantages of the vertical axis machines over horizontal axis machines are that electrical generating and control components can be located close to the ground and no machine rotation is necessary because of wind direction. Some disadvantages are that vertical axis machines have lower efficiencies, are typically not self-starting, and have blades that are difficult to manufacture.[8]

Small wind machines of 1-25 kWe capacity generally have lower cut-in and rated speeds than the large machines. Therefore, the small machines can attain higher capacity factors than the large machines. The tradeoff is that capital costs and maintenance costs for the small machines can be high.[2]

System Performance. The performance of wind turbines in an electrical system is a difficult problem for analysis.[9,10] The characteristics of the wind turbines, such as forced outage rates, are not yet well-known. Expected capacity factors are a key parameter for economic analysis. One study of wind turbine economics for the Virgin Islands estimated capacity factors of approximately 25-27% for wind turbines in the 1-25 kWe size range and a capacity factor of only 10% for a 500 kWe wind turbine.[2]

Wind turbines may be justified strictly on the basis of their fuel (oil) saving capacity. That is, the cost savings from displaced oil is the only cost savings to compare with the cost of energy from the wind turbine. Considering the very high electricity rates prevalent in the islands (approximately 18-21¢/kWh[2,4]) and the reasonable wind resources, wind power should be competitive in the Virgin Islands before it is competitive in most other areas of the U.S.

An additional consideration for wind system performance is whether the wind turbines improve the system reliability, as measured by an index such as the loss-of-load probability. In recent years some studies have pointed out that wind turbines may also have some capacity value in addition to the fuel saving value.[9,10] Considering the significant diurnal variation in wind speed, and, to a lesser extent, the seasonal variation, the capacity credit attributable to wind may not be a negligible factor at some sites on the Virgin Islands. If this were a significant factor, the economies of the small wind turbines would be helped the most because of their higher expected capacity factors.

Costs. Wind turbine costs for a mature industry are highly uncertain. Costs for a research unit are known but are generally considered substantially higher than for the same unit produced by a mature industry. The associated reduction in unit capital cost with increased production is analyzed by estimating different rates of reduction, or "learning curves." Another large uncertainty for wind turbines is the economy of scale over the size range of interest. Finally, an important additional consideration may be the fixed operation and maintenance (O&M) costs. The fixed O&M costs in 1978$ have been estimated to be approximately 60 $/kWe-yr for a 100 kWe machine, 30 $/kWe-yr for a 500 kWe machine, and approximately 12 $/kWe-yr for a 2,500 kWe machine.[9] Thus, economy of scale in maintenance cost could be a hindrance to implementation of the smaller wind turbines. A study of economic feasibility for the Virgin Islands used capital costs (1981) of $8500/kWe for a 1 kWe machine, $8000/kWe for a 1.5 kWe machine, $6000/kWe for a 2 kWe machine, and $1200/kWe for both a 25 kWe and a 500 kWe machine.[2] (The cost figures for the last two machines appear inconsistent; normally, one would expect the capital costs for the 500 kWe to substantially less per unit capacity than the 25 kWe unit.) Operation and maintenance costs were assumed to be 5% of the total capital cost on an annual basis. The results of this study indicated the commercial and electric utility applications had reasonable economic incentives.

The recent Phase II of the Territorial Energy Assessment estimated capital costs for large machines to be $2500/kWe currently.[4] Costs by the year 2005 were estimated to drop to $700/kWe, which would make wind highly competitive with other energy sources. Whether or not such mature industry costs will occur remains uncertain.

Potential Users. Electrical generation by large wind turbines appears to have the best chance to make a significant contribution to energy supply in the Virgin Islands. However, if electricity prices continue to be very high, some penetration in the commercial and residential markets, (i.e., user-owned small machines) could occur. Four major factors affect the economic feasibility of wind energy use in the Virgin Islands.[2] They are wind turbine generation, system sizing and load match, installed system cost, and the Water and Power Authority interconnection policies (retail and buyback rates, and interconnection regulations).

The Governor's Water and Power Task Force[5] estimated that three wind turbines were suitable for both St. Croix and St. Thomas. The Phase II Territorial Energy Assessment[4] estimated 5-10 MWe of wind capacity for each island by the year 2005 would be possible. These applications assume installation of the large wind turbines for electric utility use. Assuming a 15% capacity factor and an eventual installed capacity of 10 MWe implies an annual wind generation of approximately 13 million kWh.

Potential Oil Use Reduction. The potential displacement of oil depends on the capacity installed and the expected average capacity factor for the wind machines. The capacity factor depends on the wind turbine characteristics and the wind availability at the site. However, assuming 1 barrel of oil produces approximately 450 kWh, the estimate of 10 MWe installed capacity at 15% capacity factor would displace nearly 30,000 barrels per year by the year 2005. A more realistic estimate for the near term would be an installed capacity of 500-1000 kWe and an oil displacement of approximately 1500-3000 barrels per year.

Implementation. Land use could be a potential problem along coastal areas. Other potential concerns include access roads for remote sites, noise, interference with television, radio, and other communications, aesthetics, bird kills, and safety.[4,8] Visual impacts will be present unless remote siting is utilized in the National Park on St. John, neighboring uninhabited islands, or on St. Thomas.[4] Another important barrier to wind power is the financial impact of the large capital cost to be paid before the unit begins generation. This barrier probably affects the residential and commercial potential most. Whatever wind implementation occurs, financing of a large capital intensive program must be possible.

A factor in wind's favor is the relatively short lead time required between the decision to buy and installation (approximately 3 years). Also, wind is available to add to capacity in small increments, thereby allowing the WAPA to minimize problems of over- or under-capacity.

In order for wind to make a significant contribution to the energy supply of the Virgin Islands in the next 20 years, several favorable circumstances for wind must either continue or develop: (1) the price of alternative generation must stay high, (2) the research, development, and commercialization program for wind power in the U.S. must succeed with successful demonstrations (reliability, construction, and cost), (3) land must be available for siting, and (4) financing must be available. Since it is unlikely that all of these factors will be very favorable to wind power at the same time, the most likely implementation plan for the Virgin Islands is one or two turbines of the large variety for electrical utility application and, perhaps, a few of the smaller wind turbines for other applications. If, in fact, the favorable circumstances did occur, then the maximum penetration to be expected would be less than 20% of installed capacity because of reliability considerations.[4,9] The major incentive for wind at this time is the extremely high electricity prices; if wind is competitive anywhere in the U.S., it should have a good chance in the Virgin Islands.

BIOMASS

Biomass resources, including crop residues, urban waste, and specially grown energy crops are candidates for the energy supply system in the Virgin Islands. The potential for biomass use is, however, limited by the lack of land for extensive cultivation of biomass crops. St. Croix is the only island with sufficient land to consider such a system.

Bagasse, wood chips, coconut shells, and municipal waste are the biomass materials considered as the most likely to be used to provide energy.[1] They would all be used in a direct combustion process and would be fired individually or mixed with oil. Bagasse has been considered as a candidate for special energy cropping. It has been estimated that 2000 acres in St. Croix could be used for this purpose with a 2-year cutting cycle.[1] There are problems with the growing of sugar cane that stem from adverse reaction to earlier colonial days. It may be difficult to get sufficient farm labor to harvest sugar cane.

Municipal waste has been suggested as a source of fuel although there are varying opinions as to whether it could be economically justified.[2,3] The quantity of solid waste generated and collected in the Virgin Islands may not be sufficient to support an urban waste energy system. The use of industrial and agricultural waste in combination with urban waste may be more attractive.

The production of liquid fuels (primarily ethanol) from biomass has also been suggested.[1] The problems of land use and acceptability of sugar harvesting are the same as mentioned before.

Reference 1 states that the competition for biomass sources from non-energy uses will require "a drastic shift in market values or government incentives" to result in a major biomass energy program.

OCEAN THERMAL ENERGY CONVERSION

Ocean Thermal Energy Conversion (OTEC) is a concept for utilizing the temperature difference between the warm surface waters of tropical oceans and the deep cold waters in a thermodynamic cycle to produce electrical energy. In the open-cycle concept, the warm waters are flashed at low pressure, expanded through a turbine, and then condensed against cold water; this cycle can produce fresh water as a by-product. In the closed-cycle concept, a working fluid such as ammonia is used in the traditional Rankine cycle. The open cycle was tested by Georges Claude in Cuba in 1930: it produced electricity, but not enough to run the equipment.[1] The closed cycle, using ammonia as the working fluid, was successfully tested off Hawaii in 1979 by the Mini-OTEC project, producing net electrical power for the first time in an OTEC plant and demonstrating the feasibility of the concept.[2]

Resource Base. An ideal OTEC site would meet the following criteria: (a) high thermal differences between the surface and deep water (generally taken to mean a difference of 20°C to a depth of 1000 meters); (b) nearness to the market for the OTEC products; (c) absence of storms; and (d) low-velocity ocean currents.[1] St. Croix is acknowledged to meet the first two conditions off the southeast coast where deep water can be found within a few miles of shore.[1,6,7,8] Moreover, the other two criteria are more important for floating OTEC platforms moored in deep water than for shore-based or tower-mounted OTEC plants that could be built in the Virgin Islands. For example, the suitability of a St. Croix site is evidenced by the fact that two proposals for OTEC plants have been based upon facilities at this location.[9,10,11]

Technologies. A considerable technology base for OTEC exists because of the work done in the past decade in the United States and elsewhere. Although this technology base is not now adequate to justify the construction of the large plants (250 to 400 MW) that are believed to be necessary to be competitive in most markets at today's energy prices,[12] it may well be adequate for small plants in the range of 10 to 40 MW.[13] This is especially true for locations (such as St. Croix) where the plant can be placed on shore or put on a shelf-mounted tower platform.

Historically, major emphasis in OTEC research and development has been placed on heat-exchanger design and on the means for prevention of biofouling and corrosion. Because of the research done to date, several promising heat-exchanger concepts have been developed, and effective biofouling control techniques have been selected for long-term testing at the Seacoast Test Facility in Hawaii. At the present time, the major technical uncertainties are believed to be (in order) in the designs of the riser power cable, the cold-water pipe, and the ocean platform.[14] However, these are mainly problems for floating OTEC platforms moored in deep water, and can be largely avoided by a shore- or shelf-based plant.[15] It is probably significant that most of the pilot-plant proposals were shore or tower installations; although probably less efficient than floating plants, they entail substantially less technical risk.

Although most effort has been directed toward the generation of electrical power, OTEC can also be used for the production of fresh water, which is a critical problem in the Virgin Islands. In the hybrid cycle[9,10] a fraction of the power produced in a closed-cycle system can be used for desalination of ocean water in a reverse-osmosis process. In the closed-cycle process,[11] potable water is produced directly through the flashing (under low pressure) of the warm seawater. The salt-free water vapor is expanded through a large-diameter turbine driving a generator; if the turbine exhaust is condensed against the cold water in a surface condenser (instead of being directly mixed with the cold water), the run-off will be potable. The open-cycle concept has not been proven by experiment, and requires more development than the closed-cycle concept.

<u>System Performance</u>. The efficiency of an OTEC plant is inherently low because of the small difference between the temperatures of the heat source and heat sink. For seawater temperatures of 40°F and 80°F (figures commonly used in OTEC examples), the ideal Carnot cycle efficiency is only 7.4%. For large OTEC plants, overall efficiencies of the order of 2.5% are expected; this compares with efficiencies approaching 40% for large fossil-fueled plants. Efficiencies of shore-based plants would be lower because of the longer pipe runs and (probably) lower temperature differences.[13] Although these low efficiencies do not impact on energy cost (the energy source, of course, is free), they do have a major bearing on capital cost and require that parasitic losses (e.g., the power requirèd to pump large quantities of water) be kept to a minimum.

OTEC has an important advantage over other solar energy systems in that it is essentially uninterruptible. The energy-storage capacity of the oceans is so great that there is no difference between day and night operation, and only a slight variation over the year. Therefore, OTEC is suited for base-load operation, an important consideration in a system with high capital costs and low operating costs.

Maintainability and durability of OTEC systems have not been demonstrated. For the shelf-mounted plants proposed for St. Croix, the main uncertainties would appear to be in the lifetimes of the cold-water pipe and heat exchangers, and in the cleanability of the latter. Major risk elements for heat exchangers have been minimized by some designers through the choice of materials (e.g., titanium) and geometries (e.g., configurations that can be easily cleaned). The cold-water pipe presents a more difficult problem, at least in the large sizes. For a shore-based 10 MW plant, however, fabrication and deployment of cold water pipes with expected lifetimes of 30 years are believed to be within the state of the art.

Reliability of a fully-operational OTEC plant should be as good or better than that for a conventional power plant. Heat exchangers would be modular (for fabrication reasons), permitting serial shutdown for cleaning or other maintenance. The other mechanical equipment is typical of that found in conventional power plants. There is no reason to believe that operations would necessarily be interrupted by adverse weather (e.g., hurricanes). In this regard there is encouragement from the experience of the OTEC-1 ocean-going test platform, which continued operations during a Pacific storm of a magnitude which the designers had expected to require the jettisoning of the cold-water pipe.[4] Moreover, tower platforms are commonly used in the Caribbean for oil exploration.

<u>Costs</u>. OTEC, like all solar-energy concepts, is capital intensive because it requires large amounts of equipment to take advantage of the low-intensity energy sources. Since the energy source is free (and assuming other operating costs are comparable to those for conventional plants), the economics of OTEC is reduced to comparing the savings in fuel costs against the cost of amortizing the construction expense over the lifetime of the plant.

Cost estimates for OTEC plants are site-specific and design-specific, and depend to a large extent upon the size of the plant assumed. A wide range of estimates can be found in the literature.[8,12,13,15,16,17,18] For the purpose of this report, it is sufficient to note that the estimated unit cost of a 40 MW OTEC plant is of the order of \$5000/kW, with unit costs of 4 MW and second-generation 400 MW plants being roughly twice as much and half as much, respectively. This compares to generally quoted figures of \$1000/kW for oil-fired plants and \$2000/kW for coal and nuclear plants.[8] Using a plant amortization charge of 18%/yr and a plant availability factor of 80% (both figures are typical of those found in OTEC studies), the incremental cost of the OTEC plant over the oil-fired plant represents a busbar power cost of about 10¢/kWh. By comparison, current electricity prices in the Virgin Islands are 18-21¢/kWh.[2,4] Thus, if the estimates of OTEC electricity production costs turn out to be valid, it could compete against current systems. OTEC becomes relatively more attractive as interest rates come down and the price of imported petroleum goes up. For all practical purposes, therefore, a commitment to OTEC is a hedge against the prospect that the world price of oil will increase at a rate which exceeds the long-term interest rate. This certainly has been the case during most of the past decade, although it is not true at present and may not be true for the next several years.[18] In any event, predictions of this sort are difficult to make and have proved to be unreliable in the past.

Potential Users. OTEC plants for the Virgin Islands could be designed to produce electrical power, fresh water, or both. The TRW proposal[9,10] for the pilot plant would have produced 10 MW of net power plus 5 million gallons per day of fresh water using a hybrid cycle. The Westinghouse study[11] envisioned an open-cycle plant that would produce 15 million gallons of fresh water per day with no net power to the grid. Additional supplies of both fresh water and electrical power are needed to assure the growth of the Islands.

Potential Oil Use Reduction. OTEC used for generation of base-load power would be a direct substitute for power produced in oil-fired plants. Using the figures presented above, and assuming a heat rate of about 10,000 Btu/kWh for an oil-fired plant, substitution of OTEC for oil would result in a yearly savings (in the cost of purchased oil) of about \$400 per year per installed kilowatt of OTEC capacity. In a like manner, fresh water produced by OTEC could substitute for that produced in oil-fired flash evaporators. Thus, for the 40 MW plant, the savings in avoided oil purchases would pay the incremental cost of the OTEC plant (over that of the oil-fired plant) in ten years. Although this in itself does not provide economic justification for constructing an OTEC plant, it can be an important consideration if it is desired to reduce dependence upon imported energy resources or if it is desired to preserve foreign-exchange currency that would otherwise be spent on petroleum imports.

Implementation. The major barriers to the implementation of an OTEC strategy for the Virgin Islands are those related to technology and financing. Environmental impacts and land-usage issues should not be major problems.

Although the United States OTEC program has been directed at the technology required to build very large plants, there has been recent recognition of the possibility that initial commercialization of OTEC may occur in island markets dependent on imported oil, and where smaller plants in the range of 5 to 40 MW may be more appropriate.[8,20] A 10 MW OTEC plant can be built with existing technology but may not be economically viable except as a hedge against an oil embargo or a rapid escalation in the price of petroleum. A 40 MW OTEC plant is potentially attractive for economic conditions that may exist within this decade but requires some extrapolations of existing technologies. The large plants (250 to 400 MW) that are believed to be competitive under today's conditions require major technological extrapolations that will take years to achieve. The Virgin Islands Energy Office estimates[21] that 10MW of OTEC capacity can be installed in St. Croix by the year 2005. This appears to be conservative if the present economic and technical projections for OTEC are borne out.

Land use is not an issue because little land is required for an OTEC installation. OTEC plants are either located on floating platforms far out to sea, or on shelf-mounted towers as proposed for a few favored locations such as St. Croix. Shore-based plants have been proposed, but these would be little larger than a conventional power plant.

Environmental impacts from OTEC plants are not expected to be a hinderance to their use. There is some mixing of deep water and surface water, but this can be controlled so as not to produce undesirable effects. The most promising anti-biofouling system requires intermittent chlorination, but at levels that do not exceed EPA standards. Some working fluids (e.g., ammonia) impose environmental risks if accidentally released in large quantities, but the risks can be minimized by careful design and operation. Overall, the environmental impacts from OTEC-produced power are probably less harmful than those associated with conventional sources.

COMBINATION SOLAR POND/OTEC ALTERNATIVE

A scoping study has recently been completed for a 5 MWe power plant combining two developmental technologies - solar ponds (SP) and ocean thermal energy conversion (OTEC) - into a hybrid system that offers potential advantages over either pure SP or pure OTEC systems for production of electrical power.[19] Although this study was based upon a Hawaiian location, the concept is applicable to any tropical location with a near-shore source of deep ocean water and an on-shore topography suitable for construction of solar ponds. The Virgin Islands, particularly St. Croix, fits into this category.

In the SP/OTEC combination, a salt-gradient solar pond replaces the warm surface water of the ocean for the collection and storage of solar energy. Solar radiation is absorbed and stored in the water at the lower levels of the pond. The water temperature at the lower levels can be scalding hot while the surface temperature remains very close to the ambient air temperature. Convection is prevented by the presence of a salt gradient that develops naturally in the pond causing the salt concentration to vary from near seawater concentration at the surface to over 20% at the bottom. Because of this salt gradient, the fluid density at the lower levels is higher than that at the surface, thus preventing the hotter fluid at the lower levels of the pond from moving upward. The concept of collecting and storing solar energy by means of salt-gradient solar ponds was derived from studies of various natural lakes that have salt concentration gradients. A salt gradient solar pond normally consists of three zones: a thin convective zone at the surface, a non-convective gradient zone in the middle that provides thermal insulation, and a convective storage zone at the bottom. A typical pond would be about 10 feet deep and require 30 or more acres per megawatt of net power production.

The resource-base requirements for the SP/OTEC combination are more restrictive than for a pure OTEC or a pure solar-pond system. As with OTEC, a tropical location is required. The Hawaiian study was based upon a mean annual solar insolation value of 280 W/m^2, with a lower practical limit of perhaps 200 W/m^2. The source of deep, cold water must be very near the shore. The on-shore topography must be suitable for the construction of the large pond complex. Finally, there must be available an inexpensive source of salt, or at least the means of producing the salt from seawater. The St. Croix site meets the first two requirements. The Virgin Islands Energy Office reports[21] the existence of natural salt ponds in the Islands, but notes that limited land area may preclude the widespread use of this technology.

Although small solar-pond and OTEC plants have been built, the combination has never been tried. In locations where the requirements of both systems are met, the SP/OTEC hybrid is potentially superior to either. Using deep, cold ocean water in combination with a tropically located solar pond results in a substantial increase in the thermal efficiency of a pure solar pond power plant and a significant decrease in the size of the pond required. Conversely, using a solar pond as a source of warm water for an OTEC plant provides a many-fold increase in efficiency over that of a pure OTEC system. In the 5 MW SP/OTEC plant, for example, the Carnot efficiency would be about 21.5% and the net realizable cycle efficiency about 11.7% (compared to 7.4% and 2.5%, respectively, for OTEC alone.). In addition, using a solar pond in conjunction with OTEC eliminates the need for the warm-water and mixed-discharge pipes, and permits a many-fold decrease in the size of the cold-water pipe and heat exchangers. For example, the cold-water pipe - a major risk item in a pure OTEC installation - would have a diameter of only 5 feet in a 5MW SP/OTEC combination (compared to 12.5 feet for a 5 MW pure OTEC plant) and would entail significantly fewer uncertainties in its deployment and expected useful life. The other side of the trade-off is, of course, the solar pond itself, which becomes the major cost item and which has uncertainties of its own.

As the result of theoretical and experimental work done in the United States and Israel, the thermal and hydrodynamic behavior of solar ponds are sufficiently well understood for conceptual design purposes.[23] Major technical unknowns remain in the areas of wave formation and suppression (believed to be site-specific problems requiring site-specific solutions) and in the design and installation of a suitable pond liner to prevent leakage of water. Other areas requiring careful attention are the construction of the ponds themselves and the accumulation of the extensive salt inventory; the costs for these items are high and very site-specific. Moreover, because large solar ponds have not yet been built and tested, the first SP/OTEC plants would probably consist of many ponds of a few acres each rather than a few large ponds. On balance, however, the risks due to uncertainties may be less for the hybrid than for a pure OTEC plant of the same capacity.

The cost of the 5 MW Hawaiian SP/OTEC plant was estimated to be about $5000/kW, which makes it competitive with the 40 MW pure OTEC plant discussed above. This makes it potentially attractive within this decade, and because of its smaller size, much more affordable in terms of initial capital outlays. The primary use would be for the production of electrical power. A major difference from pure OTEC is that the SP/OTEC combination is also suitable for peaking operations; the energy-storage capacity of the ponds -

unlike that of the oceans - is not unlimited. In addition, the hot water from the ponds could also be used in flash evaporators for the desalination of seawater, an application that could be important in water-short locations such as the Virgin Islands. The savings in oil use would be the same as for OTEC: about $400 per year per installed kW of baseload capacity.

A major barrier to implementation could be in finding enough suitable land. The 5 MW plant discussed here would require about 160 acres of contiguous, relatively flat land at a shore location near a source of cold water, with a 40 MW plant requiring about two square miles. An initial step would be to survey potential sites to see if these criteria can be met. Another potential problem could be the environmental effect of leakage of brine through the pond liner into the soil. Factors tending to encourage implementation are the smaller size, the smaller capital investment, and the fact that the technology for the OTEC portion is sufficiently advanced to justify plants of this size.

3.4 THE ENERGY PROGRAM

The energy program for the Virgin Islands focuses on six major areas. These are:

1. Electricity
2. Water Supply
3. Fossil Fuels
4. Renewable Resource Use
5. Energy Conservation, and
6. Energy Planning

In each of these areas three components of the program can be identified:

a. Issues - these are the major factors in each area. The previous discussions have provided the basis for the identification of these issues.

b. Approach - the fundamental premise that can guide the development of specific actions.

c. Specific Actions - based on the premises above, the steps that can be taken to address the issues. These actions include both policy measures (e.g., regulations, incentives, etc.) and projects (studies as well as hardware installations).

The energy program in each of the six areas will be described in terms of the three components.

3.4.1 Electricity

The electricity area includes generation, transmission, and distribution.

Issues. The issues involving electricity in the Virgin Islands may be enumerated as follows:

1. The electricity generation system is exclusively dependent on imported petroleum. All of the units are fired by either #6 or #2 fuel oil.

2. Electricity is the largest component of energy consumption, accounting for 65% of the total in 1980.

3. Electricity costs are very high (18-21¢/kWh, 2-3 times mainland costs) because of the total oil dependence, the relatively small size (and high heat rate) of the generating units making up the system, and the unavailability of detailed performance data that can be used to dispatch the various units economically.

4. The electrical system has reliability problems due to the isolation of both the St. Thomas/St. John and the St. Croix systems, the small variation in daily system peak loads (and hence the difficulty in working out proper unit maintenance schedules) and maintenance and operational procedures in general.

Approach. The approach to be taken with respect to electricity is as follows:

1. The primary immediate emphasis for the electrical system is operation and maintenance of existing equipment including major overhaul and/or replacement of units that are in need of repair. New generating capacity is not a focus of immediate attention.

2. Measures that reduce the peak load on the system (e.g., rate structure changes, thermal storage, etc.) need to be identified, evaluated, and implemented.

3. Alternative renewable resource technologies for the generation of electricity (e.g., wind, OTEC, etc.) need to be tested and carefully evaluated. Only then can commitments be made to full-scale implementation.

Specific Actions. The specific actions in the electric sector are as follows:

1. Implement system repair and overhaul recommendations. A number of recommendations have been advanced on the repair and overhaul of the current electrical system. These need to be prioritized and implemented.

   Schedule: The priorities can be established in a 3-6 month period.

   Resources: The cost of the overhaul program depends on the maintenance to be done.

2. Provide advanced training to WAPA personnel in operation and maintenance techniques. A program to increase the skills of the WAPA personnel in the area of system maintenance and operation needs to be conducted on a periodic basis for both current and new staff. The latest techniques for system repair, maintenance, dispatching, and fuel conservation need to be covered. Personnel can be trained in formal sessions or at on-the-job sessions (perhaps in a mainland utility).

   Schedule: Intensive training should be for 2-4 weeks per year.

   Resources: About 3-5 people per year should receive training. A training budget of $15,000-$20,000 per year is estimated.

3. Perform long range generation planning study. A long term (20-30 year) analysis of the generation requirements needs to be made. This would include the development of a load forecast and the application of appropriate analysis techniques to determine the optimum generator mix.

   Schedule: The planning can be done in a 9-12 month period.

   Resources: Approximately $75,000-$100,000 would be required.

3.4.2 Water Supply

Water supply is among the major energy areas since it is intimately connected to the energy supply situation.

Issues. The major issues in water supply are:

1. Potable water supply is a major problem for the Virgin Islands because of rapid run-off of rainfall, evaporation due to trade winds and high temperatures, and lack of ground water supplies.

2. Water supply is heavily dependent on the energy supply system as there is need for energy-intensive desalination equipment and water transport methods (i.e., barge, tank truck).

3. There are opportunities for developing integrated energy/water supply systems that will provide water with efficient energy use (e.g., cogeneration systems, renewable-resource-driven desalination units, etc.).

Approach. The approach to the water supply issues is that water supply systems will be evaluated as an integrated component of the energy system with advantage to be taken of energy (and oil) savings potential.

Specific Actions. The specific actions to be taken in the water supply area are:

1. Implement a water supply system overhaul. A number of recommendations have been made to upgrade the water supply system. These include repairs to the distribution piping and storage, upgrading of the desalination units, and development of more effective water catchment basins. These need to be prioritized and implemented.

    Schedule: The priorities can be developed in a 3-6 month period.

    Resources: The cost of the upgrading depends on what measures are chosen.

2. Study the groundwater potential in St. Croix. Tests need to be made to determine the amount of groundwater available in St. Croix and the costs of utilizing it.

    Schedule: Approximately 9-15 months.

    Resources: Approximately $75,000-$150,000.

3.4.3 Fossil Fuels

The fossil fuels area covers the use of petroleum products, the Hess refinery, and the potential for alternative fossil fuel use.

Issues. The issues involving fossil fuel use in the Virgin Islands are as follows:

1. The Virgin Islands are almost exclusively dependent on imported oil as an energy source. This applies to the demand sectors as well as the energy-producing sectors (petroleum refining and electricity).

2. The Hess Oil Refinery (third largest in the world) and the Martin-Marietta alumina plant are the largest energy consumers on the islands accounting for about 90% of total consumption. These operations are entirely self-sufficient with respect to energy and water requirements.

3. Diesel fuel represents the largest component of petroleum demand at 28% of total energy consumption. Gasoline is next at 4.4%. The only other products of significance are propane gas, jet fuel, and aviation gas, which together are only 2.7% of consumption. (The balance of consumption is electricity.)

4. Other fossil fuels (coal and gas) are not now in use in the Virgin Islands. Martin Marietta is in the process of installing a 15 MW coal-fired plant. The economics are favorable partially as a result of the company's ability to use a portion of the ore-handling system already in place.

Approach. The approach taken in the fossil fuel area is:

1. The potential for displacing fossil fuels for use in electricity generation (i.e., using renewable resources, coal, etc.) should be thoroughly evaluated.
2. The displacement of gasoline use with biomass-based alcohol should be studied.
3. Energy conservation efforts to enhance the efficiency of electricity and fuel use and thus reduce the demand should be undertaken.

Specific Actions. The specific actions in the fossil fuel use area include:

1. Establish a program of data collection on petroleum product use. The existing data set needs to be supplemented with additional information on the import, production, and distribution of petroleum products on the Islands. The data can be useful to determining where substitutes for petroleum can be employed.

   Schedule: The data collection process can be designed in a 6-9 month period and the first set of information collected 6-9 months later.

   Resources: The design of the process and its first implementation would cost $75,000-$100,000.

2. Determine feasibility of extended coal use. In cooperation with the Martin Marietta project to install a coal-fired unit, a feasibility study should be undertaken to determine if the experience and the facility designs used on the project can be extended to other potential coal users. The economic and technical viability of broadening the use of coal to other facilities in the Virgin Islands needs to be studied.

   Schedule: The study should coincide with the completion of the Martin Marietta unit.

   Resources: The study should cost approximately $75,000-$100,000.

3.4.4 Renewable Resource Use

Renewable resources include solar, wind, biomass, and ocean systems.

Issues. The renewable resources issues in the Virgin Islands are:

1. There is currently very little use of renewable resources except for some individual solar systems and other demonstration units.

2. Land availability is a major concern for the implementation of any renewable resource system requiring extensive commitments of land. Other environmental impacts must also be considered.

3. The tropical climate of the Virgin Islands is especially suitable to a wide range of renewable resource technologies. Appropriate priorities will have to be developed to efficiently allocate available resources (money, staff) to the development of the best systems.

4. Cost is a major factor in the implementation of the renewable resource technologies. The high price of electricity in the Virgin Islands may enhance the penetration of various systems into the market.

5. Renewable resource technologies are being considered for incorporation into the electric generating system (e.g., wind, OTEC, etc.). There is little operating experience with some of the new technologies and system reliability will have to be carefully monitored.

Approach. The approach for dealing with renewable resource technologies is:

1. The full range of renewable resource systems will be investigated and considered for implementation.

2. All of the renewable resource technologies to be implemented are likely to need some government backing to carry them to full implementation.

Specific Actions. The specific actions to be taken in the renewable resource area are:

1. Expand the evaluation of the renewable resource base. The data available on the extent of renewable resources needs to be expanded. Field data collection needs to be done for solar insolation and wind potential especially. The data presented here are limited and need to be reinforced. An integrated program plan outlining the information requirements needs to be prepared and implemented.

   Schedule: Data collection for most renewables needs to be assembled over an annual cycle and preferably should be collected continuously.

   Resources: The cost of the program will depend on the extent of the data gathering effort decided upon.

2. Establish a renewable resource technology data base. A complete set of current information on various renewable resource technologies needs to be assembled. The data should include technology configurations available, performance, and costs. The information can be in the form of a report library or a computerized data retrieval system. The data should be made available to energy planners, researchers, private industry and the general public as a means of increasing the awareness of renewable technology potential.

   Schedule: The first set of information should be compiled for use in a 6-9 month period.

   Resources: A budget of approximately $25,000 would be necessary.

3. Conduct a study on the integration of renewable resource technologies into the WAPA system. An integrated study to determine the role that renewable resource electricity systems can play needs to be carried out. The perspective needs to be that of the electric system planner and should consider issues such as capital and operating costs, effects on system reliability, rate structures for renewable technologies, etc.

   Schedule: The study can be completed in approximately 9-12 months.

   Resources: The study cost is estimated at $75,000 to $100,000.

4. Implement pilot scale demonstrations. The most attractive renewable technologies need to have field demonstrations to gain experience on their operation. An integrated program plan should be prepared that outlines which technologies should be given priority. The plan should then be implemented as sufficient resources are available.

   Schedule: The plan can be prepared in a 6-9 month period.

   Resources: The costs depend on the demonstrations to be carried out.

5. Evaluate institutional structures influencing renewable resources. The institutional issues affecting the use of renewable resources need to be evaluated. Energy pricing,

tax incentives, permit requirements, financing opportunities, and other items need to be addressed. Appropriate policy measures to deal with potential barriers to renewable resource use need to be identified and evaluated.

Schedule: The review can be done in approximately 9-12 months.

Resources: The costs are estimated at $50,000-$75,000.

3.4.5 Energy Conservation

The energy conservation areas cover efforts to improve the efficiency of energy use by the various end-use demand sectors.

Issues. The energy conservation issues are:

1. The major areas where energy conservation efforts can be expected to have an impact are in electricity consumption and personal transportation.

2. In the residential sector, the largest electricity uses are water heating (35%) and refrigeration (20%). Both are amenable to significant efficiency improvements.

3. Commercial facilities (offices, hotels, hospitals) use about one-third of the electricity on the Islands; air-conditioning is the largest use. These facilities are also amenable to significant efficiency improvements.

4. Transportation energy consumption is most affected by gasoline prices, which are generally higher in the Virgin Islands than on the mainland.

5. Energy conservation efforts in the Hess refinery and the Martin-Marrietta alumina plant are implemented by the companies themselves.

Approach. The approach taken in energy conservation is as follows:

1. For the residential and commercial sectors a series of programs is implemented to encourage more efficient energy use (e.g., thermal efficiency building codes, roof insulation, solar water heating, etc.).

2. For the transportation sector, a series of measures is employed to reduce the number of vehicle-miles-traveled (e.g., carpooling/vanpooling) and to increase the efficiency of traffic flow (e.g., left turn on red).

3. The industrial sector improvements as carried out by Hess and Martin-Marrietta are monitored by VIEO for their resultant oil savings.

Specific Actions. The specific actions in energy conservation include:

1. Revise the Island's energy conservation plan. The energy conservation program needs constant review and revision as appropriate. A methodology needs to be established to monitor the effectiveness of the various measures. New measures need to be identified and evaluated.

   Schedule: The energy conservation program should be reviewed and updated approximately every two years.

   Resources: The review will cost approximately $75,000-$100,000 each time it is done.

2. Implement the conservation measures. A variety of conservation measures have been

identifed for the Virgin Islands. These need to be implemented and monitored for effectiveness.

3.4.6 Energy Planning

This area covers overall energy planning in general and electric utility planning in specific.

Issues. The issues in energy planning are:

1. There is no comprehensive integrated energy/economy analysis for the Virgin Islands.

2. The data and the analytical tools are not complete for the conduct of such an analysis.

3. Electric system expansion planning will be needed once the current system is rehabilitated. A complete expansion planning program (including load forecasts, reliability analysis, cost comparisons, etc.) needs to be conducted.

Approach. The approach toward energy planning is a recognition that there is a need for this type of integrated effort in order to make more informed energy decisions. The necessary resources (funds, effort, time) will have to be made available to implement such a program. It is also recognized that the planning activity is an ongoing iterative process that must be updated periodically.

Specific Actions. The specific energy planning activities are:

1. Develop an Energy Planning System. An energy planning system suitable for use in the Virgin Islands needs to be developed. The system should include a data base and a set of analytical tools to conduct appropriate analyses. The data base needs to be designed to suit VIEO needs. Data on energy consumption by sector needs to be compiled on a regular basis. Additional computer hardware and/or software may need to be added to existing equipment.

   Energy planning tools (e.g., computer models) need to be developed especially to suit the Virgin Islands situation. Procedures used by many states in the U.S. mainland can be modified appropriately.

   Schedule: The data base can be compiled in approximately 1-1 1/2 years. The analytical tools can be designed and implemented concurrently.

   Resources: Cost of the activity is in the range of $150,000-$250,000. Computer equipment would be extra.

3. Conduct Updated Energy Planning Effort. The next iteration to improve upon this work should be initiated. This should be part of an on-going effort to revise and update the energy program periodically.

   Schedule: The energy analysis should be carried out at least every 2-3 years.

   Resources: With new data collected periodically, the update should cost $50,000-75,000 each time it is done.

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