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NATIONAL SCIENCE AND TECHNOLOGY POLICY ISSUES

1979

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PART I

A COMPENDIUM OF PAPERS

COMMITTEE ON SCIENCE AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES
NINETY-SIXTH CONGRESS
FIRST SESSION

Serial H

APRIL 1979

Printed for the use of the Committee on Science and Technology

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LETTER OF TRANSMITTAL

COMMITTEE ON SCIENCE AND TECHNOLOGY,
HOUSE OF REPRESENTATIVES,
April 5, 1979.

To the Members of the Committee on Science and Technology:

As the Committee's work for the 95th Congress was being concluded and preparations for the challenges of the 96th Congress begin, I believe it is useful to review the science and technology related issues which face the United States and which are within the purview of our Committee.

To review those questions the Committee originally planned a series of hearings in September of last year. When we were forced to cancel those hearings Chairman Teague asked the witnesses we had invited nevertheless to submit their prepared statements. In addition, Mr. Teague asked a small number of other distinguished American scientists, educators, and industrialists to give us the benefit of their thinking concerning these questions.

Based on the Committee's earlier legislative work on the organizational structure for science and technology policy and our concern about current and future national policy issues affected by developments in science and technology, the Committee decided to focus on three main questions:

1. The organization and operations of the Office of Science and Technology Policy established by Public Law 94–82 for the purpose of providing science and technology policy support in the Executive Office of the President. Since that Act had its origin in this Committee, oversight of the OSTP is the responsibility of the Committee under the Rules of the House.

2. The relationships and interactions between science, technology and the economy including the role of industrial research and development, university performed research, and their relationship to the Federal Government with specific emphasis on the question of technological innovation.

3. Any other important issues of public concern which have strong scientific and technological overtones and with which the Congress may have to deal in the years ahead.

All members of the Science and Technology Committee share with our former chairman and colleague, Mr. Teague, an interest in these matters, especially since the work done on the Science Policy Act over the period 1973–1976 had been done entirely in the full committee under his chairmanship.

The result is the following compendium of papers on "National Science Policy Issues." Each contributor has focused on questions which he or she felt especially competent to discuss. In addition the

staff of the Committee has developed a brief overview of the issues discussed in the papers. We are indebted to the 22 authors for giving us their time and wisdom on these significant questions. (Part I, Serial H)

The compendium also includes, in a separate volume, a comprehensive review of the "Implementation of the National Science and Technology Policy, Organization and Priorities Act of 1976". This status report on the Act after two years shows that, while progress has been made to implement the intent of the Congress, much remains to be done. We are fortunate to have this thorough analysis by Mrs. Dorothy Bates of the Congressional Research Service. (Part II, Serial I)

Sincerely yours,

DON FUQUA, *Chairman.*

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LETTER OF CHARLES A. LINDBERGH

The following letter, not previously made public, was written to former Representative Emilio Q. Daddario when he was chairman of the Subcommittee on Science, Research and Development. The subcommittee was then completing Congress' first comprehensive survey into "science policy" as a discrete government interest—a study resulting in the subcommittee's report "Toward a Science Policy for the United States," released in October 1970.

Mr. Lindbergh's observations in this area represent a distinct and fundamental point of view. Their inclusion in this compendium is with the permission of Mr. Daddario who subsequently served as the first Director of the Office of Technology Assessment as well as president and board chairman of the American Association for the Advancement of Science.

We are indebted to Mr. Daddario for making this thoughtful letter available to the Committee and his permission to reprint it as part of this compendium.

DON FUQUA, *Chairman.*

SWITZERLAND, *July 1, 1970.*

HON. EMILIO Q. DADDARIO,
Chairman, Subcommittee on Science, Research and Development,
Rayburn House Office Building, Washington, D.C.

DEAR CONGRESSMAN DADDARIO: I have been thinking a great deal about our correspondence, and about the breakfast table discussion at your home in Washington last month. I become constantly more impressed with the wisdom of your new approach to scientific research and development through consideration of its effect on the future welfare of mankind.

In the success of the ideas you advance here may lie, at least symbolically, the answer to whether our human species will continue to progress (even to exist) far into the future—whether we are the trunk or only an overspecialized branch of evolutionary life.

The critically important fact that man is beginning, vaguely, to realize in this 20th-century A.D. is that the impact of the human mind on life's evolution has been negative, and that major changes in his thought and action are essential. We see our surface-of-the-earth environment breaking down at the same time our genetic defects are increasing—both rapidly.

Our science and technology are at once responsible for the rapidity of breakdown and our realization that a breakdown is taking place. Speaking fundamentally, the human intellect is becoming aware of the vulnerabilities that accompany its power, that a crisis exists, and that to avoid self destruction it must exercise control over its accumulating knowledge.

In this new sense of humility impacting on intellectual arrogance, I find cause for hope. It is practically exemplified in the attempt you

and your committee are making to estimate the effect of research and development projects on human welfare, and to relate your findings to the support these projects are given.

What you are trying to do, as I see it, and what man has not yet accomplished, is to relate intellectual action to human progress and evolution in the basic sense. Here, I think, it is necessary to bear in mind that life and awareness were developed by instinctive evolution working over aeons, that the human mind impacted on this instinctive or "natural" evolution only a short time ago, and that the titanic problems we now face have been caused by a still much shorter period of intellectual domination. (I am tempted to say intellectual tyranny.)

Has our human intellect the wisdom to replace instinct or—since I think replacement is neither possible nor desirable—to work with it in basic evolutionary progress? We have no acceptable alternative to making the attempt. Ways must be found, through approaches such as you are planning, to give intellectual support to the fantastically complicated requirements for basic progress—requirements that are here obvious, and there so infinitely subtle that no mortal will ever be able to fully recognize and control them.

It seems to me essential for us to accept the fact that intellectual support of basic progress will necessitate reconsideration of long cherished ideals, laws, and customs. In guiding such reconsideration, we can lay down certain principles, one of them being that man must place more value on the human lifestream than on himself as an individual—realizing that he is only a temporary manisfestation of that lifestream, that his salvation and immortality lie in it rather than in himself. Possibly this will involve an intellectual religion rooting into intuitive religions of the past. I do not think it will involve sacrifice when its full significance is understood.

Since all projects must relate to our environment, I believe your studies will quickly bring out the primary and pressing needs of protecting that environment both for our lifestream and for existing individuals. I do not see how adequate protection can be achieved other than by government supervision of natural resources, based on the proposition that each generation is their custodian for generations that will follow and that no one has a right to despoil or waste mankind's aeon-formed inheritance.

Such supervision will not be a curtailment of freedom but an emphasis of it, for we have reached a time when a framework of regulation is unavoidable if we are to maintain an environment in which the freedoms we have known are meaningful or can continue even to exist.

In hindsight, realizing the damage that has been done through our science and technology, I do not see how it could have been prevented except through laws, regulations, and accompanying education. It seems to me the same situation will apply to most future research and development projects. The study of probable effects may well indicate that support should be increased for one project and reduced or eliminated for another. I should think that major savings in talent and money could be made in this way. But I believe that sufficiently effective results can be achieved only by paralleling research and development programs with the laws, regulations, and education needed to turn the final results of these programs to the basic benefit of man.

Here we return to the ultimate question of whether the human intellect has enough wisdom to regulate its own creations, to use its science and technology for real rather than apparent progress. If it has, our future seems unlimited, with man's present day awareness only an indication of what an immortal human lifestream may achieve. If it has not, then we may be close in time to our own extermination.

Let me say again that I believe you and your committee's approach to the problems involved gives cause for encouragement.

Sincerely,

CHARLES A. LINDBERGH.

OVERVIEW OF THE ISSUES DISCUSSED IN THE COMPENDIUM PAPERS

A variety of subjects are discussed in the 27 contributed papers which make up this compendium and which were submitted to the Committee in response to an invitation to comment in 3 categories: (1) The operation of the OSTP, (2) The relationship between science, technology, and the economy, and (3) Any other important issue in the field of science and technology policy.

Given this very broad invitation, however, there is a notable degree of concentration and commonality in the subjects which the contributors chose to discuss. By far the greatest amount of discussion is in response to the second question, the issue of science, technology and economy, and the associated issue of university research. The discussion of the OSTP is limited to the comparatively small number of contributors who felt sufficiently informed to comment on the subject, and the invitation to discuss "other important issues" produced only a modest number of ideas and suggestions.

The following is a brief overview of the more prominent, common themes discussed in the compendium papers.

Office of Science and Technology Policy

Although each of the contributors was asked to comment on how the Science Policy Act is being implemented and the role of the OSTP, only a few did so. The others feel that their knowledge of OSTP's functions and operations is not sufficient to permit them to have an informed opinion.

Among those who responded is the OSTP Director, Dr. Frank Press, who presents an optimistic picture of OSTP's operation and how the Act is being implemented. But, notably, the small number of contributors from outside Government who address this question express various degrees of concern about how certain provisions of the Act are being carried out.

The 1977 reorganization of the Executive Office of the President affected the OSTP in several ways. Most notably, some of the organizational units established by the Act, such as the Federal Coordinating Council for Science and Technology and the advisory panel on intergovernmental science and technology were abolished, and the responsibility for several reports required by the Act, such as the Annual Report on Science and Technology and the Five-Year Outlook, were transferred elsewhere.

Commenting on these changes in OSTP's statutory mandate Press observes:

> I do not believe that these changes have diminished the effectiveness of the OSTP or frustrated the achievement of the intent of Public Law 94–282. Indeed, the resources that are now being brought to bear on some of these tasks are greatly expanded beyond those that OSTP could muster. (p. 16)

The Federal Coordinating Council for Science and Technology, abolished in the reorganization has been reestablished by Executive Order and its functions reviewed and realigned by the OSTP. As a result, the number of committees has been greatly reduced and many functions shifted to individual departments and agencies. For example, Dr. Press notes, while the review of U.S. space policy was done by a Policy Review Committee chaired by the OSTP Director, the implementation of the Earthquake Hazards Reduction program established by Public Law 95–124 will be transferred to the new Federal Emergency Management Agency (p. 11).

The emphasis in the Office has been on the day-to-day questions of science and technology policy formulation, and here, Dr. Press notes:

> Indeed, we are an integral part of the White House team and find ourselves at the heart of the Administration's decision process on scientific and technological issues (p. 3).

In contrast, the outside observers of the OSTP in this compendium feel that the Office has neglected some important aspects of the Act. Former Congressman Emilio Q. Daddario observes: "I believe the experience of your Committee, as well as those of the Senate Commerce Committee, suggest that much of the Science Policy Act is being ignored, farmed out to other agencies, or given only casual treatment" (p. 46).

Speaking specifically about policy making for technology, and comparing it with economic policy making, Branscomb observes:

> In the Executive Branch, economic policy seems to be made in every agency; technology policy is made in virtually none. The intersection between economic and technology policy is thus very superficially addressed (p. 123).

Commenting in more general terms on the nation's approach to policy making for science and technology, Ramo makes the following comparison:

> * * * we can be likened to a bunch of carpenters, sawing and hammering away, often getting fingers in the saws, sometimes hitting each other's heads as they bring their hammers back, and hitting their own thumbs as the hammers come down. They don't quite know what they are trying to build, sense an unsatisfactory situation, and meanwhile blame the saws and hammers (p. 128).

Some think that there is an imbalance in the kind of issues on which OSTP is investing its time. After noting the involvement in such questions as industrial innovation, East-West technology transfer, and the Federal R&D budget, Basiuk, an independent science policy consultant, observes:

> These issues and initiatives are important and deserve the attention of the Science Advisor to the President and his staff. They also indicate that some sense of direction for policy does exist in OSTP. But there are many other problems and issues handled by OSTP which are distinctly secondary and of relatively small importance. A number of them, apparently, were undertaken at the request of other departments or agencies (p. 58).

This imbalance is felt to be especially notable in the case of OSTP's lagging involvement in broader, longer-range policy planning questions and the desired debate on them between the Executive and Legislative branches. Daddario states: "There was an intent to create a continuing dialogue between the branches on the matter of policy.

* * * That OSTP has not made full use of the authority given to it under the basic legislation is a circumstance I find disturbing" (pp. 45–46). Similarly Branscomb notes:

> Since the Executive Branch has not yet implemented those features of the Act designed to make explicit the long range science policy of the Administration, it is appropriate indeed that the Congress should stimulate public discussion of these issues in order to lay the basis for the consensus on which positive action must rest. (p. 121)

Basiuk finds that "The Act emphasized the development of a coherent approach, comprehensiveness, and a sense of direction in U.S. science and technology policy" (p. 52) and suggests that the OSTP is "tailoring it's intellectual horizon to the constraints of its own ability . . ." to mobilize the necessary resources (p. 57).

Innovation and the Funding of Research and Development

It has long been known that an important factor in achieving a healthy level of industrial innovation has been an adequate level of investment in research and development. This is noted, for example, by Low who states:

> I studied the relationship between the rate of spending on research and development, and the rate of growth in productivity. The results showed a direct correlation between the two, with the decline in productivity lagging the decrease in R&D spending rate by about five years. There is no doubt that there exists a direct tie between innovation and productivity, and, hence, a direct relationship between innovation and economic growth. (p. 81)

Atkinson, specifically addressing the role of basic research, refers to the scholarly studies of this factor:

> Edward Denison, in his important studies of the causes of economic growth and productivity gains in the United States over the past four decades, finds that the factor, "advances in knowledge," has been the "biggest single source" of growth. (p. 24)
>
> Mansfield has examined 17 specific innovations and estimated their returns to society as a whole and their returns to the industries and firms involved. The median societal rate of return was about 56 percent. The median rate of return to the innovating firms involved (or the private rate of return before taxes) was about 25 percent. (p. 25)

Both of the senior government science policy executives responsible for basic research, Press and Atkinson, note that the private sector has reduced its investment in research. Press states: "There is evidence of decreasing private investment in the research that could lead to entirely new products and processes" (p. 8). Atkinson provides one explanation of why this reduction in research spending has come about:

> Any investment in R&D, of course, involves a large element of risk. But the risk increases as one approaches the basic research end of the spectrum. For the individual firm or industry, the payoffs may not be realized for 10 to 15 years. (p. 26)
>
> Another reason why economists believe that the private marketplace is likely to produce an underinvestment in research from society's viewpoint is that the private investor, looking at alterna-

> tive uses of capital, must be concerned with the rate of return to the particular individual or firm. R&D may produce benefits to an individual investor or firm, but much of the benefits frequently accrues to other firms and industries or to society as a whole. (p. 26)

But a number of senior industrial executives who contributed papers view the question of investment in research in a different light. They suggest that the new ideas are plentiful and that other factors account for the reduced growth in innovation and productivity. Ramo observes:

> The important drag on innovative effort in U.S. industry is certainly not a lack of creative, inventive talent, but rather the incentive to provide funds to back it, which condition goes with the other present characteristics of the U.S. economy: inflation, high taxes, high costs in dealing with government regulatory requirements, high consumption to investment ratios, and high ratio of government to private sector spending. (pp. 129–130)

The emphasis on research and development funding tends to overlook the other steps in the innovation process, Bucy notes:

> A focus only on increased R&D is not sufficient to advance American technology, as R&D is only one phase of the technology process. Incentives must be provided for downstream costs in engineering and manufacturing investment. It is only these latter investments that produce products and services, produce jobs, and increase trade. (p. 185)

This theme is also stressed by Bueche, who emphasizes that research and development is only a small part of the total investment needed to bring about innovation:

> Now, you and I know that all the R&D in the world is of little value by itself. In other words, to complete the innovation process—to bring about technological change and the resulting new products, increased productivity, more jobs, and better living standards—we usually have to invest still larger sums in new plants, modernized machines, market development, and so on. (pp. 159–160)

The solution, these contributors feel, lies not in new funding for research and development, but rather in providing stronger incentives for the private sector to engage in all the steps leading to successful innovation, a point made by Ramo:

> In industrial technological innovation, the government can help most, not by funding new efforts, but by improving the economy, as already stated, so the private sector will have the financial means and incentives to perform more R&D of its own choice. (p. 137)
>
> Given the state of the economy, no government program to stimulate more innovative effort and R&D in private industry could be nearly so effective as, for instance, a successful government program to lower inflation or one to cause more discretionary cash flow to be available to technological corporations by a lowering of taxes. If the government could create these changes, the seeds of beneficial science and technology advance would quickly blossom into copious crops. (p. 130)

Furthermore, if more research is needed, it should be done in a manner which assures that communications between researchers and users works effectively. Goldman notes:

> There are several steps that deserve consideration. One of these is to accept as a national responsibility the expansion of the basic research capability of industry. For industry to be able to relate to the large world of scientific enterprise that exists within the walls of academia it must talk the same language. This means that it must engage to at least some measure in basic research at the frontiers of relevant science. The pressures of the marketplace have kept industry's commitment to basic research to a bare minimum and limited to but a few of the giants in technology-sensitive industry.
>
> It must become a national goal to strengthen basic research in industry just as we have been committed in the last few years to strengthening it in universities. (pp. 110–111)

Innovation and the Regulatory Environment

One area where the innovation process is believed to have run into growing barriers is the wide variety of government regulations. An example of such growth of regulations is given by Bueche:

> Some members of the American pharmaceutical industry estimate that post-1962 regulation has doubled the cost of new drugs and halved the rate of introduction. Whatever the exact numbers, we simply don't know whether this increased regulation has cost more pain and lives than it has saved. (p. 161)

Examples from other fields could be cited, and their effects are summed up by Press who states:

> Industrial research managers tell us that they are having to put a larger share of their income into so-called "defensive" measures to meet new environmental and consumer safety standards. (p. 8)

A further aspect of this new regulatory environment is its impact on the smaller companies, many of which are especially affected, as Weidenbaum notes:

> A related and generally overlooked aspect of the impact of government regulations is that they tend to hit the smaller companies disproportionately hard. This is true in every case that I have had the opportunity to examine—recordkeeping, job safety, labor relations, environmental controls, etc. (p. 117)

The longer term general effect, writes Weidenbaum, may not be entirely evident today:

> One important but hidden cost of government regulation is a reduced rate of introduction of new products and of improved production processes. The longer it takes for an innovation to be approved by a government agency—or the more costly the approval procedures—the less likely that the new product or process will be introduced. (p. 115)

The regulatory system affects innovation both directly and through the environment of uncertainty it creates:

> By creating uncertainty about the future of regulations governing the introduction of new processes and products, the governmental decision making process can have other adverse effects on innovation. (p. 116)

Summing up the effect of regulation on innovation, Weidenbaum states:

> The key price that this nation may be paying for overregulation is the weakening of the riskbearing and entrepreneurial characteristics of our private enterprise system which, in the past, have contributed so effectively to rapid rates of productivity, growth and progress. (p. 117)

Innovation and Investment

Technological innovation is also strongly dependent on economic conditions and especially on the various economic factors which influence the private sector in decisions to invest or not invest in innovations. This relationship has come to be better understood in recent years, as noted by Gilpin:

> . . . the subject is a new one in the sense that the relationship of technology and the economy was poorly understood until recently and that very few appreciated that there was a problem here that really needed examination. I mean it also in the sense that it was generally assumed that technological advance took care of itself and that there were no public-policy issues requiring attention and resolution. (p. 165)

The same close connection between innovation and the economy is noted by Goldman:

> But the body of earlier analyses—and I am sure the current studies will confirm this—suggests a very intimate link between the state of our economy—particularly the balance of payments—and the intensity of technological innovation. (p. 110)

The reduced growth productivity in the American economy can be traced to a drop in investment, according to some of the contributors. Press notes, for example:

> Equipment and facilities are aging and not being replaced as rapidly as necessary to keep U.S. industries productive and competitive. In some industries the level of technology used in production lags behind that in other countries. (p. 4)

And Tesar cites specific figures showing the extent to which the level of investment has gone down:

> Part of the cause of this poor relative growth in the U.S. could be the inadequate investment of capital which went down from $258 per worker in 1967 to $220 in 1973. By contrast, this indicator rose from $298 to $693 in West Germany and from $191 to $324 in Japan in the same period. (Data from the U.S. Accounting Office). (pp. 140–141)

The remedy, in the view of many of the writers in this compendium, is to strengthen the economic incentives for investment. Bueche observes:

> Given that the fundamental effect of technological change is to increase potential output, I believe government could stimulate productivity best by helping to create appropriate incentives for saving and investment in the productive base of our economy. This means action to remove barriers to risk taking and long-term investment in technological innovation that have been created in our system of taxation and by Federal economic policies—both domestic and foreign. (p. 158)

Ramo suggests the same approach in his analysis:

> For most technological innovation, the straightforward economic limitation is now the most important. Technological advance occurs mainly in industry and technological corporations, large and small, which are not now on the average earning enough to provide adequate funds for plowback to extend their technologies. After the small difference between selling price and costs is used to pay taxes, the interest on borrowed money, dividends to the shareholders and the inflated costs of replacing depreciating facilities, too little is left to improve methods and develop new products. (p 129)

A number of specific suggestions for adjustments in the Federal tax structure are outlined by Bueche (see p. 163). Other approaches such as government financing or tariffs directed at foreign products are rejected by Branscomb, who observes:

> Government subsidy is not required for such commercially-motivated industrial research, but adequate profitability and the environment for an optimistic attitude toward future economic opportunities are required. Technological protectionism does not help in the industries where our technology lags, and it hurts in the industries where we lead by denying opportunity to exploit our advantage. (p. 124)

There may, however, be exceptions to these general conclusions. The service industries, Truxall feels, should be considered one such exception:

> In all the cases of personal technology, directed use of the Federal Government purchasing power represents a seldom-used opportunity for stimulating technological innovation.
>
> Most of the minor national attention on automation has focused on manufacturing industries, while the principal areas for exciting technological innovation lie in the service industries. In this case, however, the role of the federal government is essential. (p. 36)

The Changing Role of the Universities

The role of America's universities as the largest single group of research performers is of concern to many of the contributors. One source of this concern is the apparent leveling off, over the last 10 years, of Federal support for university research. Low sums up this development:

> Although U.S. basic research expenditures in current dollars have increased since 1960, in constant dollars these expenditures have declined in total since 1968, and just barely held their own in the university sector. Specifically, in constant dollars, university expenditures increased on the average 15.5 percent compounded annually from 1960 to 1968, but have been constant since 1968. The largest portion of the funds for these expenditures comes from the federal government. (p. 82)

Some argue for a restoration of the annual growth rate in this funding. Branscomb, for example, concludes that simply maintaining the level of funding is insufficient, because the universities would find this difficult to adjust to: "A long period of zero growth in our universities

will challenge their ability to serve as the driving force for new knowledge and new ideas" (p. 121). Attempts have been made to restore this growth in funding for basic science as is noted by Press:

> In the summer the Director of OMB, with my concurrence, wrote to each of the heads of the mission agencies asking them to assess and, if necessary, correct the balance between long-term and short-term research in their agency's programs. (p. 6)

He observes that the Congress has not in all cases supported this approach:

> The paradox is that the Congressional actions have been taking place at a time when there is widespread support for science and engineering and a growing recognition of its important role in the Nation's future. (p. 7)

Willenbrock notes specifically that "the need for external funding is greater for faculty members engaged in experimentally based research than for those engaged in analytically oriented research (p. 88).

But others are more ready to accept this new situation. Observing that the Government's need for the research capabilites of American universities, which began during World War II, amounted to a form of "mobilization" of the universities, Mueller goes on to observe:

> The great dread of the American research university in the wake of demobilization is stagnation. Fear abounds that lack of growth, declining enrollments and support, lack of faculty mobility, and the resulting aging of faculties almost entirely vested with the rigidity of tenure will in combination produce a university institution deprived of self-renewal. (p. 106)
>
> The first reaction of the demobilized American university to the altered relationship with the federal government therefore still suffers from the shock of restored normalcy and its consequences. (p. 97)

Another source of concern about the changing role of the universities is the demands for relevance and pay-off of research being heard with increasing frequency. Ramo states:

> . . . the growing emphasis by the government on proven relevance for research underestimates the high eventual payoff in probing the unknown secrets of nature. . . . It costs less to accept that some research will prove useless, than to try to guarantee that all research will pay off. (p. 137)

Similarly, Atkinson notes the concern about pay-off and concludes that past performance suggests increases rather than decreases in research support:

> Given the high rates of return associated with R&D in the past, it would appear that we are currently underinvesting in this area in relation to the economic benefits to be realized. Over the past 10 years (1967–1976), for instance, Federal spending for R&D has declined by nearly 20 percent in constant 1972 dollars. (p. 26)

But even where a potential for pay-off exists, it does not automatically take place. Goldman recommends that:

> We must find a way of tapping that huge resource—the academic scientific community—for the benefit of the practical needs of the country and intensifying those links that bind academic research to the innovative process. (p. 110)

In some cases the link between research and industrial innovation is working better than others. In the defense sector, Bucy observes:

> The Department of Defense has been more successful with its R. & D. because it used the products of its research. It is user oriented. Few government technical establishments have this incentive or "final exam." (p. 185)

In more general terms, there is a need to couple more closely the needs of the users in industry, as Goldman writes:

> What has often been overlooked in these deliberations and their stated conclusions is the relationship between academic research and the body of industrial innovative capacity. It is, after all, the industrial environment that is most conducive to promoting a discovery or invention to the status of innovation. If we are to invigorate our national capacity to innovate we must enhance the coupling of the academic technical culture to the fertile innovative fields of business entrepreneurship. (p. 112)

The question of pay-off extends beyond the value of research results to the question of advanced training in science and engineering. On this subject Tesar notes:

> The lack of close relationships between engineering schools and manufacturing industries also impedes the technological innovation process—a barrier not present in some of the major competitive countries. Although the supply of engineers appears to match the demand, the skills of young engineers supply do not always match what is demanded of them. (p. 150)

A factor which has contributed strongly to this is the pattern of Federal funding for research in Willenbrock's view:

> Most strong engineering schools have focused their research efforts in technical fields in which external, primarily Federal, funding is available and have sharply reduced their attention to other technical fields. A result has been that many of the most highly qualified engineering graduates are concentrated in some industrial sectors while other industrial sectors have available fewer and less qualified engineering graduates. (p. 84)

This has led to a distortion, he believes:

> Another significant impact of external funding on schools of engineering has been to focus the faculty attention on research activities in contrast to other engineering functions such as design, production, and quality control. The result has been that the most academically capable students have directed their efforts towards the research and development aspects of engineering. Other engineering functions have had relatively minor attention. (p. 84)

As a result, highly trained manpower has been available in some sectors, and this fact has undoubtedly contributed to the level of innovation in these sectors:

> Those industrial sectors which are well-served such as electronics, aeronautics, and computing machines are also sectors in which technological advances have been the most rapid. While there are many factors which contribute to the rate at which technological advances are made, the availability of the engineering talent is certainly one of the most significant. (p. 84)

A corrolary to this research emphasis is that engineering education gives less emphasis to other, equally important aspects engineering education:

> An area of civil engineering which has not been an area of significant federal agency research support is building construction. There is relatively little activity in this area in schools of engineering. As a result, the building sector has not had available highly qualified engineering graduates well-matched to the needs of the industry. (p. 90)

Furthermore, Willenbrock concludes:

> Many of these areas, such as consumer products and building technology, are cost-oriented. Few, if any, strong engineering schools in the USA have faculties which are oriented toward cost reduction techniques. There is little active research in design and manufacturing techniques which lead to reduced costs of production. Significant technological advances in such areas will be more likely to occur if above critical-sized groups of engineering faculty members undertake relevant research and if graduate students become involved. (pp. 91–92)

As a result of these concerns many of the contributors see a striking change in the relationship between the universities and the government. Mueller sums up this change as follows: "The great postwar partnership between them turned sour after 1968. The relationship between them that has since emerged is in part almost adversary." But, he observes, "The new American university cannot afford either the embrace with the Federal Government that characterized the decades of affluence, or open hostility between itself and government" (p. 93).

The dilemma is that in today's environment only government can provide the resources which are needed to sustain university research, but for the university this reliance on government has brought with it not only dependence but also conditions which are both onerous and impose limits on academic freedom.

The case for continued government funding of university research is made by Ramo: ". . . the Federal Government must continue to be the main sponsor of basic research in the nation's universities." But he goes on to note: "Unfortunately, even here, in this necessary role, the government is not performing well." . . . And he sees several associated problems: "The low funding level leaves good research talent unemployed. The Government's bureaucratic approaches are causing too large a chunk out of every dollar granted for research in the universities to go for administrative expenses" (p. 137). Low puts the case in more detail:

> Sponsored research has become an essential ingredient of the educational process at technological universities. It helps attract faculty members, allows them to do scholarly work in the mainstream of current activity, provides research experience and essential financial support for graduate students, and adds an additional degree of realism to the undergraduate curriculum. In short, it is the lifeblood of modern scientific and engineering training.
>
> It directly affects the output of research in terms of scientific discoveries and their practical application. But of far greater importance, it also affects the output of people—scientists and

engineers—people we must count on for the innovations of the future. (p. 83)

Mueller agrees that the government must continue to provide most of the resources for university research: "As for the research university, its dependence on national government for support of much of its large-scale research is natural and unavoidable." But from the university point of view he sees the question in different terms: "The issue for the university, therefore, is not dependence on government, but the degree and conditions of an inevitable dependence." (p. 94)

Analyzing the present state of affairs in terms of the historical developments over the 25-year period from the war years up to 1968, he notes:

> A quarter century of mobilization did not enslave the university. It brought with it, from government and society, unprecedented and sustained support, prestige, encouragement of growth, and prevailing confidence. But for all that, a price was paid. The consequences of prolonged mobilization—largely voluntary—and of resulting splendor in the government's service were excessive university dependence on government. (p. 95)

The flaws in the relationship have been many, in Mueller's view, and he sums up the principal ones:

> They include the assumption by government that the research university was obliged to respond without reservation to every offered initiative deemed to be in the national interest; the overeagerness of the universities to respond that way, based in part on university assumptions that ever-increasing government support and unlimited growth had become the norm; and the error of both parties in agreeing to do so much in common on the basis of short-term, nonpermanent funding. (p. 94)

Mueller's conclusions and recommendations about how the university-government relationship must be approached can be summed up through the following excerpts:

> We took a great deal for granted—affluence, growth, the respect of society, a clear sense of purpose—all now diminished. We are not where we were, and there is no going back. A new American university is taking shape. (p. 93)
>
> The yearning for the recent past by the American research university is still so great as to inhibit the needed evolution of a new partnership with the federal government. (p. 93)
>
> Nowhere is it ordained that the university institution shall be richly well supported and untroubled—especially not the modern research university committed to free science and reason in the midst of human societies that at their best tolerate reason and freedom only within limits. (p. 97)
>
> To date the university's reaction has been mostly a futile mixture of pleas for renewed or increased support, undercut by sharpening protest against the rising flood of regulation. (p. 94)
>
> A nonmobilized community of research universities can and should be more cautious and selective with respect to initiatives from government for new research activities, and more insistent that government support be granted on conditions that preserve the integrity of the university institution. (p. 94)
>
> The health of the new American university depends on its ability to strike a new and sound internal balance. Basic research

> and pure scholarship must once again be accorded their due. Fundamental values within the university must receive reemphasis. (p. 101)

Public Participation and Public Expectations

The role of the public in science and technology policy has always been difficult to define. Two of the major difficulties are discussed by a number of the contributors. One is the issue of public participation in a complex field where sophisticated expertise is frequently believed to be necessary, and the other is the question of public expectations which at times exceed the performance which science and technology can deliver.

The public's limited understanding is noted by Harrison:

> Much of the public does not understand the nature of and the consequence of either scientific capabilities or technological options and much of the scientific and technological community does not understand the nature of the social, economic and political matrix of which science and technology are a part (p. 40).

But, notes Truxall, a general understanding of the issues in this field must be achieved if public decision making about them is to succeed:

> Technology or applied-science literacy is vital for the individual interacting continually with the technological environment and also essential if rational public decisions are to be made on national issues such as benefit/risk analysis of chemical use or auto passive restraint systems. (p. 38)

They are, insists Fusfeld, matters about which each citizen must inform himself, and it can be done, if not at the technical level, then at a level sufficient to permit the citizen to act intelligently:

> These sound like important questions and they are. But they are matters of public policy, not of technical expertise, and they are within the competence and thus the obligation of every intelligent and conscientious citizen as much as any political issue in the headlines. (p. 33)

The effort to do so, Branscomb notes, may be considerable, but it must be made to establish mutual trust and confidence:

> But such issues cannot be avoided or covered up; scientists and public bodies must gain experience and confidence in each other, and both communities must invest in the public's ability to understand and make correct decisions in its own long term interest. (p. 4)

In the specific area of regulation the many side effects and longer term consequences must be analyzed and evaluated by the public, according to Weidenbaum:

> A more fundamental change is needed, and it does not deal with technical economic or financial issues. The public must come to understand that ever more detailed government regulation is no panacea and may even be self-defeating. At best, government regulation is a powerful medicine which must be taken carefully, in limited doses and with full attention to all of the adverse side effects. And those side effects are not trivial. They include more inflation, more unemployment, loss of productivity, reduced capital formation, and lost opportunities for technological innovation. (p. 119)

Related to the question of public understanding is the question of the public's expectations of science and technology. Several of the contributors suggest that in the public mind expectations of what science and technology can contribute to help solve society's problems and bring about a better quality of life are high. Baker, for example, observes:

> On the other hand, it is undoubtedly a genuine reminder that the public expects a constantly renewed volume of invention and discovery. But more than that, the public expects constant innovation for human benefit, economic stimulus, and national security. Now this is where the challenge lies: assuring that this is done with the same skill and efficiency that have earned us the respect of the rest of the world in this century. (p. 66)

These expectations are, in part, unrealistic. Harrison notes:

> I also suspect that for a time the scientific and technological community sold, or more probably the public bought, an unrealistic concept of that which science and technology can deliver. (p. 40)

Furthermore, there may have been a tendency to stress the benefits of science and technology to the exclusion of the less desirable consequences they sometimes bring:

> The above contrasts sharply with endeavors seeking to create a "favorable image" by focusing exclusively on the positive contributions of chemical technology to our life style and our standard of living. There is much that can be said and should be said about these accomplishments. But to merit creditability, we also must address the problems publicly. Much of the public knows or at least suspects that problems exist. (p. 44)

Scientists and engineers themselves may have been mislead to some extent by the outpouring of public support for their activities. Baker notes this:

> Nevertheless, the illusion of popular support for science engendered by the magnificent upsurge of higher education and the success of national programs mentioned previously spread widely through the scientific and enginering world. (p. 76)

There have been indications in the past, Baker writes, that questions about the benefits of publicly supported scientific research have occurred at the highest level of the government:

> But already foretold by President Johnson's discomfort about biomedical research and the funding of high energy machines in 1966, by the spring of 1970 the true position of science and technology in the executive branch had clearly confirmed the realities of the speech of 1957, and the futility of dreaming that somehow science for its own sake had gained popular affection and respect forever. (p. 76)

These developments suggest, according to Harrison, that in the longer term, the scientific community will be well advised to help educate the public about what realistically can be expected from science:

> A favorable, but unrealistic, environment could and probably would enhance the support for research, and would accelerate the innovative process and all of the things that flow from the technological process. Undoubtedly, there would be short-term gains in some sectors. But the risk is high that the euphoria would dissipate, the accommodation to reality would be difficult, and the

> consequences of an overswing to an unfavorable, but equally unrealistic, environment would be traumatic. (p. 42)

A New Direction for Science and Technology Policy?

An underlying theme in many of the contributed papers is the thought that the time for a reassessment of science and technology policy is at hand. The feeling appears to be that science and technology policy is in somewhat of a blind alley, and that a rethinking of the broad objectives and the means being employed to achieve those objectives is needed. In 1970 Charles Lindbergh wrote the Committee, commenting specifically on the need for a reassessment arising from basic changes in society:

> It seems to me essential for us to accept the fact that intellectual support of basic progress will necessitate reconsideration of long cherished ideals, laws, and customs. (p. viii)

Today the same reconsideration is in order Baker suggests:

> But now we may face a period of stagnation or regression. This is largely because of the bizarre conflicts between the presumptive laws and regulations of pervasive government in a low-risk, welfare society, and the present realities of technical and scientific advance, which, more than ever, demand the freedom to experiment and innovate boldly. (p. 66)

Historically, in the period since 1945, the Federal government's responsibility for the support of basic research came before its current involvement with technology. This responsibility was recognized during the years when the buildup of a strongly university based research enterprise was constructed. In those years technology was not to the same extent under the same broad umbrella of Federal support or regulation as Gilpin notes:

> It had become accepted that the federal government had a responsibility for the support of basic scientific research and for the support of technological developments relevant to the carrying out of its own responsibilities, particularly in the areas of national security and public health. It was generally assumed, however, that the government's role did not extend to the private or civilian sector of the economy. This is to say, the government was not responsible for the general state of American technology. (p. 167)

In recent years, as the contributors analyze what has happened, government has tended to overlook the benefits of technology while focusing on the undesirable aspects. Bueche writes:

> But it [U.S. technology] hasn't done enough. And what is worse—much worse—there are indications that as a nation we are being increasingly neglectful of the technological hand that has been feeding us so well in the past. (pp. 158–159)

Putting it a different way, Baker asserts:

> We are experiencing a curious anomaly with respect to science and engineering. Great attention has been paid to their political effects and to their impact on other areas outside of industry, even though industry is the very agency by which the public gains the fruits of discovery and innovation. I now suggest that federal doctrines may be less formidable than has been assumed because the complex technologies on which these doctrines are based demand a much more pluralistic search for fact and insight. (p. 65)

> Essentially I am saying that science and technology, nominally among the last independent activities left to industry, are also deeply entangled in this regulatory network. (p. 65)

In the broadest terms the answer is to seek a reduction of the adversary nature of the technology-government interaction and a stronger push for a cooperative relationship. Ramo puts it this way:

> Free enterprise can only provide for a part of our needs and a creative, cooperative relationship between the private sector and the government should be sought. (p. 138)

Fusfeld similarly notes:

> The critical question today in science and technology policy is how to combine the legislative authority and financial resources of government with the skills, investment, and marketing abilities of industry while preserving the independence of both. (p. 34)

VIEWS FROM
THE FEDERAL GOVERNMENT

DR. FRANK PRESS

Director, Office of Science and Technology Policy, Executive Office of the President

This review of the activities of the Office of Science and Technology Policy (OSTP) is submitted in response to the request of the Chairman of the House Committee on Science and Technology. It focuses on some of the major activities of OSTP during the past year, provides an assessment of some critical issues that require the attention of science and technology in the years ahead, and discusses the effectiveness of OSTP as measured against some of the principal provisions of Public Law 94–282, the "National Science and Technology Policy Organization, and Priorities Act of 1976."

Rather than give an exhaustive survey of our activities, I have tried to focus on a few of the issues in which I think OSTP has had a distinctive impact. I believe the selection of a few issues for detailed treatment will give the Committee a better idea of how we actually operate than an exhaustive survey. Indeed, as the report shows, we are an integral part of the White House team and find ourselves at the heart of the Administration's decision process on scientific and technological issues. I think the role we are playing demonstrates already the wisdom and foresight of the Congress in recreating the office.

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Over the past year the Office of Science and Technology Policy has been involved in numerous science and technology issues. We can divide them into three categories: Many of these projects have been undertaken at the request of the President and the heads of other government agencies. Some have resulted from initiatives that began in the Congress. Many have been undertaken because my staff and I felt that there was a useful role that we could fill. I will not attempt to describe all of these activities.[1] I hope that by summarizing a few of our major activities the Committee will gain a perspective on the way OSTP is operating in the Administration, with the Congress, and the public. I hasten to add that some of the activities I will discuss have only just started; however, their promise is so great and their commencement so auspicious, that I feel they are worthy of mention now.

At the outset I feel I should indicate that not all of the work on issues in which we are involved is performed by OSTP alone, nor

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[1] A more comprehensive summary of all the activities of the Office of Science and Technology Policy has been submitted to the Congress earlier this year. Testimony by Dr. Frank Press before the HUD–Independent Agencies Subcommittee, House Committee on Appropriations, House of Representatives, Mar. 14, 1978.

does all of it necessarily bear a distinctive imprint from our office. Many issues at the Presidential level involve technology as only one component and we therefore work as part of a White House team with the National Security Council, the Office of Management and Budget, the Domestic Policy Staff, the Council of Economic Advisers and the Council on Environmental Quality, or others, in defining the Administration's position. Indeed, I am the member or chairman of policy review committees in numerous areas: arms control, technology transfer, space, science and technology relations with the People's Republic of China, foreign aid, and energy. Fortunately, OSTP enjoys close working relationships with the President's senior White House staff and the various agencies in the Executive Office of the President. I will comment further on the interrelationships of the Executive Office units later in this statement.

FORGING NEW INTERNATIONAL TIES THROUGH SCIENCE AND TECHNOLOGY

This summer I led a delegation of officials from the principal research and development departments and agencies to the People's Republic of China.[2] It was the first official government-to-government visit by the leadership of the Federal research and development agencies with their counterparts in the People's Republic. The purpose of the visit was to explore some of the possibilities for scientific and technological cooperation with the Chinese—an initiative which the PRC welcomes. One outgrowth of this mission is already being implemented—a student exchange program in which Chinese students come to American universities to study and in which our scholars will visit and study in the PRC. The program will eventually involve undergraduate, graduate, and post-graduate students and is premised on the principle of recriprocity: we will have access equal to that of the Chinese. We also have an understanding that each side will pay their students' way. I cannot emphasize enough the significance of the mutual exploration of cooperative relationships with PRC and, in particular, of this student exchange program.

In light of the immense population of the PRC and their need for resource exploration and technological development, it seems clear to me that science and technology will play at least as strong a role in their lives as it does in ours. The program offers us the opportunity to educate and thereby to build bridges of understanding with individuals who may eventually be the technological leaders of the PRC. I believe this program is an important step in our continuing search for global peace and prosperity.

There are several additional cooperative activities emerging be-

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[2] The delegation included: Robert A. Frosch, Administrator, National Aeronautics and Space Administration; Richard C. Atkinson, Director, National Science Foundation; M. Rupert Cutler, Assistant Secretary for Conservation, Research, and Education, Department of Agriculture; Jordan A. Baruch, Assistant Secretary for Science and Technology, Department of Commerce; John M. Deutch, Director of Energy Research, Department of Energy; Donald S. Frederickson, Director, National Institutes of Health, Department of Health, Education, and Welfare; William H. Menard, Director, U.S. Geological Survey, Department of the Interior; Roger W. Sullivan, Deputy Assistant Secretary for East Asia and Pacific Affairs, Department of State; Benjamin Huberman, Assistant Director for National Security, International and Space Affairs, Office of Science and Technology Policy, and staff member, National Security Council; Anne Keatley, senior staff member, Office of Science and Technology Policy; Michel Oksenberg, staff member, National Security Council; and, Scott Halford, Country Officer for East Asia/People's Republic of China and Mongolia, Department of State.

tween the United States and the People's Republic of China that originated in the initial visit in June. These include the exploration of collaboration in energy and agriculture. A delegation headed by Secretary Schlesinger and another led by Secretary Bergland are now in China and others will travel in both directions soon. Cooperation in the application of space technology will be among the initiatives explored in the months ahead.

We are all aware that many of the world's people do not have the food, the health care, the education, or the material comforts that we take for granted. Much of our current foreign assistance effort is directed at easing the imbalance by the transfer of American goods or American services to foreign soil. What is needed in addition, however, is an increase in the productive capacity of the developing countries themselves. Obviously, science and technology are important, and perhaps the most significant, factors in determining the rate and direction of economic and social development. The strengthening of technological capabilities could help these countries to help themselves. Moreover, such a development could have additional benefits. Admiration of American technological accomplishments and the desire to share this country's expertise are a steady strand in the web of constantly changing views of the United States in the developing world. Perhaps we could strengthen this element in order to establish an improved and more normalized set of relations with the developing countries.

In recognition of these facts, the President announced his intention to create a Foundation for International Technological Cooperation in his speech to the Venezuelan Parliament on March 29, 1978. The Foundation is conceived as an important new part of our foreign assistance effort which is dedicated, among other activities, to increasing the scientific and technological capabilities of developing countries. OSTP is closely involved in the planning now underway to set up the Foundation and we have high hopes for this new thrust in our assistance efforts. To assist AID and the Department of State, and also as a means of establishing working relationships with the Executive Office Units, we have established, together with the President's Development Coordination Committee Chief, Governor Gilligan, a Planning Office for the Foundation. The group is headed by Dr. Ralph Smuckler and Princeton Lyman. Dr. Eugene Skolnikoff, Senior Consultant to OSTP, is working with these and the others in the planning office to prepare for this new organization's start-up as a part of the revamped Agency for International Development program. It should be noted that this planning staff and activity will be "spun off" from the EOP at that time.

Another important activity is the prospective increased cooperation in R&D between the U.S. and Japan. In May, Prime Minister Fukuda proposed to President Carter that the two countries embark on joint projects aimed largely at solving longer-term energy problems. At the President's request, I organized the U.S. response to the Fukuda proposal. I expect that we will be reaching formal agreement in the coming weeks on what specific projects will form the initial focus of the cooperation. Projects will include those in the areas of nuclear fusion and coal liquefaction.

STRENGTHENING THE SCIENCE AND TECHNOLOGY ENTERPRISE

There is an important indicator that has obvious relevance to the health of science and technology—the trend in the overall level of funding for the conduct of basic research. As the Committee is aware, the President singled out basic research as one of a half-dozen thrusts in his fiscal year 1979 budget message to the Congress. The President stated:

> The Federal Government must lead the way in investing the Nation's technological future. Shortly after taking office, I determined that investment in basic research on the part of the Federal Government had fallen far too low over the past decade. Accordingly, I directed that a careful review be undertaken of appropriate basic research opportunities. As a result of that review, this budget proposes a real rate of growth of almost 5 percent for basic research in 1979. I believe this emphasis is important to the continued vitality of our economy.

I would like to dwell for a moment on the formulation of the fiscal year 1979 appropriation requests and the subsequent developments. I believe that the process illustrates one of the paradoxes of government at this time. It also, in my view, illustrates a need that could be usefully discharged by the House Science and Technology Committee.

Our involvement in the formulation of the Administration's budget started during the spring review in May 1977 when certain issues were clarified in the OMB planning sessions with the President. My staff and I participated in all of these discussions. Subsequently, OMB and OSTP met with a number of leaders in science and engineering from universities, industry, and government to review their impressions of trends, issues, and alternatives. In the summer the Director of OMB, with my concurrence, wrote to each of the heads of the mission agencies asking them to assess and, if necessary, correct the balance between long-term and short-term research in their agency's programs. The letter reflected our concerns that in some agencies the emphasis in meeting short-term goals may have squeezed out funding the long-term research. Bowman Cutter, Executive Associate Director for Budget, of OMB and I met with heads of the major agencies to discuss our perception and to gain their views. We then submitted a memorandum to the President describing the problem briefly and suggesting that basic research funding should have some real growth above inflation. The President agreed to this approach, emphasizing, moreover, his interest in strengthening the research capability of the universities.

In the fall budget review, my staff and I worked closely with OMB on various aspects of the agency budget submissions, but with a particular focus on basic research. The outcome was that the proposed obligational activity for the support of basic research totaled over $3.6 billion, a 10.9-percent growth rate over fiscal year 1978 (about 5 percent real growth). The budget as proposed to Congress leaned toward fundamental science—the basic research that is an investment in the future strength of the nation.

The President reaffirmed his views in a meeting with newspaper editors in August:

> One of the substantial changes that I have made in preparing the Federal budget has been to increase the portion of each major agency's budget that goes into basic research and development. This is carried out not only within government in laboratories and so forth but with direct grants to colleges and universi-

ties, in addition to that, in some appropriate ways to encourage business through government sharing of costs to improve research and development.

I would say that the countries that have maintained a high commitment to research and development have a tendency to have much higher productivity. I think we might be suffering in 1978 because 15 years ago, there was a lessening in research and development commitment among business.

One reason, of course, is the extreme incentive that permeated the American scientific and technological industries with the space program, when during the sixties, we had a major thrust there. And this permeated the whole structure of our economy, not only in electronics, computers, but also in health care and other factors.

So, I'd say research and development is a very fruitful investment. And we're trying to turn that trend around.[3]

The appropriation process reveals that the thrust of the President's initiative has been blunted by the actions of the authorizing and appropriating committees and subcommittees of the Congress. A number of new initiatives, for example, the Defense Science Engineering Program and basic mathematical and engineering research in the Department of Energy have been reduced or eliminated. The basic research competitive grant program in the Department of Agriculture, for which the Administration has requested $30 million, has been held at $15 million. Overall, it appears that the real growth for basic research will be far below the 10.9 percent requested by the President.

The paradox is that the Congressional actions have been taking place at a time when there is widespread support for science and engineering and a growing recognition of its important role in the Nation's future. For example, when asked in a national survey to estimate the factors that will make this country great in the future, the sampled public selects in order, scientific research, industrial know-how, and technological genius.[4]

The blunting of the Administration's thrust is most disappointing to those of us who share this sense of the importance of science and technology to the Nation. My staff and I are now involved in helping prepare the fiscal 1980 budget that the President will send to the Congress in January 1979. We are operating with severe fiscal constraint, but we are committed to maintaining our initiatives in support of science and technology. Indeed, in his recent inflation speech the President emphasized again the importance of research and development.

We have made a start toward improving productivity. . . . Federal support for research and development will continue to increase, especially for basic research. We will coordinate and strengthen Federal programs that support productivity improvements throughout our economy.[5]

Obviously, however, the 96th Congress will play a critical role as a partner in this enterprise as it acts on the proposed budget. The Committee on Science and Technology could, and in my viewpoint must, play a very active role in explaining within the Congress the importance of science and technology as an investment in the Nation's future.

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[3] Weekly Compilation of Presidential Documents, pp. 1416–1417, Aug. 12, 1978.
[4] The Harris survey, "Factors in Making America Great," Jan. 16, 1978. In looking back to account for America's present greatness, the respondents listed, in order of importance, rich natural resources, hard working people, and scientific research. Id.
[5] Washington Post, p. A–11, Oct. 25, 1978.

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Another of our many activities touching on the health of our scientific and technological enterprise concerns the rate and direction of industrial innovation in this country. There is a substantial agreement that innovation has been the major factor in our economic growth in this century. Innovation is clearly an element in the solution of many of our current economic problems—inflation, lagging productivity, unemployment, and an unfavorable balance of trade. Moreover, as world resources become more limited, we must rely on the innovative application of science and technology to provide novel materials or more efficient ways to use existing supplies. Finally, it is in part through innovation that we must find the solution to our energy, health and environmental problems.

In the United States, whole new industries have been developed by creative entrepreneurs working in an environment—political, economic and natural—that was supportive of their genius and creative business spirit. While there is no reason to assume that our supply of geniuses or potential industrial giants has in any way diminished, the environment in which they are nourished has changed substantially over the last century. We should remember that some of the world's leading nations in technological development in the nineteenth century have found that their leadership has substantially eroded. Indeed, several recent observations cause me concern about innovation in the United States:

> There is evidence of decreasing private investment in the research that could lead to entirely new products and processes. Industry leaders tell us it is "safer" to market incremental improvements in tried products and processes than to undertake bold innovation. Support for longer-term research has waned.
>
> Industrial research managers tell us that they are having to put a larger share of their income into so-called "defensive" measures to meet new environmental and consumer safety standards. As desirable as these standards may be and while many have spurred technological innovation, we must recognize that they often require resources that might otherwise be used for more innovative work. Some recent economic studies have identified regulatory impacts as a major restraint on economic growth.
>
> Equipment and facilities are aging and not being replaced as rapidly as necessary to keep U.S. industries productive and competitive. In some industries the level of technology used in production lags behind that in other countries. The steel industry is an example of an industry that has not kept pace with its international competitors.
>
> Small firms, which play a particularly important role in the innovation process, seem to be encountering difficulties in entering the public markets to obtain venture capital. With a shortage of capital, the small companies never get started, or they die young, or they are absorbed by larger companies.

Because of the importance of innovation and because of these troubling observations, the Secretary of Commerce and I urged the President to direct that a cabinet-level study be undertaken of the issue. The President agreed. The objective is the development of policy options for the President's consideration that would induce the continuation of an environment supportive of technological inno-

vation. The study will be chaired by Secretary Kreps, and my staff and I will continue to be deeply involved in this important effort. Because our aim is to influence private-sector behavior, much of the work in the coming months will be with an advisory committee drawn from industry, labor, academia, and consumers to get their sense of the important issues and the solutions. Thereafter, various task forces will focus on and develop options for the President's consideration. The innovation study is in my view a very important activity, although I recognize the path ahead will be arduous.

RENEWING THE NATIONAL COMMITMENT IN SPACE

During 1978, the Office of Science and Technology Policy has played a key role in an Administration-wide review of the Nation's defense, photo reconnaissance, and civil space activities. The review has involved a number of background studies,[6] a National Security Council review of national space policy, and a review of civil space policy, which I chaired.

The National Security Council review resulted in important Presidential decisions in May 1978 on the National Space Policy.[7] These included:

A government policy oversight system to review and revise space policy as needed.

Ground rules for the balance and interaction among our space programs to insure achievement of the interrelated national security, economic, political, and arms limitation goals of the United States.

Modifications to existing policies, the appropriate extent of the overlapping technology, and product dissemination by the sectors.

This review did not deal with the long-term objectives of our defense, commercial, and civil programs, but set the basic framework for this Administration's civil space policy:

It reaffirmed the existing management mechanism among the space sectors that has preserved the security required by military space systems, while maintaining an open and internationally positive image for civil space activities.

It reaffirmed and established broad U.S. policy principles including the commitment to maintain U.S. leadership in space, to encourage wide distribution of space research data, to search for peaceful uses of outer space, and to pursue activities in space in support of national security and arms control.

It established new guidance encouraging technology transfer and sharing among the civil, military, and intelligence sectors.

It encouraged domestic commercial exploitation of remote sensing under government authorization and supervision or regulation.

In the further review of the policies that will guide the civil space policy during the next decade, the President determined that the program would be centered around three basic tenets.

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[6] "Earth Information from Space by Remote Sensing," a report prepared for the Director of the Office of Science and Technology Policy, June 2, 1978; "State and Local Government Perspectives on a Landsat Information System," a report of the Intergovernmental Science, Engineering and Technology Advisory Panel, June 1978; "Summary of Survey on the Role in Statellite Communications Research and Development," by the Office of Science and Technology Policy, July 1, 1978.

[7] White House press release, June 20, 1978.

First: Our space policy will reflect a balanced strategy of applications, science and tehnology development containing essential key elements that will:

Emphasize space applications that will bring important benefits to our understanding of earth resources, climate, weather, pollution and agriculture, and provide for the private sector to take an increasing responsibility in remote sensing and other applications.

Emphasize space science and exploration in a manner that retains the challenge and excitement and permits the nation to retain the vitality of its space technology base, yet provides short-term flexibility to impose fiscal constraints when conditions warrant.

Take advantage of the flexibility of the space shuttle to reduce the cost of operating in space over the next two decades to meet national needs.

Increase benefits for resources expended through better integration and technology transfer among the national space programs and through more joint projects when appropriate, thereby increasing the return on the $100 billion investment in space to the benefit of the American people.

Assure American scientific and technological leadership in space for the security and warfare of the nation and continue R&D necessary to provide the basis for later programmatic decisions.

Demonstrate advanced technological capabilities in open and imaginative ways having benefit for developing as well as developed countries.

Foster space cooperation with nations by conducting joint programs.

Confirm our support of the continued development of a legal regime for space that will assure its safe and peaceful use for the benefit of mankind.

Second: More and more, space is becoming a place to work—an extension of our environment. In the future, activities will be pursued in space when it appears that national objectives can most efficiently be met through space activities.

Third: It is neither feasible nor necessary at this time to commit the United States to a high-challenge space engineering initiative comparable to Apollo. As the resources and manpower requirements for shuttle development phase down, we will have the flexibility to give greater attention to new space applications and exploration, continue programs at present levels or contract them. To meet the objectives specified above, an adequate Federal budget commitment will be made.[8]

This review has already resulted in actions by several officials. For example, Assistant Secretary Henry Geller, National Telecommunications and Information Administration, in addressing the Public Service Satellite Consortium indicated that his agency will move vigorously to fulfill the mandate assigned by the President in an effort to extend communications to remote areas, and to explore new ways to utilize satellite communications.

The policies that the President has set forth lead to a number of further interagency reviews and initiatives. These will be carried out

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[8] White House press release, Oct. 11, 1978.

by the Policy Review Committee (Space) where I serve as Chairman. I expect to discuss the President's review of space policy with the Committee early in the 96th Congress.

REDUCING THE IMPACT OF NATURAL AND MAN-CAUSED HAZARDS

The threat of natural disaster caused by hurricanes, floods, earthquakes and other events of nature remains a serious problem for society. Indeed, many feel that the severity of the threat is increasing as the population of the world clusters into dense urbanized regions that are often located in flood plains, along sea coasts, or in other areas where the full force of nature's catastrophic events can be the most severe. Similarly, the failure of man's engineering efforts can cause major disaster when there failures occur in populated regions.

In 1978, the Office of Science and Technology Policy has been directing two interagency efforts and participating in a third that bear on these issues. They are the formulation of a National Earthquake Hazards Reduction Program, a review of safety practices of the Federal agencies that are responsible for the construction, operation, and maintenance of dams and the licensing of dams for power and other purposes, and the review of technological alternatives for the safe storage and disposal of nuclear wastes.

The 95th Congress in the first session passed Public Law 95–124, the National Earthquake Hazards Reduction Act of 1977. Formulation of the plan specified in the Act was assigned by the President to the Director of the Office of Science and Technology Policy and was developed with the assistance of an Advisory Committee (now discharged). The implementation of the Federal Earthquake Hazards Reduction Program [9] is now an interim responsibility of OSTP until the new Federal Emergency Management Agency (FEMA) is established.[10] Priority emphasis on this program is placed on the completion of contingency planning for responding to earthquake disasters, the development of improved seismic building codes and their application to Federal construction, the assessment of the earthquakes hazards posed by existing Federal facilities, the examination of the economic implications of earthquakes and their prediction, and the maintenance of a strong research program. During this interim period, OSTP is providing leadership to the newly established Interagency Committee on Seismic Safety in Construction and coordinating the activities of Federal agencies as they develop a comprehensive set of building standards for use by Federal agencies.

According to recent Federal inventory data, at least 20,000 of the 2,100 Federal and 47,400 private dams in the nation are so located that failure could result in the loss of human life and appreciable property damage. In response to this enormous potential for death from dam failures, and because of several disastrous dam failures in recent years, President Carter, in April 1977, requested a review of Federal agency practices that could affect dam safety, and in December 1977, he initiated a five-year non-Federal dam Corps of Engineers' inspection program of 9,000 high hazard dams. The Federal dam safety review effort has involved a three-step process of (1) agency and subagency review; (2) interagency review in preparation of proposed Federal manage-

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[9] Submitted by the President to the Congress, June 22, 1978.

[10] President's Reorganization Plan No. 3, submitted June 22, 1978; approved Sept. 16, 1978.

ment guidelines, accomplished under a Federal Coordinating Council for Science, Engineering and Technology Ad Hoc Committee; and (3) an Independent Review Panel arranged by the Office of Science and Technology Policy. After eighteen months of intensive policy and technical review, recommendations for improving both Federal and non-Federal programs are being proposed. The ongoing inspection has already resulted in the reporting of almost 300 unsafe dams to State governors. A first-year report on the status of inspections, development of State programs, and recommendations for assuring non-Federal dam safety will be issued by the Secretary of the Army in December of this year.

Another area in which we have been working is radioactive waste management and disposal. The need to dispose of radioactive waste in a manner that protects humanity and the natural environment has been with us for 35 years and will continue as long as we reap the benefits of nuclear energy—for medicine, for expanding the frontiers of human knowledge, for national security and for power production. As part of the work of the Interagency Review Group (IRG) constituted last March by President Carter to examine all aspects of radioactive waste disposal, OSTP accepted the Chairmanship of the Subgroup developing and analyzing alternative technology strategies for disposal of high level and transuranic-contaminated nuclear wastes. We and other agencies, with the help of a Nuclear Waste Management Technical Advisory Group constituted by myself and John Deutch, Director of the Office of Energy Research, Department of Energy, have assessed the status of knowledge relevant to nuclear waste disposal and have formulated a series of options and recommendations for consideration by the Interagency Review Group and the public.[11]

The work of the IRG and of the OSTP-led Subgroup on Alternative Technology Strategies reflects the spirit of broad consultation that characterizes the Administration's approach to technology policy issues. In addition to public meetings and meetings with a wide cross-section of technical, public interest and public policy groups, the IRG has worked closely with the National Governors Association and other state and local interest groups. The Subgroup received technical peer review on its technical assessment of geological alternatives from more than 500 scientists, engineers and organizations. More than 10,000 copies of the draft report to the President and the Subgroup's reports have been circulated for public comment. We consider the radioactive waste disposal problem to be serious and solutions are long overdue. We hope that the work of the IRG, and of that part which we led, will be an important step toward forging a national consensus on how to go about safely disposing of waste in this country.

IMPROVING THE SCIENCE BASE FOR ENVIRONMENTAL REGULATORY DECISIONS

The Office of Science and Technology Policy has been working with the environmental regulatory agencies (EPA, FDA, OSHA, CPSC), the basic research agencies (especially the National Cancer Institute and the National Institute for Environmental Health Sciences), and the appropriate groups in the Executive Office to establish a better

[11] Interagency Review Group on Nuclear Waste Management, "Subgroup Report on Alternative Technology Strategies for the Isolation of Nuclear Wastes" (draft), (October 1978).

framework for the scientific evaluation of environmental hazards. The leading concern is the potential for some hazards to cause cancer in humans. OSTP has proposed a two-stage process for evaluation: the first stage would consist of the scientific testing and evaluation of data to identify and characterize chemicals in terms of relative risk for cancer in humans; and the second stage would consist of analysis of risks in terms of sources and extent of exposures, benefits, means to reduce and monitor exposures, and cost-effectiveness of various regulatory actions. OSTP is also working with the agencies to enhance the resources for and effectiveness of research capability and information-sharing about carcinogenic and other toxic properties of chemicals.

II

The description of some of the current activities of the Office of Science and Technology Policy that I have given above is by no means a comprehensive list. There are numerous other areas where equal attention is being given to contemporary issues, usually with action-oriented policy or management decisions in mind. The OSTP activities on issues of interest to the National Security Council provide a good example. Rather than attempt to give an exhaustive summary of our past activities, however, let me turn to an issue in which the Chairman has expressed an interest—the identification of some national issues on the horizon that have strong elements of science and technology. Of course, we will all benefit in this regard by the five-year science and technology forecast mandated by Public Law 94–282. Without attempting to prejudge that effort, let me mention a few of the issues that will become increasingly important as time goes on:

LIMITATION OF RESOURCES

Although the hopes and aspirations of humans are without bound, the earth provides only finite resources. As our population grows and as our demands for an improved standard of living increase, we will increasingly have to confront the fact that nature's bounty is not infinite. We confront one aspect of this fact in the area of materials—the stuff from which goods are fabricated. We have to find new ways to use old materials more efficiently, or alternatively, to find novel materials. The leading edge of this effort is, of course, research and development by both the government and the private sector. Although, the Federally supported effort directed at materials already is substantial, we have to be sure that opportunities are not missed and that we are able to anticipate and prepare for declining or interrupted supply.

Much of our Federal R&D effort is directed at the production of products with superior performance qualities. Although this work is important, perhaps we need increased emphasis on R&D to improve the processes of the extraction, production, and fabrication of routine materials so as to increase the productivity of these important industries and to improve resource efficiency. In any event, the domestic policy review on non-fuel minerals should provide a cornerstone for continuing surveillance by both the Executive and the Congress on materials-related issues.

ENERGY-ENVIRONMENT-ECONOMY

We are all very much conscious, of course, of energy, environmental, and economic issues. To a large extent our society has tended to try to deal with these issues in isolation from one another. For example, in the energy area, we have all been grappling chiefly with the problems of assuring an adequate supply of energy for ourselves and our children. Over the coming years, however, I believe our decision processes will have to broaden in focus to accommodate the hard trade-offs between energy, environment, and the economy. The debate that has now started over full scrubbing for steam generating plants is likely to be only the precursor of a large cluster of issues surrounding energy and environment. And the impacts of such decisions on the economy, although less well articulated and framed at the moment, will also emerge as a significant factor in our deliberations. We will have to overcome the tendency toward polarization—the adoption of one objective as always paramount—that may be encouraged by organizational structures and political pressures. Although energy problems are already complex, we can expect the complexity to increase as all the elements implicated in the decision process are revealed.

THE HUMAN CONDITION: MIDDLE-TIER COUNTRIES

Much of our foreign aid effort to date has been directed at the impoverished nations so as to improve standards of living, health care, and to encourage the development of stable and growing economies. Some nations with our help and those of other affluent nations around the globe, have succeeded in picking themselves up by the bootstraps; their economies are growing and modernization and cultural change are occurring. These nations—the middle-tier countries—have graduated from our traditional aid categories. I believe, however, we should continue to assist these nations and to encourage the devlopment of economies that are mutually supportive of our own. These nations are often politically important and by helping them, often we help ourselves. Since science and technology are particularly important to middle-tier countries—they want to use the most modern methods—the transfer of technical knowledge and capability are a likely foundation for our relationship with these nations. Indeed, for this reason, the Foundation for International Technological Cooperation, which I have already described, is expected to reach out to those countries as well as the lower tier nations. There is an obvious need, however, for continuing work to assure that the transfer is effective. as well as appropriate and supportive of our global, economic. and strategic goals.

GENETICS

Perhaps one of the most exciting scientific advances of recent years is our emerging understanding of the genetic code. and more recently, of how to manipulate it. The breakthrough has enormous theoretical and practical implications: it provides a window to new knowledge basic to research on cancer and on embryological development, as well as a potentially broadly applicable mechanism for the production of useful substances. It was only recently announced that human insulin has been produced in bacteria by alteration of the bacteria's genetic

code with recombinant DNA techniques. Although such research might lead to remarkable improvements in the human condition, debate over the past year has emphasized its dark side: for example, the prospect of producing a virulent new disease for which no natural protection exists. Recent months have seen the reduction of these fears. Continued efforts are warranted by us all over the years ahead to assure there are adequate safeguards, but without compromising significantly the scientific freedom that is essential if the benefits of such research are ever to be realized. The informed work by this Committee over the past year has been most helpful in this regard.

III

I have been asked by the distinguished Chairman of this Committee to discuss Public Law 94–282 and the functioning of the OSTP in the Administration. I will comment briefly on aspects of the interrelationship of OSTP to the Executive Office and to the Federal Coordinating Council for Science, Engineering and Technology (FCCSET). Then, I will discuss briefly the work of the Intergovernmental Science, Engineering and Technology Advisory Panel (ISETAP), and some of the various functions that were associated with Titles II and III of Public Law 94–282.

Of all of the aspects of the role of a Science and Technology Adviser to the President that received attention prior to the enactment of Public Law 94–282, none was more widely discussed than the access of the Science and Technology Adviser to the national security and budget processes and deliberations. I have already described in some detail the relationships that have been established with the Office of Management and Budget in this Administration. There are equally close communications with the National Security Council. Indeed, our close relation with the NSC is reflected in the fact that one of my Assistant Directors, Ben Huberman, holds a joint appointment to the NSC staff. Relations with the other elements of the White House and Executive Office are equally effective.

The Federal Coordinating Council for Science, Engineering, and Technology (FCCSET) is the chief formal government-wide coordinating mechanism for science and technology issues. It is operating as a sub-cabinet group under my chairmanship with a membership composed of chief officials for R&D in the various agencies and departments. In my view, FCCSET provides a very useful mechanism for dealing with important scientific and technological issues that cut across the government. Over the past several months, my staff and I have reviewed the structure and function of FCCSET, and, in particular its various subcommittees. As a result, we formulated a plan whereby the function and responsibilities of the existing committees was either confirmed or assigned to a much smaller number of the committees, or to a lead agency. In the latter case, the lead agency will coordinate agency activity and periodically will report back to me.

This concept is in accord with the President's desire to emphasize program management by the agencies where possible. When a special problem arises, it will be handled by way of an ad hoc group assembled for the purpose. I believe that my actions have helped to revitalize FCCSET and to enhance its ability to play a helpful role in formulat-

ing, anticipating, and resolving of science and technology issues that confront us.

Let me mention that in recent weeks the President has nominated and the Senate has confirmed the appointment of Ambassador Thomas R. Pickering as Assistant Secretary of State for Oceans and International Environmental and Scientific Affairs. Ambassador Pickering is prepared to take a very active role in the formulation of international policy in science and technology and to effect improved coordination of interagency effort and its periodic review and assessment. To assist him in this work, there is a newly activated subcommittee of FCCSET for international science and technology affairs.

Of course, the coordination of scientific and technology activity is not a problem merely of ensuring adequate decision mechanisms between and within departments and agencies. We often lose sight of an important user group—state and local governments—and I would like to spend a moment to describe our efforts there. OSTP supports the Intergovernmental Science, Engineering, and Technology Advisory Panel (ISETAP) which consists of 19 State and local government officials, the Director of the National Science Foundation, and myself. Members include: Governor Carrol of Kentucky who is the Chairman of the National Governors Association; Governor Milliken of Michigan; Governor Lamm of Colorado; Governor Carey of New York; Mayor Kenneth Gibson of Newark, New Jersey, a former President of the U.S. Conference of Mayors; and Mayor Margaret Hance of Phoenix.

ISETAP is working with Federal agencies and the State and local government community to identify high priority problems of State and local governments that science and technology can help resolve and to determine research issues associated with these problems that the Federal government needs to address. ISETAP is also developing recommendations for enhancing the utilization of research funding by the State and local government community. ISETAP task forces meet at least ten times each year.

There has been quite a bit of correspondence between the Congress and the Administration on the subject of the functions that were assigned under Title III of Public Law 94–282 to a Presidential commission. Reorganization Plan No. 1 of 1977, which was approved by the Congress, reassigned these responsibilities to OSTP and OMB. In my view, they are being discharged in an effective way. The OSTP has, for example, worked very closely with the President's Reorganization Project on the formulation of the Federal Emergency Management Agency, the relocation of the Smithsonian Science Information Exchange to the Department of Commerce, and some aspects of the Administration's proposal for a Department of Education.

Similarly, the responsibilities under Title II to prepare annual and five-year forecasts are being discharged effectively. As you know, the Reorganization plan transferred the responsibility for preparation of both these reports to the National Science Foundation. The NSF's first annual report has been submitted to Congress and work is underway at NSF on the forecast, in conjunction with the National Academy of Sciences, the National Academy of Engineering and the Institute of Medicine. I do not believe that these changes have diminished the effectiveness of the OSTP or frustrated the achievement of the intent

of Public Law 94–282. Indeed, the resources that are now being brought to bear on some of these tasks are greatly expanded beyond those that OSTP could muster.

There is one further point that I would like to make in completing this assessment. At the time OSTP was created, none of us could have predicted how the office would best function. Indeed, continuing flexibility is essential so as to enable us to adjust our operations to maximize our effectiveness and impact. Nonetheless, I think the Congress' wisdom and foresight in recreating OSTP is already demonstrated by the vital role that we have taken in the White House. As the above remarks indicate, OSTP is an active office at the heart of the Administration's decision processes on scientific and technological issues. The President is interested in science and technology and I am sure that our activities in partnership with the Congress and in particular with this Committee, will continue to bear fruit in the years ahead.

DR. JORDAN J. BARUCH

ASSISTANT SECRETARY FOR SCIENCE AND TECHNOLOGY, U.S. DEPARTMENT OF COMMERCE

Mr. Chairman and Members of the Committee, thank you very much for the opportunity to present this statement for inclusion in the record of the Committee's hearings on science policy matters. It addresses three issues raised by the Chairman in his letter inviting me to testify.

ORGANIZATION AND OPERATIONS OF OSTP, AND HOW THEY MAY BE AFFECTED BY THE PRESIDENT'S REORGANIZATION PLAN NO. 1

I feel it is more appropriate for Dr. Frank Press to discuss this point.

RELATIONSHIPS AND INTERACTIONS BETWEEN SCIENCE AND TECHNOLOGY AND THE ECONOMY

It is very timely for the Committee to seek information regarding enhancements that research and development are able to effect on various aspects of this country's economy. The economy and the attendant issues of inflation and employment command the highest attentions of the Carter Administration—and indeed, of the country in general. Industrial innovation affects not only the rate of economic growth and inflation, but also the rate of unemployment, balance of trade, and ability to realize other national goals such as conservation of resources, national goals such as conservation of resources.

Pride in Yankee ingenuity is also a significant element in our national identity and confidence. In January, 1978, the Harris Survey reported that approximately 80 percent of the American people are convinced that the United States' greatness in the future will depend more on scientific research industrial know-how and technological genius than on other factors.

Innovation impacts on economic growth and unemployment by introducing new products and even whole industries. In 1945, the semiconductor, jet transport, and computer industries were commercially non-existent. Today, these industries contribute billions of dollars to the economy, and employ over a million people, many in professionally challenging work. A 1976 study by our Commerce Technical Advisory Board found that while the average growth of mature companies from 1945–74 was 7.8 percent in sales and 1.9 percent in jobs, innovative companies experienced rates of 16.5 percent in sales and 10.8 percent in jobs.

However, we in the Carter Administration believe that growth, itself, is inadequate as a focus for public policy. Balanced growth

with minimal inflation is the real goal. Innovation affects the minimization of inflation through the improvements in productivity that result from the commercialization and diffusion of new processes and products.

Process innovations increase the average worker's productivity, decrease the price, and/or improve the value of the product through improvements in terms of better quality and recovery of more desirable products.

For example, innovations in petroleum refining; e.g., the use of molecular sieve catalysts, has allowed oil companies to meet consumer demands by increasing the utilization of existing capacity. Another effort was that of more economically increasing the fraction of desired products (i.e., gasoline) recovered from a charge of crude oil. Product innovations increase the value of the product to the consumer and to society through improvements in product quality and the introduction of new products. For example, the substantial improvements in computers have given us more and more computational capability at lower and lower equipment, energy and space costs.

When viewing the contributions of productivity improvement, it is important to extend our view toward total productivity, that is, to the efficient utilization of energy and raw materials and to the use of less expensive and more adaptable materials. For example, a recent study by the National Bureau of Standards (NBS) showed that of the $75 billion annual cost of corrosion to the U.S. economy, $10 billion could be called avoidable were the best currently available corrosion technology used in some industries. NBS, as a case in point, recently organized a series of discussions between the building industry and corrosion experts, so that the industry might learn of the benefits of corrosion technology, thereby lowering costs.

The U.S. position in international trade may be explained, at least in part, by reference to technological innovation; for, as innovation declines, so does productivity and competitiveness. The impact of innovation on the U.S. balance of trade by innovation is graphically shown in a report prepared by the Domestic and International Business Administration (now the Industry and Trade Administration) of the Department of Commerce. In R&D-intensive manufactured product groups, the U.S. showed a positive trade balance of almost $29 billion in 1976. In the same year, non-R&D intensive products accounted for a deficit of $16.5 billion. This deficit has worsened dramatically over the last two decades; for example, the deficit was only $12 million in 1961.

It is important also that jobs be protected from the encroachment of foreign competition. Recent studies show that innovation may contribute to this objective by increasing productivity thereby reducing the costs of labor. It is also possible to innovate in such a way that consumers obtain more value and/or better market service as an offset to greater cost. For example, computer-aided design, for years a fact of life in the automotive field, is being adapted for use in consumer goods manufacturing, thus allowing manufacturers to offer better and more prompt designs as a way of enhancing their competitive posture. Because of this increased ability to compete, increases in jobs can be forecast, and communities where the industry is concentrated are better able to retain solid tax bases.

I shall sum up my views by noting that economic development must take into account structural barriers to balanced growth. These economic development problems can be more fundamentally stated as: What is good for one industry, community or sector, is most often to the disadvantage of another. The way out of this formula for unbalanced development—a zero-sum game—is to change the basic organizational structure of industry through technological innovation.

IMPORTANT ISSUES OF PUBLIC CONCERN WITH STRONG TECHNOLOGICAL OVERTONES, OR WHICH CONGRESS MAY HAVE AN INTEREST IN THE FUTURE

Clearly, the Federal Government plays a critical role in the innovation process. President Carter stressed this role in his State of the Union message in January 1978:

> The health of American science and technology and the creation of new knowledge is important to our economic well-being, to our national security, to our ability to help solve pressing national problems in such areas as energy, environment, health, natural resources. I am recommending a program of real growth of scientific research and other steps that will strengthen the Nation's research centers and encourage a new surge of technological innovation by American industry . . . I am determined to maintain our Nation's leadership role in science and technology.

The Commerce Department's Office of Science and Technology takes the stance that cooperative effort on innovation—where the Federal Government, industry, and supportive institutions such as the academic community work together—is our best hope for stimulating new innovations and enhancing the utilization of existing ones.

Several examples serve to illustrate the need for government-industry cooperation in one type of situation: where an industry has been impacted by outside forces (e.g., regulations, imports, changes in energy costs, etc.):

> The disaggregated jewelry industry is an employer of more than 60,000 individuals, and is located primarily in one area of the country. However, it lacks the expertise and financial base to meet Federal and state environmental regulations. If the industry is to survive—and the economy of the region to remain healthy—new processes and technologies must be developed, compatible with the characteristics of the firm.
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> There are some 40 to 60 blast furnaces which have been idled by obsolescence and the growth of foreign imports. These units might be used as coal gasifiers. Working with industry, new innovations in this area would result in the economic revitalization of the affected areas. Moreover, as the result would be the availability of industrial fuel gas, the possibility would exist for attraction of new industry to those areas.

With this kind of active cooperation, we can thus assure the pursuit of innovations that will be viable in practice, thus providing the fullest support of the government to the country's industrial strengths.

Another context in which government-industry cooperation might yield innovative results concerns our need for technologies which will conserve our country's environmental and other resources. The need for such conservation has been a strong force behind the growth in regulatory actions by government. Sometimes regulatory compliance

involves straight-forward adoption of simple procedures or even sophisticated, but well-known, technologies. However, at other times, it can involve massive, costly changeovers to processes that are not well-characterized and may in the end not achieve the desired goals. Regulatory compliance often requires the development of a new technology.

Major barriers exist to private sector investment in the basic technologies which regulated industries, particularly disaggregated industries, need for compliance or voluntary action:

They often lack the skills, creative technological talent and wide-ranging knowledge of technologies available from other industries.

The financial resources—and often the risk—associated with such development is high compared to the individual firm's resources.

The benefits of such development accrue across the entire industry rather than to the individual firm.

There is a need for new Federal orientation toward advancing critically needed compliance technologies common to the regulated industries. Work leading to compliance technologies should, ideally be conducted outside of the regulatory agencies and should operate quite separately from the agencies' work. By separating regulation from work on compliance technology, there is less chance that regulations would be promulgated in response to technology generated in another part of the regulatory agency without a clearly perceived need for the regulation. Such a stance by government would:

Foster potentially more advanced and efficient compliance technologies than could be achieved by individual firm efforts;

Reduce duplication of R&D and demonstration efforts in many firms at once;

Provide vital resources to small firms in disaggregated industries which might otherwise be driven from the market by regulation; and

Enhance social benefits which would not accrue to any one firm.

A third context in which government-industry collaboration would be useful is that of emerging technologies which promise significant improvements in future productivity, quality and trade gains.

Electronics, specifically the area of "Very Large Scale Integration," (VLSI), offer such a phenominal opportunity for economic growth in the United States today. In addition to general economic growth, other hoped-for benefits from VLSI are the creation of new jobs, improvement in productivity and improvement in the U.S. balance of trade. In recognition of this promise, other nations such as Japan and Germany have committed massive funding to stimulate industrial innovation in VLSI.

VLSI is an extension of the natural increase in the number of circuits, or functions, incorporated on one semiconductor chip (i.e., greater than 1,000 functions). Economically, the advent of VLSI brings with it the foundation for continued U.S. dominance of the electronics component industry and the computer industry on the world market. Mass production of extremely complicated circuits will keep costs down while allowing the sophistication of our electronics products to increase. These factors point to the improvement of produc-

tivity and insure the continued growth of the industry and the number of job along with it.

It is reasonable to ask that if the industrial promise is so great, how does government fit in? The answer to that is that there are problems which hold back the rate of development in VLSI; problems which are primarily related to basic, or cross-cutting infratechnologies, as distinguished from individual inventions or other items of a firm-specific, proprietary nature. Basically progress in VLSI requires a better understanding of fundamental parameters of design such as yield, performance, reliability, materials properties, and manufacturing processes.

The next generation of manufacturing procedures will be too costly in capital equipment and associated infratechnology for single-firm development; government support of basic infratechnology will free industrial funds for focus upon developments with high proprietary content. Although the private sector typically under-invests in these infratechnologies, they are, nevertheless, critical to the overall successful development and competitiveness of the industry as a whole. The support of the development and dissemination of these technologies is, therefore, an appropriate area for government-industry collaboration.

A final area for government-industry cooperation focuses on the diffusion and utilization of existing innovations. At the present time, Federal agencies contain literally hundreds of laboratories focused on research and development activities related to that agency's specific mission (i.e., NASA, DOD, HEW, etc.). While there have been many efforts to "transfer" the results of those activities to industry to increase the social payoff of those large initial investments. the success has been all too often uneven. The idea that a technology, developed for a specific Federal agency purpose and under that agency's constraints, can be simply transferred to industry has proven false.

In conclusion, I have but touched on the issues relating to the role and interrelationships of science and technology and the Nation's economy. There are many more, compounded by the complexities of the issues, themselves, and of the number of elements involved in such a discussion (government, industry, public interest groups, academia and the like).

In May of this year, President Carter directed that a domestic policy review be conducted that would accord the issues of industrial innovation the highest level of policy attention by the Executive Branch. Under the chairmanship of Secretary Juanita Kreps, the Advisory Committee on Industrial Innovation has been formed, composed at present of five working subcommittees. These subcommittees are on public interest, economic and trade policy, environment, health and safety regulations: patents and information; procurement and direct support of research and development; and regulation of industry structure and competition.

The recommendations and analyses of this advisory group will be carefully considered by the President in formulating Federal policies and programs to enhance and support the ability of the private sector to undertake technological innovation of economic significance.

Growth in the quality and standard of life is clearly the goal of this Administration. But those goals must be achieved without dis-

rupting the economy by way of inflation, unemployment, disruptions to regional economics, and the like. Nor can those goals be achieved through reshuffling existing resources.

Balanced growth requires innovative change in industrial processes, the skills of workers, and the economic bases of our communities. The Office of Science and Technology is dedicated to working on the Administration's team by using its expertise and its abilities to act cooperatively with other Federal agencies and the private sector in developing strategies for meeting the challenges facing today's society.

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DR. RICHARD C. ATKINSON

DIRECTOR, NATIONAL SCIENCE FOUNDATION

I will begin by tracing the role of research and development in helping to alleviate some of the economic concerns of our nation today—such as sagging productivity, loss of competitiveness in international trade, and the shortage of employment opportunities for an expanding labor force.

Next I would like to make an economic appraisal of R&D as an investment. What have been the overall returns on that investment? Are we under- or overinvesting in R&D? These questions are crucial if we are to make sound judgments about allocations of public and private funds, particularly in times of scarce resources.

First, what do we know about the degree to which R&D contribute to economic progress? By economic progress I am not referring just to the growth in the volume of goods and services, or what is commonly measured by gross national product. Many innovations do not add significantly to the volume of goods but do provide a product or service that better serves our needs. One example would be a new antibiotic which saves lives, the full impact of which cannot be measured by the GNP.

By economic progress I am referring, in the main, to increases in both productivity and real national income. Productivity indices describe the efficiency with which inputs of capital, labor, technology, and managerial skills are converted into goods and services. Real income measures the actual quantity of goods and services provided in constant terms.

Studies funded by the National Science Foundation and others provide persuasive empirical evidence that R&D and technological innovation have, indeed, played a significant role in our economic progress.

Edward Denison, in his important studies of the causes of economic growth and productivity gains in the United States over the past four decades, finds that the factor, "advances in knowledge," has been the "biggest single source" of growth. Denison estimates it accounted for about one-third of the growth in the nation's output in the period from 1929 to 1969. Between 1948 and 1969, advances in knowledge contributed 48 percent, making it an even greater determinant than inputs of capital for that time period. Even more important, however, is the contribution of advances in knowledge to productivity, or growth of output per unit of input. Denison concludes it is "the most fundamental source" of productivity gains.

Denison and others readily acknowledge that there are significant limitations to the quantitative measures used in their studies. Never-

theless, the results point in a single direction: the contribution of R & D to economic growth and productivity is positive, significant, and high. Other studies show that the returns are also significant and positive to particular industrial groups or individual firms conducting R & D with their own funds. Some typical rates of return that have been calculated in studies of specific industries are: Chemicals—30 to 50 percent; petroleum—40 percent; and food, apparel, and furniture—15 percent.

Results from studies of specific innovations also show positive and high returns. One of the leading researchers in the field is Edwin Mansfield of the Wharton School at the University of Pennsylvania.

Mansfield has examined 17 specific innovations and estimated their returns to society as a whole and their returns to the industries and firms involved. The median societal rate of return was about 56 percent. The median rate of return to the innovating firms involved (or the private rate of return before taxes) was about 25 percent. This difference results because the social rate of return includes profits to users as well as profits to the innovating firm. Both the social and private rates of return appear to more than justify the investment, with some qualifications for the private sector to which I will return.

Apart from these direct returns to the firms involved, economists also are beginning to document the indirect benefits resulting from use of R. & D.-intensive capital goods or intermediate goods. An example would be the productivity increases made possible by the use of computers in the banking, insurance, and other industries.

One study of indirect benefits found the following rates of return (as measured by productivity growth attributed to the incorporation of R. & D.-intensive goods purchased from other industries during the period 1948–1966) in 33 manufacturing and non-manufacturing industries: All industries—62 percent; manufacturing—45 percent; and non-manufacturing—187 percent.

I have passed very quickly over a very complex area of economic measurement. I hope I will be forgiven for oversimplification. The main point of these studies that I want to leave with you is not the specific percentages but the consistently high rates of return—and the fact that the return tends to be higher for the nation as a whole than for the particular firm or industry involved.

But how do these returns relate to the economic concerns of our nation today?

We know, for instance, that productivity as reported by the Labor Department (output per employee hour) has grown more slowly since World War II, and from 1966 to 1976 it has lagged behind the rate of advance in other industrial economies such as Japan and West Germany.

The causes of this phenomenon as well as the appropriate remedies are subjects of debate among economists and policymakers. But in looking for long-term remedies, hard economic data and experience suggest that the role of R & D should not be underestimated. One does not have to be an economist, for instance, to note that the expansionist, industries of today—those that are providing new jobs and income—tend to be those industries in which the rate of investment in R&D is relatively high. Computers and telecommunications—two industries represented among the medal winners here tonight—come to mind.

In some cases, of course, new technology resulting from R&D eliminates jobs. But overall it makes a net addition to employment.

A recent study by Data Resources, Inc., makes interesting reading in this regard. It shows that over the past three decades high-technology industries have led the way in economic progress. Compared with the low-technology industries, high-technology industries have grown almost three times as fast, increased their productivity twice as fast, expanded their employment nine times as fast, and, at the same time, raised their prices only one-sixth as much as the low-technology industries.

In addition, high-technology industries have been the leading edge of our exports. Our balance of trade from industries that are R&D-intensive has shown the largest surplus compared to other industries over the period 1960 to 1974. According to Commerce Department studies, the surplus increased fourfold from 1960 to 1974 and doubled between 1970 and 1974. In contrast, those products from non-R&D-intensive industries showed an increasing trade deficit during the same periods.

Given the high rates of return associated with R&D in the past, it would appear that we are currently underinvesting in this area in relation to the economic benefits to be realized. Over the past 10 years (1967–1976), for instance, Federal spending for R&D has declined by nearly 20 percent in constant 1972 dollars. Industry has generally increased or maintained the level of its R&D investment during the same period; but industrial R&D has its own requirements and cannot meet the total R&D needs of the nation. Its traditional emphasis has been at the applied research and development end of the R&D spectrum. In 1976, for instance, industry financed about 43 percent of our applied research, 49 percent of development, and only 15 percent of basic research.

The main support for basic research has come from the government and universities. Some basic economics explain why this is the case. The key concepts are risk and what economists term the non-appropriability of the benefits of research.

Any investment in R&D, of course, involves a large element of risk. But the risk increases as one approaches the basic research end of the spectrum. For the individual firm or industry, the payoffs may not be realized for 10 to 15 years. Managers and boards of directors live by much shorter time demands. Business publications report that the time allowed for R&D payoffs has recently shrunk to as low as two to three years. This is even less time than is normally allowed for payoffs in applied research.

Another reason why economists believe that the private marketplace is likely to produce an underinvestment in research from society's viewpoint is that the private investor, looking at alternative uses of capital, must be concerned with the rate of return to the particular individual or firm. R&D may produce benefits to an individual investor or firm, but much of the benefits frequently accrues to other firms or industries or to society as a whole. As noted recently by William Nordhaus of the Council of Economic Advisers: The social benefits of much—but not all—R&D exceed the private benefits. This means that not all of the social benefits can be privately appropriated.

This is especially true in basic as opposed to applied research, development, or commercialization. Some of the reasons, as Nordhaus noted, are that:

> Advances arising out of basic research are likely to apply to a very wide range of fields;
>
> Enforcement of property rights in knowledge gained through basic research over so wide a range of activities is likely to be extremely difficult;
>
> Advances arising out of basic research are likely to include unpatentable "laws of nature", and
>
> The complexity of modern technology makes for patent rights which are difficult to define and therefore difficult to appropriate.

The studies by Mansfield and other economists help to explain the degree of the government's and universities' support for research, especially basic research. As I noted earlier, Mansfield found that of the innovations he studied, the average rate of return to society on R&D investment is more than twice as high (56 percent) as that to the firms that developed the innovations (25 percent). Although the latter rate might appear high enough to justify expenditure of private funds, Mansfield concludes that it "does not seem unusually high when one considers the riskiness of this kind of investment (and the fact that these are pretax figures)." It should be noted that Mansfield regarded the innovations he studied as of average or routine importance and not major breakthroughs. They included such items as a metals industry product that reduced the cost of making household appliances, a new type of cost-saving construction material, and various chemical process improvements. One would expect that for long lead time research that leads to major breakthroughs, the social returns would be even higher. Studies underway should shed more light in this question.

From the consistent findings of positive returns on R&D, however, we can, I think, draw some conclusions. First, the economic incentives operating in the private marketplace can be expected to drive private industry to invest in research with relatively short-term payoffs. At the same time, the high social returns—particularly from basic research—would suggest that government focus on research with longer-term payoffs. The trends in Federal R&D expenditures in recent years do not, as a whole, reflect the logic of this division of investment.

Federal outlays for basic research held virtually constant from 1965 until 1976. And in 1977, estimated Federal R&D spending is divided as follows: 62 percent for development, 22 percent for applied, and only 16 percent for basic.

In stating the case for more Government funding for basic research, Nordhaus characterized the risk factor for social investments in R&D as "virtually nil." "Over reasonable periods of time," Nordhaus explanied, "successes and failures will wash; a normal rate of return for the entire group of projects is virtually certain."

It would seem, then, that R&D is a good investment for both the public and private sectors. But exactly what level of investment is appropriate, particularly in the public sector? Here we enter into a realm of public policy that is the subject of continuing debate. A summary

of a colloquium of economists finds, nevertheless, that "Recent research has reinforced the earlier findings that the contribution of R&D to economic growth/productivity is high . . ." and that ". . . there may be some underinvestment in R&D on an aggregate basis."

If we accept the thesis that we are underinvesting what can be said about the likely future returns from increments to R&D spending? Or as an economist would state the question: Have we reached marginal returns in which further investments will produce a declining rate of return? The economists who participated in an earlier NSF colloquium generally agreed that "There is good reason to expect that well diversified, incremental R&D investment will result in high payoffs similar in magnitude to those of the past."

In looking at potential areas for public investment to produce economic progress, they must be compared on the basis of their relative potential returns. In this light, science has a special attraction. The various branches of science have a tendency to build on each other. And, as Nordhaus's remarks suggest, ". . . unlike other scarce goods, knowledge is not a depletable resource. No matter how many times the second law of thermodynamics is used or abused it will remain for future generations."

Furthermore, the annual cost per scientist for research is not going up faster than inflation—another factor to consider in an era of resource scarcity. This means that additional funds will result in more R&D being done and not just "bid up" the costs.

Thus, as we look at the task of improving economic progress and productivity, investments in R&D would appear an attractive option. The agencies of Government concerned with the long-term economic welfare of our nation have repeatedly cited the important role that R&D plays. Last year, for instance, the National Center for Productivity and Quality of Working Life warned: "A continued decline in our basic research capacity will tend to have a negative effect on productivity growth."

If we wish to continue to create new jobs and better products and services and a better quality of life, I think prudence would dictate a review of both the aggregate level of our national R&D outlays and the division of that effort between the private and public sectors.

One way to measure the level of effort in the private sector is to compare total R&D expenditures to total net sales. As might be expected, this ratio varies widely among industries. But it is generally higher in technology-intensive industries such as chemicals, machinery, and communications, where R&D outlays range from a low of about 3 percent of net sales to a high of about 12 percent. This compares to less than one percent in the less technology-intensive industries such as textiles, lumber, and primary metals. It is not surprising that some of these industries are experiencing declining productivity growth rates, production cutbacks, layoffs, losses of domestic market share to foreign imports, and even plant closings.

Whether added investments in R&D would help alleviate the problems in particular industries is a matter for individual industries and companies to decide. However, from the viewpoint of aiding the national economy as a whole over the long term, the answer is clearly yes.

We have seen the practical payoffs of research time and time again. While the returns of any specific investment may be uncertain, the overall record provides strong incentives to maintain and strengthen our nation's R&D effort in both the private and public sectors. If we don't make the effort, then over the long run this nation is going to run short of the very things that made it great: new ideas, new knowledge, new developments, new industries, and economic, intellectual, and social progress.

TRENDS IN SCIENCE AND TECHNOLOGY POLICY

YOUR KEY ROLE IN SCIENCE POLICY

DR. HERBERT I. FUSFELD

DIRECTOR, CENTER FOR SCIENCE AND TECHNOLOGY POLICY, NEW YORK UNIVERSITY, NEW YORK, NEW YORK

Science and technology provide options for solving national problems, and occasionally wholly new directions for society. How effectively we make use of our overall technical resources, public and private; how we call upon science and technology to help with such broad issues as economic growth, foreign policy, and achieving regulatory standards; how we build science and technology into our pursuit of specific goals concerned with materials, energy, transportation, communication—all of this is the stuff of science and technology *policy*.

These sound like important questions and they are. But they are matters of public policy, not of technical expertise, and they are within the competence and thus the obligation of every intelligent and conscientious citizen as much as any political issue in the headlines.

There is no single national science and technology policy. Rather, there are a number of policies for involving or using science in many different arenas of national life. This is not only reasonable, but probably essential.

There is no one master plan or authority for distributing the $47 billion to be spent on science and technology in 1978 by government agencies, private companies and universities. Rather, this represents the adding up of the many separate decisions and appropriations of all the agencies, all the companies, and researchers at universities. This, too, is surely preferable to a single decisionmaker attempting to divide this vast effort in accordance with a single view of needs and solutions.

Nevertheless, the multiple decisionmaking that defines the domain of science and technology is not random, but is under the influence of a moderate number of rational forces. Some of these are market-oriented, some are political, some strategic—*all* can be influenced by public policies, clearly stated, and expressed in terms of legislation, executive orders, taxes, and treaties. *All* can and must be a matter of public debate and action.

Why should this be a matter of public focus and involvement now? The rapid growth of science and technology during and after World War II followed two simple, though unstated, policy guidelines. The federal government expanded greatly its support for the basic structure of science and for those developments for which the government was the primary customer, e.g., military and space. The private sector developed those new products and processes which went into the marketplace and increased industrial productivity.

Given the dramatic technical advances produced in part by massive federal support, it was probably inevitable that some adaptation of these techniques would be considered to address new problems arising in our society. This, starting with the economic downturn of the early 1970s, government attention began to shift to the use of science and technology within the economy and in matters of foreign trade and aid. Surely technical approaches, supported and/or encouraged by government, could stimulate the economy with needed innovation, reduce our trade deficit, balance energy production with use, improve relations with the U.S.S.R., aid developing countries. . . .

These are indeed the proper concerns of the federal government today. But now these concerns and the subsequent technical support are focusing on programs for which the government is *not* the final customer. The results can only have benefit for society following the decisions of companies to manufacture and of consumers to purchase.

Government activism in civilian sector technology means increased interaction with the private sector, and often increased conflict. In an effort to improve the efficiency of the process, we must now face questions of proper legal guidelines for government-industry cooperation, tax and patent policies to encourage innovation, possible modifications of anti-trust laws, criteria to meet regulatory standards without jeopardizing economic growth, and mechanisms whereby government with the skills investment, and marketing abilities of industry belongs to the private sector. These are the questions that make todays science and technology policy of public concern.

The critical question today in science and technology policy is how to combine the legislative authority and financial resources of government with the skills, investment, and marketing abilities of industry while preserving the independence of both. It is the obligation of technical leadership in government and industry to present issues so that the public policies involved are well defined. It is the obligation of the informed citizen to evaluate and to act upon this evaluation.

NATIONAL PROBLEMS IN TECHNOLOGICAL CHANGE

DR. JOHN G. TRUXAL

DISTINGUISHED TEACHING PROFESSOR, DEPARTMENT OF TECHNOLOGY AND SOCIETY, COLLEGE OF ENGINEERING AND APPLIED SCIENCES, STATE UNIVERSITY OF NEW YORK, STONY BROOK, NEW YORK

Important science-technology problems of today and the year immediately ahead concern those aspects of technological change which strongly impact the quality of life for all American citizens. Such impact may arise because of the interaction of the technology with the individual or with social institutions, or because of the relationship between that technological change and the state of the national economy. The problem exists because of the role of governmental policy and actions in the development of the innovation.

Certain major questions in science and technology have already received wide public attention: e.g., the development of energy technology to lead the nation toward independence or, on a more limited scale, the science of earthquake prediction and the development of a policy on levels of confidence required for public action. While such problems are clearly critical to future economic and social health, there also exists a range of less publicized problems which promise to be critically important and which fall within the concerns of the Committee on Science and Technology of the U.S. House of Representatives. In the following paragraphs, we consider briefly five such problem areas in which positive and imaginative governmental action will yield significant public benefits.

AUTOMATION OF SERVICE INDUSTRIES

Employing 60 percent of the labor force and plagued by static, low productivity, the service industries present major difficulties when we try to introduce modern information and decision-making technology—difficulties which arise because of such factors as the "cottage-industry" characteristic, the inability to aggregate markets, the low profit levels of technology suppliers, and the absence of centralized R and D capabilities.

Supermarket automation is one of the more advanced parts of the field, but even here the slow pace of innovation (with less than 400 complete systems now in place) results in a rapid fall-off in industrial interest (with only four companies remaining) and an unwillingness by these companies to invest in R and D to compete with the strong national effort in Japan. An even more unfortunate, international comparison exists in suburban motor-vehicle traffic control, where the Japanese are already testing a system with roadside computers com-

municating with microcomputers in passing cars to optimize the route to the destination to minimize travel time and cut fuel consumption.

Most of the minor national attention on automation has focused on manufacturing industries, while the principal areas for exciting technological innovation lie in the service industries. In this case, however, the role of the federal government is essential.

PERSONAL TECHNOLOGY

Within this category, we refer to technology for the individual, particularly the citizen who is a member of a group with special needs. Technology for the physically handicapped is one area in which significant developments have been rare, primarily again because of the poorly defined market, the time lag in development which exceeds a reasonable investment period for industry, and the absence of organized and well-directed R and D.

The Kurzweil reading machine for the blind or the cardiac pacemaker are examples potential of modern technology, but there are no real parallels in mobility aids or artificial limbs. If the Exxon Research claims for liquid membranes to cut sharply the required dialysis frequency for artificial-kidney patients prove correct, the dollar saving for the government and improved quality of life for patients promise to be impressive, but mechanisms must be developed to accelerate the introduction of this technology.

Personal technology goes far beyond biomedical engineering, however, to include technology for the aged (for transportation, entertainment, and useful employment), for the individual in his home and anxious to learn in new areas, and for the citizen seeking "appropriate technology" for amelioration of energy-consumption, communication, and other problems. For instance, the over-illumination of the American interior represents an exciting potential for major energy conservation, but the engineering community has not made available the instrumentation, the technology, or the know-how.

In all the cases of personal technology, directed use of the federal government purchasing power represents a seldom-used opportunity for stimulating technological innovation.

PERSONAL COMPUTERS

Personal computers are now primarily used for games or hobbies, but the inexorable drop in cost toward essentially no-cost hardware and the expanded utilization of low-cost (audio and video) technology for software foretell the use of millions of microcomputers within the next decade in the house, office, and car.

Serious consideration now needs to be directed toward the form of the future, home communications-computing console and the federal role in the regulation of the external communication system. With the Japanese now operating a fiber-optic link of 55 kilometers without a repeater, the "wired city" or, more likely, "wired suburbia" is close enough to demand planning.

The anticipated use of microcomputers (e.g., in automobiles) by 1985 has another critical aspect: to what extent can system mainte-

nance be automated, or will we be limited by the availability of trained technicians? The training and educational system of this country is remarkably conservative and slow to changes.

MINORITIES AND WOMEN

Even though major efforts have been made in the last five years to attract more minorities and women into science and engineering, this country still is far from equity—a situation that becomes increasingly serious as the societal environment grows more and more technological, as we experience shortages of qualified technical people, and as positions of industrial and governmental leadership require technical abilities.

Since 1973 private industries and foundations have invested $40 million in the national minorities-in-engineering effort; the federal government investment (primarily through the National Science Foundation and HEW) has been very much smaller. Indeed, at the September National Research Council symposium in Washington, federal representatives were noticeably forced to discuss programs in health sciences and pure sciences—neither really directed toward the interests of minority young people in relevant, people-oriented careers based on the physical sciences and mathematics.

The national effort in engineering (and the older program in medicine) has demonstrated that attention must be focussed on education in the secondary schools, where girls and minority youth turn away from quantitative subjects. A relatively minor federal commitment would catalyse and direct private efforts in an effective, continuing national program which could realize population parity among engineering and applied science graduates in a decade—thereby achieving equity in educational attainment as well as education opportunity.

TECHNOLOGICAL LITERACY

Throughout the above items as well as areas such as energy and earthquake prediction, there is a common problem: inadequate public understanding of modern technology. Any hope for significant energy conservation is unrealistic when there is a general lack of awareness of the basic concepts of energy use. Supermarket automation is fought by a public unfamiliar with either the technology or the economic system. Personal computers can have an impact on education only to the extent of minimal public understanding. Excessive fire losses in property and life in this country compared to any other nation come, at least in part, from widespread ignorance about the science of fire and the technology of prevention, detection and control.

The National Assessment of Educational Progress has clearly documented the weakness of public technological literacy. Although the National Science Foundation has publically emphasized this area within its Science Education Directorate since 1970, the major programs are still addressed to the pure sciences and the education of future scientists. Mass media have not been used effectively (one recent survey showed young people have no awareness of the Nova series on television, for example).

Technology or applied-science literacy is vital for the individual interacting continually with the technological environment and also essential if rational public decisions are to be made on national issues such as benefit/risk analysis of chemical use or auto passive restraint systems. While education is a local responsibility, the federal government has an obligation to provide materials and teacher training in areas of vital national concern. As just one example, the absence of any significant experience in fire in pre-college education represents a problem of national importance.

In presenting these areas, we have attempted to discuss the concepts with specific, illustrative examples—references to particular areas of science and technology. Each of the five areas could easily be expanded to embrace the wide range of problems which confront a society so strongly technological, where science impacts so fully on the individual, and where technological innovation is so critical for economic health.

SCIENCE, TECHNOLOGY AND PUBLIC BENEFITS

DR. ANNA J. HARRISON

PROFESSOR OF CHEMISTRY, MOUNT HOLYOKE COLLEGE, SOUTH HADLEY, MASSACHUSETTS, AND PRESIDENT, AMERICAN CHEMICAL SOCIETY

The benefits to be derived by society through the use of science and technology are determined by the value judgments made by the public and by the productivity of the scientific and technological community. The two are closely coupled.

As an academic chemist, my commitment to the value of basic research has been and is essentially an article of faith. As a member of the National Science Board (1972–1978) and as a current officer of the American Chemical Society, I have been and am deeply concerned about the social, economic and political factors which impact the productivity of the scientific and technological community. These flow from the value judgments made by the public and it is this aspect of the total picture that I shall seek to address in this letter. The word "public" will be used to refer to all of those who have the right to participate in the democratic process through the exercise of the right to speak and the right to vote.

All technological change, regardless of how great its positive contribution to society, has associated with it negative impacts. This is a characteristic of change, all change, and is in no way a unique characteristic of technological change. One example: development in medical technology have served society well; these same developments have also contributed to our unprecedented population growth and all of the problems associated with greater numbers of peoples.

Herein lies the basis of the concept of benefit/risk analysis. This is a useful concept; its evaluation, in the quantitative sense, eludes us. Our capacity to perceive the future seldom, if ever, encompasses either the total benefits or the total risks. If both benefits and risks can be evaluated in dollars, economists can, at least in principle, arrive at a numerical value for the benefit/risk ratio. Similarly, if the benefits and risks associated with a particular drug can be evaluated in terms of lives saved and lives lost, the medical profession can, at least in principle, assess a numerical value for the benefit/risk ratio. If benefits are in terms of lives and risks in terms of dollars, or vice versa, the ratio can only be evaluated by assigning a dollar equivalent to life. To do so is a value judgment par excellence. In most cases, benefits and risks are both complicated functions involving short term and long term social, economic and political consequences.

The concept of benefit/risk analysis is a useful concept and every effort should be made to understand the nature and the magnitude of all benefits and all risks in whatever units they can be assessed. Such information, inadequate as it may be, is the only rational approach to

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the value judgments that must be made as to the net value to society of a given technological development.

The public is, for the most part, not prepared either psychologically or philosophically to capitalize upon the opportunities and to accept the responsibilities inherent in the use of modern science and technology. Much of the public does not understand the nature of and the consequence of either scientific capabilities or technological options and much of the scientific and technological community does not understand the nature of the social, economic and political matrix of which science and technology are a part. This limitation of understanding is a significant barrier to meaningful communication and a significant barrier to the intelligent use of science and technology in the service of society. I believe it to be the greatest barrier and that we must re-evaluate our educational programs in science for all students, those who are to become professional scientists and those who are not.

It is too early to assess, but it is timely to pursue, the factors that have led to the frequency and the vehemence with which the implementation of technological options are opposed by segments of the public. Four such factors are readily identifiable:

For a time, the rate of introduction of technological options was unprecedented in terms of total numbers and in terms of diversity.

A great deal is being learned about toxic responses, particularly chronic toxic responses, to exposures of radiation and to exposures of specific chemical substances and combinations of chemical substances.

An expanding population has placed unprecedented demands upon renewable and nonrenewable resources and placed an unprecedented burden of waste products upon the environment.

That which is socially acceptable in one period may become unacceptable in another.

I suspect that historians will attribute an abrupt change in attitude toward the conservation of the world's resources and the protection of the world's environment to the emotional impact of those magnificent space photographs of the earth as it receded into the distance. It was not that the photographs provided us with new information but that the photographs so dramatically portrayed the finite nature of the planet and its beautiful but fragile environment.

I also suspect that for a time the scientific and technological community sold, or more probably the public bought, an unrealistic concept of that which science and technology can deliever. So many wonderful things had been produced, it was perhaps easy to assume that science and technology can produce anything, including a riskless society. This, for a time, was compounded by confusion as to who is to make those inescapable value judgments in regard to the use of science and technology—the total public or the scientific and technological community. This conflict is now clearly resolved in favor of the public as defined earlier but apprehension lingers on.

The Committee on Science and Technology is a surrogate for the public in making value judgments as to the appropriate role for science and technology in our democratic society. The Committee on Science

and Technology is also the designated leader of Congress to develop appropriate mechanisms to facilitate the fulfillment of the role for science and technology. The decisions made and the actions taken are powerful forces in determining the future of the nation and the quality of life of its people.

The scientific and technological capabilities of this nation are a living legacy of unprecedented value.

NEEDED: A REALISTIC ENVIRONMENT FOR SCIENCE AND TECHNOLOGY

DR. ANNA J. HARRISON

PROFESSOR OF CHEMISTRY, MOUNT HOLYOKE COLLEGE, SOUTH HADLEY, MASSACHUSETTS, AND PRESIDENT, AMERICAN CHEMICAL SOCIETY

The number of letters received following the publication of an earlier Comment, "Needed: champions for an informed public" (C&EN, June 26, page 25), far exceeded those previously received by me on any other single topic. Those letters plus a number of discussions concerning that Comment lead me to believe that it would be useful to extend the analysis of some elements of the previous Comment.

This Comment is based upon the thesis that long-term benefits derived by society from science and technology are directly related to how realistic the environment is for science and technology. An unfavorable, but unrealistic, environment could unnecessarily deprive the public of goods and services that are currently technologically feasible and would unnecessarily impede research and innovation leading to goods and services that would serve the public well. The loss to society goes beyond the goods and services themselves to include the impact upon our domestic economy, the availability of employment opportunities, and the U.S. international competitive position in technological matters.

A favorable, but unrealistic, environment could and probably would enhance the support for research, and would accelerate the innovative process and all of the things that flow from the technological process. Undoubtedly, there would be short-term gains in some sectors. But the risk is high that the euphoria would dissipate, the accommodation to reality would be difficult, and the consequences of an overswing to an unfavorable, but equally unrealistic, environment would be traumatic. It may be that we have seen and are now experiencing such an overswing.

On balance, society, including the scientific community, will be best served by a realistic environment. To achieve a realistic environment for chemistry and chemical technology is a goal we can pursue constructively and effectively and in the process increase our understanding of the relation of chemistry and the chemical profession to society as a whole. Being a scientist in no way ensures that one understands the relation of science and technology to society. My conclusion is that very few of us do, but that a rapidly increasing number of scientists are making an effort to do so, and that employers are increasingly seeking employees who have an interest in these matters.

There are tremendous advantages in seeking to foster a realistic environment for science and technology. In the first place, it is in the best interest of all of society, including the scientific community, to do

so. In the second place, with that as a goal, scientists will be more willing to explore with all others the relation of science and technology to society and in the process examine and re-examine current assumptions, evaluate and re-evaluate current practices. Many of these assumptions and practices are social, economic, and political as well as technological. There can be no sacred cows. We can be more objective; we can be active without becoming aggressive or defensive. We can be advocates on selected issues without unduly provoking others to become aggressive or defensive.

What are the primary characteristics of a realistic environment? If we are to foster these characteristics, we should know what they are. They are about equally divided between science and technology in general, and chemistry and chemical technology in particular. A realistic environment is a public including scientists that understands that:

Sciences are amoral.

The use of science and technology may be judged by society to be moral, amoral, or immoral.

All technological change (all change for that matter) has a positive as well as a negative impact on some segments of society.

There are things science and technology can accomplish, and things that science and technology cannot accomplish (i.e. create a risk-free technology).

Innovation is a slow process based upon technological competence but highly dependent upon social, economic, and political factors.

The extension of scientific knowledge is a slow process and the productivity of 20 research scientists working for 20 years cannot be matched by 400 research scientists working for 1 year.

There are areas in which scientific knowledge can be extended rather quickly and other areas in which scientific knowledge can only be acquired through sustained periods of effort.

The numbers and quantities of natural chemicals far exceed the numbers and quantities of synthetic chemicals produced by industry.

Synthetic chemicals are a large factor in achieving the high standard of living enjoyed by technological societies.

It is the exposure to chemical substances and combinations of chemical substances that leads to acute and chronic toxic responses in specific species of plants and animals.

Toxic responses to exposures to chemical substances are in no way limited to synthetic chemicals.

Much of medicine is the selective and controlled use of chemical substances to produce toxic responses.

Some of the traumatic misadventures associated with exposure to chemical substances have arisen through a lack of scientific knowledge but many have been the consequence of mismanagement.

A number of other characteristics could be listed. The ones listed here may not even be the most important. The list is, however, sufficient to indicate that each of these can be dealt with and that none of these is particularly difficult; moreover, each solution leads to another. To

address the problems is absolutely essential if we are to achieve a realistic environment for science and technology.

The above contrasts sharply with endeavors seeking to create a "favorable image" by focusing exclusively on the positive contributions of chemical technology to our life style and our standard of living. There is much that can be said and should be said about these accomplishments. But to merit creditability, we also must address the problems publicly. Much of the public knows or at least suspects that problems exist. They deserve to know that the chemical profession is concerned and what we are doing to identify and to alleviate these problems. To emphasize the positive and deny the negative can become merely a public relations activity or be perceived as such by the public, and in the long run may be neither justified nor creditable.

The chemical profession is achieving a new level of maturity and it is time to get on with the business of fulfilling our unique role in society.

THE DICHOTOMY IN NATIONAL SCIENCE POLICY

EMILIO Q. DADDARIO

CHAIRMAN, BOARD OF DIRECTORS, AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE, AND FORMER MEMBER OF CONGRESS

In acceding to your request to make some comments on the general theme of "science policy", I would like *not* to go over old ground. Over the years, since its formation in 1958, the Committee on Science and Technology has tried to shape, through numerous public hearings and reports, an identifiable role for science and technology in the attainment of our national goals and objectives. One is bound to hear over and over again that while science and technology are at the source of many of our problems, the failure is in the way man has chosen to use them. It will be repeated that while man has made them the instrument of progress and a way to improve or assure quality, he has also, on his baser side, made them the servant of his aggression and his greed.

In recognition of those basic assumptions, your committee in various ways has emphasized the following: the importance of the *physical* sciences in controlling population and learning how to recycle our resources, at the same time gaining better control of the environment; the *social* sciences in reshaping our goals, values, economic beliefs as part of a more accurate understanding of what man really wants out of life; and the *political* sciences in providing a legal and political framework within which reasonable people can better recognize and presumably better accept the limitations of this new world we live in and without which all new knowledge may very well prove impotent.

In that process you have tried to involve the whole of the Congress, establish improved relationships with the Executive, and seek the advice of a wide variety of non-governmental advisors. And although the problems of the present are persistent, and those of the future difficult even to define, you have established a reputation for concern about both.

I am troubled somewhat, however, by a dichotomy I see developing at a time when there is the appearance of more support for science and technology. It was under your leadership that the Office of Science and Technology Policy was established and so structured as to strengthen the decisionmaking mechanisms within the Office of the President. From all accounts you have done your work well, for it seems to have been of use to the President. That the OSTP has not made full use of the authority given to it under the basic legislation is a circumstance I find disturbing.

It is frequently difficult to maintain a continuing working relationship between the Legislative and Executive branches in a given area once a piece of legislation concerning it has passed. For the Con-

gress to expect the Executive to provide a series of major reports on Science and Technology, for example, may very well place an onerous burden on the Executive. Such tasks may not always be of vital importance. Yet what your committee was attempting to do, I am sure, was assure the improvement of the scientific and technical capabilities of both branches.

Since the middle 1960's the funds for science and technology have had to compete with an increasing number of other issues which have gained budgetary prominence. This is understandable, and yet we are fortunate that there are some Members of Congress who are willing to give their time and attention to long-term scientific objectives which do not have the attraction of immediate political appeal. That was a major reason why the Committee on Science and Technology was created. Former Speaker John McCormack often said, in referring to that aspect of the Committee's work, that Congressional specialists on science and technology were of great importance in this modern technological age. If the White House can share that philosophy and deal with Congress on a continuing basis about such matters, it will be helpful to both the Executive and Legislative branches.

There is hardly a problem which does not look to science and technology for at least part of its solution. Hence, your committee stipulated in the Science Policy Act.

> Comprehensive legislative support for the national science and technology effort requires that the Congress be regularly informed of the conditions, health and vitality, and funding requirements of science and technology, the relation of science and technology to changing national goals, and the need for legislative modification of the Federal endeavor and structure at all levels as it relates to science and technology.

This was not intended to push an unnecessary burden onto the Executive. It was in recognition of the need to be kept informed of the changing circumstances of our society and the hope that skills could be developed to be sure science and technology are applied wisely and effectively—not corrupted, misused or devoted primarily to parochial political ends.

On the basis of my experience with Science Policy, in and out of Congress, I am sure that there was no intent in the 1976 Act to get the Legislative branch involved in operational matters which are properly the domain of the Executive. There *was* an intent to create a continuing dialogue between the branches on matters of policy. It is my impression however, that the latter purpose is being implemented on a somewhat pro forma basis.

The relationship of OSTP's director to the President appears to be very good and his role as Science Advisor quite effective. The utility of OSTP itself, however, if measured in terms of carrying out the functions stipulated in P.L. 94–282, seems in considerable doubt.

I believe the experiences of your committee, as well as those of the Senate Commerce Committee, suggest that much of the Science Policy Act is being ignored, farmed out to other agencies, or given only casual treatment. This appears to apply with regard to most sections of the Act—including the reporting requirements of Title II, the survey requirements of Title III, and any real implementation of Title IV's "Coordinating Council."

This is unfortunate, in my view, especially the loss of the essential *independent* survey of Federal Science and Technology activities and needs which followed Reorganization Plan No. 1 of 1977. Of course, that is water over the dam.

Mr. Chairman, I do not mean these comments to be pejorative. I am sure the Administration and OSTP are faced with conditions and circumstances about which most of us are unaware. Moreover, we do know that OSTP has been given minimal funds and personnel and must, of necessity, place its efforts and resources in accordance with the Executive's determination of priorities.

Yet I am sure your committee will persist in its efforts to see the Science Policy Act—on which Congress and the Executive Office worked so carefully for so many years—fully administered in the future. In any absolute sense, I am convinced that such administration must occur if our nation is to retain (or regain) its leadership in world affairs, as well as provide all reasonable support for the needs of its people.

The crux of the matter is well stated in the opening lines of the Science Policy Act:

> The general welfare, the security, the economic health and stability of the Nation, the conservation and efficient utilization of its natural and human resources, and the effective functioning of government and society require vigorous, perceptive support and employment of science and technology in achieving national objectives;

It is this broad approach integrated to include both the Executive and legislative branches, with OSTP serving as the focal point, which I believe is needed.

Perhaps there is nothing new in this. But as a great French philosopher once remarked: "All this has been said before—but, since few have listened, it must be said again."

U.S. SCIENCE AND TECHNOLOGY POLICY: QUO VADIMUS?

DR. VICTOR BASIUK*

CONSULTANT IN SCIENCE AND TECHNOLOGY POLICY, WASHINGTON, D.C.

This paper is addressed to the question of the direction of U.S. science and technology in general and in particular to the organization and operations of the Office of the Science and Technology Policy (OSTP) in carrying out the statutory functions assigned to it by the National Science and Technology Policy, Organization, and Priorities Act of 1976 (Public Law 94–282).

In developing some perspectives on this subject, I shall draw especially on findings derived from my work for the Commission on the Organization of the Government for the Conduct of Foreign Policy ("The Murphy Commission"). My responsibility at the Commission was to examine U.S. Government organization for science and technology as related to foreign policy and recommend organizational options.[1] Inasmuch as, in areas of science and technology, domestic and foreign policy elements are so intertwined as to be virtually indistinguishable, my examination focused on the effectiveness of organizations as such, rather than specifically on their application in foreign affairs only.

The functioning and the adequacy of our national science and technology machinery can be best comprehensively assessed in a broader context of the function of the U.S. Government and the nature of decision making which it generates.

NATIONAL DECISION MAKING AND SCIENCE AND TECHNOLOGY

In theory, we can make a distinction between two apparently opposite "pure" types of decision making: "constituency" and "rational." "Pure" consituency decision making is essentially a political process in which each group, interest, or organization ("constituency") narrowly pursues its own self-interest and competes with the others. The ultimate decision is the outcome of this competition between the various constituencies; it may or may not be in the best interest of the nation as a whole.

The "rational" type of decision making involves consideration of all the relevant factors in a given issue or set of problems and a policy decision based on what is in the best interest of the nation. The inter-

*Dr. Caryl P. Haskin's comments on this paper are gratefully acknowledged. Of course, I alone am responsible for its content.

[1] See Victor Basiuk, "U.S. Government Organization for Science, Technology and Foreign Policy," in Commission on the Organization of the Government for the Conduct of Foreign Policy, Appendixes (Washington, D.C.: U.S. Government Printing Office, 1975), vol. 1, pp. 192–205. This is my report to the Commission, published in an abridged form.

ests of the various groups bearing on the subject are given due consideration and, to the extent justifiable and compatible with the overall national interest, their claims and desires are met. However, in the last analysis, the decision would be based, as objectively as possible, on the good of the nation as a whole. It should stand above the power, vociferousness, bureaucratic skills, or similar attributes of a particular constituency.

Each of these two types of decision making has its advantages and disadvantages. While in their "pure" forms rational and constituency decision making can be envisioned as opposite poles of a spectrum, in practice decisions are actually made between the poles by combining both rational and constituency elements. The question is: Where to strike a balance between the two in a particular period of history?[2]

In the past, nearly "pure" constituency decision making was predominant in the United States and it made a major contribution to the growth of the nation. Operating in a laissez-faire environment with a lot of space for maneuver and a continent to conquer, the various interests were competing between and among themselves in the development of the nation's resources and industries. But as the process of developing the continent was completed, as competition for dwindling resources intensified, as the world became more interdependent, and as the United States found itself increasingly in competition with other nations, the concept of the national interest—emphasizing "rational" decision making—has gained in importance. An awareness emerged that although there is some validity to the statement that "what's good for General Motors is good for the country," not everything that is good for General Motors is necessarily good for the country.

The theory of the U.S. Government combines the rational and the constituency approaches to decision making. The President, who represents the interest of the nation as a whole, is expected to be guided mainly by the rational approach. He is the ultimate arbiter as to whose claims are to be satisfied in order to maximize the benefit to the United States. The President is also responsible for steering the country in the direction of "progress," however defined at a given time.

The various executive departments and agencies are, in part, expected to incorporate the rational method in their internal decision making and in their relationship to the President, since they, too, have a responsibility to the nation. But they also act for their particular segment of the national decision making process—labor, commerce, foreign affairs—and pertinent vested interests find their expression through governmental departments and agencies. Their activity is thus strongly influenced by their constituency roles.

The establishment of the position of the Special Assistant to the President for Science and Technology ("Science Advisor") and the creation of the Office of Science and Technology (OST) as his staff in 1957 represented primarily an expression of "rational" decision making. It was recognized that scientific and technological considerations must be introduced at the highest level of the U.S.

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[2] The constituency and the rational decisionmaking are discussed at greater length in Victor Basiuk, "Technology, World Politics and American Policy" (New York: Columbia University Press, 1977), pp. 197–200.

Government in order to ensure that they are not overlooked and are properly balanced with other top considerations in the national interest. At the same time, there was a constituency connotation in the establishment of the Office of the Science Advisor to the President; it acknowledged the importance of the scientific and technological community as a group whose voice should be heard at the highest level.

THE EARLIER STAGES OF THE NATIONAL SCIENCE AND TECHNOLOGY POLICY APPARATUS: THE WHITE HOUSE AND THE NSF

Apart from certain mission-oriented technical agencies—such as NASA and NSF—science and technology were and still are widely dispersed throughout the U.S. Government. Because of their dispersion and pluralism, science and technology as an area of policy concern exhibit perhaps more of constituency characteristics and competition for national resources among the various components than most other fields.

Acting on behalf of the President, the Science Advisor and his staff—principally embodied in the Office of Science and Technology (OST)—would have been expected to overcome the dispersion and compartmentalization of the U.S. science and technology effort and to provide it with a sense of direction. There was awareness in OST of its role in the national decision making. But, by and large, it was not especially successful in carrying out its mission.

The competence of the White House science and technology policy apparatus was predominantly biased toward the scientific and technological side. It was weak in its understanding of social goals, of the potential role of science and technology in achieving them, and in general of the impact of science and technology on society. The shortcomings of OST in this regard were especially manifest in 1971. OST was patently slow in appreciating the importance of, and acting upon, the declining leadership of the United States in high technology products and the U.S. unfavorable balance of trade which emerged then for the first time since 1893.[3]

Although the Science Advisor and OST were nominally responsible for the formulation of science and technology policy, the ultimate decisions on policy were left to the White House political arena, and here the science and technology policy machinery did not carry much weight. A number of other organizations in the Executive Office were involved in science and technology policy (e.g., the Office of Management and Budget, the NSC, the Council on Environmental Quality, and the Office of Telecommunications Policy), and OST had no control over them. Perhaps even more importantly, OST had little "clout" over the operating departments and agencies involved in science and technology —the "constituencies." OST could modify their budgets and programs marginally here and there. However, in the last analysis, it was the political interplay among the "constituencies,"

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[3] Going over the head of OST, the President, in September 1971, appointed an outsider, William M. Magruder, as his special consultant, with the task of mobilizing science and technology in support of the economy. Acting on a crash basis, Magruder produced in a couple of months the so-called new technological opportunities program, which was much too hastily created to provide a solution and proved to be unacceptable to the White House because of its high cost. See Claude E. Barfield, "Science Report: White House Views Intense Technology Hunt as a Useful Exercise, though Few Projects Emerge," National Journal, vol. 4 (May 6, 1972), pp. 756–765.

projected to, and somewhat modified at, the White House arena, that determined the course of U.S. science and technology policy and not the Science Advisor and OST.[4]

The White House S&T policy apparatus was also handicapped by the fact that it itself displayed certain characteristics of a constituency. It tended to represent the interests of the scientific and technological community, with partiality for science being more pronounced than that for technology. The constituency outlook of the White House science and technology machinery was not especially strong,[5] but the image persisted and tended to weaken the credibility of the Science Advisor and OST at the White House level and elsewhere.

President Nixon's transfer of the Science Advisor from the White House to the National Science Foundation in 1973 was a politically motivated act, but more fundamentally it reflected the lack of effectiveness of the Science Advisory apparatus.. The status and "clout" of the Science Advisor to the President, now in NSF, were reduced. His staff, principally embodied in the Science and Technology Policy Office (STPO), adapted itself to the situation. Unlike OST, which had a rather Olympian attitude with regard to the agencies dealing with science and technology, STPO injected itself into the governmental process, trying to be useful to the many S&T activities conducted in the government.

This more flexible and pragmatic approach could have been an improvement. It opened the opportunity to get direct access to influential personnel in the operating agencies, to persuade them, and to bring about desirable change from the inside. But to be fruitful, such an approach required a clear-cut identification of priorities, of the leverages necessary to bring about desirable change in accordance with those priorities, and a strong perception on the part of the Science Advisor and his staff of the imperative of acting in the interest of the nation as a whole. To put it differently, the Science Advisor to the President had to act with a view of the role of the President, even if he and his staff were neglected by the President.

The Science Advisor and STPO, however, lost the perception that they were acting on behalf of the President and the nation. In a number of cases, they provided useful advice and assistance. But even excellent scientific and technical advice aimed at strengthening a constituency—be it a technical government agency or a group with an interest of its own—serves the national goal only if the interest of this constituency coincides with the national interest and to the same degree. This is by no means always the case. Helping most everybody in the government with good science and technology advice can on occasion run counter to the interest of the nation.

In spite of being in NSF, the Science Advisor and STPO appeared to have less of a constituency outlook than their predecessors. How-

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[4] The problem of responsiveness of operating agencies to the activity and initiatives of OST was continuous, but it can be illustrated by a single case which is rather striking in the light of later developments. As early as 1964. OST produced a major, future-oriented study which urged long-range development of alternative sources of energy. The study was considered at an interagency level, but the existing agencies saw no particular advantage to themselves in implementing the study and it was quietly shelved. See Executive Office of the President, Office of Science and Technology, Energy Study Group, "Energy R&D and National Progress" (Washington, D.C., 1964).

[5] It was more pronounced in the President's Science Advisory Committee (PSAC) than in OST.

ever, the scientific and technological community—their constituency—felt strongly that the Science Advisor should be in the White House. As President Ford assumed office, pressure began to be generated by scientists and engineers to restore the Science Advisor to the President to the Executive Office.[6] The position of the scientific and technological community was supported by many other individuals (including those in the Congress) who believed that the national science and technology policy machinery should be strengthened and that it properly belongs at the highest level of the U.S. Government. These developments led to the passage of the National Science and Technology Policy, Organization and Priorities Act of 1976.

THE NATIONAL SCIENCE AND TECHNOLOGY POLICY, ORGANIZATION, AND PRIORITIES ACT OF 1976 (PUBLIC LAW 94-282)

In several ways, the provisions of Public Law 94–282 attempted to remedy the shortcomings of the previous science and technology policy machinery, both in the White House and the NSF. To return to the distinction between rational and constituency decision making, the Act placed greater emphasis on the rational mode by strengthening the Office of the Science Advisor to the President and introducing a number of stipulations which, if implemented, would have given the national science and technology policy both added coherence and an added sense of direction.

The appointment of the Science Advisor to the President—now called the Director of the Office of Science and Technology Policy (OSTP)—became subject to advice and consent of the Senate, a requirement which, at least symbolically, strengthened his office. A similar strengthening feature was the provision for up to four associate directors, also subject to Senate approval. OSTP was further potentially strengthened by the requirement that the President transmit to the Congress an annual Report on Science and Technology, to be prepared by OSTP.

The Act emphasized the development of a coherent approach, comprehensiveness, and a sense of direction in U.S. science and technology policy. By requiring a production of a five-year outlook on current and emerging problems and the identification of the potentials of science and technology for resolving them, it provided an avenue for assessing and anticipating both the opportunities and the hazards presented by modern science and technology and for future-oriented planning.

Public Law 94–282 did not provide for long-range planning as such, but it did specify that a two-year President's Committee on Science and Technology stipulated in the Act should consider, among other things, the need for "long-range study, analysis, and planning in regard to the application of science and technology to major national problems and concerns." [7]

There is no explicit provision in the Act designed to strengthen the authority of the Director of OSTP with regard to operating depart-

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[6] See e.g., "Scientists Want the President's Ear," press release of the Federation of American Scientists (FAS), dated Dec. 27, 1974; a letter from Dr. Alan C. Nixon, chairman, Committee of Scientific Society Presidents to the President, dated Oct. 9, 1974; and "Organization for Science and Technology in the Executive Branch; AAA White Paper," Science, vol. 187 (Mar. 7, 1975), pp. 810–814.

[7] Subsec. 303(a)13 of Public Law 94–282.

ments and agencies.[8] However, through the establishment of the two-year President's Committee on Science and Technology, the Act made a stipulation which could have led to such an outcome. A principal function of the Committee was to examine the entire Federal scientific and technological effort and to consider, among other things, need for organizational reforms.

The issue of the relationship of the Director of OSTP to the operating agencies was, in effect, delegated to the President's Committee. The latter could have faced it directly or could have resolved it indirectly by recommending reforms of the U.S. science and technology effort which would have made that effort more responsive to the national science and technology policy machinery at the White House.

While, through Public Law 94–282, the Congress undertook to strengthen the rational approach to decision making in the White House science and technology policy machinery, it did not overlook the vitality and other advantages which constituencies bring into the national decision making process. Under Section 208 of the Act, the Director of OSTP is expected to consult with State and local governmental agencies, with appropriate professional groups, industry, the universities, agriculture, labor, consumers, conservative organizations and other public interest groups. The Congress provided for hearings to be conducted in various parts of the nation in order to solicit the views of the above groups and organizations, as well as the general public, concerning national needs and trends in science and technology.

In summary, Public Law 94–282 appears to have attempted to strike a new balance between rational and constituency decision making in science and technology policy, a balance which would place greater emphasis on the rational decision making.[9] Moreover, in formulating Public Law 94–282 the Congress, apparently, did not consider the machinery it established as the last word on the subject. It was to be further modified and expanded in response to the findings and recommendations of the President's Committee on Science and Technology. In short, the Congress appears to have realized that the subject of the national science and technology policy and organization is much too complex to be legislated into life by a single act. An initial framework must be established, but then the field must be examined in greater detail by appropriate instruments and further changes and improvements must be made.

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[8] Public Law 94–282 provided for the establishment of the Federal Coordinating Council for Science, Engineering, and Technology (FCCSET) to coordinate the activities of Federal agencies in science and technology. The Director of OSTP is designated as Chairman of the Council. Actually, the establishment of the FCCSET is little more than the resurrection of the old Federal Council for Science and Technology (FCST) under a different name. The FCST was a fairly weak body which typified the extremes of constituency decision making process. It was useful for exchange and information, coordination in secondary matters, and avoidance of obvious duplication. However, it was not very useful for determining priorities and implementing them, since the agencies involved tended to consider their respective interests as being of primary priority.

[9] A major exception in this regard was military R. & D., an important constituent element of science and technology which was left largely outside of the purview of the Director of OSTP. In accordance with subsection 207(f) of Public Law 94–282, the Director of OSTP, *"at the request of the National Security Council*, shall advise the National Security Council in such matters concerning science and technology as relate to national security" [emphasis added]. OST used to have jurisdiction in military R. & D., but when the Science Adviser to the President was moved to NSF, his authority in this area was severely curtailed. Apparently, the limited authority of the Director of OSTP in the military sector was a concession to the Ford administration, which was not fully convinced of the utility of the Science Adviser in the White House and was not prepared to give him substantial power.

Any effort to assess the organization and operations of OSTP in carrying out the statutory functions assigned to it by Public Law 94–282 by an individual who does not have close personal familiarity with that Office or ready access to it must be incomplete and, in some respects, tentative. However, if we place our assessment in the perspective of OSTP's predecessors, certain generalizations and conclusions are possible in spite of the relatively limited availability of information.

The Reorganization Plan No. 1 of (July) 1977 significantly changed the substance of Public Law 94–282. The President's Committee on Science and Technology (PCST) was abolished. Its function to examine and reorganize the U.S. science and technology effort was transferred to OMB. The Director of OSTP was expected to provide advice to OMB on this subject. The other functions of PCST were assigned to OSTP. The responsibility for preparing the annual Report on Science and Technology for the President and the five-year outlook were initially taken from OSTP and transferred to the President, but later assigned to the National Science Foundation.[10]

The Reorganization Plan No. 1 of 1977 affected some of the key components of Public Law 94–282. Insofar as they have not been carried out or as their implementation was degraded, the design of the Act suffered. Various organizations and programs in the Federal science and technology effort have been established incrementally over decades. Their organization and activities have never been examined in a comprehensive fashion to ensure their rationality and avoidance of duplication.[11] Moreover, as the experience of previous administrations suggests, organizations in science and technology were not responsive to the efforts—to the extent that they existed—of the Science Advisor to the President and his staff to rationalize science and technology policy and to give it a sense of direction.

Preoccupied with top presidential initiatives—such as the establishment of the Department of Energy and the Civil Service reform—OMB assigned low priority to the organization for science and technology. There is no indication at this point when this subject will be addressed.

Thus, receiving no assistance from a reorganization which could have made the operating agencies more responsive to its leadership, constrained by the President's emphasis on cabinet government,[12] its

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[10] The Reorganization Plan No. 1 of 1977 also abolished the Federal Coordinating Council for Science, Engineering and Technology (FCCSET) and the Intergovernmental Science, Engineering and Technology Advisory Panel (ISETAP, responsible for identifying, and dealing with, problems on State, regional, and local levels). Later, however, these organizations were reconstituted by the President. For details, see Dorothy M. Bates, "Implementation of the National Science and Technology Policy Organization and Priorities Act of 1976 (Public Law 94–282) : A Two-Year Status Report" (Washington, D.C. : Congressional Research Service, the Library of Congress, Aug. 30, 1978), pp. 26–31, and the testimony of Dr. Frank Press of Feb. 10, 1978, in U.S. Congress, Senate, Committee on Commerce, Science, and Transportation, Subcommittee on Science, Technology and Space, hearings, 95th Congress, 2d sess. (Washington, D.C. ; U.S. Government Printing Office, 1977), pp. 110–111, 147–148.

[11] The annual budgetary review by OMB, conducted under pressure of deadlines, deals only with large aggregates and has a short span of vision. It is therefore not an adequate substitute for an organizational review in an effort to avoid the overlapping or duplication of activities.

[12] In response to questions from the Senate Subcommittee on Science, Technology, and Outer Space, Dr. Press stated that the President's emphasis on cabinet government had precluded him from undertaking long-range planning, which would have been viewed as interference into the internal management of the agencies. Dr. Frank Press' testimony of Feb. 10, 1978, op. cit., pp. 155–156.

four associate directors never appointed, and handicapped by its small size, OSTP has failed to achieve what apparently was the intent of Public Law 94–282—to give it greater "clout."

The President's policy on cabinet government appears to be changing toward stronger leadership from the Executive Office. There is thus hope that things may improve with time, although it it doubtful that the improvement could be adequate unless a comprehensive effort is taken at the organization of the U.S. science and technology effort and its responsiveness to the leadership from the White House is strengthened.

Another critical issue is that of the sense of direction in science and technology policy. Apart from organizational matters, one of the principal functions of PCST was to help to provide a sense of direction for U.S. science and technology policy through (a) the improvement of planning and analysis for the Federal science and technology programs and (b) long-range study and planning in regard to the application of science and technology to major national problems and concerns. The abolition of PCST, in effect, wiped out the development of these functions.

According to the Director of OSTP, he cannot do long-range planning because this would be tantamount to interference with internal management of the agencies and contrary to the President's policy of cabinet government.[13]

The annual Report on Science and Technology by the President and the five-year outlook are some other instrumentalities which would be expected to help crystallize a sense of direction in policy. The five-year outlook is being conducted by NSF, with about a half of the effort contracted out to the National Academy of Sciences. It will be completed in late 1979 or early 1980; therefore, it will be only then that its utility can be assessed. The annual Report, however, was completed in September 1978. Although it was basically prepared by NSF, OSTP is credited in the transmitting letter with preparing the strategic overview chapter and with helping substantially in structuring the report, in preparing draft material, and improving the text.[14]

Rather than providing a comprehensive assessment of science and technology, the Report focuses on selected issues primarily related to the economy. Even so, it does provide an indication of OSTP's priorities. Quite appropriately, it points out the lag in productivity in the United States and emphasizes the Domestic Policy Review of industrial innovation, initiated by OSTP and conducted under the lead of the Department of Commerce. We are told that, in the next year, the Administration will give higher priority to the analysis of the proper relationship of R&D sharing between the government and industry so as to stimulate development—certainly an important area. But then the sense of direction of policy as reflected in the Report becomes much more obscure. The Report states that there is no clear evidence that the transfer of U.S. technology abroad adversely affects the United States. Accordingly, the Report summarizes its position by

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[13] See footnote 12. Dr. Press mentioned some studies and analyses, but they were conducted on an ad hoc basis and on peripheral matters.

[14] For the text of the report, see National Science Foundation, "Science and Technology: Annual Report to the Congress" (Washington, D.C., September 1978).

citing a 1974 NSF colloquium: "Except for national security purposes, the U.S. Government should not at this time consider actions to discourage or restrict international transactions involving technology transfers." [15]

This is a rather peculiar conclusion for 1978. James C. Abegglen and Thomas M. Hunt, observers of, and participants in, U.S.-Japanese economic relations for many years, note in the July 1978 issue of Foreign Affairs that the result of sales of U.S. technology to Japan in the 1950s and 1960s "has been a disaster. . . . That technology has nurtured competitors who now enter or threaten the U.S. market." [16]

Although the Soviet Union is relatively backward in civilian technology, Samuel P. Huntington, a former key official at NSC who has recently returned to Harvard University, sheds some interesting light on the subject of technology transfer to the USSR in the Fall 1978 issue of Foreign Policy: "The export of technology in the form of turnkey plants may itself have long-term adverse effects on the balance of payments. German chemical and petrochemical firms are now facing stiff competition in Western Europe from the underpriced products of the factories they themselves helped build in the USSR in the early 1970s." [17] Huntington further reports on a new policy in NSC which is to provide a more centralized control over East-West economic relations, including restrictions on the transfer of certain technologies not related to weapons. NSC has established an Ad Hoc Technology Transfer Group to assist in this task. It is perhaps ironic that the new policy is a direct result of Presidential Review Memorandum (PRM) 31 on East-West technology transfer initiated by OSTP jointly with NSC. Apparently the annual Report, written at NSF, has not caught up with this development.

The issue of technology transfer is fundamental. It affects the ability of the United States to compete in the world market and its long-range viability as a world power. It must be faced squarely.

At present, we have two contending groups in this area. One group, consisting of business executives and those individuals who share the ideology of laissez faire (including people in the government), takes the position that sales of technology should not be restricted, that they benefit individual companies and are immediately beneficial to U.S. balance of payments. Another group, also including business executives but mostly consisting of government officials and individuals in the academic world, contends that unregulated transfer of technology, in the longer run, creates competitors abroad, threatens U.S. balance of trade and payments, and undermines economic viability of the United States in the world arena. This, according to this group, is especially damaging since U.S. competitors do not seem to abide by the rules of free trade.

Traditionally, the former group's position dominated. It appears, though, that the picture is changing. However, in a typical constituency decision-making environment which prevails in Washington, at best an uneasy, watered-down compromise between the two groups appears to be evolving.

The paradox of this situation is that both of these groups present valid arguments and that their views are not irreconcilable. Enhanced

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[15] Ibid., p. 23.
[16] "Facing Up to the Trade Gap with Japan," Foreign Affairs, vol. 57 (fall 1978), p. 160.
[17] "Trade, Technology and Leverage," Foreign Policy, No. 32 (fall 1978), p. 74.

technology exports can and should be beneficial not only to individual companies and the U.S. economy in the short run, but in the long run as well. However, to ensure that the exported technology will not backfire at us later in the form of competing products, we must develop a viable science and technology policy and appropriate mechanisms to implement it which will ensure that the U.S. products stay in the forefront of technological advance and retain their competitive margin.

Opportunities along these lines appear to exist especially in the area of reimbursable technical assistance to the developing countries. Here a far-sighted, comprehensive science and technology policy, combined with the development of appropriate organizational mechanisms, could be beneficial to American companies and, at the same time, could meet certain important objectives of U.S. foreign policy with regard to the developing world.[18] There is no evidence that any agency of the U.S. Government has addressed the issue of resolving the divergent views in this area through a comprehensive policy aiming at both stimulating the exports of U.S. technology and safeguarding the long-range viability of the U.S. economy. It would be a suitable function for OSTP to undertake.

In general, the annual Report concludes on a complacent note. It does not see any "hard evidence" that the U.S. technological position, affecting the nation's economic viability, is eroding. On the contrary, we are told that "The U.S. continues to gain strength in the commercial exploitation of technology."[19] This leaves the reader ill at ease.

Given the precipitous decline in the value of the dollar, a drop in U.S. productivity in recent years, an unfavorable balance of trade which is due not only to imports of energy alone, and severe inflation at home, is it really true that all these phenomena emerged in spite of a very healthy, commercially vital state of U.S. science and technology?[20] It is not entirely clear whether, or to what extent, OSTP is responsible for the aforementioned conclusions, inasmuch as the official author of the Report is NSF. If, however, the Report reflects the position of OSTP, one cannot help wondering whether OSTP (like STPO, which tailored its activity to its reduced stature) is not tailoring its intellectual horizons to the constraints on its own ability to mobilize the necessary instruments to bring about desirable results.

Lastly, the operational aspects of the Director and OSTP must be addressed. A great deal has been said about the miniscule size of the OSTP staff (a total of 22 professionals, 12 regular members and 10 on loan from other agencies).[21] As compared with corresponding organizations in other countries, the U.S. national science and technology policy apparatus is small indeed.

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[18] Cf. Basiuk, "Technology, World Politics and American Policy," p. 51.

[19] NSF, "Science and Technology : Annual Report to the Congress," p. 84.

[20] A number of expert witnesses, testifying before a joint hearing conducted by the Senate Subcommittee on Science, Technology, and Space and the House Subcommittee on Science, Research, and Technology in February 1978, deplored inadequacy of our scientific and technological effort and policies in general and their relationship to the economy in particular. See, in particular, the testimonies of Dr. N. Bruce Hannay, Stanley Ruttenberg, Dr. Bela Gold, Dr. Lewis M. Branscomb, Dr. Derek de Solla Price, and Hazel Anderson in U.S. Congress, "Oversight of Science and Technology Policy" ; joint hearing before the Subcommittee on Science, Technology, and Space of the Senate Committee on Commerce, Science, and Transportation and the Subcommittee on Science, Research, and Technology of the House Committee on Science and Technology, Feb. 14, 1978, 95th Congress, 2d sess., pt. I.

[21] As of October 1978. Source : OSTP. In an effort to alleviate the personnel problem, OSTP has been using part-time advisory bodies, a practice which its predecessors also pursued in varied degrees.

In Japan, science and technology policy is handled by the Council for Science and Technology (STC); it is chaired by the Prime Minister and includes four cabinet ministers. The Science and Technology Agency (STA), with personnel of about 500 (including support personnel), serves as the staff agency for STC.[22] In the Soviet Union, the State Committee for Science and Technology is in charge of civilian science and technology policy. It is headed by a Deputy Chairman of the Council of Ministers and is directly responsible to the Council. The total staff of the State Committee is believed to be over 3,000, with many other part-time personnel located throughout the U.S.S.R. Both of these organizations were rated by Western observes as highly competent and powerful bodies within their own governments.[23] This, in short, is the kind of competition that OSTP with its 22 professionals is facing.

When viewed in the context of its small staff, OSTP handles a large number of problems and issues. In his testimony before the Congress and elsewhere, the Director of OSTP pointed out certain high priority items. These included the Domestic Policy Review of industrial innovation, East-West technology transfer reviewed by PRM 31, and the work of OSTP on the R&D budget. Another high priority item was an effort to strengthen scientific and technological ties with China, in which OSTP played a leading role.

These issues and initiatives are important and deserve the attention of the Science Advisor to the President and his staff. They also indicate that some sense of direction for policy does exist in OSTP. But there are many other problems and issues handled by OSTP which are distinctly secondary and of relatively small importance. A number of them, apparently, were undertaken at the request of other departments or agencies.

One has no reason to doubt that many of the things OSTP is doing are done well. But one can hardly escape the conclusion that a substantial part of the OSTP activity consists of fighting many small current fires. Considering its limited staff and the magnitude of truly important problems in science and technology, OSTP can ill afford to be preoccupied with this kind of activity.[24]

How does OSTP compare with its predecessors, OST and STPO? Because of the limitation of available inside information, this attempt at comparison can only be tentative at best. Unlike OST, OSTP is not tinted by a constituency image and does not appear to have a constituency outlook. It is more conscious of societal problems and their solution through science and technology. However, it seems to be less, if at all, aware of its role as representing the President and the "rational" decision-making process; in this regard, it bears some resemblance to STPO. (It is not, however, entirely clear whether this is a matter of perception or the constraints imposed by cabinet government and the way OSTP is used by the President.)

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[22] This is not the total personnel of STA; it has many more people in the laboratories under its jurisdiction.

[23] For details on these organizations and their operations, see my book on "Technology, World Politics and American Policy," op. cit., pp. 63–64, 119–120.

[24] For a summary of activities of OSTP, see U.S. Congress, House Committee on Appropriations. "Department of Housing and Urban Development—Independent Agencies Appropriations for 1979" Washington, D.C.: U.S. Government Printing Office, 1978), pt. 5, pp. 9–14.

OSTP seems to have more of a sense of direction that STPO, but, like STPO, it tends to disperse its efforts over many brushfires. It appears to be more flexible and dynamic than OST and, by virtue of being at the White House, it has more "clout" than STPO. It has also strengthened its position through such moves as close relations with NSC (through a joint appointment of one of the assistant directors) and OMB. However, whatever "clout" has been gained, it does not seem to be utilized up to its potential by virtue of a still limited sense of direction and an apparently inadequate perception of its role. In spite of its being in the Executive Office and apart from what it does on its own initiative, OSTP appears to work mainly for other key offices and agencies rather than the President himself.[25]

In summary, the four essential components of the national science and technology policy machinery—its role as representing the President, its "clout" (or the capability to play out its role), its sense of direction, and its size [26]—are interdependent and reinforce one another. In the last analysis, the most important and closely interrelated components are the sense of direction and the perception of one's role. If the Director of OSTP is strong in these two attributes, focuses his efforts on what is truly important and does not disperse them over brushfires and secondary pursuits, he is likely to make his influence eventually felt and, hopefully, recognized by a perceptive President. But if a clear-cut sense of direction is lacking, obtaining more staff and authority can hardly help. It would simply mean that there would be more busy people in the U.S. Government, but not necessarily a lasting improvement in U.S. science and technology policy.[27]

The path for improvement thus appears to lie in the following:

1. An improved perception on the part of the Director and his staff of their role as representing the Presidency (or the interest of the nation as a whole) and a focus on developing a strong sense of direction corresponding to that role.

2. A clear perception by the President of the proper role of his Science Advisor and the President's use and support of the Science Advisor in that role.

3. The development of appropriate instruments which would help clarify the proper direction for U.S. science and technology policy and expedite the development and implementation of that policy.

The first two items are highly important, but by themselves they are not sufficient unless augmented by the third. Without the instruments specified in that item, we are courting a distinct and unnecessary danger that our efforts in science and technology policy will be less than optimal and too little and too late. One such instrument has been proposed by H.R. 13939, a bill for establishing a Commission on the Impact of Science and Technology on Society.

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[25] See "Press and Predecessors Hold a Bull Session," Science and Government Report, May 1, 1978, p. 7. Dr. Frank Press stated that he does not meet alone with the President, but only as a member of one or another group whose interests include research-related matters.

[26] Quality, obviously, is a key component, but it is subsumed in, and usually finds its expression through, other characteristics. For example, if a sense of direction is lacking, it is a reflection on quality of the effort as a whole.

[27] For a discussion of what I consider to be an appropriate organization and activity of the staff of a national science and technology policy machinery, see my "Technology, World Politics and American Policy," op. cit., pp. 211–213.

H.R. 13939 AND A COMMISSION ON THE IMPACT OF SCIENCE AND TECHNOLOGY ON SOCIETY

H.R. 13939 was introduced on August 17, 1978 in the House of Representatives by Representative Olin E. Teague who, as the Chairman of the House Committee on Science and Technology, presided over the evolution of Public Law 94–282 until its final passage by the U.S. Congress. The Commission on the Impact of Science and Technology on Society, proposed by H.R. 13939, would be a joint Presidential-Congressional body, consisting of 14 members. The stipulated term of the Commission is three years. In several respects, the establishment of the Commission would restore the initial intent of Public Law 94–282. In some respects, the activity of the Commission would go beyond the letter of Public Law 94–282, although it would adhere to its spirit and intent. The intent of the Commission is essentially double:

1. To provide an instrumentality for helping to crystallize a stronger sense of direction for U.S. science and technology policy;
2. To strengthen the effectiveness of the Director of OSTP in carrying out U.S. science and technology policy by providing him with useful means for implementation of policy and by removing certain constraints under which he operates in our constituency-oriented governmental system.

The Commission would restore the functions of the President's Committee on Science and Technology under its own aegis. This, as discussed earlier, would both help to develop a stronger sense of direction in policy and to improve the responsiveness of the Federal science and technology effort to the policy through an appropriate organizational reform.

H.R. 13939 recognizes the utility of the five-year outlook for mid-range planning, but proposes to go beyond it. Considering that lead times in many advanced technologies are as long as 15 to 25 years, the Commission would examine the potential of science and technology and their impact a quarter of a century into the future. Both the benefits and the hazards of the potential technological impact would be analyzed. By comparing our present science and technology policy against such projections, we would be in a much better position to assess the validity of our sense of direction. The future perspective of developments in science and technology should give us a better grasp of how to cope with present problems.

According to the National Science Foundation, the United States supports more than 50 percent of the world's research and development.[28] However, our socio-economic benefits from this R&D are disproportionately small. Among other things, this suggests that our methodology of resource allocation to R&D may have room for improvement. One must recognize that in a number of areas of basic research results cannot be predicted, but such research nevertheless must be supported. The Commission, on the other hand, would focus only on those sciences and technologies where prediction is possible and where results would be expected to produce an impact on society, beneficial or otherwise. By analyzing various sectors of science and technology one by one, and disregarding those areas where societal impact is likely to be small or non-existent, the Commission would

[28] NSF, "Science and Technology: Annual Report to the Congress," August 1978, op. cit., p. 57.

be expected to improve our resource allocation to R&D. Just as important, it would help identify those areas of scientific and technological impact requiring focused societal attention and problem-solving.

There have been earlier specialized future-oriented studies in various departments and agencies, and there are some that are currently being conducted. The Commission would not duplicate those studies. It would review them in the context of the purpose of the Commission and, insofar as they are useful, would highlight their findings, giving full credit to their authors. One problem in our system is that many useful studies are not implemented because there is no influential constituency to give them support in a timely fashion. Both the environmental and the energy crisis caught the country by surprise, even though these hazards had been recognized in specialized private circles and in the government years before they appeared in full force and before the U.S. Government acted to meet them. The Commission would avoid such a possibility by placing strong emphasis on an effective implementation of its findings.

The emphasis on implementation is incorporated into H.R. 13939 at several levels. Each recommendation of the Commission would be accompanied by specific and pragmatic options for its implementation. After the Commission published its final report, the President would be required to submit to the Congress a list of those recommendations of the Commission which he had decided to implement. A corresponding action would be taken in the Congress through a Select Committee.

Lastly, the final report of the Commission would be given wide exposure to the American people. In this way, a timely constituency could be created to support governmental action. If the American people are forewarned in advance by an impartial and authoritative commission, the passage of appropriate legislation would be facilitated. We shall thus avoid such anomalies as we have seen in the disbelief on the part of some segments in the U.S. public that the energy crisis actually exists.

The Director of OSTP would be an ex officio member of the Commission and his office would benefit from the Commission's activity throughout its three-year life as well as from its final report. The Commission would have the mandate to issue special reports to the President or the Congress at any time. Such reports could be initiated by the Director of OSTP, thus providing him with both a source of intellectual capital for policy initiatives and a platform for launching them, to be followed through by his staff.

The Commission's authority with respect to the operating departments and agencies would exceed that currently available to the Director of OSTP. The Commission would have the power to hold hearings, administer oaths, and secure directly from any agency of the U.S. Government the information needed for carrying out its duties. It would thus expand the capability of the Director to obtain the necessary information from the agencies and significantly strengthen the capability of OSTP to formulate broader policies and programs at the interagency level.

The activity of the Commission, in effect, would loosen the constraints imposed on OSTP by the constituency behavior of the operat-

ing agencies and open opportunities for exercising its leadership in the science and technology field consonant with its role in representing the President and the interest of the nation as a whole. By performing certain functions which OSTP would have to do by its own initiative (or could not do at all because of its limited resources and lack of "clout"), the Commission, in effect, would reduce the constraints imposed on OSTP by its small staff and expand its scope of operations and effectiveness.

The Commission could be a catalyst in integrating and strengthening the science and technology effort at the White House level. The Chairman of the Council of Economic Advisers and the Director of NSC would be ex officio members of the Commission. At present, a relationship between the Director of OSTP and the Council of Economic Advisers (CEA) exists, but mainly on an ad hoc basis. Our economy has been orchestrated mainly by fiscal and monetary means through the operations of CEA and the Federal Reserve System, but technological factors have never been fundamentally and effectively integrated into this kind of activity. With a CEA representation on the Commission, the picture could be significantly improved, perhaps resulting in a lasting "spill-over" involving the integration of technological considerations into the daily activity of CEA.

At present, an institutionalized relationship between OSTP and NSC exists. However, with the Director of NSC represented on the Commission and the Commission focusing on major issues requiring integration of technological considerations with those of national security and foreign affairs, the scope and depth of cooperation between these two bodies could be significantly expanded.

Last but not least, the relationship between the Congress and the Executive Branch in scientific and technological affairs must be addressed. In the past two decades, U.S. science and technology policy has been conducted on a bi-partisan basis and this has been one of the elements of its strength. In recent years, the Congress has significantly upgraded its own capability in science and technology. A closer relationship and improved cooperation between the Congress and the Executive can only strengthen U.S. science and technology policy and its contribution to the nation's well-being. The Commission on the Impact of Science and Technology on Society, by virtue of being a joint Presidential-Congressional Commission and including the Director of OTA as one of its ex officio members, could present a suitable forum for bringing the Congress and the Executive together in this field. It is possible that the Commission could serve as a catalyst in improving the relationship and coordination between these two bodies in science and technology policy which could long outlive the tenure of the Commission.

NATIONAL R&D FUTURES: WILL PUBLIC OR PRIVATE INTERESTS PREVAIL?

DR. WILLIAM O. BAKER

PRESIDENT, BELL LABORATORIES, MURRAY HILL, NEW JERSEY

The Program Committee for the National Academy of Engineering has identified with admirable timeliness an issue central to the role of engineering and science in our nation's future. This is the implied contest between public—or essentially governmental—interests and private interests in guiding the future of research and development. Now there is one more chance—hopefully not the final chance, though time is becoming shorter—to resolve this contest into a joint effort of both public and private interests. There is still a chance to explain to the nation what we in industry believe has been demonstrated in the past century, even two centuries, of independent enterprise and, most particularly, of independent research and development. This is that private and public interests in a free society work when merged and waste time and resources when they are at odds.

There are, of course, basic differences between governmental and independent efforts. One of these deserves early comment. In the realms of basic creativity and bold new discovery and innovation, we cannot expect the massive federal government itself to be generally effective. In evolving systems for national security, public health, transportation, and some others (particularly in fields such as national and international standardization, measurement, and quality assurance), federal laboratories and personnel can make and have made superb contributions. There are also examples in the biosciences, agriculture, and geosciences where eminent studies are done. But the fundamental mission of government—to control, to regulate, and, in so doing, to balance a multitude of pressures in a pluralistic society—creates a restricted environment for free-ranging origination. New developments may mean abandoning or demolishing an existing practice or technology—a difficult change for big government to make. For instance, it is not accidental that serious studies were conducted on the quality assurance of Manila hemp used in the rigging of sailing vessels long after the Navy ceased to depend on wind for propulsion. And there are many similar examples.

Thus, only by contract or similar involvement can federal agencies be expected to sponsor deep changes in the status quo, or super-evolutionary jumps in technology.

On the other hand, the populace expects major technical progress. In agriculture, where development is conducted by federal and state agencies, by independent seed companies and by farm machinery makers, public and private efforts have already been combined for

high productivity. But we have yet to work out similar combined efforts for most of our social and economic needs.

So I would like to report on what seem to be new trends in meeting public expectations for progress through free, private enterprise in America. Dean Jackson Grayson, Jr., former head of the federal Wage and Price Control program, spoke eloquently at the 40th Annual Executives' Conference of the Institute of Paper Chemistry about a most pressing industrial and ecomonic issue of our times. He noted that "there is always a remote possibility that free enterprise may be able to overcome the trend toward increasing government regulation, but the probability grows less with time. Business would be well advised to begin coping realistically with government now and stop trying to either ignore it or outwit it."

This is indeed the compelling issue for our future—the Bell System itself has been engaged in such a struggle for survival for about a decade. Dean Grayson's wise counsel cautions industry against ignoring the problem, insulating itself from the problem, or capitulating to the government. While, like the rest of us (particularly those who have worked in Washington for many years), he generally expects the worst, he emphasizes that enlightened and immediate actions of various kinds might stem the onslaught.

SCIENCE AND TECHNOLOGY: WHOSE RESPONSIBILITY?

The really powerful strategy for such an effort involves economics, politics, human nature, psychology, the press, and a lot of other things far from modern science and engineering. But in the Bell System we have also found in our own struggles some fairly potent roles for science and technology, and I believe they will play a part in the struggles of all industry in the near future. These roles arise from people's expectations of industrial progress and innovation and their desire for better lives—gains that come nowadays primarily from proper technological applications.

Many of the obstructions that government imposes are based on the presumption, often fallacious, that it has the facts, that it knows the technology and operation of overall macrosystems better than anyone. And there has been a long basis for this presumption because macrosystems—like the environment, public health, and mineral and water resources—have been characterized by scientific and technical programs that have been largely conceived and operated by governments. In fact, governments have often carried out these functions very effectively. But the complexity of industry's technology, especially that being evaluated by legisaltors and regulators, is such that there must be a more independent systems assessment and mastery of industrial science and engineering.

By the way, there are those who say, and say very loudly, that one result of this extensive governmental preoccupation with major systems, ranging from defense through the environment, weather, health, space, and energy, is a fallout that provides a magnificent source of new technology on which industry builds all its new products. This is largely fallacious, as has been honestly recognized and reported by the White House Science Office and by many citizens' groups over the years. A current Arthur D. Little study of perception and depth, sponsored by the National Bureau of Standards Experimental Tech-

nology Incentives Program, states a very important finding on this situation: federal programs on energy, environment, transportation, and agribusiness have not led to socially and economically useful innovation except in one or two special, though important, areas such as nuclear power.

On the other hand, a recent National Association of Manufacturers study identified ten major independent regulatory commissions (beginning with the Interstate Commerce Commission—ICC—established in 1885). There are 14 other independent agencies doing regulation (such as the Occupational Safety and Health Administration—OSHA), 52 Executive Branch departments that exert control of one kind or another, and 21 other agencies having at least some regulatory functions. So, there are some 97 offices and activities in Washington with overlapping functions that must be encountered in the course of doing business. Their influence on innovation can be profound, for they affect technical positions of nearly all private interests.

Essentially I am saying that science and technology, nominally among the last independent activities left to industry, are also deeply entangled in this regulatory network. I believe that present advances in research and development have furnished those committed to maintaining independent enterprise with methods and capabilities that will permit negotiation with government, rather than capitulation. These resources include automata, computer systems, sensors, and methods of statistical and operational analysis. These, in fact, can relate to a particular industry's need to be expert in relevant portions of the macrosystem, such as environment, health, and natural resources. Such work enables industry to assess the validity of its position, and to learn early and adroitly to act on what is also a legitimate government role: deciding whether a particular activity is consistent with public expectancy and welfare.

The whole matter can be summarized in the proposal that industry and other independent institutions can and must deal with technically complex systems in such a way that they will be able to account both to the public and to the government (which, unfortunately, can be very different). Industry must account for the present or planned impact of complex systems on the environment, on safety, health, conservation, national security and the like.

We are experiencing a curious anomaly with respect to science and engineering. Great attention has been paid to their political effects and to their impact on other areas outside of industry, even though industry is the very agency by which the public gains the fruits of discovery and innovation. I now suggest that federal doctrines may be less formidable than has been assumed because the complex technologies on which these doctrines are based demand a much more pluralistic search for fact and insight.

In this context, let me outline the factors of research and development in U.S. society especially the governmental and political aspects, that seem to have influenced most crucially the position of industry and entrepreneurship.

INDUSTRY AND THE PUBLIC'S EXPECTATIONS

Overall, I feel that various headlines in the media are overstated. One such headline, "The Breakdown of U.S. Innovation," was used for a feature article in *Business Week*, February 16, 1976. Maybe over-

statement occurs because public expectancy is already too high. For example, the *Business Week* article begins, "From the first squawky telephone and the first airplane to the original transistor, the fruits of American innovation have probably done more than anything else to shape the quality of this country's economy and national life. Innovation creates jobs, boosts productivity, and contributes to exports and a strong, healthy balance of trade."

The expectancy implied covers too short a range; it ignores two centuries of innovation by the iron and steel industry, agriculture, the automotive, railroad and energy industries, and others. On the other hand, it is undoubtedly a genuine reminder that the public expects a constantly renewed volume of invention and discovery. But more than that, the public expects constant innovation for human benefit, economic stimulus, and national security. Now this is where the challenge lies: assuring that this is done with the same skill and efficiency that have earned us the respect of the rest of the world in this century.

But if the media overstate the gloom, what is a realistic assessment of the promise of the past 15 years? I am forced to reply that relatively little has come along with the speed and force that some in both public and private positions properly expected—in particular, too little has reached the anticipated stage of benefit for the people. In examining specific examples of this unhappy result, I am led to conclude that the technical complexity of innovative systems and their elements is now such that not only are most issues unintelligible to the public, but they are also frequently in conflict with the ever-growing proliferation of laws, regulations, and authorities that complicate innovation and change.

Thus we face a major contradiction in the expectations of our people. After the historic gains in the human condition in 200 years of free enterprise, initiative, and self-reliance, which were based on invention and technology (supported in the past 50 years by basic science as well). We now may face a period of stagnation or regression. This is largely because of the bizarre conflicts between the presumptive laws and regulations of pervasive government in a low-risk, welfare society, and the present realities of technical and scientific advance, which, more than ever, demand the freedom to experiment and innovate boldly.

SATELLITE COMMUNICATIONS: VICTIM OF INTERFERENCE

These concerns are not just speculative, they are real, here and now. Just over 15 years ago, the bright promise of a new resource emerged for linking human beings and industrial and governmental facilities—that of electrical communication through earth satellites. The whole world shared our enthusiasm as the Bell System successfully experimented with NASA's Echo satellite and later with the Telstar communications satellite, which in the following year linked Europe with the United States.

But it was not until a decade and a half later, on May 13, 1976, that Comstar, becoming the first U.S. domestic satellite involving inventors and private investors in communications satellites was launched. In the many intervening years, various cumbersome attempts to mix scientific and technical development with political, social, and eco-

nomic issues diverted and slowed these promised benefits—perhaps the principal benefits of space activities—from helping the public.

Part way through that period, some international links were established by the Intelsat consortium, represented in the United States by Comsat, a hybrid public-independent corporation. One of the central economic issues of stationary satellite systems is reflected in recent rulings by the Federal Communications Commission that Comsat overseas rates are 30 percent or more above an "allowable" profit margin. I doubt if anybody knows what the real cost of that system is, since the bulk of it is incurred in expensive launching by Atlas Centaur rockets, whose eventual cost is met by large public subsidy. But the vital point is not this matter of true cost. Rather, it is that by such government interference and political compromise, by taking away from the initiators and independent supporters of such new technology the opportunities for early development, the government has managed to stifle scientific and technical progress related to the future improvement of these systems. Nevertheless, Comsat and its affiliates have managed to achieve competence by extra effort.

[By the way, it is interesting to point out that the considerably cheaper SD undersea cable system installed in 1963, about the time of the first satellite experiments, has a capacity of 140 telephone channels, whereas one installed in 1976, the SG system, has a capacity of 4000. This is the kind of relative evolution that is possible when independent enterprise is allowed to improve, piece by piece, its own products and systems. What could have been done if this approach had been allowed in space technology?]

Advances in satellite communications now have to face worldwide competition, mounting technical complexity, and governmental obstruction. In the last 15 years, what were the elements of complexity that deserved a pluralistic approach combining public and private interests?

In the first place, John Pierce, Rudi Kompfner, and their associates at Bell Laboratories pointed out in the early 1960s that large synchronous satellites should have highly directional antennas and should operate in the upper (15 to 30) gigahertz frequency region for high capacity and freedom from terrestrial interference. But there were misunderstandings, and even ignorance, about many technical aspects of such a system. Alleged experts said that in that region of frequency the envelope of water about the earth in the form of rain, clouds, fog or vapor would prevent effective transmission. Indeed, for years we had long arguments with government agencies to get simple beacons put on experimental satellites so that we could determine what the propogation qualities would be in this exceedingly valuable and promising upper gigahertz frequency band. We were so frustrated by opposition on this that we even used the sun as the microwave source for many of these observations which, by the way, showed that we can indeed operate in this region.

There was an even more interesting question—rainstorms containing concentrated amounts of water, which absorb microwaves in the regions of interest, were expected to blank out signals. We had to out-know, out-measure and out-think the fallacies that politics and bureaucracy wanted to apply to this problem. We had already dealt with oversimplification of science and technology in terrestrial systems by a method

called diversity, which simply permitted us to take advantage of the nonuniformity of rain and other natural obstacles to have new, economical, alternate paths. These do, in fact, permit excellent high-frequency radio transmission on earth.

The nominal experts said, we know the average rainfall, and we have had bad experiences with signaling from satellites, so we know that there is no sense in having systems that operate in the otherwise efficient and unused high-gigahertz region. And, they said, we will just rule the telephone company out of the communications satellite business anyway—innovation will come from others!

So in this vital matter of applying technological development for the benefit of the public in a consistent and evolutionary way, we were effectively ruled out. I cite this episode to urge that industry never give up any path toward the future by failing to deal with complexity or by being bluffed out of initiative by naive generalizations about science and engineering. Such generalizations will increasingly come from these conflicts, which are caused by imposing human laws and regulations on technological systems. We must always act on opportunities for showing how such systems can be developed if sufficient study and discovery are applied to them.

A central point in this controversy over telecommunications satellites was the structure of rainfall on earth. It was felt that with average rain conditions, the use of communications satellites operating in the 15- to 30-gigahertz region would be impractical. Having had terrestrial experience with diversity and with the fact that rainfall did not seem to be uniform, Bell Labs established an experimental system at the Crawford Hill Laboratory to find out what was really true in the comparatively restricted area of north central New Jersey.

The results started a modest revolution in meteorology and, incidentally, are being heeded in many parts of the world outside the United States. The tests show that there are such extensive variations in the intensity of water precipitation over small regions that it is wholly practical to have a few scattered earth stations receive high-frequency signals from satellites, with high reliability, despite intensive rain or snow near one particular station.

Obtaining this result was not simple, for it involved marked improvement of the best automated rain measurement equipment that existed at that time. And it entailed the assembly, by computer, of information from mechanized rain-collection sensors. My point is that these capabilities are now accessible to industry and to independent enterprise. As we face the complexity of science and technology, we must not permit the momentum, visibility, audibility, and majesty of big government to discourage us from making the innovations necessary for survival and advancement.

I need hardly emphasize the implications of what I said about the role of just one industry in determining what the weather really does (instead of merely taking about it!) to satellite communications. It is this same meterology that governs much of the air pollution and environmental effects that are the concern of iron, the steel making and other industries, and that weigh heavily on the costs and technical qualities of our products. New technology (particularly in computers, automata, communications, and the physical sciences) can equip independent enterprise to exert a role. Industry must take the initiative

and assess the controls and obstructions imposed by government and politics. Such a role can permit industry to meet some of the expectations of our free system.

I am saying that industry and other independent institutions can challenge the government's role in assessing air quality, measuring air movement, and assuring that our people enjoy an environment conducive to both health and well-being and to commercial and private productivity.

AIR QUALITY: AN EXAMPLE OF FRUITFUL COOPERATION

There is a broader example of industrial participation that federal agencies welcomed, and with which they eventually cooperated. This example concerns analyses that our statisticians and chemists conducted on air quality in the Northeast corridor. The same political momentum and bureaucracy that I mentioned earlier was first imposed in the form of legislation on environmental standards. The result was a regulation for the Northeast corridor that was simply lifted from the air-quality studies of the Los Angeles basin. In retrospect, this seems ridiculous; but at the time it was done, it was the only path open to bureaucracy.

[Incidentally, national enterprises, such as the Bell System, had already had serious encounters with the complexity of air-pollution cycles in the Los Angeles area. In collaboration with Professor Haagen-Smit at the California Institute of Technology, we discovered unexpected properties of the ozone and nitrogen-oxide cycle from the photochemical reactions of that region. We also had a few experiences with the technical complexity of air reactions as a result of our responsibilities for other government programs, requiring an understanding of missile and other space-vehicle reentry phenomena. The encounter of a spacecraft with the atmosphere generates a large cycle of reactions that was completely unknown to meteorologists and other government technologists until reentry effects and their radar and radio propagation properties were recently worked out.]

The original monitoring and air-quality standards proposed for the Northeast industrial and urban regions are invalid. The harried bureaucracy threatened to reduce motor vehicle traffic in the New York region by 66 percent. But at Bell Labs we have been able to demonstrate in the past few years that motor vehicles contribute only a fraction of the dangerous air ingredients, and that some of their supposed emissions are actually higher on days, such as Sundays, with lower motor vehicle activity.

This saga demonstrates that it was possible for independent enterprise, incidentally in close collaboration with local and state authorities, to shift what seemed to be an impregnable bureaucratic position on industrial and motor-vehicle air alteration. The hour is already late for the iron, steel, chemical, and power industries, and their host of affiliates to take the initiative, to master the technical complexity of environmental emission by methods already available. But they can do it. Only by acquiring superior expertise will industries have at least a position of discussion and negotiation in dealing with often ill-informed special interests who seek to use government to impose their views.

The energy industry is particularly challenged to recognize that the public expects it to show courage and skill in return for the independence and private initiative it has had. Courage and skill are needed in finding what the best ways of dealing with the technical complexity of environmental quality and economic efficiency in creative collaboration with government.

INDUSTRY MUST UNDERSTAND THE MACROSYSTEMS

The technical people in government—scientific and engineering personnel—are generally as reasonable and as anxious for public progress as people anywhere. They do have high principles and ideals. That is something I have seen directly in reporting to five Presidents and in working with the technically based agencies these Presidents have created and administered for the public well-being. Neither incompetence nor intransigence is the cause of this dreadful national conflict between initiative and innovation on the one hand, and regulation and political repression on the other. These professional personnel, and the strong scientific and technical centers in which they work, have superb qualities and, in general excellent records of achievement. But they are not connected satisfactorily to the policy-making centers, and, above all, to the legislative processes. Therefore, the only way we can keep moving ahead is for industry and the universities to understand the macrosystems, such as the environment, weather, and meteorology, that we have too easily and casually assumed could be comprehended and assessed only by governmental methods and resources.

Exactly the same idea is indispensable in the crucial areas of public health and the life sciences. The pharmaceutical and drug industries, with a more fragile base and more specialized activities than conventional manufacturing, are in grave danger of letting the vital questions of health vis-a-vis therapy, and atmosphere vis-a-vis chronic disease be dealt with only by big government. This is especially so in the case of Congress, which has neither the time nor the understanding necessary for the technical complexity involved.

We in industry face a dual responsibility to a public that expects informed regulation as well as technological progress. The tasks will not be easy; the complexity of the science and technology involved is generally far beyond the assumed role of independent enterprise. Here we must invent new forms, seek new ways of cooperation and, especially, academic and industrial interaction. Recent controversies over both supersonic transport and pollution by fluorocarbons and other halocarbons have again pointed out the fragility of knowledge on which governments, the media, regulators, and special interest groups base drastic measures. Fortunately in the case of halocarbons, sufficient skepticism was skillfully forwarded by industrial firms so that more realistic approaches are under way.

Again, new science and technology are even enabling nongovernmental organizations to make independent estimates and studies. The success that Kumar Patel and his associates have had with highly sensitive, laster-based spin-flip Raman spectroscopy has given new insight into what actually happens in the upper atmosphere. These data and the elegant statistical studies of John Tukey and his associates will provide a credible base for examining numerous assumptions about

environmental carcinogenesis and other features of ozone/nitrogen-oxide-derived sequences. In addition, the Bell System's own plant, representing an investment of about $88 billion, is heavily exposed to atmospheric reactions, as is all industrial plant, and we must minimize the degradation of such equipment.

Such capabilities are not only essential for the survival of innovation and industrial vigor, but for markedly enhancing the understanding and cooperation between government (as a public) and the independent sectors of society. For example, an independent technical grasp by private resources of the variables influencing atmospheric purity and cleanliness would yield much better approaches to resolving air standards than the present situation.

A letter that Richard Lesher, President of the Chamber of Commerce of the United States, addressed to President Ford describes the situation. This letter charges that "the Environmental Protection Agency (EPA) has systematically distorted scientific data to support its own regulations pertaining to clear air standards and that such charges need immediate investigation."

This communication was based on reports in *The Los Angeles Times* that quoted an EPA official as saying, "We are making multibillion-dollar decisions about controlling air pollution on a 25-cent data base." While Dr. Lesher's comments to the President were carefully phrased, they reaffirm the problems and approaches I cited earlier. On the other hand, if a vitally affected, often crucially affected, industry itself has a grasp of the technical base for decision, then mutual respect and cooperation with government officials can be pursued.

I have spoken of macrosystems such as the environment and outer space. Indeed, these are vitally important to the great basic manufacturing industries, which need to have further experience in systematic ecological and geophysical analysis. The 130 million tons of steel that American industry will produce this year (reflecting a 36.6 percent gain in dollar value) indicates the dimension of industry's interaction with society and with public expectations.

Moreover, derivatives of this manufacturing and refining process—carbon dioxide and sulphur oxides in the air and water—have an impact on large material resources, such as the estimated 155 billion tons of cellulose formed each year in the biosynthesis of plants and trees. Recalling the density differences between steel and cellulose and the dispersion of cellulose in hydrated and lignin forms, we acquire a certain humility about the technical complexity of just one industry's involvement with natural substances.

. . . AND THE MICROSYSTEMS

Let us now look at the technical complexity that must be explained to the public in the most elementary features of industry's products. These are the aggregates of atoms of which solids—metals, plastics, textiles, timbers, rubbers—are composed. Here, too, we need to widen the scope of study and comprehension, not only for the progress of business and the consumer, but also to keep independent enterprise in balance with human laws, agencies, restraints, and emotions that now seek to govern the world. These actions are often taken by people oblivi-

ous to the natural forces that, if properly recognized, could greatly ease human endeavor and provide human benefits.

Just such an encounter with the fundamentals of atomic and crystal interaction occurs, for example, in the preparation of steel, each atom of this compelling mass must in order to function as a part of the solid continuum of steel, find a place in a crystal in precise relation to a shell of its nearest neighbors. The whole mass within a given crystal must maintain a specific geometry to prevent immediate and extensive disintegration as a result of external stressing.

These general principles have long been understood as knowledge of crystallography in the solid state has grown. But only more recently have we established alternatives to an unattainable perfection in nature. As the atoms shift from the disorder and high agitation of the liquid state (or even more so in the gas), they wondrously form the three-dimensional lattice of the solid. The alternatives in such solidification are vacancies and dislocations. Since Pfann and Vogel discovered them in the early days of preparing perfect single crystals for the new electronics, we have found that they are the basis for most of the mechanical and structural behavior of real matter. Thus in the first steps of nucleating and forming the crystal itself (the very birth of the higher order), it is likely that so-called screw dislocations will, in fact, favor the total process of regular packing of the rest of the solid. Then there may be interstitial impurities and precipitates that are probably the magic of the strength of steel, since they inhibit the other major factor in the behavior of dislocations in a crystal, which is their ability to migrate and to coalesce in the solid right up to the stage of fracture.

These remarkable effects, which have been understood only in the last two decades, are undoubtedly the base for the real strength and durability of all steel and similar structural material. I cite their role to emphasize on the microscale the same principles of individual and industrial responsibility I applied to macrosystems. The connection is that to produce two pieces of solid matter having precisely the same properties requires exact replication of the atomic array. Now we assumed that these things would average out eventually among the millions of billions of billions of atoms per cubic centimeter, but fracture and yield are catastrophic and not average properties. Thus, for the makers of steel and its alloys to provide precisely duplicate behavior when an aircraft, a vacuum cleaner, a can opener, or a nail under heavy load or vibration approaches failure requires a level of duplication of crystal configuration that is quite impossible. Yet the attitudes of human laws, the regulations of consumerism, and the consequent need to assure perfectly uniform behavior increasingly put the blame for variation on the supplier, and increasingly cultivate a public expectancy for utter conformity and uniformity that is unjustified.

MASTERING TECHNICAL COMPLEXITY: INDUSTRY'S CHANCE AND CHALLENGE

This conflict, which, I believe, will intensify in the next few years, can be resolved only by a rapidly enhanced knowledge of the realities. This knowledge should be gained first by the suppliers and then, hope-

fully, by the public and even the legislators, regulators, and agitators. Once more, invaluable derivatives will also come from this higher stage of grappling with technical complexity. The makers of steel and the suppliers of matter throughout our industrial and commercial world will find that the mysterious and expensive variability that they always have had to allow for in their products can nevertheless be reduced. The new era of miniature electronics, integrated circuitry, and automata will permit control of thermal, chemical, and mechanical processing to levels previously unimagined. Thus quality and economy through homogeneity will, in fact, improve.

But above that must come a conviction (and, in deed, its effective expression by manufacturers and suppliers) of what the real limits of conformity to human demands and regulations actually are. Once properly oriented, it is likely that this movement will also have reasonable government recognition. Individuals—the professionals—in government desire integrity in their dealing with innovators, entrepreneurs, producers, and consumers. But they are increasingly surrounded by public misconception and warped expectancies through the naive and overextended pseudolegalisms of legislative, judiciary, and other political bodies.

So let us resolve that we must keep in our free and independent institutions the abilities to learn, to do, to challenge, and to create that our people had at the beginning. We can no longer rest with the notion that just making a new product, a new market, a new profit will do it. We have to couple that with an ability to meet not only the people's expectations for better things and better lives, but their expectation that we will not be swept away by technical complexity. We must not allow progress to stop because of a failure to work with government regulators and even with extremists on ways to preserve what is good without losing the promise of what can come.

RECENT FEDERAL SCIENCE POLICIES

DR. WILLIAM O. BAKER

PRESIDENT, BELL LABORATORIES, MURRAY HILL, NEW JERSEY

The present state and structure of Federal science and technology were implicit at the beginning of the mid-century actions which took science to the highest level of government. This move by President Eisenhower was announced in his speech to the nation on the evening of Thursday, November 7, 1957, which he began with the sentence: "My subject tonight is Science in National Security." The President went on to describe the present U.S. position with respect to missile and nuclear weapon development and said:

> According to my scientific friends, one of our greatest and most glaring deficiencies is the failure of us in this country to give high enough priority to scientific education and to the place of science in our national life. . . . They believe that the second critical need is that of giving higher priority, both public and private, to basic research. . . . Tonight I shall discuss two other factors, on which prompt action is possible. The first is the tragic failure to secure the great benefits that would flow from mutual sharing of appropriate scientific information and effort among friendly countries. . . . The second immediate requirement is that of greater concentration of effort and improved arrangements within the government in the fields of science, technology and missiles—including the continuing requirement for the closest kind of executive—legislative cooperaton. As to action: I report the following items to you tonight. . . . The first thing that I have done is to make sure that the very best thought and advice that the scientific community can supply, heretofore provided to me on an informal basis, is now fully organized and formalized so that no gap can occur. The purpose is to make it possible for me, personally, whenever there appears to be any unnecessary delay in our development system, to act promptly and decisively. . . . To that end, I have created the Office of Special Assistant to the President for Science and Technology. This man, who will be aided by a staff of scientists and a strong advisory group of outsanding experts reporting to him and to me, will have the active responsibility of helping me follow-through on that program of scientific improvement of our defenses that I am partially outlining tonight and next week. . . . I am glad to be able to tell you that this position has been accepted by Dr. James R. Killian, President of the Massachusetts Institute of Technology. He is a man who enjoys my confidence, and the confidence of his colleagues in the scientific and engineering world, and in the government. . . . Through him I intend to be assured that the entire program is carried forward in closely integrated fashion, and that such things as alleged inter-service competition or insufficient use of overtime shall not be allowed to create even the suspecion of harm to our scientific and development program.

President Eisenhower ended the speech with a typically noble belief in the future:

> Never shall we cease to hope and work for the coming of the day when enduring peace will take these military burdens from the back of all mankind, and when the scientist can give his full attention, not to human destruction, but to human happiness and fulfillment.

Now from these excerpts, to say nothing of all that has been experienced in the past twenty years, it is clear that science and technol-

ogy were advanced in national policy for the purpose of defense. With his keen insight into politics and public attitudes, it was clear to all of us who worked with him that President Eisenhower had no illusions about the public support of research and development for their own sake or for social, cultural purposes beyond their demonstrated, though admittedly self-generated, roles in defense and possibly public health. What happened thereafter reflected the wise leadership of the White House Science Office and the historic success of the national scientific and technical and engineering community in implementing the original policies of the President. Nuclear energy, space, and domestic biomedicine derived immediately from the original themes of national security through a host of by-ways that are now familiar to you all. Throughout this whole period up to the present, Representative Olin Teague, aided by a devoted staff, marshalled invaluable Congressional support and initiative. But the original thrust has been obscured by the complexity of paths and of social revolution throughout the world. Nevertheless, I submit that the basic political, public, basis for science in the White House is what we have just described and has not varied deeply in the past decade and a half. Remember President Eisenhower's carefully chosen words, "The purpose is to make it possible for me, personally, whenever there appears to be any unnecessary delay in our development system, to act promptly and decisively." Succeeding sentences said the same, that he, the President, wished to work personally and intimately with the science office for assuring the freedom of our society.

As this was achieved in the early '60s, all of the realities of the Science Advisor, PSAC, and his staff shifted. A progressive and unmodified decline in involvement of political leaders with the national scientific community set in. Indeed at the beginning of the Kennedy Administration it was clear that maintenance of momentum in behalf of the broader purposes of Federal science and engineering required institutionalization of the White House resources and we submitted an extensive report accepted by President Kennedy and activated as Reorganization Plan No. 2, establishing the Office of Science and Technology in the executive office of the President. However already a small panel of us in PSAC, the Panel on Research Policy chaired by Dr. E. R. Piore, had prepared a paper responding to President Eisenhower's call for attention to basic research. Entitled "Strengthening American Science," this report was adopted by the President December 27, 1958, and he thereafter acted on its proposal for the Federal Council for Science and Technology and for the establishment of Assistant Secretaries or their correlates for research and development in the major technical departments of the government. Both he and very soon President Kennedy were mindful of our conclusion in the report:

> As America approaches the decade of the 1960s it can take reasonable satisfaction in its past scientific and technical accomplishments. Thoughtful men now see another role for science and technology—a new and creative role that is still only thinly grasped. . . . The endless frontiers of science, now reaching to the stars, can provide rich opportunities for men to seek a common understanding of the natural forces which all men must obey and which govern the world in which all men must live together.

So over these years each successive administration without fail has extended the public funding of basic research, leading for instance, in the case of the National Science Foundation, from $20 million in the

early times to the present program of $740 million for research itself and an overall budget of $928 million. And in similar terms of what is now officially classified by the Science Foundation as basic research, the Federal obligations went from $200 million in 1958 to about $4 billion near the end of this decade. As you know, a striking record exists for biomedical research.

Nevertheless, the illusion of popular support for science engendered by the magnificent upsurge of higher education and the success of national programs mentioned previously spread widely through the scientific and engineering world. You all know the chronicle—vast increases in numbers in both academic and industrial as well as governmental staffs, understandable but naive publicity about the solutions of social problems through science and technology, wars, inflation, and economic duress—the story will be rewritten in history for decades to come. But already foretold by President Johnson's discomfort about biomedical research and the funding of high energy machines in 1966, by the spring of 1970 the true position of science and technology in the executive branch had clearly confirmed the realities of the speech of 1957, and the futility of dreaming that somehow science for its own sake had gained popular affection and respect forever. Thus the problem immediately became how to readjust without dumping the heroic capabilities which had indeed been engendered in the earlier years. Rather than looking for change, adaptation and new pathways the mood of the national scientific community often reflected self-pity and despair.

However as Dr. E. E. David came into the White House staff aided by immediate conferences and advice from all the prior Science Advisors and leaders in the national science and engineering groups, new turns were taken. These were especially to begin the spread of responsibility for research and development throughout the operating agencies and to create a sharply enhanced interaction with the Office of Management and Budget in efforts to embed the funding for Federal science and technology intrinsically into the total and severely stressed resource allocations of the Executive Branch. In the succeeding two years, what might have been a devastating regression in our national capabilities was modulated into sharply reduced growth and emphasis on quality and excellence, which many now assert was overdue. Nevertheless, basic to these changes was also the realization that despite the President's abiding commitment to keep American science and engineering strong, a fiction that it had been a self-standing activity in the White House for the past decade could not be sustained. Quite probably, as the history of these times emerges, it will be seen that to have continued this fiction would have been at least unwise and probably unkind and deeply damaging to the culture of science and engineering.

Anyway, the mandate of the American people regarding the Federal Government and its organization was interpreted by the President and his staff. They who eventually heeded our deep belief in the importance of learning and discovery, so that strong charges were given in Reorganizing Plan No. 1 of 1973 to transfer "necessary continuing functions to line departments and agencies where they can be better performed." Two principal leaders of these agencies, Dr. Roberts representing the national function of the Department of Commerce, and Dr. Stever the NSF, the central agency for basic research and educa-

tion in science were special examples of this change. In the official announcement it was said:

> OST has performed with distinction since its creation in 1962, during the post-Sputnik period when major evaluation and coordination of science and technology programs was vital. Increasingly, the research and development capabilities in line department and agencies have been upgraded, and our R&D programs have stabilized. With the growing range of capability in the NSF, the President will now look to its director as a principal adviser in science and technology matters.

The key words, as we have reported earlier, are "post-Sputnik period," for that was what it was all about. In further accord with this theme you will know that the 60 days since its forwarding elapsed and that Reorganization Plan went into effect. In the Congressional Hearings were apparently mindful of the President's words in the Plan, "This Administration is firmly committed to a sustained, broad-based national effort in science and technology, as I made plain last year in the first special message on the subject ever sent by a President to the Congress." No witnesses opposed the change, which became effective April 7, 1973, with the organizational conclusion to have been done by July first. The stage was thus set for the new legislation of 1976, the culmination of years of effort by Congressman Olin Teague and his associates. A new mandate was given this Federal role in science and technology, in the Science and Technology Policy Act. But full achievement of those visions remain for the future.

Now we continue our plea that the national community respond to the new opportunities and above all to maintain the vital indpendent linkages between those who know and do science and technology and those who govern and administer for the public benefit. Our Academies, and above all our scientific and professional societies, have been repeatedly and warmly considered in creating new combinations of public and private resources for the progress of research, learning, and development. As always the integrity and courage for initiative must come in science and engineering from those who practice and are skilled, to those who govern and are apolitic.

We are heartened by the recent open letter to the President and to the Congress of the Joint Engineering Societies representing several hundred thousand of premier and loyal citizens. They note in calling for a sustained policy for use of science and engineering "... we offer our earnest cooperation and talents in helping to devise such policy and in providing for its rational execution." (If anything, they overreach in extending the hand of collaboration by attributing a partnership of Government not only to those developments in which it functioned, such as Atomic Energy, Apollo, but also those which really came from private ventures, such as synthetic fibers, computers, television, Telstar, and the transistor. But this Administration will not confuse the primary role of independent initiative, either.)

In the physics community, through the American Physical Society and the American Institute of Physics, most welcome initiative has been taken in an informal committee, chaired by Professor Philip Morse, in considering special new needs, such as research and development for the enlargement of energy sources. Here again, in accord with our earlier findings, the Federal structure to pursue this challenge, which may eventually compare with defense and health in its urgency has taken a political and administrative form, as reflected in various Presidents' Messages on Energy, sent to the Congress. Consistent with

the present concepts, responsibilities have been assigned to various operating groups, including a Domestic Council, and a new Cabinet Department of Energy was recently established. There are wide-ranging plans for responding to inputs of the national community of engineering and science to help with this mission, and new ways to engage the intellectual resources of our universities, industry, and other independent institutions are urgently needed.

So, in this specific example and many others which could be cited and which are known to you all, the new pattern is evident. The world perspective in science and engineering, invoked by President Eisenhower's words, will ultimately judge the wisdom of what has been done. Certainly we in the U.S.A. are not alone in the public and political soul-searching about the proper national role of science and technology. You all know of the White Papers and Green Papers which have been fluttering throughout Western Europe, of the many conferences involving the Soviets and Chinese, of the fabulous utilization of western invention achieved by Japan, and so on. Perhaps the depth of tribulation is expressed as well as anywhere by a conference a couple of years ago in Britian between the Confederation of British Industry and the select committee on expenditure and higher education. Here the dismaying conclusion of the Confederation of British Industry was that "M.Scs. and Ph.D.s are out of their depth once they leave the ivory towers of universities." According to the report:

> The CBI also complained that universities absorb their best graduates, spending many thousands of pounds producing scientists only interested in pure research. A few of these remain in the university after obtaining a higher degree, expanding the boundaries of knowledge, but the remainder are left to find employment in a highly competitive economic world for which they are not suitably trained.

We expressed a completely contrary view at The White House Conference on the Future of Business a few years ago, which has recently been published in detail. We felt that our American graduates with higher degrees in science and engineering represented a magnificent new intellectual evolution for the advance of commerce even beyond its technological elements. So great questions remain to be resolved, but in our Federal science now we have moved again to answer with hope and resolve the sobering query of the philosopher George Santayana:

> Science . . . has flourished only twice in recorded times, once for some three hundred years in ancient Greece (when its life was "brilliant but ineffectual"), and again for about the same period in modern Christendom. Its fruits have only begun to appear, the lands that it is discovering have not yet been circumnavigated, and there is no telling what its ultimate influence will be on human practice and feeling . . .

ENGINEERING, RESEARCH AND EDUCATION

THE IMPERATIVE OF BASIC RESEARCH

DR. GEORGE M. LOW

PRESIDENT, RENSSELAER POLYTECHNIC INSTITUTE, TROY, NEW YORK

The United States is in a period of economic and industrial decline, both in an absolute sense, and relative to other industrial nations. Although it is difficult to pinpoint and to obtain complete agreement on all of the causes for this decline, it is a generally accepted fact that the slowdown in U.S. innovation and the resultant slowdown in the rate of productivity increase is a major factor—perhaps even the most important factor.

For nearly a century, from 1873 to 1971, we were a net exporting nation. Now, in the 1970's, we are incurring huge trade deficits. We are inclined to blame these on oil imports, and of course we are in dire need of an energy policy to do something about those. But we are also losing ground in our traditional area of strength—in our exports (and in concurrent foreign imports) of high technology manufactured goods—this in spite of a substantial devaluation of the dollar since 1971. Is this not proof enough of the effects of the lag in innovation?

When I speak of innovation, I mean the entire spectrum of a process which begins with scientific discovery, includes experimental or exploratory applications, and ends with commercialization to meet the needs of the marketplace. Each step in this process depends on research and development.

A few years ago, while I was with the National Aeronautics and Space Administration (NASA), I studied the relationship between the rate of spending on research and development, and the rate of growth in productivity. The results (Figure 1) showed a direct correlation between the two, with the decline in productivity lagging the decrease in R&D spending rate by about five years. There is no doubt that there exists a direct tie between innovation and productivity, and, hence, a direct relationship between innovation and economic growth.

The process of innovation is complex, and perhaps the last step—that of commercialization—is the most complex of all because it depends on so many factors, including economic incentives, government rules and regulations, societal pressures, and the combination of all of these as it affects the willingness to take risks and the probability of profit.

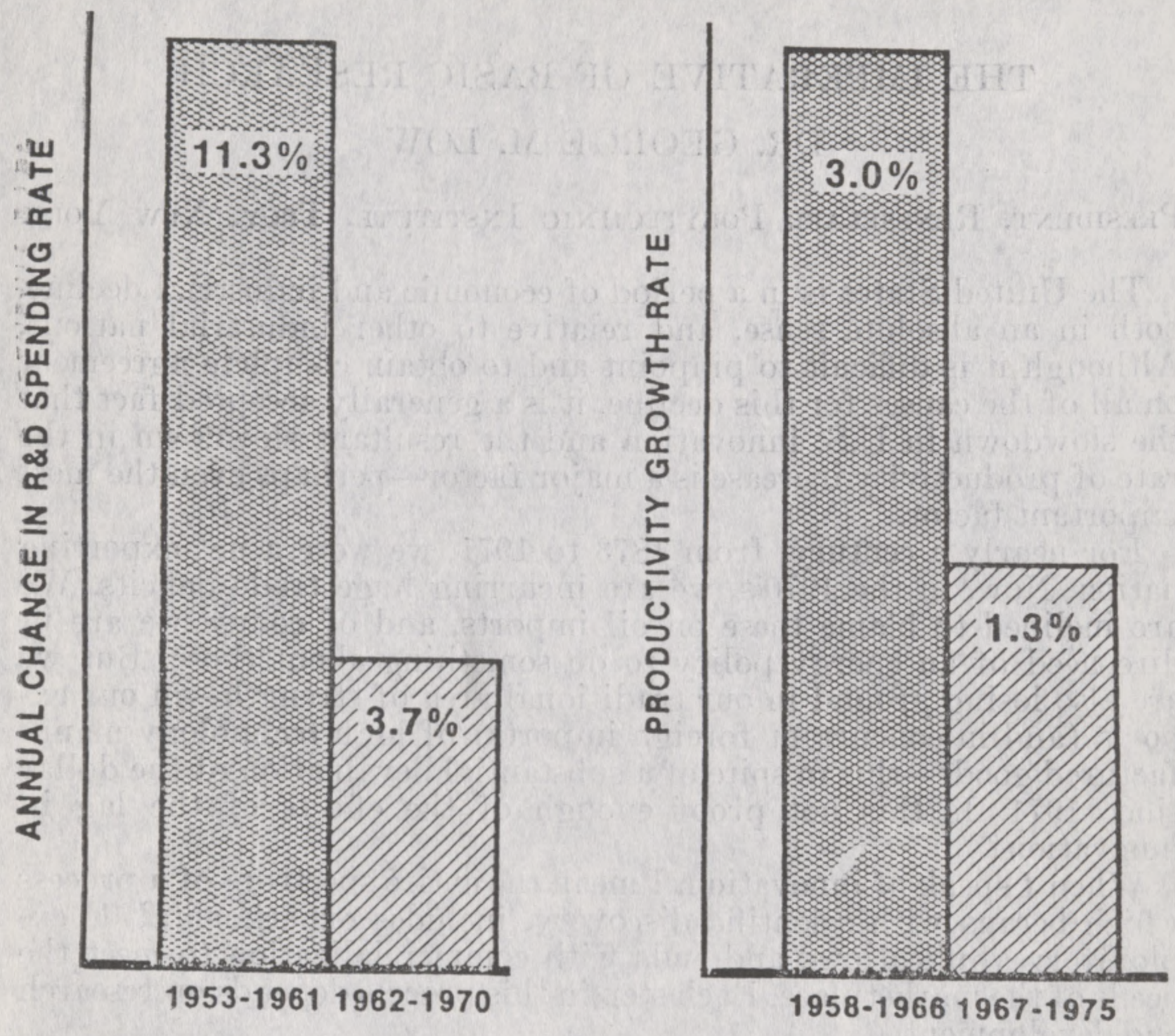

FIGURE 1

In this paper, however, I will address the first step in the innovative process, commonly called basic research, because it is this step which is most influenced by what happens in the university. Today 55% of basic research is carried out in universities; the remainder in industry and in national laboratories. Although U.S. basic research expenditures in current dollars have increased since 1960, in constant dollars these expenditures have declined in total since 1968, and just barely held their own in the university sector. Specifically, in constant dollars, university expenditures increased on the average 15.5 percent compounded annually from 1960 to 1968, but have been constant since 1968. The largest portion of the funds for these expenditures comes from the federal government.

Unfortunately, we are in a business where staying constant is not nearly good enough. It takes real growth to promote innovation; it takes an increase in the rate of R&D spending to promote an increase in the rate of productivity (see Figure 1).

There are many reasons for this. Basic research is becoming more complex, requiring larger research teams, increasing sophistication in equipment and instrumentation, and special facilities. On top of these

fundamental factors there is a plethora of new rules and regulations having to do with environmental standards, occupational health and safety, protection of animal and human test subjects, access for the handicapped, the hiring of minorities and females, privacy programs—mostly highly desirable programs which we support, but which do bring about much added paper work (which we do not support) and significant added costs.

A most serious concern is that there has been a cutback in the funds available for graduate fellowship programs. NASA had a farsighted program along these lines in the 1960's, at the height of its activities, but had to discontinue it at the end of the Apollo program. To my knowledge, none of the newer agencies, those now working on the forefront of current problems, has followed suit. Yet if we are to stop the decline in innovation, as I think we must, the most important factor will be an increasing supply of trained scientists and engineers. Instead, we are now taking steps toward creating a shortage.

The education of engineers and scientists is expensive, and tuition charges alone cannot begin to cover all of the costs. We strive to educate young men and women to solve problems and find practical solutions, to make decisions, to be the innovators of the future. This requires a great deal of laboratory instruction. Modern teaching laboratories require up-to-date instrumentation and equipment, highly complex equipment which generally becomes obsolete in five to seven years. A recent study by sixteen independent (private) engineering colleges has shown that the cost of keeping our laboratories up-to-date is $1500 per bachelor's degree granted. In addition to that expense, RPI is now in the process of installing a new, large computing system—a machine which we believe is essential in our educational process. The cost of this machine, amortized over its seven-year life, is an additional $1,000 per degree granted.

Sponsored research has become an essential ingredient of the educational process at technological universities. It helps attract faculty members, allows them to do scholarly work in the mainstream of current activity, provides research experience and essential financial support for graduate students, and adds an additional degree of realism to the undergraduate curriculum. In short, it is the lifeblood of modern scientific and engineering training.

The level of research funding is therefore doubly important. It directly affects the output of research in terms of scientific discoveries and their practical application. But of far greater importance, it also affects the output of people—scientists and engineers—people we must count on for the innovations of the future. The net result is that the pace at which some of our most pressing problems are addressed—problems having to do with energy and materials, health care and food, housing and transportation, communications and information handling—is much slower than it should be.

As I mentioned before, basic research is only the first step in the process of technological innovation—but a most important step in the process of economic growth, international competition, and in meeting the domestic needs of our society.

THE IMPACT OF FEDERAL RESEARCH FUNDING ON SCHOOLS OF ENGINEERING IN THE UNITED STATES

DR. F. KARL WILLENBROCK

CECIL AND IDA GREEN PROFESSOR OF ENGINEERING, SOUTHERN METHODIST UNIVERSITY, DALLAS, TEXAS

INTRODUCTION

This paper addresses an issue which I feel has received inadequate attention. The post World War II advent of federal agency funding for University-based research by faculty members and graduate students has had a generally positive impact on engineering education in the USA. However, it has also had a number of effects on both the content and the character of engineering education which have not been generally recognized. Most strong engineering schools have focused their research efforts in technical fields in which external, primarily federal, funding is available and have sharply reduced their attention to other technical fields. A result has been that many of the most highly qualified engineering graduates are concentrated in some industrial sectors while other industrial sectors have available fewer and less qualified engineering graduates.

Another significant impact of external funding on schools of engineering has been to focus the faculty attention on research activities in contrast to other engineering functions such as design, production, and quality control. The result has been that the most academically capable students have directed their efforts towards the research and development aspects of engineering. Other engineering functions have had relatively minor attention.

Although the industrial sector is the major employer of engineering graduates in the U.S.A. the industrial needs of employees are not a strong influence in schools of engineering. The output of engineering schools is not well-matched to the needs of the various industrial sectors. Some industries are well-served by the engineering schools; others are poorly served. Those industrial sectors which are well-served such as electronics, aeronautics, and computing machines are also sectors in which technological advances have been the most rapid. While there are many factors which contribute to the rate at which technological advances are made, the availability of the engineering talent is certainly one of the most significant.

A conclusion of the paper in a more complete understanding of the effect of external funding in the schools of engineering is most desirable. The changes in the schools are significant to the industrial sector and to federal programs involving technology. Many of the strengths and weaknesses in the technology-based sectors of the national economy correlate with the strengths and weaknesses of the engineering educational system.

SUMMARY

Engineering education has undergone remarkable changes in the post-World War II era. A major cause of change has been the availability of external funding to support faculty and graduate student

research. The cost of the graduate research is greater than the financial resources available to any private or public university in the USA. In many of the stronger engineering schools, the annual expenditures of externally funded research are now commensurate with or exceed the funds provided the school through the usual University budgeting process. The primary source of this funding has been and continues to be the executive agencies of the federal government.

The amount of funding available in the various technical fields has been determined primarily by the programs and missions of the federal funding agencies and have not been uniform over the traditional fields of engineering. As engineering faculty members and administrators have responded to the availability of external funds, some technical areas have undergone rapid growth and change within the schools while others have remained relatively static.

Although most engineering graduates are employed by industry, the growth of specific technical areas has not been primarily the result of the demand of employers for engineering graduates. The concentration of faculty strength has been more dependent on the availability of funds to support research. The faculty members who are most successful in obtaining external funds also attract more of the most academically capable graduate students since they can provide direct financial support and also make more research facilities available. External research support has also had an indirect effect on undergraduate engineering education. The content of the undergraduate programs are determined by the members of the faculty and reflects their technical interests and judgments. As faculty members have increasingly focused on research in contrast to other aspects of engineering, the undergraduate program has become farther removed from engineering practice and from technical areas in which there is not active faculty research.

These changes within the engineering schools have a significant impact on the industrial sector. Some of the sectors such as aerospace, computers, and electronics have been greatly benefited. The access to relevant research results and expert faculty consultants as well as the availability of students with highly relevant education and training as employees have assisted companies in these sectors to make rapid technical advances. In contrast, other sectors such as the construction and consumer product industries have been less directly and less favorably impacted. In these industries, fewer University research results are relevant and there have been fewer and less academically capable graduates available. The rate of technological advance in these sectors has been relatively slower.

The mission-oriented federal agencies have also been impacted by the changes in the schools of engineering. Some agencies such as the DoD and NASA have exploited the capabilities of the research team consisting of faculty and graduate students. They have also gained a long-term benefit in that many of the most capable engineering graduates have done their graduate work in technical areas related to the missions of those agencies. The missions of these agencies are primarily performance-oriented and cost is usually a secondary consideration. These missions are peculiarly compatible to the academic research environment where cost-factors are not a primary consideration.

Other mission-oriented federal agencies have not made extensive use of the academic faculty-graduate student research team. The technological areas relevant to their missions have not had available either

relevant research results from schools of engineering or the most capable engineering graduates. The rate of technological advance in such areas has been relatively slower.

A thorough and in-depth analysis of the interrelation between the funding patterns of the federal agencies, the distribution of faculty strength and the nature of the academic program in schools of engineering, and the rate of technological advance in the industrial sectors is warranted. Such an analysis should reveal cause and effort relationships which would enable the administrators of engineering schools, industrial managers, and federal agency administrators to strengthen programs which will lead to desired technological development and avoid the overdevelopment of areas of decreasing national importance. Improved understanding of these interrelations will also enable the Congress to deal more effectively with the public policy issues involving science and technology and the health of the US economy.

COMPARISON OF PRE-WORLD WAR II AND POST-WORLD WAR II ENGINEERING EDUCATION IN THE UNITED STATES

World War II introduced a discontinuity in the development of engineering education in the USA. Prior to the war, engineering schools were primarily focused on undergraduate education. While there were a number of schools offering master's degree programs, there were relatively few schools with active Ph.D. programs in engineering. The relatively few students seeking Ph.D.'s were interested in academic positions even though at the time most faculty members in engineering schools did not have doctorates. A number of years' experience in engineering practice was the generally accepted qualification for a faculty position.

Another characteristic of the pre-World War II era was that the content of the academic programs was primarily based on current engineering practices. Engineering students studied existing technology and gained skill in the use of the handbooks which summarized past practices.

World War II not only interrupted the flow of students through schools of engineering but also the activities of many faculty members. A number of institutions, such as the Massachusetts Institute of Technology and Columbia University, undertook research on war-related devices and equipment which were based on new engineering developments. It was a period of highly accelerated advances in technology. Radar, atomic bombs, and improved aircraft were striking examples. The rapid advances in technology, to which many engineering faculty members contributed, convinced them that the previous engineering curricula was inadequate to prepare students for rapid changes in technology.

As a result, there were major changes made in engineering curricula in the post-World War II era. The content was modified so that there was a greater emphasis on the physical sciences and mathematics with correspondingly less emphasis on current practice. Along with the shift towards a more science and mathematics based curricula came an increased emphasis on graduate education and, in particular, on the Ph.D. degree. Returning veterans who had been exposed to much of the newly developed military technology were strongly interested in graduate education.

The schools of engineering would have been unable to respond to

this sharply increased demand for graduate education if a new source of funding had not become available. The military services wished to maintain the close tie to the University community which they developed during the War. They continued to support research in universities in areas of science and technology relevant to their missions. These funds enabled the engineering schools to increase the size of their faculty, and develop appropriate facilities, and to provide support for the increasing number of engineering graduate students.

RELATIONS OF SCHOOLS OF ENGINEERING TO FEDERAL FUNDING AGENCIES

The costs of carrying on research in engineering far exceeds the financial resources available to the private or public Universities in the USA. The increased emphasis on graduate-level engineering education which included training in research made the engineering schools dependent on sources of external funding. The primary sources of this funding were the agencies of the federal government. Relatively minor roles were played by private foundations or private industry.

The schools of engineering and the federal funding agencies were able to develop good working relations. One reason for their compatibility was the willingness of federal agencies to allow free publication of research results. In cases in which classified research was involved, special organizational arrangements were usually developed. There was also relatively little concern about patent rights since these were usually not of great importance to either the sponsoring agency or the engineering school.

Another reason for the compatibility was that in many cases the agency's interest matched well the disciplinary based organizational structure of the engineering schools. It was organizationally simple for a single faculty member or a group of faculty members in a single department or a single school to put together a research program which met the requirements of the funding agency. It was usually not necessary to undertake the complications of organizing an interdisciplinary research group with members of different organizational units involved.

Perhaps the most basic reason for the compatibility was that the federal agencies involved were frequently oriented towards increased performance with relatively less concern about cost considerations. Engineering faculty members, particularly those appointed after World War II, had relatively little experience in industrial engineering practice and consequently little interest in, or in-depth understanding of, the economic aspects of engineering practice. They were philosophically in tune with their performance-oriented sponsors.

External funding made significant changes within the schools of engineering. Faculty members with external funds were paid summer salaries and had reduced teaching loads. Better equipment, more supplies, more computing-time and travel funds became available. Their graduate students were no longer supported primarily as teaching assistants but as research assistants who were expected to devote full-time to research activities. Faculty members had very positive incentives for working cooperatively with federal agency program managers. The administrators of the schools also clearly recognized the many benefits which external funds provided.

The degree of the dependence of the engineering schools varied with the emphasis placed on graduate education and research. Today in many of the stronger graduate-oriented schools, the amount of funding expended for externally supported research is commensurate with or exceeds the funding obtained from the usual University budgeting processes.

CHANGES IN SCHOOLS OF ENGINEERING AS A RESULT OF EXTERNAL FUNDING

With the post-World War II availability of federal agency funding to support research in schools of engineering, a number of changes took place. Of the greatest importance was the great expansion of engineering research in the schools of engineering. The academic engineering community undertook, at a much greater rate, the task of adding new knowledge to the various fields of engineering. These additions were not uniform across the various fields of engineering but rather followed the availability of external funding. The addition of research programs improved the intellectual level of academic programs available in engineering and led to the development in the USA of probably the strongest engineering educational system at both the undergraduate and graduate levels in the world.

While the greatest impact of external funding in schools of engineering was on graduate programs of instruction and research, the undergraduate programs were also affected. These latter effects are primarily due to the impact of external funding on the faculty appointment procedures.

A primary criterion for a tenure appointment to the faculty of a school of engineering which offers doctoral level graduate programs is a record of research accomplishments. Since the costs of carrying out engineering research is far in excess of the resources available, external funding is essential. The need for external funding is greater for faculty members engaged in experimentally based research than for those engaged in analytically oriented research. However, even in the latter case, the costs of computer time and graduate student stipends is not negligible. To carry on a successful research program, the faculty member must be able to gain external support. Since the primary sources of such funding are federal agencies, the faculty member must not only develop the professional stature to pass the peer review system used by most federal agencies but he also must work in a technical area in which there is federal agency interest. While some federal agencies such as the National Science Foundation, have a broad mandate to support basic research in science and engineering, most federal agencies which fund University-based engineering research are mission-oriented. Consequently, the junior faculty member seeking tenure or the senior faculty member seeking a reduced teaching load is under considerable pressure to work in a technical area in which his research can be supported by a federal agency. The net result of this pressure is that schools of engineering make more appointments in those technical areas in which federal funding is available. Fewer junior faculty members with research interests in technical areas in which external funding is not available can expect tenured appointments.

The character and direction of growth of a school are largely determined by the faculty appointment made. The present faculty members have a primary voice in the future appointments to tenure. Current

faculty members frequently seek to appoint new faculty members in technical areas continguous to their own and also to apply the criterion of successful research performance as a requirement for appointment. Thus, the faculty has a tendency to reproduce itself.

With research productivity a primary criterion for appointment to the faculty, it is not surprising that present faculty members in schools of engineering are much less qualified to undertake the teaching of aspects of engineering other than research such as design, production, and quality control. Thus, today's engineering students do not receive a balanced picture of engineering activities as they are carried on in industry. Their educational program has been designed and implemented by a faculty which is strongly biased towards research and whose technical areas are largely determined by the availability of external funding.

EFFECTS OF CHANGES IN ENGINEERING SCHOOLS ON FEDERAL AGENCIES

The effect on the mission-oriented federal agencies which fund University-based research of the post-war changes in engineering schools has been positive. The research team of faculty members working with graduate students have proved to be both creative and relatively low-cost. There have been many significant technical advances made in areas of importance to the missions of the agencies. As the mission requirements of the agencies have changed, the agencies have flexibility in modifying their funding programs.

A second effect on the funding agencies of a more long-term nature has been the development of a cadre of highly capable graduate engineers who are knowledgeable about areas of importance to the agency. Such engineers are valuable as employees of in-house laboratories or as technical program managers. They are also available to the industrial organizations which supply products and services to the agency. The Department of Defense (DOD) and the National Aeronautics and Space Agency (NASA) have been particularly successful in capitalizing on the availablility of such technical personnel. The missions of these agencies are such that they are primarily performance-oriented and they benefit from the compatibility of their objectives to the particular research capabilities of the faculty-graduate student teams.

In contrast there are a number of other federal agencies which have not used the engineering faculty-graduate student research teams in support of their missions. There are a number of reasons why the program managers in these agencies have not done so. Many of their missions are only partially dependent on technological developments and so would require interdisciplinary research groups to investigate their problem areas. Also, the agencies may not be a major purchaser of high-technology goods and services as the DOD and NASA are. A tradition of active interrelationship with the Universities has not been developed in a number of such agencies. In general, such agencies have less advanced technologies available to them and have not carried on systematic programs of technological developments with University or industrial support. They have also not had the benefit of continuing supply of highly capable engineering graduates educated in the technologies relevant to their mission areas.

Technological developments have been relatively slow in a number of these areas such as building technology, which is of importance, the

Department of Housing and Urban Development (HUD) and the General Services Administration (GSA) and law-enforcement technology which is of importance to the Department of Justice as well as to State and local governments.

EFFECTS OF CHANGES IN ENGINEERING SCHOOLS ON THE INDUSTRIAL SECTOR

Since the characteristics of the industrial sectors vary widely, it is difficult to generalize about their interrelationships with schools of engineering. However, there is a very fundamental relationship between them. The schools of engineering educate and train most of the nations' engineers and the industrial sector is the primary employer of these engineering graduates. Thus, changes in the content of the academic programs offered by schools of engineering, shifts in the character of faculty appointments, changing emphases in technical areas, changes in student interests will all impact those parts of the industrial community which are involved with technological developments.

The different engineering fields are affected in varying degrees by federal agency funding. In some areas such as aeronautical engineering, federal agency programs have a dominant influence on the activity of the industrial sector and also on the programs in schools of engineering. Much support has been given to aeronautical engineering research in schools of engineering by the US Air Force and NASA. In contrast, the chemical engineering area is relatively less influenced by federal funding in the industrial sector or in schools of engineering. The ties between this industrial sector and the engineering schools are relatively strong in this area.

The case of electrical engineering is somewhat different from the two previous examples. Departments of electrical engineering have been strongly influenced by the availability of federal funding. They have been active participants in the rapid advances in areas such as solid state electronics, communications technology, and automatic computing machines. In each of these areas, there have been many post-World War II faculty appointments and federal agency funding has been relatively readily available. These areas have also been very attractive to very capable students who migrate within a school to the area of greatest research activity. In a certain sense, the schools effectively operate as sorting mechanisms which bring the academically most capable students to those areas of greatest faculty activity. The output of electrical engineering graduates has been strong at all levels and the industrial sector has clearly benefited from the availability of the highly qualified technical personnel who are well-matched to their technical requirements. The industrial sector is partially dependent on government procurement for its level of activity but also has a number of very strong commercial products and services which are relatively independent of federal agency procurements.

An area of civil engineering, which has not been an area of significant federal agency research support, is building construction. There is relatively little activity in this area in schools of engineering. As a result, the building sector has not had available highly qualified engineering graduates well-matched to the needs of the industry. It has also been an area in which the rate of technological advance has been relatively slow even though the construction industry is one of the nation's largest.

These examples illustrate some of the variation in the closeness of the interrelationships between different academic engineering fields and the industrial sectors in which their graduates are employed. There are also variations in the hiring patterns of the various industrial sectors between graduates with baccalaureate degrees and those with higher degrees. The electronics industry hires relatively more Ph. D. recipients than the construction industry.

There has been considerable variation among the engineering fields as to the availability of federal funding for University-based research. For the fields in which relatively large amounts of federal research funding have been available, there has usually been a high rate of technological development. The academic engineering community has been an active participant through its research results, through the activity of faculty members as consultants to industry, and through the output of graduate engineers at various degree levels well-matched to industrial needs. For fields in which there is relatively little research funding, there has usually been a relatively slow rate of technological development and relatively little academic activity. Such industrial sectors are relatively poorly served by the academic community since there are fewer relevant research results and the engineering graduates are less well-matched to the industrial needs.

Although the supplier/consumer relationship between the schools of engineering and the industrial community is a fundamental one, the coupling between them varies considerably among the engineering fields. The funding programs of the federal agencies are a much more powerful influence on engineering school program developments than industrial employers of engineering graduates.

EFFECT OF CHANGES IN ENGINEERING SCHOOLS ON THE NATIONAL ECONOMY

Universities, industry, and the government are the three principal entities which influence the growth and development of the nation's science and technology. They are coupled in a variety of ways and changes in the relations between two of them can have significant effects on all three.

The needs of the industrial sector for engineering talent are not satisfied in a uniform fashion. The match between the schools of engineering as suppliers of engineering graduates and the industrial community as the primary employer of these agencies varies among the engineering fields. It has also been influenced by the availability of external funding for research. Faculty strengths and many of the most capable students are concentrated in those technical areas which are well-supported by federal funding.

The relative rates at which technology has advanced in the various industrial sectors is attributable to a great many factors. However, there is a strong correlation between the technical areas in which schools of engineering have their greatest faculty and student strengths and those areas in which the USA has a leading technological position. Well-educated and creative engineers are one of several ingredients necessary for rapid technological developments to take place.

The areas of technology in which the rate of development has been relatively slow or even static and in which the USA does not hold a

leadership position correspond to the fields in which engineering schools have not concentrated faculty strength. Many of these areas, such as consumer products and building technology, are cost-oriented. Few, if any, strong engineering schools in the USA have faculties which are oriented towards cost reduction techniques. There is little active research in design and manufacturing techniques which lead to reduced costs of production. Significant technological advances in such areas will be more likely to occur if above critical-sized groups of engineering faculty members undertake relevant research and if graduate students become involved. Such research and instructional programs can only succeed if they are able to attract able students. In turn, such students will be attracted only if there are good post-graduate employment opportunities available to them.

To what extent the health of the nation's economy is dependent upon technological advances is not entirely clear. However, it is clear that advances in technology cannot be made unless engineering talent of appropriate quality and quantity is available.

CONCLUSIONS

During the three decades since World War II, the schools of engineering have undergone remarkable changes. A major cause of these changes has been the availability of external funds for research support. The volume and nature of these funds have profoundly affected the characteristics and operating policies of the schools of engineering. The engineering schools as the major producers of engineering graduates have far-reaching effects on the rate of technological advance in the various industrial sectors.

A thorough and in-depth analysis is overdue of the interrelations of the schools of engineering and the industrial and governmental sectors in the post-World War II era. The ramifications of the changes in engineering schools are widespread but as yet they are not well understood. With a greater understanding of these interrelations, decision-makers in each of the sectors should be able to improve their decision-making capability. Engineering school administrators should understand the impact of federal agency funding on their faculty appointment procedures and the content of their curricula. The implications and dangers inherent in becoming too decoupled from the industrial sector should be recognized.

Industrial managers who wish to stimulate the rate of technological development in their companies should understand how to operate effectively with the schools on which they are dependent to supply the engineering graduates. The characteristics and policies of industries which are well-coupled to the academic community should be sufficiently understood so that the less well-served industrial areas can improve their access to the available engineering talent.

In the federal sector, executive branch program managers should understand the impact of their present and proposed programs on the schools of engineering and the relations of the schools to the industrial community. Without such understanding, their programs may not be successful and may result in undesirable effects. Finally, the Congress should have a better base of knowledge in which to judge the merit of proposed federal technological programs and to set the policies necessary to strengthen the nation's ability to use technology effectively in the solution of national problems.

A NEW AMERICAN UNIVERSITY

DR. STEVEN MULLER

President, Johns Hopkins University, Baltimore, Maryland

We are not where we were. That much is obvious on every campus. We are moving, but not as yet with clear purpose, direction, or confidence. Most palpably evident still is our sense of loss: the American research university yearns to return to the 1950s and early 1960s. After that period came the great upheaval. We survived. But even though we know ever more clearly that the crisis of the late 1960s marked the end of a time during which we flourished, we search still for a new beginning. Where we are is uncomfortable. Perhaps the most revealing fact about us is our acute resentment of our discomfort. We have yet to accept again the reality that discomfort is normal for universities. The fact is that we were spoiled. We took a great deal for granted—affluence, growth, the respect of society, a clear sense of purpose—all now diminished. We are not where we were, and there is no going back. A new American university is taking shape. Its features are still obscure. The traits that will define those features are becoming describable.

I

Already under way is a painful and wrenching change in the relationship between the American research university and the federal government. They need each other. The great postwar partnership between them turned sour after 1968. The relationship between them that has since emerged is in part almost adversary. The new American university cannot afford either the embrace with the federal government that characterized the decades of affluence, or open hostility between itself and government. Required are the terms of a new partnership, more distant than that of twenty years ago, less abrasive and potentially sterile than that of the present.

The yearning for the recent past by the American research university is still so great as to inhibit the needed evolution of a new partnership with the federal government. Therefore what must be understood is that the quarter century between 1941 and the mid-1960s was abnormal. In an overall sense the American university was mobilized for war by the federal government in 1941, and demobilization did not occur until twenty-five years later. When the United States went to war in 1941, so did the American research university. Some faculty and students served the war effort off-campus; others were involved with on-campus training; research was needed, and new laboratories were founded for the purpose, with federal funds and under university auspices.

War's end brought not demobilization but the Cold War. National defense research continued, still under university auspices, as the era

of nuclear weapons, unmanned missiles, and space flight unfolded. After Sputnik federal sponsorship of research in basic science became for a time a national security priority. For a few years Korea was the scene of a return to real war. The Cold War enveloped the Third World. Here also the universities were enlisted. Foreign-language and area studies under the National Defense Education Act; assistance to less developed nations by faculties under contracts and grants from the Agency for International Development; and even the training of Peace Corps volunteers by university staff, on and off the campus—all were evidence of the continued mobilization of the American university in the national security interest. So also was the continued involvement of the university community with the national intelligence establishment, which began but did not end with the Office of Strategic Services of World War II. In this very general sense the still-mobilized American university was drawn into Vietnam as the United States became more and more deeply committed here. The disaster of that commitment troubled the partnership between government and university; in large part produced the student revolt of the late 1960s; and ended in the partial demobilization of the 1970s, and with a distance between government and university that was not in fact new but that had not existed during the preceding twenty-five years.

To speak of the American research university as having remained in a large sense mobilized by the federal government for so long must in no way be taken to mean that the university was enslaved. Quite the contrary: mobilization for the most part reflected a partnership entered into with enthusiasm, first at the outbreak of a war that was nearly unanimously regarded as just, and later sustained by the prevailing preference of both parties. The cooperation of the university was consistently less demanded than volunteered. The idealism of the international assistance effort in general, and of the Peace Corps is particular, was sincere and honorable. Dissent on the campus was not stifled. If any proof were needed that the university remained mobilized by choice it can easily be found in the fact that when Vietnam changed the university's choice the partnership of mobilization came to an end.

No, a quarter century of mobilization did not enslave the university. It brought with it, from government and society, unprecedented and sustained support, prestige, encouragement of growth, and prevailing confidence. But for all that, a price was paid. The consequences of prolonged mobilization—largely voluntary—and of resulting splendor in the government's service were excessive university dependence on government; exaggeration within the university of the virtues of applied research; and a pervasive university expectation of affluence. The price of these consequences was paid—willingly or unwillingly—at the time. As is customary, the accounts were rendered only later. They became due in the 1970s. They are hell to pay.

II

By now, the American university knows the penalties of excessive dependence on the federal government. Ambitious programs of basic research, foreign-language and area studies, and graduate education are shrinking because support once lavishly given was abruptly withdrawn. At the same time, the federal government is using the power of its purse to regulate the conduct of universities, attaching ever new

conditions and requirements to its programs of support. On the campus yesterday's partner now appears increasingly as today's oppressor, indispensable but stingy, and ever more intrusive. To date the university's reaction has been mostly a futile mixture of pleas for renewed or increased support, undercut by sharpening protest against the rising flood of regulation. There is the appearance of a confrontation—even talk of crisis. But there is also the prospect of a new relationship which may not be as difficult for the new American university to achieve as present pain might indicate.

The federal government and the American research university continue to need each other. Even though the government's mobilization of the university, and the university's readiness to remain mobilized, have ended, a high level of national interest in the university's services remains, and still includes a substantial national security component. As for the research university, its dependence on national government for support of much of its large-scale research is natural and unavoidable.[1] The issue for the university, therefore, is not dependence on government, but the degree and conditions of an inevitable dependence. A nonmobilized community of research universities can and should be more cautious and selective with respect to initiatives from government for new research activities, and more insistent that government support be granted on conditions that preserve the integrity of the university institution. With the clarity of hindsight, some principal flaws in the relationship between government and university during the long mobilization period can now be seen. They include the assumption by government that the research university was obliged to respond without reservation to every offered initiative deemed to be in the national interest; the overeagerness of the universities to respond that way, based in part on university assumptions that ever-increasing government support and unlimited growth had become the norm; and the error of both parties in agreeing to do so much in common on the basis of short-term, nonpermanent funding.

The new American university will seek to receive federal support for research on the basis of substantial long-term funding. An effort will be made to designate selected universities as major research centers and to obtain endowment for them as such. In order to include the largest possible number of research universities, this effort may take the form of suggesting that major research centers be designated by area of research rather than on a universal basis: so as to make it possible, for instance, for one institution to be endowed as a major research center in one area, such as cellular biology, whereas another university might be endowed for a quite different area, such as environmental engineering. The universities will answer the argument that such endowments are expensive and perhaps too permanent, pointing out that buildings have both of these characteristics but have already been funded by government to house major research activities. They will argue that the time has come to make as durable a commitment to the people needed for research and training as has already become customary for the facilities in which they work. As for research initiatives from government that involve entirely new activities and/or levels of commitments that preclude endowments, the new American university will attempt to bargain for a scale of effort and guaranteed term of funding that will not place the internal and fiscal stability of the university at risk, as a result either of sudden overgrowth or of sudden

abandonment of support with inadequate lead time. The federal government is likely to respond positively at least in some measure to these university suggestions. They are practical and reasonable, and government remains dependent on the major research universities for research and training in the national interest. Therefore, government has its own unavoidable stake in the viability of the new American university, as well as in the continued desire of the university to engage in needed research and training.

III

The new American university will also resist the tendency of the federal government to attach a growing body of regulations and conditions to its measures of support for higher education. The need of the university to do so is more fundamental than either the substance or motivation involved in such conditions or regulations propounded by government, or the financial costs also imposed. At stake is the essential need of the university to maintain the unfettered freedom of the human mind to apply its powers and methods of reason. On the one hand it is precisely the unfettering of reason which occurred in the Enlightenment of the eighteenth century that permitted the development of modern science, and which allowed the university to become the mighty and productive engine of science represented by today's great academic research institutions. On the other hand, the free exercise of reason means not loose speculation, but disciplined, rigorous, relentlessly unprejudiced testing of ideas against observable reality and, therefore, is totally dependent on the existence of standards for the conduct of work and the selection of participants that promote rational competence and defy the inhibitions of prejudice (meaning prejudgment not founded in rational analysis) in every form. It is not accident but cause that the modern research university has flourished within societies whose governments are limited in their powers to impose the tyranny of orthodoxy on research and teaching. Nor is academic freedom in this sense self-serving in the sense of being self-indulgent. It spells self-preservation—preservation of the ability of the university to select and promote faculty and students, and to maintain standards of research, in accord with criteria insulated as much as possible from the pressures of public sentiment that otherwise would restrict the free and full exercise of reason.

Such brief and ineloquent words do inadequate justice to so vital a need. However, leaders of the university have dealt with the subject more effectively many times and should and will do so in the future. What the new American university must realize is that, on the issue of freedom of reason, exposition and persuasion alone will not suffice. The tendency of representative government to impose in all respects the prevailing sentiments of the public majority is as natural and fundamental as the need of the scientific university to resist that tendency directed against itself. The key word is *resist*. Excessive dominion on the part of government seldom results from malevolent will that is ruthlessly enforced. It grows from the frailty of resistance on the part of the governed, who accept successive mixtures of benefits and burdens until it is too late and they have become subjects rather than remaining citizens. Fear of the tyranny of the majority evoked the concept of limited government. Obviously this occurred without thought being given to the university specifically. But the American university is

uniquely blessed both by a constitutional framework and a political tradition and climate that can sustain its resistance to excessive impositions by the federal government—if the university itself has the need and the will to resist.

In this crucial context the conclusion that the American university is only just demobilized assumes special importance. Mobilization implies a relationship between government and university that transcends mutual benefit. The root of mobilization is the assumption that a higher public cause governs all, including the government-university partnership. Under that assumption, government—representing the national interest institutionalized—is an overpowering partner, in both practice and spirit. For the demobilized new American university, partnership with government should once more be based, not on the abnormal assumption of mobilization, but on the normal assumption of mutual need and self-interest. Such a partnership is less unequal but also less cohesive. Within its terms, the university can stake out its own inviolable conditions of participation. Only to speak to these, however, may not suffice. Therefore the university must have the will and determination to reject and do without selected aspects of partnership with government that invade essential university prerogatives. At the end of what is here characterized as an overlong period of mobilization this is doubly difficult for the university: first, because it means a relationship with government that is permanently full of tension, requires tenacious negotiations without end, thus denying even the prospect of ever reaching calm and safe waters; second, because it puts increasingly at risk the affluence to which the university had become accustomed.

Nowhere is it ordained that the university institution shall be richly well supported and untroubled—especially not the modern research university committed to free science and reason in the midst of human societies that at their best tolerate reason and freedom only within limits. The first reaction of the demobilized American university to the altered relationship with the federal government therefore still suffers from the shock of restored normalcy and its consequences. The new American university's emergence has to be based on full rerecognition that affluence too is a relative good. Self-preservation may depend more on freedom retained than on funding, no matter how desirable or urgent the need for such funding may appear. The integrity of free science is of greater fundamental importance than the resources at its disposal. The power of the purse may have to be opposed by the power of penury put at risk.

In the extreme these dichotomies, of course, would be suicidal for the university. But in present American society the extreme is unlikely. The federal government has a declared, profound, and irreplaceable interest in the university and need for its research and training programs. When the federal government trespasses too far on the ability of the university to maintain standards essential to itself, a few refusals of support will count for far more than arguments. The short-term risk involved in such refusals is great. They require courage, especially because they imply acceptance of an enduringly uneasy partnership. But the long-term risk is not great. Representative government comprehends resistance, especially from an institution upon whose services both government and the public are dependent. The

new American university must cultivate a new and lasting assertiveness, and abandon abnormal expectations not only of affluence but of harmony in its relations with government.

IV

Another consequence of prolonged mobilization, noted earlier, is an imbalance within the university caused by excessive emphasis on the application of science and research. This presents a problem of vexing complexity which the changing American university is only beginning to address. Again the issue involves a question of degree. The generation of applicable knowledge—and training—is a natural and desirable component of university work. Equally natural and also legitimate is the priority which government and society at large attach to the usable fruit of research. All that is first suggested here is that during the period of modernization both government and university prized the applicable results of rational inquiry so highly and for so long that the reward system within the university became distorted. Support for research and salaries became most readily available for scholars whose work had the appearance of social applicability. For a time government and support of basic research and the overall affluence of the university that derived from steadily rising enrollments moderated the distortion. More recently, when federal support of basic research dwindled and enrollments ceased rising, the university found itself with an internal reward system less oriented to pure merit of scholarship than to the social utility of scholarship. Applied research, however, can in the long run maintain high quality only when rooted in the rich soil of pure and basic research. This alone demands a readjustment of the university's internal system of reward.

But other facets compound the problem. Emphasis on socially applicable research within the university during the period of mobilization combined with an unplanned and virtually unacknowledged deemphasis on values within the university, as well as with a diminution of the university's most traditional role in the transmission of fundamental values to successive generations of students. The decline of emphasis on values was in so many ways related to the period of mobilization that is must be regarded as a negative legacy of mobilization which a changing American university must overcome.

Between 1945 and into the 1960s the American university was possessed by an ideology in general best described as that of the New Deal. This ideology rested around two basic concepts. First, society is best governed by a pragmatic process of political compromise that allows popular majorities, on the one hand, to insist on policies that favor the most urgent interests of the greatest number and, on the other hand, to coalesce around such compromises as are necessary to keep the social system working and to avoid outraging political minorities. Second, a society so governed has the capacity to solve not only all of its own problems over time but is also capable of solving the problems of other societies—at best by the imitation by others of the American way, at worst by benign intervention to encourage such limitation.

The accent in the first concept is on the word *pragmatic*, which elevates pragmatism into ideology, while denying the need for theory or philosophy. In the second concept the accent is on the capacity to solve social problems, denying the intractability of historic and human conditions, and perceiving all social phenomena as problems, subject

by definition to solution. The real triumph of the New Deal came not in the 1930s but after the war, and its basic concepts constituted the orthodoxy of the university at that time. To the confidence of a university that had served society in war, knew itself to be needed in the Cold War, and was rejoicing in expansion, there was added the zest of an ideology that called for even greater recognition, because so much of the knowledge needed to solve the problems of America and the world emanated from the campus.

Protracted mobilization of the university would not have been possible without a prevailing rationale. This ideology provided the rationale, and so dominated the university as to constitute orthodoxy. Its dominance was partially obscured by an intriguing paradox. The university, suffused with pragmatism, luxuriated in more theory than ever before. "Luxuriated" is the right word: the university could afford theory because in the face of the dominating orthodoxy it did not matter; it was not even controversial. The sources of theory were unique. Before, during, and after the war, the American university absorbed an exceptional infusion of talent that had fled Hitler and his works.[2] That talent included some of the finest social philosophers of Europe, who were duly respected and installed on American campuses. Respected and installed, yes; listened to, scarcely. These men and women were truly refugees, not only physically but intellectually. The American university succored them, but precisely when the applause was loudest the indulgent audience was at its most deaf. No matter whether the alien thinker was a Marxist or a monarchist: he or she was alien, distinguished, admirable, and irrelevant. One may cherish the overwhelming confidence of American pragmatism that swept other philosophy aside or find cruel irony in the fact that the wisdom that understood Hitler was discredited, not only because of its perceived irrelevance but because it had been powerless to stop Hitler. The certainty remains that the greatest flowering of social philosophy in the history of the American university occurred when, and perhaps because, no one really gave a damn.

In the context of mobilization rationalized by ideology and adorned with the paradoxical richness of social theory, the American university appears to have suffered an inner erosion of values that went far beyond a simple, if protracted, overemphasis on the virtues of applied research. The chain of events began with the extraordinary success of physical science, in the early part of the century, most notably in physics and mathematics. Science produced new marvels of technology. To the extent that Russia and America won World War II as nations, so did technology as a phenomenon. Inevitably, science—a form of human creativity—became somewhat confused with technology, the application of science to human and material conditions. In the past there had been science without immediate technological consequences. In the twentieth century it was no longer commonly so. So much technology had resulted from science that technological consequences were expected from new science as a matter of course. It came to seem now that any science that produced no new technology might, solely for that reason, lack validity.

Science itself is the fruit of brilliant human reason coupled with intuition. It deals with matter, and is therefore largely susceptible to rigorous testing and evaluation of the material results it predicts. Admirable as are its reasoning and intuition, even more admirable

are its inflexible standard of proved authenticity and—in our time—its ultimate technological benefits. In this admiring spirit, it is merely logical to ask why the study of man and society should not also be science, subject also to the same measured proof and rewarded equally by resultant technology. The American university did more than ask the question. It answered, "Why not?" and gave a solid try.

In the years after 1945, a spectacular change took place on campus in the disciplines grouped together as social science. With the assistance of academic European refugees already versed in the work of Weber, Durkheim, Mannheim, and others, sociology developed a new theoretical framework and added the sophisticated new technologies of quantitative measurement. Economics exploded into new realms of mathematical abstraction, system modeling, and statistical evaluation. Political science turned from its classical tradition and adopted the theories and methods of sociology. Anthropology also adopted sociological theory and methodology and became an applied field in a wholly new sense, as American anthropologists studied less developed peoples in pursuit of patterns of social modernization as well as for the sake of research. Again with the help of academic European refugees, psychiatry emerged as a vigorous new field of its own; social psychology also turned wholly to quantitative techniques; behavioral psychology was already primarily a laboratory science. This transformation of the study of man in society into social science had a single guiding aim: scientific objectivity, or at least that degree of objectivity with which physical and biological scientists treated animate and inanimate matter. The banner that flew over the social sciences read "value-free." The leading social scientists were those best able to point with pride to the objective and carefully measured quality of their analysis.

One would have expected that this development in the social sciences would have caused at minimum extreme tension, and at maximum open conflict, between them and the disciplines grouped together as the humanities. But this did not happen. In fact the reverse happened, because the humanities attempted as best they could also to become sciences. Long before the designation of disciplines as arts and sciences became common, the old university had had only a faculty of philosophy, traditionally along side a faculty of law and a faculty of medicine. In those days the precursors of today's arts and sciences disciplines were moral philosophy, (humanities), social philosophy (social science), and natural philosophy (physical and life sciences). At least historically, the field of philosophy occupied a central place within the evolution of the university. After 1945, the discipline of philosophy in the American university was in a new and interesting conditon. Even though ethics, the history of philosophy, logic, and other traditional aspects were still being taught, the discipline had become preoccupied with the problems of linguistic philosophy that had just been imported from the British universities. Nearly all of the best young talents in philosophy took their stations along this new frontier. No criticism or disrespect is intended, but the effect was the conversion of philosophy into a discipline that at least for the moment had less to say to other fields than in the past. The philosophies did not speak of being value-free, but their newly identified problems of articulation reduced their discussion of values.

In the other fields of the humanities, particularly English and literature, the temptation to apply quantitative techniques to criticism was

inevitably followed. History, astraddle the boundary between humanities and social science, found new rewards in the application of sociological methods to its material. Whereas a few disciplines, such as classics, and many older scholars failed to make the adjustment—and in some cases suffered perceptions of intellectual isolation to the point of paranoia—the bulk of the humanities followed the social sciences toward the adaptation of scientific method and quantitative techniques for testing hypotheses. They neither resisted the trend nor opposed it.

The American university that is newly emerging in the wake of demobilization is making a start toward the correction of the fundamental imbalance which has occurred. Viet Nam and Watergate put an end both to mobilization and to the prevailing ideology that lent it justification. It is also once again becoming clear that there can be no such thing as a value-free university. That this is so in practice became painfully evident during the crisis of American university of the late 1960s. During that crisis it became apparent that the common core of values, to which students and faculty might have rallied, had substantially disintegrated.[3] The university, therefore, has since been engaged in the difficult effort to rebuild consensus on the campus and has recognized the practical need for this purpose of a restored system of values. And of course, a value-free university is also not possible in principle.

There is no value-free science. The confusion that has arisen on this point is stupid and damaging. The scientific method is emotion-free. In its perfect application it proceeds rigorously regardless of values to which there may be deep emotional reactions pro or con. But that does not make it value-free. Science is nothing more than the application of human reason in the most logical manner possible. Therefore, reason is a value upon which it rests. And because it is human reason that is involved, science also is founded inextricably upon human life as a value, and upon the rational conduct of that life. The inner core of values of the modern university is therefore founded upon reason and its rigorous application.

The health of the new American university depends on its ability to strike a new and sound internal balance. Basic research and pure scholarship must once again be accorded their due. Fundamental values within the university must receive reemphasis. The traditional function of the university in the transmission of values must be restored. Even though it is necessary to perceive and comprehend those aspects of the recent past that have resulted in imbalance, it would be in vain to look to them also for future guidance. The trend that will most mark the emerging features of the new American university is found in its curriculum. Because self-renewal must be animated by innovation, needed curricular revisions are likely to compose the vehicle for a university reformation.

V

One of the imperatives that impels the American university toward curricular revision is correction of another imbalance: the present overemphasis on vocational and professional preparation in the training of students. [4]. Recognition of the problem is already widely shared; corrective measures are already being attempted; little elaboration, therefore, is required on what is already obvious. Students in

the university have been instructed in highly specialized knowledge to an ever more intensive degree. This has been the natural result of the rapid diversification and sophistication of the state of knowledge and the unavoidably allied tendency of faculty expertise also to become diversified and sophisticated, and in the process also fragmented. At least four adverse consequences for students have recently become apparent. They increasingly tend to lack command of a common core of basic knowledge; in part because they are encouraged to specialize too soon, in part also because faculty interest and competence in the teaching of basic knowledge has been diminishing. Students in the university are also being prepared up to the most advanced state of their specialized field of instruction; but although great effort is expended to acquaint them in detail with the ultra-latest state of their art, the further refinement of knowledge continues to develop so rapidly that what students learn so thoroughly in the final and most intensive phases of university preparation is superseded by new advances within a decade or less. At the same time, the number of openings for employment or further study for which intensely specialized preparation is required has been declining; and those students who as a result are not placed in such desired openings are then doubly frustrated, both because such an extensive and demanding investment of effort has been in vain, and because its very intensity defies its alternative applications. Finally, the joy of learning and the intellectual stimulus for students has been undercut by the growing tendency to regard university education purely as vocational or professional preparation; with the result that it has been described more and more exclusively as an economic investment, to be judged solely on the basis of ultimate economic return; and that in the process it has also attained increasingly the aspect of an economic competition among students.

These very same perceived negative consequences of the regular university curriculum have also already led to the rapid expansion of a new curriculum of the university that serves the purpose of continuing education. [5]. Earlier part-time university curricula for working adults had been designed primarily for those who had missed the opportunity for full-time higher education before taking employment, or for those who wished to pursue their specialized studies further while at the same time retaining employment. Recently, however, university graduates in accelerating numbers have been returning for part-time study with additional and different motives. The most highly specialized graduates have begun to return to catch up once more with the advances in the state of their art that may have revolutionized their specialty during the relatively short interval since they took their degrees. Numbers of them have found their field superseded altogether by new knowledge and technology. so that they return to transmute their old specialty into a more applicable new discipline. Still others have discovered themselves to be too narrowly trained. They return for at least part of the general education that was earlier sacrificed to premature overspecialization.

In response, the American university is newly preoccupied with attempts to rebuild general liberal education within the regular curriculum on the one hand, and to idealize on the other hand the full potential of changing and expanded demand for continuing education. But promising as these attempts may appear to be so far, they must be viewed as merely the stage of infancy of the new American university

that is merging. The first efforts to revive general liberal education are still encumbered by preliminary difficulties. General liberal education is so closely linked to a value system that its restoration must go hand in hand with the reemphasis on values within the university which, as noted earlier, is only just beginning. Effective reemphasis of basic knowledge is also indispensable to general liberal education and requires a changed commitment from the faculty. That may become easier to achieve in the new context of sharply restricted faculty mobility, which has resulted from economic scarcity and the arrest of growth within the university. There is, furthermore, legitimate argument as to the substance of general liberal education, particularly because a mere return to much of the curriculum as it existed years ago would appear to be essentially reactionary. The efforts on the other hand to develop new curricula for continuing education is making more rapid progress. It may be seen to suffer in part from being campus based, which puts it at times in awkward geographic relation to the places of emplowment and domicile of its clients.

The future is unpredictable. Nevertheless, the best assumption appears to be that the new American university is at the threshold of a curricular revolution whose consequences will define its novelty. The chief agent of this revolution—in two very different ways—will be technology. New educational technology is already becoming a vital force in the development of curricula for continuing education.[6] Film, radio, television, computers, and recordings are all already in use as educational tools. One tends to forget how relatively recent these technologies are; how natural it is that their applications should be manifest first in society at large rather than in the university; and how much the economies of miniaturization are in fact contemporary, not even recent. The pocket calculator is one example of how cheap and personally accessible the new technology can be. The television recording, the video-telephone and other refinements appear imminent. Computer-based instruction is less and less experimental and expensive. For years the fear among educators has been that technological devices might replace the human element in education and should be resisted. Now it is becoming more credible that these technological devices are no more than tools of the teacher, and in fact may free him or her to interact personally with numbers of students in a manner superior to their encounter without technological assistance. It is possible to envision the teacher or tutor with the burden of mass instruction not only shifted from the book to new technology, but once again individualized and personalized for each student even when large numbers of students are involved. One may even speculate that American society might solve the problem of democratic mass education without lowering standards, because the promise of the new educational technology is an achievable common standard at an extraordinarily high level.

The new American university may thus emerge as an institution liberated significantly from earlier constraints of space and of human age. The campus will continue to exist as a cluster of talent, of laboratories, of resources, as a community of some students in residence, and as a communication center. But the outreach of the university will become vast. Members of its faculty will be able to interact personally by means of new communications technology with colleagues and students across the world, ultimately without doubt across barriers of

language as well as space. One implication is that the relationship between matriculant and university will become life-long, regardless of geography. Allied to that is the implication that what the youthful student first learns in residence can be truly basic, because he or she will remain literally a life-long student who can tap the resources of the university not only by returning there, but at home and on the job. Another implication is that the discipline of learning can once again be placed squarely on the student, where it must be, in that the student's progress can be tested and reinforced at every step by technology, relieving the teacher of some of the most time-consuming and least rewarding disciplinary obligations. The technological capacity to motivate, reinforce, and instruct is also potentially so varied and sophisticated as to call up a vision of high common standards of knowledge attained by almost every citizen.

On a far more profound level, technology may also become a major ingredient in the redefinition of general liberal education. It is an observable fact that university students may at their best be literate, numerate, and highly competent in their specialty; but also in large numbers they are profoundly ignorant of the technology already in daily use. The same assertion holds true for most faculty and, indeed, most citizens. Bygone is the era of the tinkerer. How many highly educated people today understand the inner workings of their televisions, their calculators, their microwave ovens, or even their automobiles and telephones? Behind such a question is an awareness of alienation from indispensable ingredients of everyday life that raises a host of other troubling questions. If we are daily so alienated from the fruits of science, will we long respect science? If this alienation means ignorant dependence, are we not subjects rather than masters of technology? Can one expect self-confident individualism from persons ever more dependent in their daily lives on tools which they comprehend only in their uses and can neither explain nor repair? Can human reason continue to flourish in a society whose most widely used artifacts, even though derived from applied reason in the form of science, seem to their users to be mysteries that to them—the users—defy analysis, understanding and, to a perceivable extent, control?

These are rhetorical questions. They point, however, to the apparent need for a new humanism. The essence would be to close a circle by refamiliarizing the individual once again with the familiar technology that is the fruit of science. Its goal would be to restore to the human person mastery of technology, to liberate the individual from ignorant dependence. If this suggestion is valid, it may have profound implications for a new university curriculum in general liberal education, and indeed for the American university institution. A new humanism of individual comprehension of technology might become the catalyst around which the value system of the university would revive in new form. It might also be the catalyst of a new liberal curriculum. In such a curriculum such essentials as literacy, numeracy, command of history, and other basic ingredients of education would have their necessary place, but the driving animus would be the effort to build individual mastery of the most essential components of everyday life. Just as the liberated mind must be free to use the tools of language and mathematics, so must it be free to use common technological tools with ready ease, and without the handicaps of mystery or alienation. The effort toward full confidence in the use of technology could and should begin

in schools, but the high level of technological development implies that its full realization could occur only at the stage of higher education. The assumption of such a new humanism would be that it is as crucial today to learn to comprehend the mysteries of everyday technology as it was long ago in the university to study the Scriptures or the law.

If that is true, more should be added to a new liberal curriculum. For example, it is as alienating to live in an incomprehensible society as it is to live with incomprehensible technology. The fact that society is undergoing rapid, drastic change as well understood and closely studied within the American university. But the focus of such study is still essentially national rather than international, and that is becoming an indefensible anachronism. Global interdependence is easy to demonstrate: picture the not atypical American, with a German car, a Japanese camera, a shirt made in Hong Kong, Italian shoes, television set assembled in Taiwan, drinking Colombian coffee, driving on Middle East oil—the inventory could go on and on. The company he works for is probably part of a multinational corporation, the bank he uses depends in part on foreign business, his investments and pension involve a stock market increasingly affected by overseas funds, what he produces probably is sold abroad as well as at home, and his security depends at least as much on international as on domestic tranquillity. But the American university remains heavily parochial in teaching the social sciences within a predominantly American context. For those Americans who do not travel abroad the real world is portrayed fitfully by the news media. They present instant news of foreign crises out of context. They do not prepare the traveler for the fact that the railroad station of Frankfurt looks and sounds more Turkish than German; for Teheran's traffic; for London's racial problems; for Brazilian industrialization; or for the countless other aspects of an international reality from which no person on the globe is insulated. This is no slap at the news media. They are not expected to substitute for higher education. The fact is that international studies remain too much a specialized field in the American university. Begun during the period of mobilization for the sake of training specialists, international studies should now at last take root in the curriculum of the newly emerging American university. Humanism never squared with nationalism; a new humanism should educate for familiarity with the reality of an international society as well as with technology. One world is neither vision nor ideal. Politicoeconomically, one world is hard, unsettling, radicalizing fact—already sensed by most, albeit understood by too few.

VI

We have ourselves now come a long way. Perhaps we have exceeded the real portents of the present. A conclusion must be attempted. It is that a new American university is indeed beginning to manifest itself, and that its prospects appear to be both brighter and very different from what is currently perceived. A major preoccupation of the university at the moment is its relationship to the federal government. We have suggested that this relationship was both abnormally close and imbalanced during the twenty-five years after 1941 that we have called the period of mobilization. Although these were years of growth and achievement, they were not necessarily golden years. A new partnership between government and university is in view—less close, more

balanced—demanding of the university a ceaseless struggle to maintain support while retaining autonomy. In this respect the immediate challenge to the new American university is to shake off nostalgia for a recent past in which too much was wrongly taken for granted, and to regain self-confidence.

The great dread of the American research university in the wake of demobilization is stagnation. Fear abounds that lack of growth, declining enrollments and support, lack of faculty mobility, and the resulting aging of faculties almost entirely vested with the rigidity of tenure will in combination produce a university institution deprived of self-renewal. This fear is matched by concern that in a climate of dejection and reduction internal rivalries within the university will further traumatize a governance structure still shaken by the trauma of the late 1960s; especially because no internal consensus of values has yet been recreated in the university. Such fear and concern stem from real problems that we have not discussed.[7] Instead our conclusion is that the new American university is already beginning to be shaped according to a new agenda that will solve such problems over time. The visible opportunity to strive for a new curriculum, inspired by the values of a new humanism, realizing the potential for the university of the new technology of education is the opening door to the future. We are not where we were. We can see where we are going. It is worth getting there. We are already moving. It is time to pick up the pace.

References

1. See, for example, in Bruce L. R. Smith and Joseph J. Karlesky, *The State of Academic Science: The Universities in the Nation's Research Effort* (New York: Change Magazine Press, 1977). It is interesting to contrast the tone of this study, done in 1976, with the tone of one produced a decade earlier in Stephen Strickland (ed.), *Sponsored Research in American Universities and Colleges* (Washington, D.C.: American Council on Education, 1967).

2. Even though this phenomenon is well known and virtually gave rise to a new institution in the form of the New School for Social Research in New York, it has never to my knowledge been fully documented. There is, however, an excellent background study done by Enid Bloch in an unpublished doctoral dissertation. *The Inverse Cultures: Politics Versus Philosophy in America and Germany* (Cornell University, 1973).

3. This point is unfailingly made in studies of the crises that occurred at individual institutions. For example, *Crisis at Columbia: Report of the Fact-Finding Commission Appointed to Investigate the Disturbances at Columbia University in April and May 1968* (New York: Random House, 1968), and Cushing Strout and David I. Grossvogel (eds.), *Divided We Stand: Reflections on the Crisis at Cornell* (Garden City, N.Y.: Doubleday, 1970). In more general terms the point is made in Theodore Roszak, *The Making of a Counterculture: Reflections on the Technocratic Society and Its Youthful Opposition* (Garden City, N.Y.: Doubleday, 1969).

4 This is, for example, a significant thesis in Joseph Ben-David, *Centers of Learning: Britain, France, Germany, United States,* an essay prepared for the Carnegie Commission on Higher Education (New York: McGraw-Hill, 1977).

5 See, for example, the institutional study, *The Lifelong University: A Report to the President* (Michigan State University, 1973), or the more general thesis in Theodore M. Hesburgh, Paul A. Miller, and Clifton R. Wharton, Jr., *Patterns for Lifelong Learning* (San Francisco: Jossey-Bass, 1973).

6. See, for example, John Fralick Rockart and Michael S. Scott Morton, *Computers and the Learning Process in Higher Education,* a report prepared for the Carnegie Commission on Higher Education (New York: McGraw-Hill, 1975), and Judith Murphy and Ronald Gross, *Learning by Television* (New York: Georgian Press, 1966).

7. I am conscious of having avoided almost the whole of the current agenda of problems confronting higher education, not because the problems are not of urgent importance but because I believe them to be—at least to a large extent—solvable only within the next context which I see in the emerging stage. These problems include equal opportunities for minorities, the handicapped, and women; faculty unionization and other aspects of change in university governance; uncertainties of federal funding under the higher education amendments of 1972 as further amended and amendable; the impact of federal regulation by any number of agencies such as the Veterans Administration or the Internal Revenue Service, or in pursuit of such new legislation as the Occupational Safety and Health Act and the Employment Retirement Income Security Act; the increasing tendency to resort to litigation in the resolution of campus-based problems; the new intervention at the level of the states which is represented by the efforts of state-wide coordinating agencies; the financial crisis produced by inflation; the tuition gap between the independent and the state-supported sectors; the potential adverse impact of tax reform proposals; the prospect of decreased full-time enrollments produced by declining birth rates; and a host of others.

TECHNOLOGICAL INNOVATION AND THE ECONOMY

SCIENCE, TECHNOLOGY AND INNOVATION

DR. J. E. GOLDMAN

SENIOR VICE PRESIDENT AND CHIEF SCIENTIST OF XEROX CORPORATION, STAMFORD, CONNECTICUT

Mr. Chairman, Honorable members of the House of Representatives Committee on Science and Technology. My name is Jacob Goldman. I am Senior Vice President and Chief Scientist of Xerox Corporation. Prior to joining Xerox as its Chief Technical Officer nearly ten years ago, I was Director of the Scientific Research Laboratory of the Ford Motor Company.

My 23 years in the management of industrial research and development following an academic career that included serving on the faculties of Carnegie-Mellon University and the Massachusetts Institute of Technology have given me a certain perspective toward the issues facing this committee which I hope will be worthy of your attention. I shall address myself in this statement to the three questions put before me by Chairman Teague: (1) The organization and operations of the Office of Science and Technology Policy; (2) The relationships and interaction between science and technology and the economy including the interaction of industrial R & D with government and university communities in achieving technological innovation; and (3) Important issues of public concern which have strong scientific and technological overtones and with which Congress may have to deal in the years just ahead.

While I do not presume in-depth familiarity with all of the activities of OSTP, my contact with the R & D community as well as such involvements as I have had with the Office and its Director have led me to conclude that this office and its Director fully understand and appreciate their role in integrating what have often been viewed in the past as the diverse interests of science and technology. The activities of this office have indeed given currency to the mutual interdependence of science and technology and have inhibited the tendency of these "two cultures" from going their separate ways.

The Director of the Office has brought practitioners of industrial R & D into his advisory apparatus, sought their counsel and recognized the unique function that they represent in translating science into technology and moving forward the technological frontiers. His initiatives in bringing into focus both the technological and the scientific facets of such pressing national problems as energy, agricultural productivity, climate control, environment, and national security, have sensitized many of us to aspects of these problems that might not have emerged in the normal channels through which particular interests press upon our society their goals and needs. But perhaps what has impressed me most is the clear-cut leadership this office has effected in sensitizing the executive branch to the crisis in innovation that we are experiencing in

our American society and caused to be put in place at the highest level of government a thorough examination of the symptoms, the causes and potential remedies for this apparent diminution of a major national asset. We, in industry, consider this to be a crisis of signal proportions that impacts our health and vigor almost as strongly as it impacts the growth and stability of our national economy.

I applaud the Director of OSTP for escalating sensitivity of this issue to the highest level of government and I acknowledge with appreciation his inclusion of industrial resources in his advisory apparatus that helped bring the issue into focus.

I should like to turn now to the second question which, indeed, strikes at the roots of this crisis in innovation that I have just mentioned. I would not presume to reduce the ingredients of a major study of the innovation process and its relation to the economy into a simple statement nor would I wish to preempt the results of this study in which I am a participant. But the body of earlier analyses—and I am sure the current studies will confirm this—suggests a very intimate link between the state of our economy—particularly the balance of payments—and the intensity of technological innovation. One has but to look at the significant fraction of our GNP that is accounted for by innovations that weren't even dreamed of three decades ago. My own industry, for example, is just 20 years old and is based on a single technological innovation, xerography, born in the mind of its inventor Chester Carlson. Yet it is now a seven billion dollar business in the United States. Add solid state electronics, computers, TV, instant photography, synthetic fibers, antibiotics, and you have a major segment of our economy. More significantly, it is largely (but not exclusively) in these areas that the United States has maintained competitive advantage vis-a-vis foreign imports.

The track from science to technology to innovation to economic exploitation is not always clear and self-evident. Sometimes the road from basic science to a particular invention is clearly and unequivocally discernible as is the case with the transistor. In other instances, some of the steps in the path may be more circuitous. In xerography, for example, the critical enabling function was applied research on new materials. In some instances it was the confluence of diverse elements of the cycle including process development and complex design processes made possible by the emergence of computational power and skill.

One characteristic of the process is self-evident: whether the path is direct or circuitous the health and welfare of our innovative capacity is linked with the vitality and acuity of our scientific community. Maintaining the health and strength of the scientific capabilities of the country is certainly an important ingredient in promoting innovation but it is not enough. We must find a way of tapping that huge resource—the academic scientific community—for the benefit of the practical needs of the country and intensifying those links that bind academic research to the innovative process.

There are several steps that deserve consideration. One of these is to accept as a national responsibility the expansion of the basic research capability of industry. For industry to be able to relate to the large world of scientific enterprise that exists within the walls of academia it must talk the same language. This means that it must engage to at least some measure in basic research at the frontiers of

relevant science. The pressures of the marketplace have kept industry's commitment to basic research to a bare minimum and limited to but a few of the giants in technology-sensitive industry. It must become a national goal to strengthen basic research in industry just as we have been committed in the last few years to strengthening it in universities. Mechanisms must be found to achieve this either through direct subsidies or indirect incentives. But without it, our nation is not optimizing its committed resources on behalf of innovation.

A second approach to linking the two cultures is through human rather than fiscal resources. A catalyst to the flow of information back and forth between the academic and industrial communities would be significant exchanges of people between these communities. While some of this does exist, like basic research, it is meagre in extent and limited to a small number of large companies that are already well integrated into the academic community. Formulae must be found to further such person interchange programs on a grander scale that will include a wider variety of industrial participants. Government support of travel abroad and sabbaticals for academics is rooted in traditions that go well back into history. A way must be found to stimulate and encourage such excursions by academics into industry and by industrial technologists into academia.

The implications of such interchanges would be manifest not only in providing stronger links into academia on behalf of the innovative capacity of industry but can assist the educational process in universities by providing a faculty resource rooted in the real world of industrial enterprise—a recognized shortcoming of many of our engineering and business schools.

There is yet another option available to catalyze inputs from the university into the innovative process—this one tending toward the sociological. In my judgment, Mr. Chairman, the heavy concentration of innovative industry in the Palo Alto and Route 128 areas is no mere accident. There are probably many reasons for this but I submit that a particularly viable reason is the tacit if not active encouragement to the innovative and entrepreneurial process coming from the universities in these two areas—particularly Stanford and MIT. The fact that so many leading practitioners of scientific and engineering research in these two regions have their feet firmly planted in both camps is ample testimony to the viability of this supposition. This pattern is one that should be emulated and encouraged by the universities. I am not clear on precisely what role the government can play in fomenting this spirit but somehow the R&D support process must take cognizance of it—perhaps through stimulating and supporting joint R&D efforts on the part of universities and local industry.

Finally, Mr. Chairman, I would like to make a brief comment on the need for particular types of shared resources between universities and industry. The costs of certain types of facilities common to the needs of both industrial and academic scientists have escalated beyond the means of either. Examples are storage rings for solid state studies attached to the larger accelerators or ion-implantation facilities. The precendent for government sponsorship of such facilities either at National Laboratories or university campuses already exists. Government can take the leadership in agglomerating the user "market" for such facilities as their need becomes evident and providing the resources to build and operate them.

HOW TO ENCOURAGE INNOVATION

DR. J. E. GOLDMAN

SENIOR VICE PRESIDENT AND CHIEF SCIENTIST, XEROX CORPORATION,
STAMFORD, CONNECTICUT

The recent preoccupation with the state of the nation's innovative capacity—emanating largely from Washington—has a familiar ring. Two years ago there was a burst of concern reflected in a series of articles in the financial press bemoaning what *Business Week* called the "breakdown of US innovation." A decade earlier a Commerce Department panel addresed in some depth the stimuli and barriers to innovation, the conclusions of which constituted the widely read "Charpie Report" on invention and innovation. The concern and methodology has changed little through the cycle; a preoccupation with attempted correlations of all sorts—geographical, fiscal, monetary and tax policies, government R&D spending, artificial incentives, market pull and technological push, commitment to basic research, and a host of other buzz words that rear their presence with increasing frequency.

What has often been overlooked in these deliberations and their stated conclusions is the relationship between academic research and the body of industrial innovative capacity. It is, after all, the industrial environment that is most conducive to promoting a discovery or invention to the status of innovation. If we are to invigorate our national capacity to innovate we must enhance the coupling of the academic technical culture to the fertile innovative fields of business entrepreneurship.

One of the most promising approaches to this goal is exemplified by the development of the high intensity of innovativeness now concentrated in the Route 128 and Silicon Valley (Palo Alto) corridors. Here numerous small high-technology companies have sprung up in the backyards of two prominent academic institutions (namely, MIT and Stanford University). Many a region has undertaken extensive studies seeking ways to emulate these two highly productive and unique centers. A major factor in their development has been the benign view of these institutions toward affiliation of their faculty members with business enterprises (permitting, for instance, flexibility in faculty schedules to make day-time hours available to these enterprises). Clearly a significant fraction of the thriving innovative companies in these two areas owe their origins to and are even today populated by a preponderance of personnel whose roots are firmly planted in the academic community.

But the street is two way. If there is to be intellectual flux between academia and industry, industry, large or small, is not free of the responsibility to keep the flow unimpeded in both directions by creating an environment that makes this possible, that opens the door to

interaction, collaboration and mutual assistance. For example, a company should have on its staff the kind of researchers who can communicate and interact with colleagues in academia and provide these staff members with opportunities to visit campuses (sabbaticals, teaching assignments, lectures and so on). In addition, similar visits by academic researchers to the industrial lab should be encouraged.

There is, in truth, a parallel argument to be invoked in the relationship between large and small industry. Just as an innovative geographical region is populated by thriving enterprises spun off in some loose and mysterious way by the presence of an academic giant, so do we find surrounding the truly innovative industrial giants nests of small enterprises spun off as it were—encouraged and nurtured by the presence and perhaps even active involvement of the large company. The best example is the active role played by the General Electric Company in encouraging these kinds of enterprises. The Technical Ventures Operation at GE has as its primary function that of helping to start up small enterprises to exploit byproducts of GE's research efforts that the corporation itself has decided not to pursue. GE has been known to motivate some of its entrepreneurially minded employees to manage these independent new ventures, help find capital investment and arrange for patent licenses and transfer of knowhow in exchange for equity.

Large industry could and should take pride in its non-product progeny to no less an extent than an elected official would boast of the economic health of his constituency. There is no better measure of the innovative health of the constituency—be it region, state or nation—than the proliferation of satellite small enterprises under the intellectual umbrella of a major university or large corporation. To the extent that both these institutional genres accept and support this thesis we can look to a rise in the national "IQ" (Innovation Quotient—a measuring yardstick proposed by transportation economist A. J. Gellman) and a greater sensitivity and perception of how the national investment in academic research can relate more fully to its infrastructure for development.

IMPACTS OF GOVERNMENT REGULATION ON INNOVATION

DR. MURRAY L. WEIDENBAUM

DIRECTOR, CENTER FOR THE STUDY OF AMERICAN BUSINESS,
WASHINGTON UNIVERSITY, ST. LOUIS, MISSOURI

The basic theme of this paper can be stated very simply: the excessively rapid expansion of government regulation of business is slowing down the rate of innovation and scientific progress in the United States. But the answer is not to propose the elimination of government regulation. Rather, the sensible approach is to reform the existing array of regulation to achieve important social objectives with less of the adverse side effects.

GOVERNMENT REGULATION RETARDS INNOVATION

The slowdown in research and development that has been occurring in this nation is pervasive and can be measured in many ways. In real terms (constant 1972 dollars), R&D spending in the United States has been on a plateau of slightly under $30 billion a year since 1965. Private sector R&D, which rose at an annual rate of over seven percent in the period 1953–67, has been increasing at a more modest two percent a year since.

The employment of scientists and engineers in industry in 1975 was lower than in 1968—1,031,000 versus 1,046,000. This compares to a 19 percent increase in the 1960–65 period. The enrollments for advanced degrees in science and engineering have represented a steadily shrinking share of college enrollments since 1965. In 1973, the Patent Office issued fewer patents to U.S. nationals than in 1963, but patents issued to foreign nationals more than doubled during the same decade. These are all measures of stagnation or worse in our commitment of resources to technological innovation, at a time when expenditures in most other sectors of the economy are growing.

This decline in new technology already has had many serious repercussions for the American economy. The slowdown in productivity and new capital formation that we have been experiencing in recent years, as well as the rise in inflation, are all interrelated aspects. Let us first examine the impact of government regulation on the resources available for investment in new products and new processes. Subsequently, let us turn to the possiblity of improving public policy to better meet the true, long term needs of the consuming public.

It is important to understand the direct connection between overregulation by government in the first instance and the subsequent pleas for more detailed government intervention in business that may follow. When excessive government regulation of business reduces the ability

of and incentive for business to invest in technological innovation, we reduce our capability to achieve important national objectives, such as greater job opportunities, rising living standards, and an improved quality of life. Public dissatisfaction with business performance is increased in the process. This, in turn, sets the scene for another round of government involvement, ranging from proposals to nationalize specific industries to subsidizing others (always of course with still more strings and federal regulations). It is a truly vicious cycle. Energy is a clear example of this phenomenon and the pharmaceutical and health care industries may be on the verge of providing another.

There is a hopeful side, to be sure. During the past year the public has learned about the direct effects of overregulation. Large portions of the public have come to realize the extent to which excessive regulation increases the prices of the goods and services which they buy. Citizens have been aroused by the knowledge that their tax dollars have been used to generate rules governing the frequency of cleaning spittoons, defining an exit, prescribing the size of toilet partitions, and deciding when a roof is a floor. Many people have also come to realize that hundreds of thousands of jobs have been eliminated as a result of federal rules.

But, what is not so obvious—yet is perhaps of more fundamental impact—is the extent to which regulation can impede the potential growth in productivity that we expect from technological innovation. Thus overregulation reduces the prospects for economic advancement of our nation and also adversely affects our competitiveness in world markets.

One important but hidden cost of government regulation is a reduced rate of introduction of new products and of improved production processes. The longer it takes for an innovation to be approved by a government agency—or the more costly the approval procedures—the less likely that the new product or process will be introduced. In any event, innovation will be delayed. As William Carey of the American Association for the Advancement of Science has stated, "Government may imagine that it is neutral toward the rate and quality of technological risk-taking, but it is not . . . regulatory policies aimed at the public interest rarely consider impacts on innovation." To the extent that management attention is diverted from traditional product development concerns to meeting government-imposed social requirements, a significant but subtle bureaucratization of business activity results.

Here are a few examples. Professor Sam Peltzman of the University of Chicago has estimated that the 1962 amendments to the Food and Drug Act are delaying the introduction of effective drugs by about four years, as well as leading to higher prices for drugs. As a result in large part of the stringent drug approval regulations, the United States is no longer the leader in introducing new medicines. We were the thirtieth country to approve the anti-asthma drug metaproterenol, the thirty-second country to approve the anti-cancer drug adriamycin, the fifty-first country to approve the anti-tuberculosis drug rifampin, the sixty-fourth to approve the anti-allergenic drug cromolyn, and the one hundred sixth to approve the anti-bacterial drug co-trimaxazole.

On occasion the regulators seem to have the private sector scared. In August 1975, the National Cancer Institute reported that the solvent trichlorethylene, known as TCE, might be a possible cause of cancer. TCE at the time was used in decaffeinated coffee. It seems that the government used a generous dose of the chemical on the test animals—the equivalent of a person's drinking 50 million cups of decaffeinated coffee every day for an entire lifetime. But did the industry laugh at this example of governmental nonsense? Hardly. With the cyclamate episode still firmly in mind and a saccharin ban being seriously considered, one major producer quickly changed to another chemical.

By creating uncertainty about the future of regulations governing the introduction of new processes and products, the governmental decision making process can have other adverse effects on innovation. An example is the report of the task force of the President's Energy Resources Council, which deals with the possibility of developing a new synthetic fuel industry. In evaluating the impact of the Federal Water Pollution Control Act Amendments of 1972, the task force reported, "It would be next to impossible at this time to predict the impact of these requirements on synthetic fuels production." In considering the National Environmental Policy Act, the task force stated that the major uncertainty was not whether a project would be allowed to proceed, but rather the length of time that it would be delayed, pending the issuance of an environmental impact statement that would stand up in court. The task force pointed out, "The cost of such delays (construction financing and inflated raw materials and labor costs) is an obvious potential hazard to any synfuels project.

Evaluating the overall impact of government regulatory activity, the task force concluded, "In summary, some of these requirements could easily hold up or permanently postpone any attempt to build and operate a synthetic fuels plant."

Similar sentiments have been expressed by executives of private R & D laboratories in other industries. B. L. Williams, director of corporate research at Monsanto, has stated that it is not the regulations themselves or the threat of regulatory action, "onerous as they may be, but the unpredictability of such action" that is at the heart of the problem.

Clearly, large and rising shares of corporate R & D budgets are being diverted from product and process improvement to meeting regulatory requirements. This trend is apparent in the automotive industry. According to the head of General Motors research laboratory, "We've diverted a large share of our resources—sometimes up to half—into meeting government regulations instead of developing better materials, better manufacturing techniques, and better products."

If long established products, such as saccharin, and creative new products are going to be arbitrarily eliminated by governmental regulations, then the very threat of future, unforeseeable government action likely will force companies in other industries, such as chemicals, to become more conservative in allocating funds to R & D, to devote their R & D budgets to reactive and defensive research or to very modest product changes which do not require new regulatory clearances. Corporate investment funds which must be dedicated to meeting

government-mandated requirements are, by definition, not available for new R & D undertakings.

The basic nature of the underlying public policy problem has been forcefully described by W. O. Baker, head of the Bell Laboratories, as a "bizarre conflict" between the presumptive laws and regulations of pervasive government in a low-risk, welfare society and "the present realities of technical and scientific advance, which, more than ever, demand the freedom to experiment deeply and to innovate boldly."

A related and generally overlooked aspect of the impact of government regulations is that they tend to hit the smaller companies disproportionately hard. This is true in every case that I have had the opportunity to examine—recordkeeping, job safety, labor relations, environmental controls, etc. The Toxic Substances Control Act of 1976 (TOSCA) may also turn out to have such an undesirable effect.

What may not be apparent to most people is the basically anticompetitive nature of these regulations. We should not underestimate the problems that are being faced by the larger companies. But it is realistic to expect that most of them will be able to adjust to and survive in the expanded regulatory environment. It is the smaller companies that may be more adversely affected, and even experience more difficulty surviving as independent entities. The foundry industry surely provides an earlier case in point; generally, it has been the smaller plants in that industry that have been forced to close down in the face of rising government-mandated costs.

Let us take stock for a moment. Increasingly, business operates in an environment in which the application of the fruits of science and engineering to products and services is coming under detailed goverment scrutiny. Federal controls are having their impact at every major stage of the product cycle, often far in advance of the sale of the product.

But it is not just a business problem. Although the expansion of government regulation of business is designed to benefit the consuming public, the consumer ultimately pays the added costs and bears the additional burdens that invariably result. The key price that this nation may be paying for overregulation is the weakening of the risk-bearing and entrepreneurial characteristics of our private enterprise system which, in the past, have contributed so effectively to rapid rates of productivity, growth and progress.

THE NEED FOR INNOVATION IN GOVERNMENT REGULATION OF BUSINESS

What can be done to improve the public policy environment in which business operates? To summarize very tersely and perhaps too simply, two fundamentally different approaches are simultaneously being urged on government policymakers right now: One is to extend further the scope of government regulation. Government is being asked to set up a consumer advocacy agency, to oversee the activities of multinational corporations, to use its chartering power to reduce the independence of the management of the modern corporation, to extend antitrust activities to effect a splitting up of the larger American corporations, and to establish a centralized planning system embracing the economic activities of both the public and the private sectors. This first approach in its essence would involve government more deeply

than ever in the day-to-day functioning of the business system. To me, that type of action is in the nature of the traditional hangover remedy, known as "having a bit of the hair of the dog that bit you."

The second approach is in many ways a more modest one and not a monolithic viewpoint. Advocates of this viewpoint, and I am one, consider the existing totality of government regulation as already an extremely vast and ambitious undertaking. Therefore, we are concerned with the serious shortcomings of existing regulatory efforts and stress opportunities for reform. Let me try to dispel some of the confusion that has arisen on the subject of regulatory reform.

Several different avenues for regulatory reform can be identified. The first deals with the older regulatory commissions each of which has jurisdiction over one or a few related industries. Here is where the issue of deregulation has been raised and, on occasion, may be an appropriate response. Frankly, one of the factors that has muddied the waters is that many of the proponents of the newer regulatory programs have been scared, perhaps needlessly, by fears that the general talk about deregulation extends to environmental, safety, personnel, and the newer areas of government involvement. It does not.

The question of deregulation relates to the ICC and CAB types of activity, where greater dependence on competitive market forces may be a practical alternative. To many economists as well as to "public interest groups," this traditional type of regulation constitutes a form of protection for the existing firms in an industry. It may serve as a barrier to the entry of new firms and thus shield entrenched firms from potential new competition.

We should avoid excessively simple approaches to this difficult subject. For example, it is appropriate to rely more heavily on market forces where a reasonable, competitive market structure exists or is likely to develop, such as interstate trucking. Yet, we should not forget the basic natural monopoly (decreasing cost) argument that has led to the chartering of public utilities and to the establishment of public utility regulatory commissions. In these cases, attention might better be given to modernizing the often excessively protracted regulatory process (e.g., reducing regulatory lag) and to providing greater incentives to regulated companies to achieve higher levels of productivity and efficiency. Stating the desire of course is far easier than identifying specific courses of action.

The newer forms of regulation constitute a more varied lot—EPA, OSHA, ERISA, EEOC, and CPSC. These agencies deal in general with the public impacts of ostensibly private actions. In the case of environmental protection, for example, there is widespread although not universal agreement that the social costs of pollution warrant government intervention. However, there is considerable disagreement as to the most effective methods to use. Many economists prefer working through the price system rather than relying almost exclusively on promulgating standards and issuing specific regulations. Taxes (usually in the form of excise or sumptuary levies) are the preferred way of working through the price mechanism. Increasing the relative prices of pollution-intensive means of production and consumption will hopefully promote more ecologically sound production and consumption patterns. To clear the air, I am not referring

to natural gas, where deregulation is the appropriate economic solution.

In the case of other cross-industry types of regulatory activity such as job health, product safety, and employment discrimination, benefit/cost analysis and cost/effectiveness analysis can be useful ways of reconciling a variety of conflicting attitudes and viewpoints. Contrary to the assertions of some, benefit/cost analysis is not a "green eye shade" approach only concerned with costs to business and oblivious to the broader needs of and impacts on the public. To the contrary, a properly applied benefit/cost test arrays all of the important impacts—good and bad, direct and indirect—that flow from a government regulatory program. To state the obvious, which is often ignored in public policy debates, this approach gives equal weight to the benefits and to the costs.

To be sure, there are great difficulties in conducting appropriate benefit/cost analysis and many studies in practice fall very short of what is desirable. But it is an objective way of looking at government regulation which is open-minded, if not eclectic. There is no advance assurance that a benefit/cost analysis will support a proposed regulation or that it will condemn it. But properly conceived and carefully executed, this approach will go a long way to ensuring that the government's regulatory decision making process will try to take account of far more effects than traditionally has been the case.

Benefit/cost or economic impact analysis could be instituted through legislation via the "sunset" bills now being considered in the Congress. These proposals would require compulsory periodic reviews of each major regulatory agency.

The enactment of this or other similar legislation would still require a fundamental turnaround in prevailing executive branch attitudes. A greater display of humility on the part of regulators would be most welcome. Contrary to what often seems to be the implicit assumption of many regulators, in my own experience, I have yet to come across the business executive who enjoys polluting the environment or producing unsafe products. What I have found is honest disagreement as to the most effective and sensible ways in which to proceed in attaining the nation's social objectives.

A more fundamental change is needed, and it does not deal with technical economic or financial issues. The public must come to understand that ever more detailed government regulation is no panacea, and may even be self-defeating. At best, government regulation is a powerful medicine which must be taken carefully, in limited doses and with full attention to all of the adverse side effects. And those side effects are not trivial. They include more inflation, more unemployment, loss of productivity, reduced capital formation, and lost opportunities for technological innovation.

SOME CONCLUDING THOUGHTS

Any realistic appraisal must acknowledge that important and positive benefits have resulted from many of the government's regulatory activities—in terms of less pollution, fewer product hazards, reduced job discrimination, and other socially desirable objectives of our so-

ciety. It should also be realized that these federal programs were established by the Congress in response to a surge of rising public expectations about corporate performance. A Neanderthal position of complete opposition is neither justified nor realistic.

But the worthiness of social objectives does not justify government closely regulating every facet of private behavior. Indeed, the experience with existing governmental efforts shows that further expansion of government involvement in the detail of business decision making is likely to be self-defeating. Some restraint would yield great rewards.

To be sure, the exercise of judgment in regulatory matters can involve striking a balance in some extremely difficult areas, literally affecting human life. As a former commissioner of food and drugs, Dr. Alexander Schmidt, has stated, "In FDA decisions, as in all aspects of human endeavor, we must accept the probability of nonexistence of absolute safety." He goes on to raise some very difficult questions: Just where and when does one draw the line in weighing demonstrable benefit against theoretical risk? Who is to draw the line? Government or industry or the individual consumer? Dr. Schmidt criticized the anti-cancer clauses in existing food safety laws because, literally interpreted, they leave no room for scientific judgment, calling for zero risk from all new food ingredients.

A new attitude of restraint in imposing additional regulations on the private sector would lower the risk and the cost of research and development by business. We need to adopt sensible, operational notions of practical threshold levels and of toxicological insignificance.

To put it bluntly, all hazards are not equal. Government policy needs to make such distinctions as between hidden and visible hazards, voluntary and involuntary hazards, easily avoidable and hard to avoid hazards, remote and commonplace hazards, and negligible and severe hazards.

Such a new attitude would have a salutary effect on the pace of technological innovation and scientific progress in the United States. The benefits would be widespread. They would include lower prices for American consumers, greater job opportunities for workers, and ultimately an improved quality of life for the average citizen.

SCIENCE POLICY ISSUES IN THE 1980's

DR. LEWIS M. BRANSCOMB

VICE PRESIDENT FOR RESEARCH AND CHIEF SCIENTIST, IBM CORP., ARMONK, NEW YORK

These hearings will, I hope, serve well the purposes of the Congress, which has demonstrated its concern for the development of science and technology policy through legislation which not only established the Office of Science and Technology Policy and the position of Science Advisor to the President, but established in the first article of that statute the policy framework that guides the nation.

Since the Executive Branch has not yet implemented those features of the Act designed to make explicit the long range science policy of the Administration, it is appropriate indeed that the Congress should stimulate public discussion of these issues in order to lay the basis for the consensus on which positive action must rest. Thus these hearings may serve as much to stimulate the thinking of the scientific community and the general public as to assist the Congress with sorting out the issues it must face in the coming years. It is a great privilege for me to participate in this historic process.

Science policy in the 1980's must, like other areas of public policy, equip the nation to deal with a changing world of opportunity, challenge and uncertainty. Americans are already well aware of the agenda of issues—finding alternatives for scarce resources, allaying the threat of the arms race, providing equitable access to participation in and the fruits of our economic life, fulfilling the public's expectations for improved quality of life and political and economic accommodation with other nations.

In the middle 1980's we can predict with confidence that these issues will still be with us, but certain trends will become much more visible to the public and more a focus of national concern. These include:

(1) The growing importance of the international dimension of our economic life,

(2) The necessity of a high innovation rate and the scientific research to support it, in order to restructure the technology to fit resource constraints and productivity requirements,

(3) A long period of zero growth in our universities will challenge their ability to serve as the driving force for new knowledge and new ideas,

(4) The continued fragmentation of global political structures with the increasing dominance of north/south tensions and demands for expanded technological cooperation as the price for resource supply stability,

(5) Information technologies will be central to a growing number of national opportunities and issues, and

(6) The continued accumulation of complex technical public policy issues—about environment, health and safety—will stress the consensus machinery of our democracy because they require controversial public decisions in the near term, despite substantial scientific uncertainty about future consequences.

This list could certainly be extended, but it should be sufficient to demonstrate that as circumstances change the institutions and traditions for public decision-making will have to change too.

We Americans must find a way to bring to public policy formulation the traditional pragmatic and objective attitude that we have prided ourselves on in the past. The historical American technology advantage has come from a flexible, pragmatic attitude, and a willingness to accept facts for what they are. Any advantage we have in education, talent or management skill follows from this pragmatic egalitarianism, which emphasizes open-ended opportunity for the individual. Yet today each faction in the public debates about technology accuses the other of relying upon fear, emotion and ideology instead of fact, analysis and experimentation. Many people want to act on technology assessments before the technology has even been reduced to practice. The Congress is repeatedly asked to choose among technologies that should be suppressed or to select technologies that should be required. The role of chief engineer to the American economy ill suits the greatest deliberative body on earth. Nevertheless, political conflicts derived from fears of new technologies must be resolved, and the Congress does the best it can.

Political conflict could be reduced if early entry into the market of innovations was encouraged, together with provision for measuring their environmental and social costs and benefits from actual experience. But many oppose this approach on grounds that once innovations are introduced, those associated with their further development would make it politically impossible to act upon the facts that might emerge from technical studies.

This is surely a counsel of despair for our democracy, for it denies us the opportunity, perhaps even the possibility, of resolving issues about future harms on the basis of present facts. But innovations derive from the public's need for energy, transportation, food, medicine and the like. The need for them will not go away. The development of more rational decision processes related to public strategies for generating, introducing and managing technology are vital to the survival of democracy itself.

Thus a high priority challenge for science policy in the 80's will be to loosen the rigidity and unpredictability of government regulation that increasingly throws the burden of technology management on the Congress, and when it cannot resolve the issue, on the courts. Each time the Congress and the executive are unable to achieve a public consensus on a technologically complex issue, and the dispute reverts to the courts, we witness another failure in the consensus process of our democracy. If this continues to happen with increasing frequency, the pressures to alter the political foundation of our society inevitably grow. A new process is needed that balances the risks associated with today's level of activity against the benefits to be gained from quantifying the knowledge of future consequences and benefits.

To build that knowledge, we will need new problem-oriented institutions for both scientific and policy research, experienced and credible enough to deal with problems that are fraught with complexity and uncertainty. Few such institutions exist today, and the principal reason is the lack of continuing financial support for work in an institutional environment reasonably free of the pressures of short term political and economic interest. Such institutions could serve as a common ground for objective evaluation of the facts and elucidation of the research agenda for the future.

In the next decade not only the expert's but the public's under standing of technical matters must improve. Unless the public understands the opportunities and the risks associated with new technology, it may be politically impossible to achieve the consensus necessary for taking prudent risks. Most scientists do not communicate effectively outside the group of experts in their field. Political leaders have a substantially better ability to understand the experts than they are usually given credit for. Their shortcoming is time, patience and the public support for taking the long-range point of view. To take a topical example, I would suggest that the DNA controversy, which was initiated by scientists responding to a sense of obligation to inform the public, leaves few scientists and few political leaders feeling good about the ability of either community to deal with such issues satisfactorily. But such issues cannot be avoided or covered up; scientists and public bodies must gain experience and confidence in each other, and both communities must invest in the public's ability to understand and make correct decisions in its own long term interest.

I have dwelt heavily on the character of governmental intervention into the technology generation and delivery system, and the decision structure that brings science to bear on public choices, for I believe the way the government manages its regulatory and legal process for guiding technology choice determines the nation's opportunity to use technology to solve problems. The wellsprings of scientific curiosity, of inventive genius and of entrepreneural dreams and ambitions are still deep in this country. Indeed, these strengths constitute the greatest economic comparative advantage we enjoy over foreign competitors. They constitute the basis for the level of well-being our citizens can enjoy in the future.

Government exercises stewardship over most of the nation's scientific and educational resources and government's regulatory and economic policy heavily influence private investments in research. But this stewardship is exercised with little explicit attention being given to the impact on innovation. In the Executive Branch, economic policy seems to be made in every agency; technology policy is made in virtually none. The intersection between economic and technology policy is thus very superficially addressed. Several abortive efforts to focus on this point have failed to achieve decisive results. The last major effort of this kind was undertaken by the President's Science Advisory Committee under the leadership of Dr. E. E. David, then Science Advisor to President Nixon. I understand that discussions are under way in the Office of Science and Technology Policy to initiate another such effort on a governmentwide basis. A Presidential review memorandum on innovation that leads to new policy and appropriate agency restructuring could be one of the most important achievements

of this Administration. Among the issues that will need to be faced are the following:

(1) An economic strategy that takes into account the strengths and weaknesses of American industry and the technology on which it rests, sector by sector. Our policy for dealing with economic well-being build on the sectors of national strength to enhance employment opportunities and to ensure that continued international competitiveness rests on a solid foundation of advanced technology. It must also promote the basic skills, retraining opportunities and adaptability of the U.S. labor force and compensate appropriately for the dislocations that sometimes accompany technological change.

(2) Government must support most of the basic scientific research upon which the innovative capacity rests. Such research has been generated primarily in universities. They will face in the 80's rising costs and falling enrollments. They need institutional as well as project support for research, at a level adequate to meet the nation's public policy and technology requirements. We must not restrict the level of research effort to that necessary to sustain the level of graduate instruction.

(3) The principal source of applied research and exploration of advanced technologies is in private industry. Larger companies also perform a significant amount of long range scientific research. Government subsidy is not required for such commercially-motivated industrial research, but adequate profitability and the environment for an optimistic attitude toward future economic opportunities are required. Technological protectionism does not help in the industries where our technology lags, and it hurts in the industries where we lead by denying opportunity to exploit our advantage.

Finally, the nation must come to grips with many issues that can be grouped under the rubric "information policy." Most of the traditional leaders of the scientific and engineering community are uncomfortable with this area of science and technology policy. It is, nevertheless, an area of growing importance and is recognized as such by a great many members of the Congress and the public. There are many facets to this issue that I shall not have time to explore. Let me only note that knowledge and the ability to use it are our nation's greatest assets. The majority of our work force is engaged in information generation, distribution, or exploitation. We lead the world technically in the industries most deeply involved—computers, communications, publishing and office systems. Yet, America faces government supported competition abroad in all these areas. Countries like Japan seek economic expansion of their information industries, which consume little energy and materials, are generally non-polluting and take advantage of a well-educated work force. Vigorous competition will continue to drive U.S. technology leadership. But competition and regulation make poor companions, and many issues are unresolved concerning the limits to communications regulation. Also, those industries, such as education and health, that are vehicles for bringing the benefits of information technologies to the public, tend to be sectors heavily dependent on government financing, operations or regulation.

Thus, government shapes the evolution of our information technologies and the services they permit, to a degree not encountered in less technically vigorous sectors. And it does so with increasingly inadequate institutional capability.

But there is an even deeper reason to focus on information policy as a challenge for the 80's. Our political values are deeply rooted in institutional principles that protect freedom of expression and personal rights. The concept of privacy is evolving and strengthening in response to social change that accompanies the new information technology. Clearly the government must be the mechanism for establishing consensus on these new concepts and principles.

But, how is the balance to be struck between freedom of expression, thought and information gathering and restraint on abuses of privacy, denigration of minorities and affront to public morals? These problems are complex enough, but the personal rights issues and the economic issues are deeply international, as illustrated by the growing debate in Europe and in OECD on transnational data flow. Today, we have no official U.S. policy and have weak mechanisms for formulating one.

This abbreviated discussion of policy issues concerning the information sector of our economy illustrates a dominant question for science and technology policy in the 1980's. Can government improve the objectivity of its interventions in technology generation and introduction, fostering research and innovation to maximize long term opportunities, while at the same time evolving a national—indeed, international—consensus on the values that motivate those interventions?

SCIENCE, TECHNOLOGY AND THE ECONOMY

DR. SIMON RAMO

DIRECTOR, TRW, INC., REDONDO BEACH, CALIFORNIA

Are we in the United States using science and technology to the fullest on behalf of our society? This is not to ask whether we are following up every clue to nature's undiscovered secrets and are building every machine it is technically possible to build. These latter are very different and less serious questions. We seek here rather to inquire if our scientific and technological know-how is being applied adequately where there is strong evidence of high economic and social rewards for the effort.

To this important question the answer is "no." While our nation today has more capability in science and technology than ever before, we are using it less—less, that is, as a fraction of what the full, beneficial potential could be. Scientific research, if more avidly pursued, can teach us how to apply our resources, natural and human, more effectively than we now do. Advanced technology can be employed more broadly to develop additional economically advantageous products whose production would create new jobs to fight unemployment. Further efforts can lead us to superior methods for increasing supply and lowering costs as a counter to inflation, to substitutes for materials in short supply and to ways of acquiring raw materials and manufacturing for our needs with less harm to the environment. But we are becoming slower, more timid and less innovative in applying science and technology toward such possible ends.

PENALTIES OF TECHNOLOGICAL LAG

Lethargy and negativism regarding research and development are especially penalizing to the U.S. society because our values and habits are so strongly based on a generous availability of the fruits of these disciplines. Our high standard of living is rooted in many decades of technological advance. Political experts assure us that no approach to our social and economic problems is politically viable if it contemplates the average citizen's accepting a materially reduced personal supply of goods and services. It is equally unrealistic politically to expect those now disadvantaged to abandon their aspirations for a higher living standard. If these are political truths, then the tools of science and technology must be sharpened and applied vigorously, because such action is indispensable for a feasible approach to national problems.

Of course, when we speak here of employing technology fully, we specifically do not mean the unthinking application of it, the misuse of technology on projects and products the public does not in the end really want and that are more harmful than beneficial. Also, even if we

were to attain perfection in the selection of technological programs and the implementation were one hundred per cent efficient, we still would not be guaranteed a healthy economy and a happy society. If we handle badly numerous nontechnological decisions, we can have inflation, recession, high unemployment and other ills all at once. However, without a strong technological foundation, our needs will not be satisfied. Science and technology are not sufficient. But they are necessary.

They are essential to the United States for more than domestic tranquility. International economic competitiveness by the United States and our contribution to world stability and progress are both dependent on the status of our science and technology. If world economic health is fostered by each nation's doing for the rest what it can do best and trading with the others for their most suitable items in return, to our doing our part. In this regard the situation is again disappointing. The areas of science and technology in which we lead are becoming fewer and in many of those areas the leadership gaps are being closed by others. In still other high-technology fields where we are close to unique in our capabilities and opportunities, we are moving ahead slowly.

High technology product exports (such as aircraft, computers, petroleum equipment, chemicals) are presently the important contributors to the positive portion of the U.S. trade balance. The only other strong such contribution comes from agriculture and that is in substantial part because our fertilizer, farm machinery and other farming and food technology leads the world. To maintain our position in these fields requires continuing technological advances to increase productivity steadily. Unfortunately, the rate of productivity increase for the United States is now lower than that of every other major industrial country. We used to be ahead of others in expenditures for R & D as a fraction of the GNP. We no longer are, despite the known dependence of productivity increase on application of new technology.

"ANTI-TECHNOLOGY"

Now why is this? One reason is the public opinion wave of "anti-technology" in the United States. A substantial fraction of our nation's citizens seem to equate technology with the devil. In attaining our high production of goods and services, as they perceive it, we have been crowded into congested cities, this before we have learned how to live together. TV means to them vapid programs loaded with violence that miseducate our children. The automobile, they note, kills 50,000 people a year, fouls the air and forces us to spend hours each day in traffic snarls. We waste money going to the moon, the atom bomb may destroy civilization and the nuclear reactor may poison our environment. We make our soil more productive, but insecticides may do us in.

It can be argued, of course, that those who make these statements obviously fail to distinguish between the tools of man, valuable when properly used, and man's own misuse of them. However, the presence in the nation of a broad anti-technology bias, applied indiscriminately, impairs our overall ability to reach objective, sound, nonemotional decisions on the development and employment of technology. This prejudice, like all prejudices, stands in the way of our arriving at meaningful value judgments.

An even more serious limitation to our wise utilization of science and technology is the public confusion as to the right roles for free, private enterprise, on the one hand, and government control, sponsorship and regulation, on the other. Admittedly, a muddle of inconsistent opinions by the citizenry about all manner of things is to be expected in a democracy, but the situation is particularly chaotic as regards science and technology matters. Thus, for example, many people are convinced "big business" is socially irresponsible. Whenever any kind of a problem surfaces, they are certain private enterprise can be counted on solely to over-exploit it, seeking monopolies and "unconscionable" profits at the expense of the consumer. They thus look to government alone, and the private sector not at all, to provide solutions. Since technological advance is most often identified with big business, they reason that such advance means unneeded product changes, or, just as harmful, withheld product advances, and higher prices in either instance.

Another large fraction of the voters are fed up with government spending, and big government generally. They see the government as a huge and increasingly incompetent and inefficient bureaucracy. As to government sponsored scientific research and technological advance, the government is believed by these citizens to be engaging in wasting dollars into the billions as it engages in boondoggles or tries to do what should be left to free enterprise.

As a capping indication of the degree of confusion, it seems much of the population holds both of these extreme views at once. They distrust both the private sector's and the government's involvement with science and technology and can be counted on for a strictly negative stance.

AN UNSOLVED SYSTEMS PROBLEM

We see in the United States today a severe mismatch between the high potential of technological advance and the low potential of the country's social-political progress. The problem is not technology per se. We are simply not organized to use science and technology to the fullest. It is the interface of technological and non-technological factors that is critical and controlling. The whole is an unsolved "systems" problem. For instance, in choosing where and how to apply science and technology, it would be helpful to have clearer national goals, because for a "systems approach" it is required that we know what we are after before we can get very far. When we find it hard to articulate what kind of a society we want, it is naturally difficult to pinpoint the effective use of science and technology as tools to help us build it. Similarly, we cannot make satisfactory decisions without an understanding of trade-offs and options. We need to be in a position to compare the "good" that can come from specific technological advances against the "bad" and the cost. As to our employment of technological change, we can be likened to a bunch of carpenters, sawing and hammering away, often getting fingers in the saws, sometimes hitting each other's heads as they bring their hammers back, and hitting their own thumbs as the hammers come down. They don't quite know what they are trying to build, sense an unsatisfactory situation, and meanwhile blame the saws and hammers.

LIMITATIONS OF FREE ENTERPRISE

We have two routes for initiatives to get things done in the United States: free enterprise and government. The approaches are not mutually exclusive. In fact, we have always had a hybrid system and the need for a balance as we allocate assignments to private or government action. The free enterprise system—private capital at risk seeking a return—has served well for two centuries to connect the needs and desires of the citizens with the capabilities of technology. This wedding has continually blessed us with an immense stream of products and services. Why does not the free market automatically solve the system and organizational bottlenecks just referred to? Why is the free enterprise route not still the practical answer to the challenge of putting science and technology to work sensibly and completely?

For one thing, inflation and government spending, tax policies, and over-regulation have impaired earnings and lowered available funds in industry for plowback to create techological advances. Furthermore, the increasing likelihood of inadequate return militates against investing funds still available to exploit technological opportunities. At the same time, an increasing fraction of promising technological projects calls for investments beyond the net worth of most corporations, and large corporations in the U.S. now are essentially not allowed to team up to share the risk. For such projects, the "risk-to-return" ratio is too great. The start-up losses are too high, the time to "turn-around" to an eventual profit phase is too long, and the dependence of success on unpredictable political decisions is forbiddingly severe. The market for these large-scale projects is far from being a free one and is instead a cacaphony of semi-autonomous and conflicting interests. Finally, many of the potentially most beneficial programs, like development of ocean resources and many space systems, require a high degree of international cooperation, something difficult to arrange.

For most technological innovation, the straightforward economic limitation is now the most important. Technological advance occurs mainly in industry and technological corporations, large and small, which are not now on the average earning enough to provide adequate funds for plowback to extend their technologies. After the small difference between selling price and costs is used to pay taxes, the interest on borrowed money, dividends to the shareholders and the inflated costs of replacing depreciating facilities, too little is left to improve methods and develop new products. So dislocating has been the effect of inflation and recession that many corporations have overborrowed. They now find themselves with too high a debt in relation to their equity capital and their net earnings. Since this condition is paralleled by high interest rates, their debt expense is extraordinary. Many companies' stocks are selling on the market at less than the book values of their assets even though because of inflation those assets could not be replaced at those stated book figures. This means new equity capital is as hard to come by as are earnings for reinvestment. It also explains why few new, small corporations are being formed now to develop positions in new technological products.

The important drag on innovative effort in U.S. industry is certainly not a lack of creative, inventive talent, but rather the incentive to provide funds to back it, which condition goes with the other present characteristics of the U.S. economy: inflation, high taxes, high costs in

dealing with government regulatory requirements, high consumption to investment ratios, and high ratio of government to private sector spending. Given the state of the economy, no government program to stimulate more innovative effort and R & D in private industry could be nearly so effective as, for instance, a succesful government program to lower inflation or one to cause more discretionary cash flow to be available to technological corporations by a lowering of taxes. If the government could create these changes, the seeds of beneficial science and technology advance would quickly blossom into copious crops.

Let us now consider a number of examples that illustrate the relation of the rate of application of technological advance to economic-political constraints.

OIL WELL TECHNOLOGY

If existing U.S. continental oil wells were equipped with submergible pumps for secondary and tertiary recovery wherever warranted, our oil reserves would be greatly increased, perhaps even doubled, the experts tell us. Technologically, such installations are thoroughly practical. Oil can be brought to the surface that otherwise would have to be left below, counted as unavailable. Most often, the installations would be economically feasible as well, that is, if the price per barrel were higher than present controls permit for old oil, more in the range of prices the nation is paying now for imported oil. Billions of dollars invested this way would bring us tens of billions in equivalent additional petroleum. But the critical pricing parameter, to make the private investment a sound one, lies outside the free market category and is a political matter. This pricing involves a contest among numerous influential constituents with wide differences of opinion on the issue. The private sector thus cannot justify investing the required funds. The "risk-to-return" ratio is too high.

IMPROVED URBAN TRANSPORTATION

Almost every large U.S. city could gain by installing a first class public transportation system. But it has to be the right system. The technology has to be carefully selected and matched to each city's layout, industry pattern, employment distribution, health care and educational facilities—i.e., to that city's economy, social conditions and life style. The economic gain, assuming a sound application of the correct technology to the cities' needs, could be prodigious. Perhaps half our population would be benefitted. A typical resident could save hours each week over present means for getting to and from work, travel at less expense, consume less energy, cut air pollution, and decrease the accident rate.

But is it intelligent for American technological corporations to invest their resources with the objective of developing, then selling, and finally earning a return from, mass transit systems for American cities? Take Los Angeles as an example. Imagine that some private company a few years ago actually decided to devote several years of effort, using a necessarily large team of systems engineers and specialists, to matching technology with L.A.'s social and economic needs and designing the multi-billion dollar transit system required. Then, further assume, as we must to be complete, that all the sub-systems and

components (vehicles, controls, energy distributing systems, maintenance and reliability procedures and organizations, legal permissions and approvals) were worked out and debugged.

All this would have involved an expenditure of a hundred million dollars or more and would be only a beginning. Much of this effort would have had to be repeated for other cities because of the importance of bringing prices down by realizing as much commonality as possible in equipment and procedures for multiple installations. Then the private concern would have to design, build and tool up several plants to start producing the specifically required hardware, refine it by full-scale testing, and manufacture parts in some quantity to be sure of price and quality before taking on contracts for shipment and installation. If the company had gone this far (it would by now be about a billion dollar investment) and had done everything perfectly, would it then have succeeded in selling a system to Los Angeles? That is extremely doubtful. Who exactly is this customer we have labeled Los Angeles? What does Los Angeles truly want and how are its requirements being decided? Can Los Angeles afford and raise the purchasing price? Hundreds of separate (and often quarrelling, apathetic, self-seeking and uncooperative) groups, both private and governmental, are involved in the answers to these questions. Critically important and potentially beneficial as the proper application of transportation technology appears to be in the city, the market in Los Angeles is not clear. The "risk-to-return" ratio would be absurdly high for the private corporation we imagined electing to go after this field. The start-up cost would be huge. Even assuming success eventually, the time to pay off would be too long and the city or county government's eventual approach to the pricing of the service, fundamental to the promise of return on the private investment, would be too unpredictable.

ENVIRONMENTAL TECHNOLOGY

Done suitably, with a mixture of creativity and common sense, the selective depolluting of major lakes, rivers, harbors and coastal waters stands to yield a good return on the investment in health, quality of life, and economic gain through preservation and maintenance of vital natural resources. To achieve optimum results, much scientific research and technological work is needed to understand pollution phenomena more deeply, develop superior non-polluting approaches to the use of the waters, and produce a myriad of specialized equipments. Of course, such technical effort would be meaningless or misguided without attention to all the complex interface problems. Learning quantitatively and qualitatively about city waste, industrial effluents, power utility outputs, transportation pollutants; developing techniques and assessing the costs of minimizing, limiting and altering these environmental impairments; puzzling out the economic value to the society of cleaner waters (how clean?)—these and numerous other factors and trade-off issues must be analyzed. The decision makers, in the end the public, must be able to see the options and compare the benefits with the price to be paid.

But what company, or group of companies, would invest in a private overall systems solution to, say, depolluting Lake Erie, working out

with their own funds the many trade-offs, developing the new chemical processes, superior purification and fuel burning methods, optimum energy use techniques and the rest? Many specific and difficult science and engineering accomplishments would be vital for an intelligent, broad changeover to an integrated lower pollution system. But in what context should the individual technological efforts be chosen? What criteria would be used? Even if a combine could be created of, say, five of our largest corporations that among them possess all the technical expertise required, how could they presume to design and install a system that would affect the economy and social make-up of the industrialized communities of millions of citizens distributed around the Lake?

If that private combine invests billions to develop a sound solution (a moon landing involved some tens of billions, but depolluting a large industrialized geographical area entails much more), it is not clear who would be their customer. To be sure, they might offer a proposal to install superior waste disposal equipment to a city, one of many contributing sewage to the Lake, but why should that city pay to pollute the Lake less unless all other polluters agree to do their part in a balanced program? The polluters would not only have to agree; all would need to possess the funds to buy their piece of the system. Finally, suppose the numerous independent segments of the entire market come together by some magic. That is, they decide to buy, stand ready with the funds and are set to contract with the entrepreneurial syndicate to install the entire developed system. Would not the Justice Department be expected to stop this combine of private corporations, claiming an illegal joining of large corporations into a group possessing domination of the market? And the government would be right, would it not? If some such partnership sank billions into the creation of a depollution system market, they probably would possess a near monopoly since a second such team (equally resourceful as to finance and technology) would be unlikely to choose to enter as a competitor.

Let us look quickly at a few quite different examples.

ELECTRONIC BRAINPOWER

Electronic data systems can now absorb, store, categorize, process, ponder, move and present information in vastly higher quantities, with greater speed, yet with radically reduced cost and more reliability and accuracy than ever before attainable. This synthetic "electronic brainpower" can make each human being smarter at his job. We all spend much of our time doing something with information because information makes the world go 'round. By a new man-technology partnership in information handling, the potential for increasing the value of every hour of a person's time, and hence the nation's productivity, is tremendous—in business and industry, banks, the professions, airlines, hospitals, educational institutions, as well as in all levels of government.

As with the telephone, then the automobile, and later, TV, such electronic information handling advances become economical only if the users are numbered in the many millions. The United States is close to unique in the world in possessing the combination of character-

istics needed for leadership in this information technology advance: a science and technology lead; a single, integrated large market; a clear need; opportunity for high return on invested resources. In fact, virtually every man, woman, and child in the United States could be aided—in his work, schooling, traveling, shopping, etc.—by the ready availability of such technology. If every worker's output were to be improved to an extent equivalent to a mere few hundred dollars a year by the application of innovative electronic information technology, this saving would justify an investment of a thousand dollars per worker for the purchase of hardware and software. However, such a mass application of electronic information technology would sum up to hundreds of billions of dollars, too big for any one corporation. The progress thus will come through a hybrid of free market and government involvement—the latter through direct government sponsorship and regulation and with the government as a principal customer—not through free enterprise alone.

To be more specific, take, for instance, Electronics Funds Transfer, the use of electronic signals to replace the present flow of billions of pieces of paper a year for control and accounting of transactions. In the future, bills will be paid, orders placed, deposits to accounts made, interest charged or credited, funds assigned and moved from individuals, companies and governments to one another, accounting completed—all in accordance with electronic signals. However, the full blossoming of this low paperwork society requires a revolution in the rules governing the flow of money. Look what the government will have to do: redefine banking; decide who can be allowed to profit from the holding and moving of money; standardize interest rates on funds involved; create new privacy and security regulations; set standards for the form of the electronic signals that carry the funds transfer information and for the many equipments making up the systems so they will all interconnect compatibly. We see that to achieve electronic funds transfer we face a challenging organization problem, one requiring the teaming of government and private industry with science and engineering. In electronic information handling, as in many other frontier areas, the speed with which society can obtain the productivity and other benefits is not limited by the technology, but rather by the rate of progress in organization.

SPACE TECHNOLOGY

The United States is ahead of other nations in space technology. In the coming decades, economic cost-effectiveness exists for numerous large-scale satellite systems: increased telephonic communication between continents and over large continental areas; the same for television broadcasting; airline navigation and traffic control; navigation and communication with ships at sea; computer-to-computer communication of the data essential to the operations of business and industry; educational broadcasting to homes and schools in a vast uplifting of education by video programming; military communications, command, control, intelligence and reconnaissance for military alertness or arms control; earth scanning to improve discovery, analysis, and utilization of mineral, water, agricultural and other earth resources; weather prediction, and ultimately the beginnings of

weather control; library networks to provide research and operating data to medical, legal and other professional activities. The rate of such developments will depend on the handling of a maze of government-industry arrangements on a world basis. Consider specifically a system to plot and examine the earth's resources by satellites working with a ground-based network of communication equipment, computers, and data analyzers. How could a private entrepreneur, in the form of one or more American companies, create the system, operate it and go about obtaining rewards to cover its investment? The private entity could not scan our nation and others and offer the information for sale to realize income without a government sanctioned position—which would carry with it government regulation—which means the price of the information made available would have to be controlled and it would not be solely a "private enterprise" project.

FUSION ENERGY

Controlled thermonuclear fusion has the possibility of providing us with cheap and plentiful energy. Many millions of dollars have already been spent trying to understand the underlying physics, and it is estimated by most experts that decades will be required before all of the remaining physical science and engineering details are worked out sufficiently that this approach to energy supply could be ready for application. It may turn out that it never will prove feasible. The total costs in the start-up phase are seen to be in the billions of dollars, maybe in the tens of billions. When we have to speak of funding at such levels and time in the decades, we are beyond the boundaries of areas suitable for speculative investment by private entities.

COAL

By all-out use of science and technology and the full cooperation of government and private industry (neither of which is in the cards today) we could have a plentiful supply of energy for hundreds of years by properly utilizing our huge reserves of coal. Technology can be advanced to desulphurize coal, produce liquid and gaseous fuel from it, mine it more safely, obtain a good deal of it without mining (in situ), burn it more cleanly and fully, and limit environmental harm. The resulting energy supply would be higher priced than today's oil but the funds to pay for the fuel would stay in the United States.

Success requires both the know-how of private industry and enormous capital placed at risk. A corporation choosing to make a major entry into new coal technology would have to commit funds in the range of billions of dollars and decades might pass before a return on that investment would be realized. Indeed such return might never come, so great are the risks associated with unpredictable decisions on critical aspects that it is clear will be made by the government. The complete "system" needed for a much greater utilization of coal in the United States involves a host of private and public organizations that are semi-autonomous and not readily directed by any one body: land owners, mine operators, labor unions, railroads, power generating and water supply utilities, numerous engineering and manufacturing organizations, and many, many agencies in the federal government

that deal with prices, environment, labor, and transport, to name only a portion. It is not difficult to appreciate why we are not moving very rapidly in developing and applying new coal technology.

FOOD AND NUTRITION

Almost every nation of the world faces food insufficiency. The United States of America, with its resources and know-how, has a special opportunity here. Science and engineering advances could improve every aspect of food and nutrition. From seed to mouth, potentials for greater economy, efficiency, nutrition, productivity, preservation and waste reduction exist. However, consider the interactive problems of land utilization, energy and water supply, environmental and health control (use of pesticides, fertilizers, food additives and preservatives), fundamental research in plant growth and nutrition, storage and packaging, distribution methods, price controls, and foreign sales policies—all pieces of a grandly complex system. Working this systems problem requires innovative teaming of government and private enterprise. Today the government is mainly in the regulatory business as regards food. No entity is providing integrated leadership. Only slow progress in the utilization of science can result.

If these organization problems could be solved, in a decade or two the U.S. position in the world in food could be like that of the OPEC nations in oil. Even now agricultural exports make a substantial favorable contribution to our balance of payments. If the U.S. technological superiority on every food resource front were exploited, the United States would not have a balance of payments problem for a century ahead.

OCEAN RESOURCES

As a final example, today we have the technological means to advance rapidly our understanding of ocean sciences. New sources of minerals, food and energy and improved transportation and weather forecasting are among the possibilities that loom over the horizon. Full exploitation of ocean resources could change the world economy. This potential is more than matched, however, by the difficulties of world cooperation. To cite only one example, who owns the raw materials that may be extracted from the deep ocean bottom? Private know-how and private capital will not be available for such efforts until there is a positive answer to this question. The governments of the world are meeting in "Law of the Sea" negotiations, and unfortunately, getting nowhere.

THE GOVERNMENT'S ROLE

Free enterprise acting alone, we observe, is a way to realize at most only a portion of all the good that science and technology can bring us. The preceding examples suggest that government is a necessary participant to cope with the remainder. But what about the government's role in direct science and technology advance? What should the government try to accomplish all on its own, not necessarily using private enterprise as a co-contributor to the advance?

Of course, the public, speaking through the government, must control and regulate against impairment of the citizens' welfare that could

arise from technological projects performed for the narrow benefit of a private group. Also, to advance some aspects of science and technology for the general society's good, the government must be relied upon for strong and essential, perhaps even solitary, sponsorship. This is perhaps most obvious in the development of military weapons systems, or for sending a man to the moon, and for similar projects considered as necessary in the national interest but where there is no consumer product, no market involving the general public. But why not have the government do more, beyond those necessary projects free enterprise cannot or will not perform alone? Why not embark on a major effort to increase the innovation and the productivity of America by all-out development, under government funding and sponsorship, of new technology? This, it could be argued, would lead to new methods and products, cutting costs, increasing supply, getting around shortages, and making for more jobs.

To go this far, to consider having the government move into direct technological advance, even into those segments where private enterprise is still strong and willing, or potentially so, takes the government right into the heart of the function of a free market. As a step in pondering this, consider that, low as is the level to which free enterprise may have sunk in public favor, there remains today a bottom limit to this disfavor. Despite the diminishing popularity of the concept of capitalism, most of those who talk or think against it in the United States are far from ready to accept as the alternative a totally government controlled economy. Most do not want a more massive government bureaucracy. They will rebel against their take-home pay's being cut further, the government's taking a bigger chunk of the gross for more spending while they lose the freedom to spend their earnings as they choose. They do not want the government allocating the resources of the nation, deciding what technology to further, and what products should be manufactured. All this is to say that most have an interest in keeping free enterprise alive and healthy, even though many may not know what this requires and may often espouse views that hurt free enterprises' ability to make the very contribution to the society these people expect and desire.

The federal government employs scientists and engineers in policy-making and management of government sponsored technical effort. Also, the government maintains laboratories in certainly highly specialized fields and these contain their share of experts. However, in the United States today, most of the expertise in science and technology lies in private industry and the universities. If the government were to launch a program of research and development with the serious objective of raising the innovative technological level of the nation it would have to set out to influence, augment and direct the efforts of thousands of technically trained individuals in the private sector and deal in a detailed way with the enormous infrastructure in which they now operate. The technological industry sees the government as particularly ineffective when it comes to matching research and development with the market's real needs, that is with the end consumer's true desires. Technology advance is infinite in its variety and dimensions. The new products that could be developed, the changes in methods and procedures that are technically feasible and the possible alterations of virtually every system for producing, distributing and using tech-

nical products and services are endless in number. The nation has only the resources, whether it be technically trained people or funding to back them up, to carry through a tiny percentage of all that can be conceived. The trick is to choose the right research and development, to assign the limited sources so as to best meet the citizen's sense of values. Even those who are convinced that the free market is an inadequate means for obtaining the proper match of resources to goals, probably would grant that if this balancing is to be attempted by the federal government instead, it could only be worse. It would require the creation of a huge bureaucratic government system for detailed analysis, selection of projects, and assignment of resources. It is submitted that today only a small fraction of the electorate really believes that the government is suited to such control of scientific research and technological development.

Concern exists today that U.S. industrial technological advance is insufficient and some believe government programs are needed to enhance industrial R&D. In industrial technological innovation, the government can help most, not by funding new efforts, but by improving the economy, as already stated, so the private sector will have the financial means and incentives to perform more R&D of its own choice. Lowering capital gains taxes and decreasing the taxation (presently "double") on dividends would especially encourage investment in innovation. (Germany's and Japan's investment ratios are much higher than ours and so are their productivity increases.)

On the other hand, the federal government must continue to be the main sponsor of basic research in the nation's universities. Unfortunately, even here, in this necessary role, the government is not performing well. The low funding leaves good research talent unemployed. The government's bureaucratic approaches are causing too large a chunk out of every dollar granted for research in the universities to go for administrative expenses. Also, the growing emphasis by the government on proven relevance for research underestimates the high eventual payoff in probing the unknown secrets of nature. Admittedly, the government must spend its money wisely, but we have gone past common sense in the control process. It costs less to accept that some research will prove useless, than to try to guarantee that all research will pay off.

SOME RECOMMENDATIONS

Now what does all this add up to? This high potential for science and technology to benefit the society more and at the same time this difficulty in obtaining these benefits. This inability of free enterprise to encompass more than a fraction of the sponsorship. This limitation on the capability of the government to take over where the private sector cannot provide the desirable advances. What views and policies should we promote as steps to improve the situation?

Let us offer some specific recommendations separately to the three concerned entities: the free enterprise sector, the government, and the public.

Those interested in preserving the free enterprise system (such as leaders of big business and others who see the free market and the private enterprise concept as valuable routes towards utilization of advanced technology) should accept that ours is a hybrid society. It is not helpful and oftentimes harmful to press so hard, as these

supporters of free enterprise often do, for it to be labeled as the all-encompassing answer to all problems. Free enterprise can only provide for a part of our needs and a creative, cooperative relationship between the private sector and the government should be sought.

Government leaders should recognize the government's involvement in science and technology matters to be permanent and set a long range-policy for that involvement. It should answer such questions as: Which research and development areas must the government sponsor, and which are best left to free enterprise? How can the required regulatory duties of the government, the setting of the rules for free enterprise, be handled so as to enhance and not impair national innovative effort? The government should appreciate the broad impact of science and technology on virtually every important government decision making area, and count a healthy scientific and technological effort in the country as vital to the overall national economy. The government should itself be innovative in creating a national environment for innovation. It should direct its sponsorship in science and technology matters towards the generation of information to remove risks and thus to enhance the contribution that can be made by free enterprise. The government should resist the creating of new government R & D efforts and expenditures to enhance innovation in private industry. Above all, the government should act on the premise that improved use of science and technology will quickly follow an improvement in the economy, this improvement characterized by less inflation, taxes and government spending, with discretionary funds for investment in innovation more available to the private sector.

The public would do well to foster neither extreme view: that the free enterprise system alone can do everything best; nor that free enterprise is bad and passé and the government must do everything. If the public is interested in the flexibility, freedom of opportunity, motivation and incentives of free enterprise, then it should recognize that free enterprise can only contribute to the nation's needed research and development if industry is allowed to generate the necessary funds for investment. "Profits" should be applauded if they are reinvested boldly and wisely for research and development.

Finally, the public should get over its anti-technology prejudices. It should decide once and for all that science and technology are not independent, external enemies but the public's own tools, and get on with seeing that these tools are used to achieve the goals the citizens choose.

ECONOMIC AND TECHNICAL FACTORS ASSOCIATED WITH MANUFACTURING AND OUR WEAKENING TRADE POSITION

DR. DELBERT TESAR

PROFESSOR OF MECHANICAL ENGINEERING AND DIRECTOR, CENTER FOR INTELLIGENT MACHINERY AND ROBOTICS, UNIVERSITY OF FLORIDA, GAINESVILLE, FLORIDA

PREFACE

The condition of our economy has worsened at an increased rate during the past two years. Careful review of the economic indicators, especially those dealing with manufacture of consumer goods, indicates that a long term deterioration has been underway and that we are now exhibiting a major technological deficit costing us a minimum of $10 billion per year. This deficit could easily deterioriate in the next 3 years to a $40 billion deficit in our trade in manufactured goods associated with mechanical technology. Combining this increased loss with those of oil (and other nonmanufactures such as coffee) provides the primary cause for the weakening of the actual purchasing power of the dollar (down a significant 2½ percent in 1977). The purpose of this report is to document these issues as well as isolate those segments of our technology which have long been ignored by government research agencies and which now must be energetically pursued. It is proposed that a cohesive national program be established in terms of 10 geographically distributed technology and innovation (T & I) institutes dealing with mechanical systems and manufacturing processes.

The management of such a system of institutes is a crucial matter. It is clear, in this case, that industry must be involved at a very high and meaningful level. They have management skills not found elsewhere. Further, the university system in the United States has an abundance of management experience dealing with research and development. Hence, a series of 10 university institutes with unique missions managed by NSF–ASRA and supervised by industry (the Industrial Research Institute, the IRI) is now recommended.

Other factors, especially financial, should be fully evaluated by appropriate government agencies and existing independent productivity centers. The final Report of the National Center for Productivity and Quality of Working Life, September, 1978 by G. H. Kuper established the following division of responsibility:

> Department of Commerce—Forecasting, management development, market and equipment information, export development, and loans and loan guarantees.
>
> NSF–ASRA (Applied Science and Research Applications)—Diffusion of technology and research and development.

It is believed that NSF–ASRA represents a preestablished mission granted by Congress for the intended national program. The mode of operation of the institutes could come from the legal framework established by the Cooperative Agreement Act of 1977 by the Congress and evaluated by a recent report of the OTA, "Applications of R & D in the Civil Sector", June 1978, OTA Report OTA–R–65.

Economic Issues Associated With Machinery and Its Manufactures

INTRODUCTION

Virtually every knowledgeable spokesman on economic issues in the United States is now concerned about our decreasing technological capacity to compete with other industrial nations. Without doubt, we have become much less effective during the past decade in international markets. The real danger, however, is protecting our home markets which directly affects our ability to employ our own workers. In our home markets, most of the economic weakness is associated with consumer products—a field many have classed as low technology, and therefore not addressable in terms of new or advanced technological solutions. The purpose of this paper is to show that this underlying assumption is in error and that a national program should be established to solve immediate and future technological problems in a universal and cohesive manner. Section II of this report presents the form of this national program for machine science and associated manufacturing technology. Section III presents a snapshot of the issues for mission oriented research in light machinery * while Section IV presents the role of robotics in satisfying our technological needs. Finally, Section V presents a review of the long term trade balances for all significant components of our trade with other countries over the past 14 years.

GENERAL ECONOMIC ISSUES ASSOCIATED WITH U.S. PRODUCTIVITY

The table below obtained from the Bureau of Labor Statistics in the Department of Labor shows that the annual productivity increase of the U.S. worker during 1960–1973 has been 3.4 percent while several countries have double or higher rates of increase.[1]

	Percent
Japan	10.5
Netherlands	7.5
Sweden	7.1
Belgium	6.5
Italy	6.4
France	6.0
West Germany	5.8
Switzerland	5.3
Canada	4.3
United Kingdom	4.0
United States	3.4

Part of the cause of this poor relative growth in the U.S. could be the inadequate investment of capital which went down from $258 per worker in 1967 to $220 in 1973. By contrast, this indicator rose from

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*D. Tesar, organizer, 1978, NSF Workshop on Robotics, the University of Florida.
[1] D. F. Lane, "Improving U.S. Productivity", Mechanical Engineering, September 1978, pp. 25–33.

$298 to $693 in West Germany and from $191 to $324 in Japan in the same period. (Data from the U.S. Accounting Office). Another indicator shows that the U.S. is lagging in capital investment.[2] Japan invests 29 percent of the value of its Gross Domestic Product in plants and equipment, West Germany invests 22 percent, France invests 20 percent, Sweden invests 19 percent, while the U.S. invests only 15 percent.

George H. Kuper [2] reports that:

> The rate of growth of the capital-labor ratio, which is a measure of capital intensity, has slowed significantly. The capital-labor ratio increased at an annual rate of 3.0 percent during the 1947–67 period; during the 1967–73 period, it declined to 2.5 percent a year, and then to 1.3 percent a year during the 1973–77 period. These figures exclude investment to meet environmental standards. According to a study for the Commerce Department, between 1969 and 1975, the direct costs of complying with air and water pollution and occupational safety regulations, and the costs of crime, appear to have reduced by nearly 20 percent the average growth rate of measured productivity. Investment in capital equipment for environmental purposes now accounts for about 9 percent of investment outlays in the manufacturing sector. If these mandated capital expenditures are excluded from the data, investment, as a share of value added, has actually declined in the manufacturing sector since 1966.

The above documentation on capital investment shows that our financial environment for technology is deteriorating at an alarming rate. Labor statistics release [3] of figures in June, 1978 indicated that the productivity of three-fourths of the U.S. industries measured was lower in 1977 than in 1967. Further, it was noted [2] that the work force will increase by only 1 percent per year in 1980 due to reduced birthrate. Hence, slowing of total product output gains can be expected to continue. Apparently U.S. productivity growth has already almost disappeared in 1978 while Japan's is 6 percent and Western Europe's is 4 percent. From 1947 to 1977, U.S. output increased by a factor of 2.5. Three-fourths of this increase was due to higher output per man hour. The present marginal increases in U.S. man-hour productivity is a comprehensive indicator of our weakness in trade competition. "Today, lower unemployment is a sign of lower hourly productivity and lessened capital investment—both of which are negative indicators for the future." [3]

By contrast:

> The record of Japan and many European countries is one of low unemployment and high rates of productivity improvement. This suggests that an expanding economy and a positive labor market policy can provide sufficient jobs for all. Rising national income tends to raise demand for all goods and services. This helps sustain, or even increase, employment in companies or industries with rapidly rising productivity, just as it does throughout the economy.[2]

It is clear from the above documentation that worker productivity, the financial environment, and new technology interact to create the whole system which produces manufactured goods. Brookings Institute economist, E. F. Denison, estimates that new technology accounts for 38 percent of the factors affecting productivity.[3] Yet, in 1971, the U.S. spent 1.8 percent of its GNP on nondefense R & D while Japan spent 2.1 percent and West Germany spent 2.0 percent.[2] Private U.S. indus-

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[2] G. H. Kuper, "Productivity in the Changing World of the 1980's", final report of the National Center for Productivity and Quality of Working Life, September 1978.

[3] "U.S. Productivity, Technology Problems Stir Up Attention on Federal Scene," Professional Engineer, September 1978, pp. 20–21.

try employed 5 percent fewer scientists and engineers from 1970 to 1975.[3] This reduced use of scientific manpower was almost totally due to the reduced R & D in NASA programs and the aircraft industry while at the same time incentives for technology innovation were diminished by harmful tax laws and regulations.

The Japanese government is giving full support to R & D on highly automated flexible manufacturing systems that are used to produce a wide variety of products at minimum cost.[2] "In Japan, the research and development efforts of universities, government, and industry are closely linked to large-scale industrial ventures destined for commercial application. Considerable support is given to new manufacturing technologies such as automated machinery which drastically reduce production costs." [2] West Germany has been using the same philosophy for the past two decades. "Thinking along that line, the Canadians, who have also been suffering from R & D lag, plan to set up five innovation centers at universities, which will supply help to industry." [3] Such innovation centers, however, must be funded at levels above the "critical mass" if they are to be responsive to technological needs. They must also have a natural function with industry in the development of better production machines and associated products.

Finally, the most significant fact associated with U.S. manufactures, is that our trade balance in manufactures became marginal in the middle of 1978 with a sizable deficit expected by the end of the year. We are now importing manufactures at twice the rate of oil. By contrast, West Germany and Japan are expected to run surpluses in manufactured goods of $49 billion and $63 billion, respectively.[5] This explains the remarkable fact that inflation has stripped 2½ cents from the buying power of the American worker's dollar at home during the twelve months ending in August even though income increased by 9.2 percent.[6]

The $9 million dollar study of the National Center for Productivity can be succinctly summarized by a quote [5] from its executive director, G. H. Kuper:

> The seriousness of our productivity situation has reached catastrophic proportions which may require a national emergency or at least a positive stance on the part of manufacturers, government, administrators, and concerned citizens.

The combination of the problems of productivity, energy, and defense is the moral equivalent of war. There seems to be little doubt that corrective action is now urgent. That this now seems possible appears to be evidenced by the following quote [3] by Senator Adlai Stevenson (Democrat of Illinois), Chairman of the Senate Subcommittee on Science, Technology, and Space:

> A recommitment by government to basic science and industrial innovation, including the commercialization of new technology on a selective basis, is essential if the United States is to compete and benefit mankind where best it can.

ANALYSIS OF TRADE DATA FOR THE PERIOD 1964–78

The Center for Intelligent Machinery and Robotics at the University of Florida has made an extensive analysis of trade documentation

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[2] G. H. Kuper, "Productivity in the Changing World of the 1980's", final report of the National Center for Productivity and Quality of Working Life, September 1978.
[3] "U.S. Productivity, Technology Problems Stir Up Attention on Federal Scene." Professional Engineer, September 1978, pp. 20–21.
[5] "The Innovation Recession," Time Magazine, Oct. 2, 1978, pp. 57–58.
[6] Gainesville Sun, Oct. 7. 1978, from the Carter administration's Council on Wage and Price Stability.

from the Department of Commerce (see Figures 1–5 in this section). From 1964–1978, the dollar reduced its buying power by a factor of two as shown in Figure 1. This is the simplest, most encompassing indicator of our weakening competitive stature in trade. The non-manufacturers curve is well known to be dominated by oil (at minus $30 billion in 1977) although the minus $5 billion for coffee is important. The manufactures curve on Figure 1 shows a rather remarkable configuration.

It exhibits three periods of trade that are very important in understanding the full nature of our economic condition. Specifically, it is known that an excess of petro dollars suddenly became available after the 1972 oil embargo and subsequent increase in oil prices. These excess dollars were spent on U.S. manufactured goods. Unfortunately, this new market soon became saturated as evidenced by the rapid turnaround in 1975. One explanation that has been suggested is that the managers of the OPEC nations' monetary accounts suddenly decided to divert their investments into international bank funds. The three distinct periods appear clearly in Figure 2. We suggest, here, that the surge of petro dollars has masked over our real technological deficit. A curve is conceptualized to have a shape similar to that from 1975–1978 but shifted down by $30 billion to form part of the lower curve. The suggested trade balance curve exhibits remarkable continuity of its basic shape. On this basis, we can say that our hidden technological deficit by the end of 1978 could be $30 billion. Hence, the conclusion that could be drawn, is that our technology is much worse off than our otherwise unattractive, unadjusted trade data indicate.

The curves in Figure 3 deal only with mechanical technology and its manufactures (tractors, automobiles, cameras, shoes, apparel, etc.). Again the two basic curves can be considered with the following comments:

Period I.—This shows that our total mechanical technology was failing in 1965–1972. This trend was recognized at the time by a few alert technologists but no action was taken. Note that the trend to reduced capacity to compete already existed in 1965 as evidenced by the negative slope of the curve in Figure 3. One conclusion that follows is that the weakening of our relative level of mechanical technology is not a recent but a long term phenomenon. Therefore, its revitalization will also be a long term process.

Period II.—This period was triggered by the October 1972 oil embargo where a great flood of dollars were made available to people who were previously limited in their purchasing power for technology related products. This $14 billion jump was equivalent to a "technological honeymoon" and left us self-satisfied with our technology. This fact fooled many experts who were touting our superior technology.

Period III.—Here we see what happens when a new market becomes saturated with a rapid influx of technology. Note that we are now at −$8 billion in the middle of 1978. If we had not had the "honeymoon" we could very well be at the level of a −$39 billion deficit for mechanical technology by the end of 1978. This is a feasible indicator of our technological weakness. Few appear to have recognized it.

Figure 4 is a breakdown of the trade balance for mechanical manufactures into the two categories of light machinery (cameras, sewing machines, shoes, apparel, etc.) and heavy machinery (tractors, pumps, compressors, cranes, etc.). The role of aircraft and spacecraft and automobiles is not included in the light and heavy machinery curves. We see that the heavy machinery trade balance was very sensitive to the surge of petro dollars (i.e., newly enhanced spending power tended to choose easily recognized large "showpiece" items). The U.S. has always prided itself on its ability to manufacture large machines (such as turbines and tractors). This curve shows that this trade is definitely in jeopardy.

On the other hand, light machinery has been a consistent negative in our trade balance. This condition is continuously worsening and only partially sensitive to the influx of petro dollars. The 1977 deficit was $7.5 billion. As documented [7] in Section III of this report, this portion of our trade balance can be influenced by proper application of new technology. Figure 5 shows trade curves for some other significant trade categories. Note that Aircraft and Spacecraft, Electrical Systems, and Chemical Processes have all been consistent positives. The trade in cars and trucks has been consistently negative with a 1977 trade deficit of $6.3 billion. All of these curves show sensitivity to the influence of the petro dollar surge in 1972 and shift in 1975.

One final comment about these curves. The role of energy clearly dominates our non-manufactures trade. It is a significant problem for our economy. It is suggested here, however, that it is far from the most significant one. Recall that Japan is expecting a $63 surplus in manufactures for 1978 while West Germany is expecting $49 billion.[5] Since their energy resources are much more limited than ours, they would be far worse off than we are if the primary problem were oil. In fact, the primary problem is the efficient conversion of energy and natural resources into consumer goods. The complete validation of this point is the purpose of this report.

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[7] Delbert Tesar, "Mission-Oriented Research for Light Machinery", Science, Sept. 8, 1978, pp. 880–887.

FIGURE I

PRIMARY TRADE COMPONENT TRENDS
(FROM 1965 TO 1978)

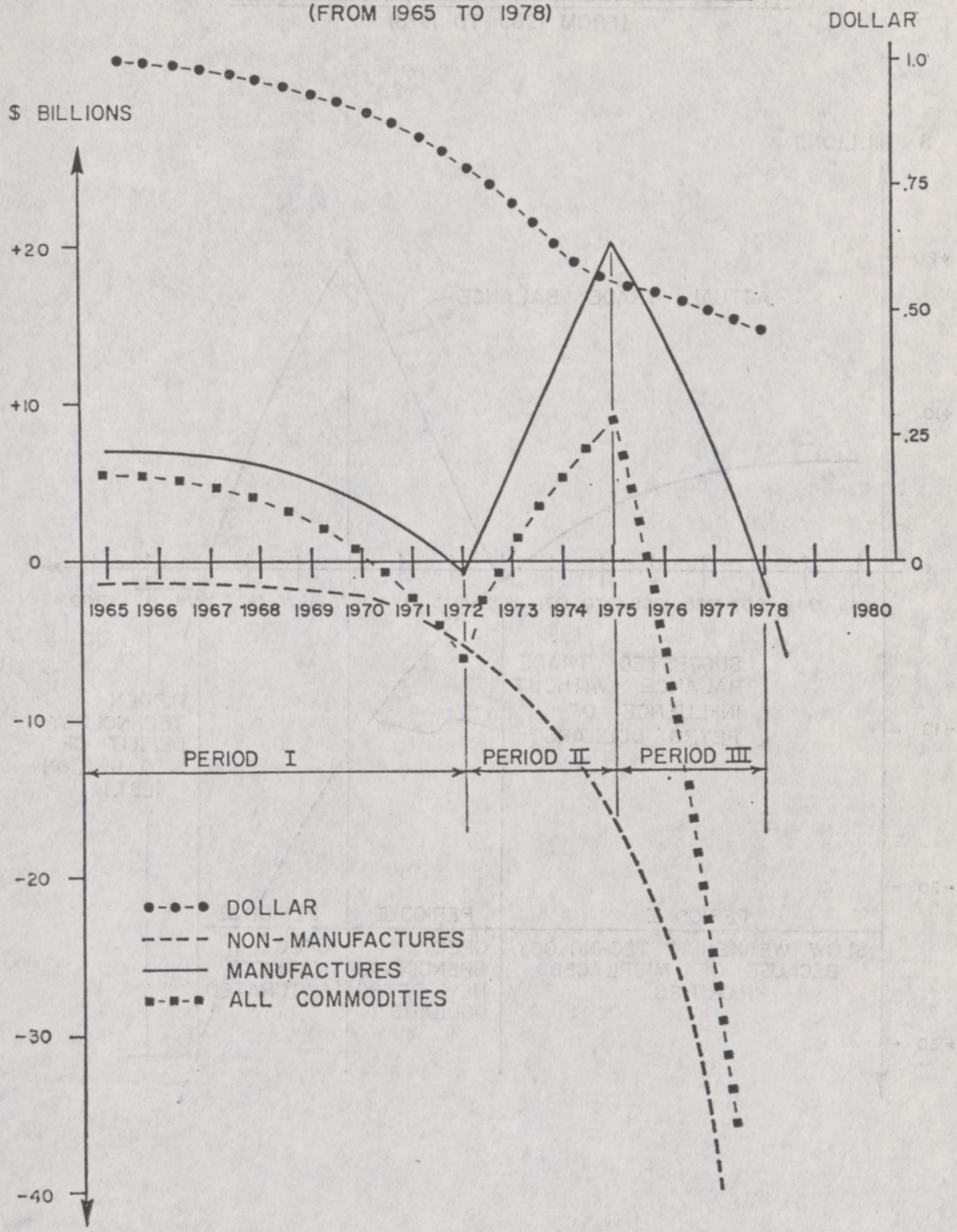


FIGURE 2

TRADE TRENDS FOR ALL MANUFACTURES
(FROM 1965 TO 1978)

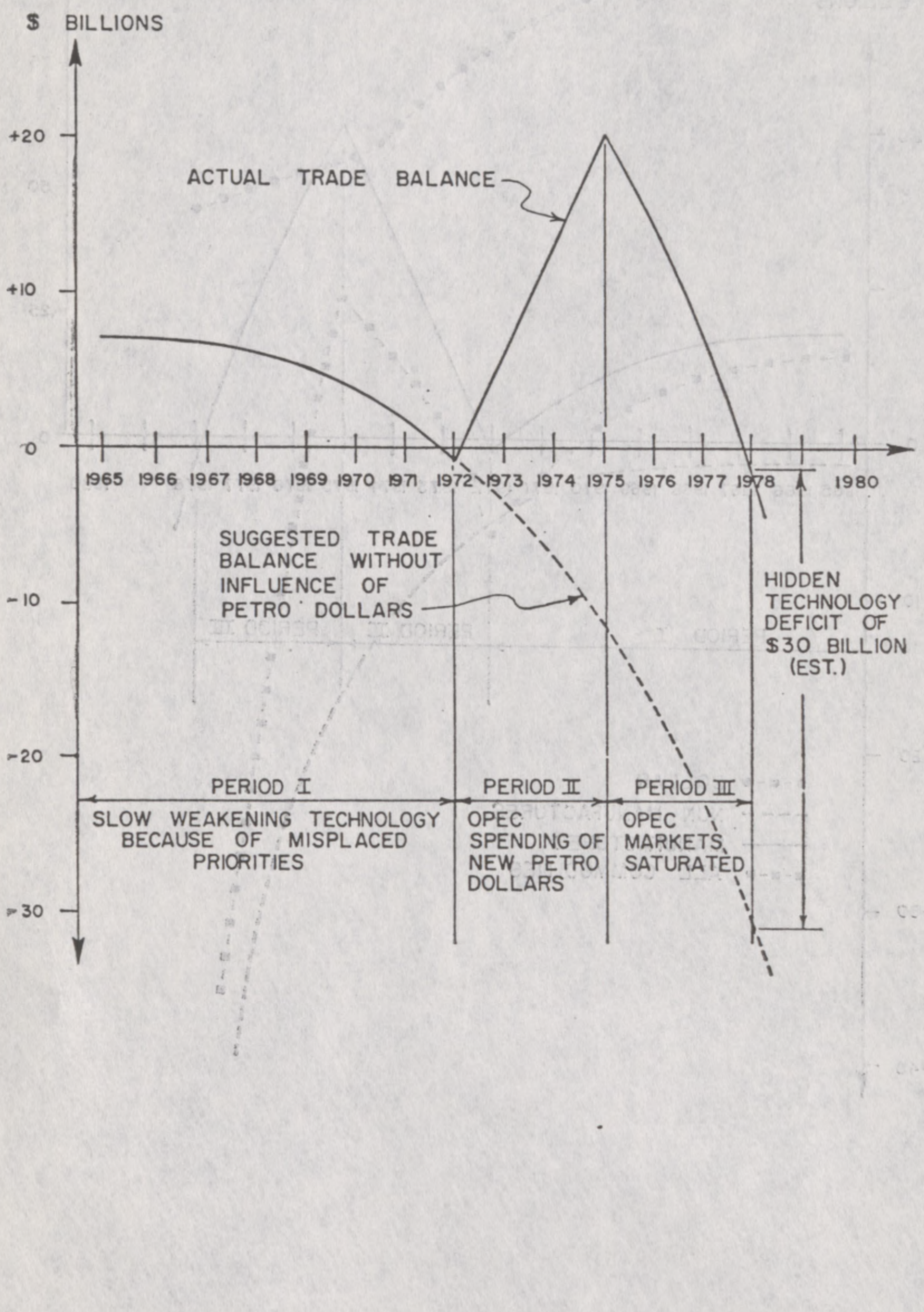


FIGURE 3

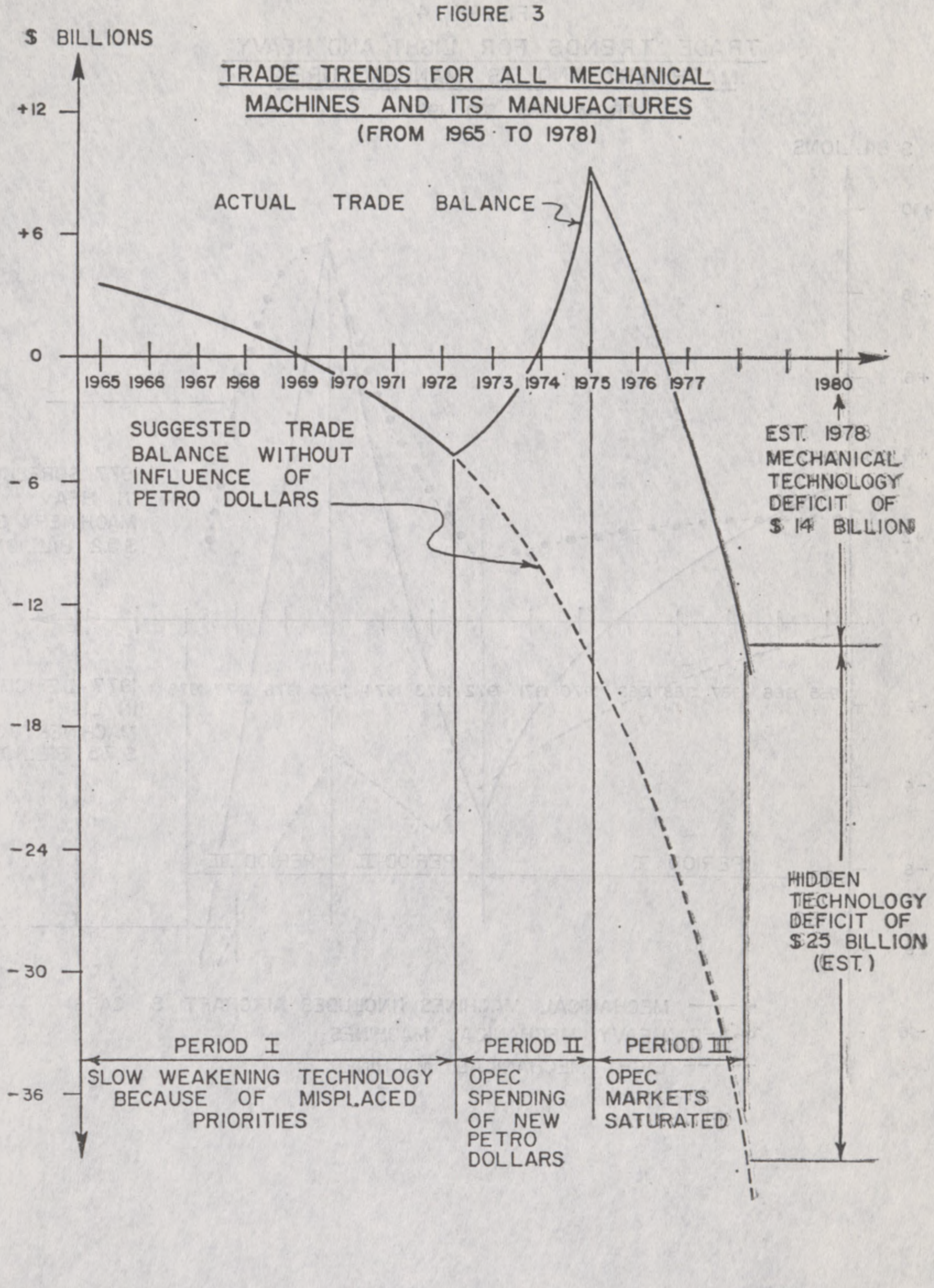

$ BILLIONS
+12
+6
0
-6
-12
-18
-24
-30
-36
TRADE TRENDS FOR ALL MECHANICAL MACHINES AND ITS MANUFACTURES
(FROM 1965 TO 1978)
ACTUAL TRADE BALANCE
1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1980
SUGGESTED TRADE BALANCE WITHOUT INFLUENCE OF PETRO DOLLARS
EST. 1978 MECHANICAL TECHNOLOGY DEFICIT OF $ 14 BILLION
HIDDEN TECHNOLOGY DEFICIT OF $25 BILLION (EST.)
PERIOD I
SLOW WEAKENING TECHNOLOGY BECAUSE OF MISPLACED PRIORITIES
PERIOD II
OPEC SPENDING OF NEW PETRO DOLLARS
PERIOD III
OPEC MARKETS SATURATED

FIGURE 4

TRADE TRENDS FOR LIGHT AND HEAVY MACHINERY AND ITS MANUFACTURES FROM 1965 TO 1978

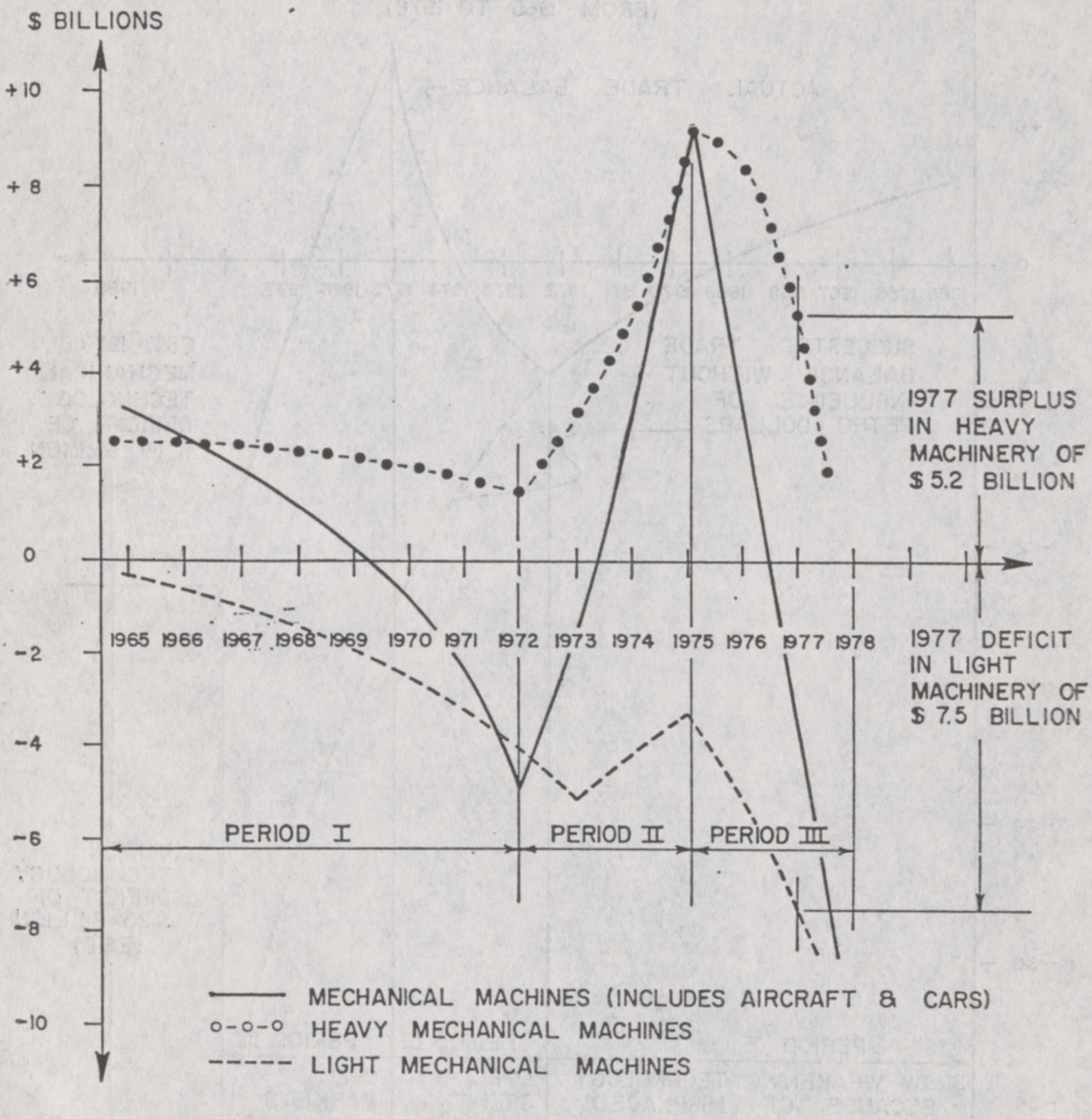
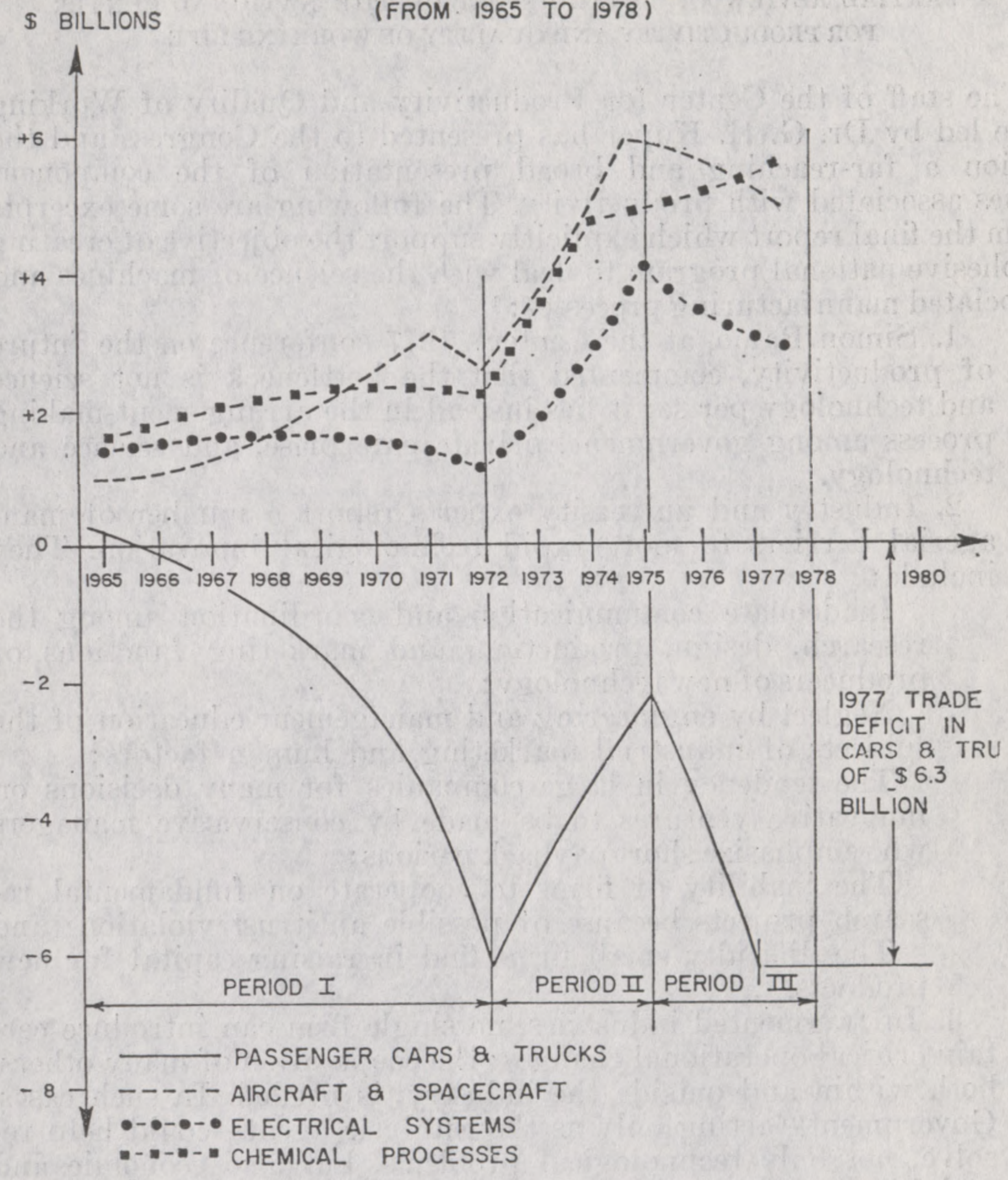


FIGURE 5

TRADE TRENDS FOR OTHER DOMINANT CATEGORIES OF MANUFACTURES (FROM 1965 TO 1978)



Proposed National Program for Machine Science and Associated Manufacturing Technology

A PARTIAL REVIEW OF FINAL REPORT OF THE NATIONAL CENTER FOR PRODUCTIVITY AND QUALITY OF WORKING LIFE

The staff of the Center for Productivity and Quality of Working Life led by Dr. G. H. Kuper has presented to the Congress and the nation a far-reaching and broad presentation of the component issues associated with productivity. The following are some excerpts from the final report which explicitly support the objective of creating a cohesive national program to deal with the science of machines and associated manufacturing processes:[1]

1. Simon Ramo, at the Center's 1977 conference on the future of productivity, commented that the bottleneck is not science and technology per se; it lies instead in the arrangement-making process among government, private enterprise, and science and technology.

2. Industry and university experts report a number of managerial barriers to more rapid technological innovation. They include:

Inadequate communication and coordination among the research, design, production, and marketing functions of producers of new technology;

Neglect by engineering and management education of the subjects of industrial marketing and human factors;

The tendency in large companies for many decisions on innovative ventures to be made by conservative managers who emphasize short payback periods;

The inability of firms to cooperate on fundamental research projects because of possible antitrust violation; and

The difficulty small firms find in raising capital for new products.

3. In fragmented industries, no single firm can introduce certain critical operational changes; the cooperation of many others, both within and outside the industry, is needed. In such cases, Government—acting only as the catalytic agent—could help resolve, not only technological problems, but also economic and social issues, which cannot be settled solely through the working of the marketplace.

4. The lack of close relationships between engineering schools and manufacturing industries also impedes the technological innovation process—a barrier not present in some of the major competitive countries. Although the supply of engineers appears to match the demand, the skills that young engineers offer do not always match what is demanded of them. Industrial employers have reported to the Center that recently graduated engineers often lack the practical knowledge needed to achieve technical change and productivity improvement at the factory level. The engineering curriculum also has been criticized for emphasizing prescribed techniques rather than creativity and boldness.

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[1] G. H. Kuper, "Productivity in the Changing World of the 1980's," The Final Report of the National Center for Productivity and Quality of Working Life, September, 1978.

As a consequence of the above widely held views, the Productivity Center recommends the following action proposals:

(i) Encouraging engineering schools, government, and industry to cooperate more closely through exchanges, conferences, workshops, internships, and training courses on advanced manufacturing technologies and the innovation process.

(ii) Assist equipment producers by gathering information about the market for innovative technology and user requirements for new technology.

(iii) Develop the concept of a technology demonstration center, not connected with particular vendors, to train small firms in managing, justifying, programming, operating, and maintaining automated equipment.

(iv) Encourage U.S. engineers and managers to capitalize on scientific and technological advances developed in other parts of the world through study tours, translations, and plant visits.

(v) Expand data on international comparisons of trends and levels of productivity to cover individual industries.

Essentially, the Center of Intelligent Machinery and Robotics at the University of Florida supports these action proposals. To achieve the intended technology base will require a legal framework (the 1977 Federal Grant and Cooperative Agreement Act) and a realistic framework of management and geographically distributed mission oriented research institutes. These concepts will be presented in the next two sections of this proposal.

FEDERAL GRANT AND COOPERATIVE AGREEMENT ACT OF 1977

The Congress has recently established the Federal Grant and Cooperative Agreement Act of 1977 which was signed into law on February 3, 1978. A well structured and organized report [2] from the Office of Technology Assessment explains in explicit terms the organizational function of this act. The major impact of the presentation centers on the new opportunity that now officially exists to directly enhance new technological development and innovation by establishing cooperative agreements among interested parties such as government, industry, and universities. In the past, grants have been provided to universities to do basic research with virtually no vehicle for implementation of the results in industry. On the other hand, procurement practices in general led to the manufacture of specific products for military application with "spin off" as the only and unpredictable means to broaden its use to industry. Attempts to combine these roles for the benefit of industrial production have met with confusion from the managerial component and has left the oversight function of Congress unclear.

The Cooperative Agreement Act of 1977 attempts to accomplish two specific goals:

1. Strengthen the existing processes for grants for basic research and procurement for specific Federal needs by defining a separate and distinct process for assistance.

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[2] John Young, "Applications of R. & D. in the Civil Sector," June 1978, OTA Report OTA–R–65.

2. Create a new pathway (or pathways) of assistance which would enable the rapid, controlled diffusion of developing technology to industry so that it can create new innovative technology and, hence, products and services for the marketplace.

The opportunity now exists to use this in-place legal framework to develop new processes to accelerate our industrial innovation. This legal framework will be further defined during the next two years by an extensive OMB study mandated by Congress. Some primary considerations related to this developing assistance process are:

1. $7 billion is now being spent annually for Federal R & D in the civil sector, its impact on everyday human needs is either unclear or disappointing.

2. Assistance processes will yield results only when industry participates in the formulation of priorities and commits sharing risk capital to meet agreed upon goals.

3. In the past when government wanted to develop clearly needed new technologies, it turned to private or academic institutions to carry out the development because of their existing management structure and interface history with government. In some cases, it established new agencies of its own for well defined missions.

4. Demonstration projects for new technology often heralded as the way to diffuse technology has had a very limited success in this regard. This is partially due to little previous history of cooperation between government and the affected group of industries.

The OTA review document contains several statements which support the function of the envisioned research institutes for light machinery:

1. Thus, in these agencies (DOD and NASA), the innovation process—from the conception of an idea through deployment and use—is under an integrated management control.

2. It should be noted that a focus on scientific and technological goals is entirely appropriate when the principal objective is the generation of new knowledge. Insofar as such knowledge is not for the Government's own use, it would be designated assistance rather than procurement.

3. The Grant and Cooperative Agreement Act places no restrictions whatsoever upon candidates for assistance awards. In view of their (profit making organizations) central role in technological change, they are clearly important candidates. However, when the award of public funds entails private gain, care must be taken that such awards are made in a recognized and impartial manner.

4. The purpose of the assistance is clearly a widespread distribution of public benefits, not the welfare of a particular firm. Assistance awards would be aimed at stimulating the widespread adoption and diffusion of a new technology.

5. The approach reflected here is to treat patent rights merely as one among many items to be negotiated between an agency and a non-Federal party.

6. Without engaging those non-Federal parties who have the incentive and the resources necessary for making technological

change actually happen, there is no purposeful fostering of such change. Thus, R & D performing institutions must be effectively linked to those institutions that actually produce and deliver goods and services, whether in the public or private sector, if the assistance of innovation is to be effective. Forging the necessary linkages where they do not exist is likely to require substantial involvement on the part of executive agencies.

7. However, for fostering the adoption and widespread diffusion of a new technology, the use of such methods (as employed by NSF) presumes that Federal officials possess the knowledge of market factors that govern a technology's rate of adoption and diffusion.

THE PROPOSED NATIONAL PROGRAM FOR MACHINE SCIENCE AND ASSOCIATED MANUFACTURING TECHNOLOGY

The concept of interaction between industry, government, and universities is not new as evidenced by the following quotes [3] by knowledgeable industrialists interested in correcting the developing technology weakness within the United States. President J. F. Bucy of Texas Instruments comments:

> One striking difference between engineering education in the United States and West Germany is the production of engineering graduates for careers in manufacturing. This tradition is well established in Germany and weak in the United States.

The following comments by B. O. Weinschel, president of an engineering firm, are indicative of a workable solution to reducing our technological deficit:

> Methods of encouraging and facilitating government-industry-academic cooperation should be examined.
>
> There is a need to identify future technologies that are likely to become important to the national interest.

The Final Report [1] of the National Center for Productivity and the OTA Report [2] on the Cooperative Agreement Act of 1977 fully support the need and feasibility of a national program envisoned for light machinery research.[4] There, it is demonstrated that the field of quality light machines (cameras, textile machinery, packaging—up to robotic devices for flexible more efficient production systems) can now dramatically benefit from developing micro-electronics technology. Further, the economic pressure of foreign manufacture is creating a yearly deficit of not less than $8 billion in our home markets. Other related technologies are also rapidly weakening from this external pressure. Hence, as of July 1978, we are now marginal in our trade in machinery and its products where two years ago we had a $20 billion annual surplus. Party in this area with a continuous loss of $30 billion in non-Manufactures will mean an unrelenting devaluation of the dollar and a reduction in our standard of living. All indicators suggest that this is now in progress and the corrective action is no longer desirable but necessary. The University of Florida Center for Intelligent Machinery and Robotics (CIMAR) suggests that a co-

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[1] G. H. Kuper, "Productivity in the Changing World of the 1980's." The Final Report of the National Center for Produtcivity and Quality of Working Life, September, 1978.

[2] John Young, "Applications of R. & D. in the Civil Sector." June 1978. OTA Report OTA–R–65.

[3] Productivity, Spectrum, October 1978, pp. 31–90. Major effort of IEEE journal to review productivity in the United States relative to that in other countries.

[4] Delbert Tesar, "Mission-Oriented Research for Light Machinery", Science, Sept. 8, 1978, pp. 880–887. Attached to this report as section III.

hesive national plan to develop appropriate technology and corresponding innovation in industry be formulated on the following lines: The preliminary national plan involves a group of 10 semi-autonomous technology institutes (managed by a research agency, say NSF–ASRA, and industry, say the IRI) which have distinct missions that in concert address the total technology need in a cohesive manner. These are:

1. Light machinery systems: To develop the technology to produce rubber tires, nails and tacks, typewriters, sewing machines, shoes, apparel, watches, etc.

2. Heavy machinery systems: To develop the technology to produce iron and steel manufactures, tractors, metal working machines, pumps and compressors, cranes and handling equipment, heating and cooling equipment, etc.

3. Manufacturing processes: To develop specific technologies for the advanced manufacture of micro-electronics, precision manufacture of machine components, laser cutting, advanced welding processes, etc.

4. Industrial robots: To develop the technology to create versatile robotic systems for precision assembly, painting operations as on automobiles and kitchen appliances, replacement of human operators in noxious or dangerous environments, boring tasks, etc.

5. Human augmentation and prostheses: To develop the technology for internal and external prostheses of the human system, orthoses to support incapacitated human limbs, machine systems to enhance an operator's precision or speed in precision manufacture or assembly, etc.

6. Remote robotic systems: To develop the technology for remote functions in space, on the ocean floor, in the artic regions, accident missions, etc.

7. Artificial intelligence: To develop the technology for vision in robotic systems, the hierarchical control of robotics, the special computer architecture for complex intelligent machines, etc.

8. Electro-mechanical components for intelligent machines: To develop the technology for actuators, sensors, bearings, stepping motors, etc. and to present their full quantified models for use by all technologists.

9. Tribology: To develop the technology of wear, friction, and lubrication as it applies to machines, especially documentation for such systems associated with minimum friction, low backlash, etc.

10. Engineering economic and human factors: To present to the R & D community a clear collection of meaningful indicators of economic trends on which to base short term and long term objectives.

The primary condition of the industry associated with light machinery and other mechanical technologies is that it is marginal, fractionated, unsupported by basic research agencies such as NSF, and has virtually no history of cooperation wtih government towards a common goal. Hence, the need exists for distributed research institutes of different magnitudes depending on their missions. The last four of the above institutes would be supportive of the missions of the first six

listed above. Each would have specially trained management aware of each industry's innovation needs. Such intimate awareness of these needs will enhance the required negotiations in the formulation of the assistance plan, in the performance of the task, and in the assessment of the results for further distribution. This specialized management capability can not be expected to be found in one centralized agency. No such industrial technology agency exists today. The accumulation of a responsive management force as a functioning whole would be a very demanding and problematical task. The single central agency concept has proven to be unworkable in the past as demonstrated by the DOD and NASA models.

I believe that this brief outline justifies the need for the envisioned national plan, managed by NSF–ASRA with ten distinct program institutes. Its early implementation in terms of the Cooperative Agreement Act of 1977 is now warranted because of our present economic weakness in machinery and its products, i.e., the demonstrated negative trend associated with our nation's technology base. Such an effort could have a significant catalytic effect on competitive industry in the United States when one company increases its share of the market for a short time because of the use of better technology forcing the others to follow suit. We know that foreign quality manufacture is benefiting from this weakness on our part. Making our own industry vital and technologically competitive with high quality products can substantially reduce the influx of foreign products into our home markets.

The institutes would be distributed geographically and their size would depend on the demand of their mission. Each of the institutes must begin with a critical mass of people and supporting equipment or failure to satisfy their mission will be certain. Each institute would have a primary responsibility for applied research in its designated range of machinery applications. Complete documentation of new results would be desseminated to academic and industrial users. Short terms and long term interaction with academic personnel from other institutions will enhance their teaching and research capabilities and also bring new ideas to the institutes themselves. A continuously updated collection of modern examples of new technological innovations would be available to all industrial groups for study and evaluation. Movies, seminars, books, computer programs, prototype testing methods, and library support are examples of specific functions that could be carried on by the institute for all external users. Teams of designers and engineers could be trained in the institute over a period of months and returned to industry as a catalyst for enhanced technology usage.

Another primary function of each institute would be to act as a clearinghouse for research and development in competitively selected academic or industrial units. Federal funds would be awarded to enhance the widest possible involvement of universities as well as industry. Long term or high risk development in industry would be supported by means of assistance if industry had too little capital or was too fractionated to pursue a major step forward in technology.

All functions of each institute would be critically evaluated and/or initiated by an interested advisory group made up of representatives from industry. This industrial board would interact with the program management in Washington as well as with the institute management itself. The most meaningful evaluation would be to assess the increased

share of the market which can be associated with improved technology in production or quality in the product.

Some specific factors associated with this national plan are:

1. It must represent a cohesive total which addresses a significant portion of the mechanical technologies.

2. It would be very useful to have a committee of the Industrial Research Institute (IRI) act as the sponsor of this national plan.

3. Each mission has a distinct application range. Hence, its interaction with industry will vary. Consequently, flexibility of approach to industry must not be limited by too rigid a preconception. The management of each institute must initially decide on the funding needed to support the critical mass of personnel, equipment, and industrial assistance in the most critically needed machine developments.

4. Each major endeavor to establish new technology should be negotiated with several interested industrial parties involving a significant sharing of the risk with the institute (i.e., the Federal government). Frequently, the formulation of the endeavor can be expected to come directly from the industrial participants. This heavy involvement of key industrial decision makers is expected to prevent gain for an isolated participant industry. Shared formulation, task performance, and responsibility between the institute and industry should be the goal.

5. Each institute will have state, regional, and national roles. It is expected that the state would provide an increasing percentage of necessary risks capital to support the institute (perhaps 25 percent) and, therefore, support in-state industry. Certainly, the states would be asked to provide land and buildings for the institutes. It is feasible that a 50 percent contribution in assets and equipment can be expected directly from industry. Hence, the Federal role can be reduced from 100 percent to 25 percent after a reasonable period (say 10 years).

INCENTIVES FOR INVESTMENT IN INNOVATION

DR. ARTHUR M. BUECHE

SENIOR VICE PRESIDENT, CORPORATE TECHNOLOGY, GENERAL ELECTRIC COMPANY, FAIRFIELD, CONNECTICUT

This responds to your recent request for views on:

1. The operation of the OSTP under the new organization,
2. The relationships and interaction between science and technology and the economy, and
3. Issues of public concern with strong scientific and technological overtones and with which Congress may have to deal in the years ahead.

The following paragraphs present some of my thoughts on these subjects.

OSTP

With regard to the subject of the operation of the OSTP in carrying out its assigned functions, I would simply state that I have been singularly impressed with the effectiveness with which Dr. Frank Press has been able to inject his influence in the Federal S&T policy making and resource allocation process. Rather than being simply a "spokesman for the technical community," he has been able to identify issues of national policy where science and technology have their strongest role to play, and has effectively obtained and utilized private sector inputs to sharpen the focus of policy analysis toward possible solutions. While this approach will not always result in the highest possible marks from the traditional "constituency" of this office, it is, I believe, the approach of greatest potential benefit to the Nation. In my opinion, the reorganization cannot be assessed apart from the performance of the incumbent and, of course, there is only one holder of the office since the change was made. I would say, however, that a definite improvement has been made and that the workability of the new organization has been demonstrated.

SCIENCE AND TECHNOLOGY AND THE ECONOMY

In line with your suggestion that a relevant speech or presentation would serve your purpose, I am enclosing a copy of a speech given at the October 1978 meeting of the Utility Technical Executives Conference. The thrust of this paper is toward the need for improvement in the environment for investment in technological innovation.

ISSUES OF PUBLIC CONCERN

Finally, you asked for identification of issues of public concern which have strong scientific and technological overtones and with which Congress may have to deal in the years ahead. My view is that

the paramount issue of public concern is inflation. You of course know of the strong scientific and technological overtones. Economists have demonstrated that our traditional success in creating the technological change needed for new and improved products and production processes has been the single most important contributor to the improved living standards of American citizens. And there are urgent needs for governmental action. Aside from the obvious and overriding need to reduce the Federal budget deficit, the government's highest priority should be to stimulate productivity growth. Given that the fundamental effect of technological change is to increase potential output, I believe government could stimulate productivity best by helping to create appropriate incentives for saving and investment in the productive base of our economy. This means action to remove barriers to risk taking and long-term investment in technological innovation that have been created in our system of taxation and by Federal economic policies—both domestic and foreign. It also means action to remove unnecessary barriers to innovation that have developed among the policies and processes of government regulation: economic, environmental health and safety, and industry structure regulation.

INCENTIVES FOR INVESTMENT IN INNOVATION

You've all heard about our nation's declining advantage in R&D . . . about international competition in high-technology products . . . about our disastrous balance-of-payments situation . . . about how we shell out $40 billion per year for foreign oil . . . about the declining value of the dollar abroad . . . about continuing inflation at home . . . about the stalemate in the fight against unemployment . . . about taxes on taxes on taxes. In our business—yours and mine—we even hear now and then about the potentially disastrous energy situation . . . and we are all much too familiar with the incredible national lethargy about it.

You don't need another after-dinner speaker spreading gloomy news. You've got the morning paper (unless you live in New York City), the evening television, and politicians of all persuasions speaking in between.

Frankly, I'd rather talk on the more positive side. As people engaged in technology—especially as people in the electric power business—we've got a lot to be proud of. Over the past 25 years, technology has helped this country generate 30 million new jobs, and a key to all this has been the power that you people in the utilities have been able to provide industry. U.S. exports of high-technology products increased more than from $12 billion in 1966 to $51 billion in 1976. Technology has helped make U.S. agriculture the acknowledged leader in feeding the world, and agricultural exports last year provided an $11 billion plus in balance-of-payments to at least help offset the $40 billion deficit from foreign oil. Medical care may be more expensive, but it is also more effective, and life expectancy in this country continues to rise—up 4 years in the last 25.

United States technology—that is, our nation's leadership in science, innovation, and good old American know-how—has indeed accomplished a great deal.

But it hasn't done enough. And what is worse—much worse—there are indications that as a nation we are being increasingly neglectful of the technological hand that has been feeding us so well in the past.

Let's look at what is happening in regard to both government and private-sector support of R&D—the R&D which is the important first step in the innovation process:

(1) As a percent of GNP, the United States is now spending only 2 percent on R&D as compared with a high of 3 percent in 1964.

(2) We are losing position to our major foreign competitors in terms of R&D as a percent of GNP. We've been decreasing while most of them have been increasing.

(3) But these figures don't tell the whole story, because Federal government expenditures represent 53 percent of total R&D and half of the Federal R&D funds are for defense. In Japan and West Germany, by contrast, the R&D budget for defense are minimal and virtually all of their R&D funds are aimed at promoting economic development and the advancement of knowledge. In other words, they're putting their money where it'll do the most good in the marketplace.

(4) As for strictly Federal expenditures on R&D, we should note that even though there is a highly touted increase in next year's Federal budget for "basic" research, the percent increase requested is actually less than what was allowed this year.

Federal Energy R&D is up—by 1.4 percent, to $3.3 billion for the next fiscal year, defense R&D is up 9 percent to $13.8 billion, but let's remember that this nation's real defense is now largely dependent on the import of foreign oil, obtained by means that are essentially non-defendable in the event of a real military attack.

So let's not delude ourselves that, as a nation, we are spending a truly sufficient amount of our dollars on the kind of technical work that has—in the past—made possible our traditional growth in jobs, productivity, international leadership, and living standards at home.

I'm not going to belabor the point of the direct connection between technology and economic progress. It's a favorite subject of speakers today. But I would like to emphasize the very close-to-home matter of providing jobs for people.

A recent study has shown that over the past 10 years high-technology companies in the U.S. increased employment nine times faster than low-technology companies, and these same high-technology companies increased overall productivity by about 4 percent per year, or twice the national rate of 2 percent.

What about private industry's investment in R&D? Enlightened management is fully familiar with the kind of figures I've just cited; therefore, industrial support for R&D should be going up. And it has been—but not very fast. It has not quite kept pace with the growth of GNP.

At the same time it must be noted that industrial R&D has been trending toward shorter-range goals. Industry's basic research effort—real effort in constant dollars—has actually been declining over the past 10 years. In a few minutes we'll examine why some industrial managers have had to make such cuts.

Now, you and I know that all the R&D in the world is of little value by itself. In other words, to complete the innovation process—to bring about technological change and the resulting new products, increased

productivity, more jobs, and better living standards—we usually have to invest still larger sums in new plants, modernized machines, market development, and so on.

So let's look at our current trend total business capital outlays. The Council of Economic Advisers says a 10-percent per year real increase is needed over the next several years in order to achieve our national goals in terms of jobs, economic growth, and a balanced Federal budget. However, the Commerce Department forecasts only about a 5-percent increase in 1978 after inflation.

Why?

Why the lack of growth of private investment?

Today I'm going to discuss mainly private investment—as contrasted with Federal expenditures—because I think such private investment must remain the dominant factor if we are to continue to rely—as we must—on the ultimate strengths of our free-enterprise system. Also, I'm going to emphasize the special role of R&D as the leading edge of the process of innovation.

Investments are things people make for a reason. They must be attractive. There must be incentives. There must be at least a reasonable return.

When a businessman examines a potential investment, he is interested in three basic questions: How long will it take for my investment to pay off? How much will I have to put in? How good is the chance that things will work as I expect so that I can make a fair return? That is, "what's the risk?"

This investment analysis can be illustrated on a simple chart like this (Figure 1). Vertically, we've plotted money—dollars, plus and minus. Horizontally, we have time.

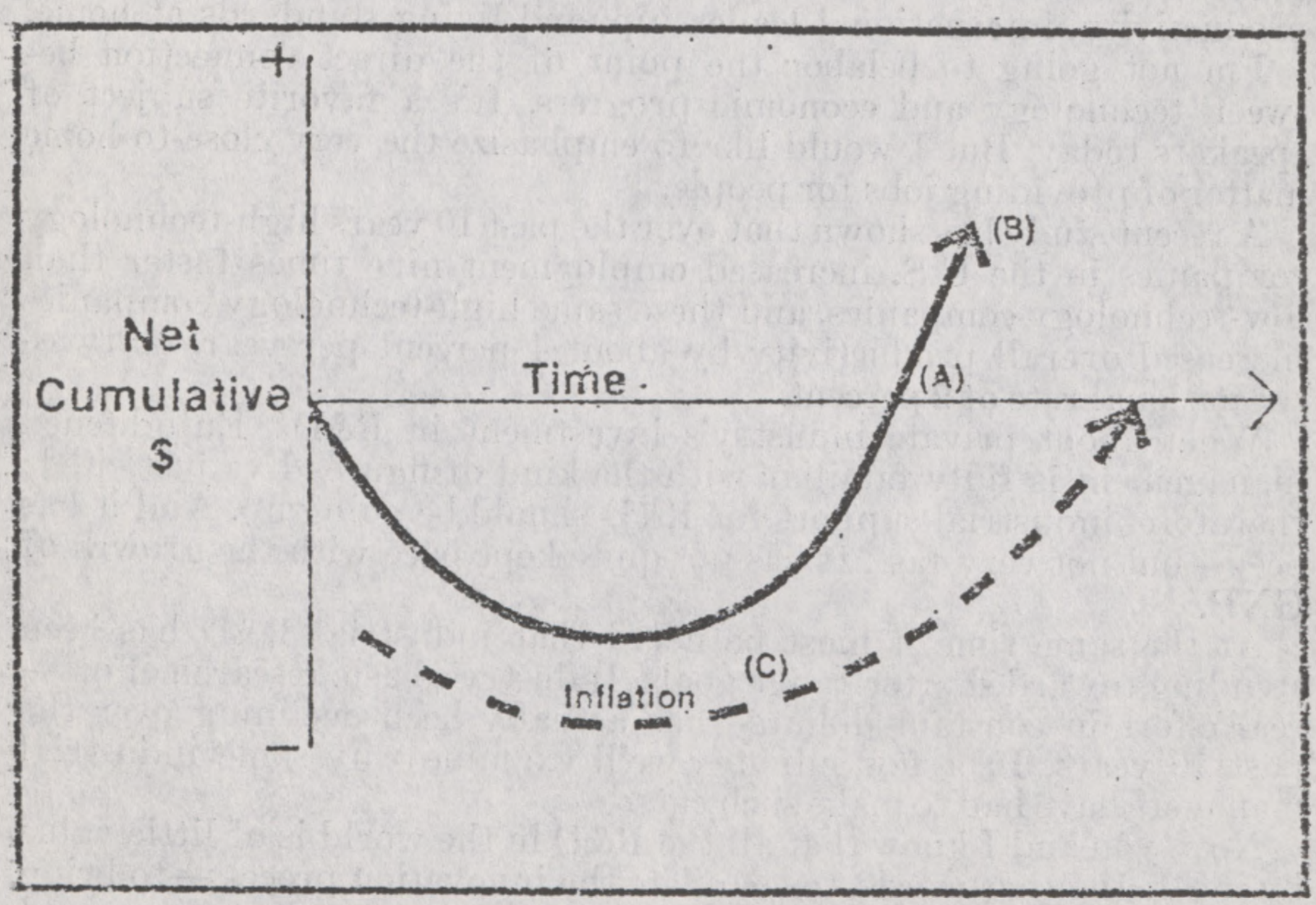

FIGURE 1

The net cumulative resources applied at any given time are a point on this line.

If the idea is a good one . . . if the endeavor is properly managed . . . if too many unforeseen things don't happen . . . if people work hard, the investment will, it is to be hoped at some point in time, begin to pay back . . . and the slope of that line will eventually turn positive (Point A, Figure 1).

Now, then, what are the factors which influence the initial investment?

First of all, you and I—as investors—want that bump below the line to be as shallow as possible, because that will keep the losses down if the project doesn't work out. It requires fewer resources; we have less at risk.

Second, we'd like to recover these resources just as soon as possible—assuming that shortening the wait won't jeopardize what happens after that.

Third, we'd like to have that "plus" curve go as high as possible—and keep going above the line as long as possible (Point B, Figure 1)—because that's what provides the new resources for reinvestment, which leads to the things we want—economic growth, more jobs, security, and future opportunity.

Fourth, we've got to have some reasonable level of confidence in the future. For example, if we're too uncertain about the policies of government—about regulatory groundrules, export constraints, energy, monetary and tax policy—we may find the negative side of the line growing to unacceptable proportions—especially for longer-term projects.

Now, I hope you'll forgive me for oversimplifying this analysis, but a consideration of these factors makes it easier for me to visualize what has happened to R&D in this country—to the willingness of peoples to invest in "knowledge capital." Let's look at some disturbing trends.

Look at the time it now requires to bring innovative ideas to the marketplace! I certainly don't need to tell this audience how we've piled regulation on regulation on regulation . . . or tell you that it now takes up to 12 to 15 years to get a nuclear power plant approved and constructed.

Some members of the American Pharmaceutical industry estimate that post-1962 regulation has doubled the cost of new drugs and halved the rate of introduction. What ever the exact numbers, we simply don't know whether this increased regulation has cost more pain and lives than it has saved.

One major chemical company has recently reported that fully 20 percent of its 1976 R&D budget was to meet Federal regulatory demands and that Federal regulatory costs associated with its U.S. operation increased by more than 27 percent last year. The Toxic Substances Act will, of course, cause this number to go even higher.

We do need effective health standards and product safeguards, but those who would regulate must recognize their responsibilities, too. Just as those of us who are regulated must be responsible for meeting the standards, so the regulators must be responsible for making an extra effort to administer their regulations in ways that will help save both time and money.

Consumer protection is fine. In the long run, of course, the consumer is also paying for it. One aspect of consumer protection is not having to pay too much to be protected.

Now let's consider the impact of inflation on investment considerations. Looking again at our resources curve we see that the longer it stays under the line, the deeper it is likely to go (Point C, Figure 1). One consequence of inflation which has not received enough emphasis is its tendency to push that negative curve deeper. As prices increase, including interest rates—the cost of money—it takes more and more dollars to finance the investment in innovation.

While the depth and length of our resource investment curve are matters of critical concern, of course, the major deterrent to investment in "knowledge capital" (as well as tangible capital) is to be found in public and governmental attitudes about what occurs after—if and when—our curve ever goes positive.

Let's look at what has happened to private investment profits over past years.

Calculations based on Department of Commerce data show that the effective amount paid in corporate taxes has increased from 38 percent in 1966 to 47 percent in 1976. Return on investment adjusted for inflation has gone from 10 percent in 1965 to 4 percent in 1977.

But it doesn't stop there. Just because one tax bite has already been taken in the form of corporate taxes, we can hardly forget what happens to what the investor gets. As I hardly need tell you, he pays tax again on what has already been taxed. The tax on distributed earnings can be as high as 70 percent in contrast with the 50 percent on "earned" income.

And then we wonder what is happening to America's technological leadership . . . where is the innovation that provides more jobs? . . . where is the improved productivity that keeps us competitive?

To me, the answers are a lot more clear when we step back and look at R&D for what it really is: an investment. It is an investment that, like more conventional investments, has become increasingly less attractive.

What needs to be done?

To cut the depth of the resource investment curve, we obviously need to streamline and avoid duplication of effort in the myriad of regulations now confronting the do-ers of our society

Also very important, of course, we must come to grips with inflation.

To shorten the length of time required to achieve payback, we again must insist that the regulators and courts recognize their responsibility to expedite decisions.

In summary, we have an urgent need for a permanent mechanism for review of national policies affecting industrial innovation—to reduce uncertainty in evaluating innovation opportunities, and to increase the incentives for commitment of resources needed to create innovation.

I am delighted to see that Frank Press has succeeded in getting this Administration to undertake a comprehensive domestic policy review of industrial innovation. The approach of establishing an Industrial Innovation Coordinating Committee to develop policy options for the President is extremely useful. I urge each of you to

keep track of this and to help assure that it receives a sufficiently high priority that something will be done.

Now let's turn to incentives for investment in innovation—or lack of them.

Here, and we may as well as blunt about it, we must face the fact that U.S. R&D isn't going to really do what it can and must do in behalf of creating jobs and promoting economic growth and insuring international leadership . . . unless there are changes in our tax structure to provide greater incentives for investment.

But we must be practical about this. Although it is clear that our tax system serves inherently to depress savings and investment, elimination of the basic bases would require some rather radical reforms which simply are not in the cards, certainly not in the time frame that is needed.

But, we can treat some of the symptoms.

First, and most obvious, we could increase both the ability and the incentive for investment most directly and efficiently by an immediate and permanent cut in the Federal corporate income tax rate. I think we should all support the current Congressional action in this direction. A general rate reduction is the most effective and equitable way to lift business spending and employment, and the promise of a permanent cut would give management in the private sector at least something to hope for when doing their longer-term investment planning. This will make a lot more cash available for investment.

Also, I think it is extremely important to provide stronger incentives for technological innovation by making permanent and more liberal the 10 percent investment tax credit. Allowing the credit to offset up to 90 percent of tax liability will be especially beneficial to small businesses and investors.

The record shows that the investment credit has been very effective in generating economic growth through capital expenditures. Studies by economists at MIT and Harvard showed that the credit introduced in 1962 made investment expenditures 7.7 percent higher after three years and 10.2 percent higher after five years.

Another tax provision—allowed depreciation rates—is very important to the innovative process. Present rates tend to work against investment in new equipment and machinery. Provision for more rapid write-off of investment would reduce the investor's vulnerability to both technological obsolescence and inflation, and provide the resources for him to continuously update and replace his tools and machinery.

And last, but certainly not least, a strong case can be made for decreasing the capital gains tax—and for increasing the amount of loss that can be claimed against ordinary income. There is strong evidence that the formation of new high-technology businesses would be accelerated by the influx of capital that such a change could produce.

Now, you've been listening to a technologist with an electrical equipment manufacturing company . . . talking to a group of good friends and customers from the technical side of the electric utility industry . . . about, of all things, tax reform.

What ever happened to advanced cycles, load management, and exotic new energy-conversion schemes?

Well, I believe that when we step back and look at it, we can't separate the health and future well-being of your industry—and of ours—from the overall health of the economic system which has given our society its past strength.

That means that you and I if we are to be true "professionals" in our jobs, have a special responsibility to understand and try to help communicate understanding about fundamental issues and ideas.

Among these ideas is the essential role of incentives for investment—especially investment in technology—to keep our economy and our society strong.

Obviously, it's not a responsibility for just the technical people—like us—who work together to provide the nation its energy, but it is a responsibility we all must share.

I appreciate this opportunity to contribute my views, and I hope they will be of some value to the Committee.

TECHNOLOGY AND THE NATIONAL ECONOMY

DR. ROBERT GILPIN

PROFESSOR OF POLITICS AND INTERNATIONAL AFFAIRS
PRINCETON UNIVERSITY, PRINCETON, NEW JERSEY

It is remarkable to note that the subject of my talk, "Technology and the National Economy," is a relatively new one. This is not to say that people did not connect technological advance and economic well-being. It has long been generally appreciated that a strong and thriving economy is dependent upon the development of technological innovations. I mean that the subject is a new one in the sense that the relationship of technology and the economy was poorly understood until recently and that very few appreciated that there was a problem here that really needed examination. I mean it also in the sense that it was generally assumed that technological advance took care of itself and that there were no public-policy issues requiring attention and resolution.

In this paper I am going to explore two major public policy issues that I believe will loom large in the years ahead. At the moment, both issues are no larger than a man's hand, but they will become increasingly important as times goes by. The first is the appropriate role of the federal government with respect to the development of commercial technologies; this issue is tied, of course, to the much larger question of government economic planning. The second issue is that of American policy toward the export of American technology not only to hostile countries but to our major allies and to developing countries as well.

The position one takes with respect to both issues is partially dependent upon one's philosophical disposition with respect to government intervention in the economy. Do you rely upon the market to determine the development and export of technology, or do you delegate more and more of these decisions to government officials? The lines are being drawn on this question, and what is noteworthy is that the division follows neither traditional ideological nor party lines. Republicans and Democrats, for example, can be found on both sides of the issue of market versus government. More remarkable is the fact that so-called staunch conservatives advocate a powerful government role in the economy which appalls many so-called liberals.

In addition to these philosophical differences, opposing schools of thought regarding national policies toward technology development and diffusion also differ with respect to the state of American technology. For this reason, prior to a discussion of these policy issues and the contesting positions regarding them, I propose to consider first the developing debate over the state of American technology.

Approximately ten years ago if I had given a talk on technology and the economy, the emphasis and tone of what I had to say would have been entirely different. I would have focused upon what was then referred to as the "technology gap," that is, the seemingly overwhelming superiority of the United States in science and technology relative to the rest of the world, particularly the Western Europeans and the Japanese. As many of you may recall, in response to the distress felt by the Europeans over their apparent falling behind in the more sophisticated areas of science and technology, a number of private and government studies were undertaken to deal with the problem.

Almost as suddenly as it arose, the technology gap issue faded into the background. By the late 1960's, it had been supplanted by a new and dramatically opposite concern. In blunt terms, the issue was the technological decline of the United States. This concern was generated by the growing balance of payments deficits of the United States and, particularly after 1967, a decline in America's international trading position. As a consequence of this deteriorating trade position, in 1971 the United States registered its first trade deficit in this century. Our international competitive position had declined to the point where we were importing more goods than we were exporting.

Several important and influential studies carried out in the Department of Commerce suggested that a major factor in America's deteriorating trade position could be traced to a decline in our relative technological position. In particular, a breakdown of trade statistics appeared to show that our traditional strength in so-called technology intensive exports had weakened. The Europeans, and especially the Japanese, had cut our historic lead with respect to high technology products—consumer electronics, automobiles, etc. As a consequence of this intensified competition, we were decreasingly able to balance our international books as we had in the past through the export of what economists call high value-added products. That is to say, the United States appeared no longer able to earn sufficiently high profits on its monopoly of certain superior technologies in order to buy the goods and resources it required abroad.

At the same time this change in America's international trading and economic position was becoming known, another important development was taking place in the American economy. The simultaneous leveling-off both of the strategic arms race with the Soviet Union and of the space program threw the aerospace industry into a state of trauma. Suddenly thousands of engineers and technicians were out of work, and many aerospace corporations were suffering for want of work. This situation in turn was to be greatly exacerbated by problems of recession and inflation. Together, America's deteriorating international trading position and the plight of the aerospace industry seemed to suggest a crisis situation in American science and technology.

In response to this situation, President Richard Nixon took the first steps toward defining a national policy toward technology. First, the President directed his advisor for science and technology to issue a report on the state of American technology. Second, and more importantly, the President appointed a Special Assistant to develop what became known as the New Technological Opportunities Program. Whereas the first Presidential message on science and tech-

nology signaled a major change in the visibility given to the economic aspects of scientific and technology policy, the New Technological Opportunities Program represented a major new departure in government policy, namely, the notion that the federal government has a responsibility for the health of civilian-related technology. In essence, this program envisaged a multibillion-dollar government financing of selected technological developments particularly in the so-called high technology areas of atomic energy and aerospace.

Prior to these actions on the part of the Nixon Administration, it had become accepted that the federal government had a responsibility for the support of basic scientific research and for the support of technological developments relevant to the carrying out of its own responsibilities, particularly in the areas of national security and public health. It was generally assumed, however, that the government's role did not extend to the private or civilian sector of the economy. This is to say, the government was not responsible for the general state of American technology. Under the American free enterprise system, the development of commercial technology was regarded as a responsibility of the private sector. Now a conservative Republican Administration was urging a massive federal intervention into the civilian sector of the economy.

Fortunately or unfortunately, depending on your viewpoint, the New Technological Opportunities Program ran aground on the shoals of fiscal conservatism. The financial managers of the Nixon Administrations were unwilling to support such a massive program, especially one that violated traditional American notions of the role of the government in the economy. Of the several technological developments proposed by the Technological Opportunities Program only the breeder reactor project survived. Another, the proposal to fund a supersonic transport aircraft, was defeated after an acrimonious struggle in the Congress.

The basic issue of a national policy for technology, however, was not, and has not been, resolved. It lay dormant for several years and then suddenly re-emerged with full force in response to the so-called energy crisis. In launching Project Independence and creating the Energy Research and Development Administration, President Nixon once again raised the question of the government's role in civilian technological development. In particular, Vice President Nelson Rockefeller put the issue in sharp relief when he proposed a $100 billion federal program of energy development.

While the energy problem casts a dramatic light on the issue of a national technology policy, the issue is really one that cuts across the whole civilian economy. In simplest terms, the issue is posed as follows: the United States over the past several decades has given unprecedented support to scientific research and technological development. In absolute amounts and as a percentage of gross national product, no other economy comes close. American science and technology remain unsurpassed. Yet, numerous sets of statistics suggest that we are not doing as well technologically as we should.

As I have already mentioned, the disquiet arises over the fact that our position relative to our world competitors has deteriorated. This fact is reflected in America's poor trading performance with respect to technology-intensive goods. These matters are not in dispute. What is

in dispute is why this change has come about. Commentators on this question tend to fall into two broad schools of thought.

The first position I shall call the "technological decline position." In essence, this position argues that America's relative position has deteriorated because of an absolute decline in our scientific and technological position. Although there is no unanimity on the matter, a number of adherents of this position explain the matter as follows: while it is true that the United States has outpaced and continues to outspend the Europeans and the Japanese, an immense fraction of these expenditures are in security-related technologies, particularly atomic energy and aerospace. While these expenditures may be justified in terms of national security, they are of little relevance for the civilian and competitive sectors of the economy. On the contrary, these huge expenditures tend to divert resources from the civilian sector and raise its research and developments costs. In short, the arms and space race with the Soviet Union has had an overall detrimental effect on the civilian economy, especially its capacity to finance technological developments.

At the same time, this position holds that the Europeans and the Japanese have devoted a far greater fraction of their total scientific and technological resources to civilian-related enterprises. Whereas American corporations are decreasing their support for civilian-related technology, their foreign competitors are increasing their own support. As a consequence, although America's competitors are devoting fewer total resources to science and technology, they are devoting a relatively much higher fraction to technologies relevant for economic growth and international competition.

The opposing school of thought has a less alarming view of America's technological position. While many adherents of this position believe that the United States has overconcentrated on defense and space technology to the detriment of the civilian, competitive economy, they do not believe that there has been a general deterioration of America's scientific and technological position in the world. They believe rather that what has happened is that the Europeans and Japanese have re-established their former positions in world science, technology, and trade; this is particularly true of the Europeans, who have long been strong in these areas. Thus, it is not that the United States has declined technologically in any absolute sense but rather that others have overcome the destruction wrought by the Second World War and have caught up to us once again. From this perspective the "technology gap" of the late 1960's was an unusual circumstance that has now been righted.

The differing perspectives of these two schools of thought may be illustrated by examining in a bit more detail their respective interpretations of America's weakened trading position. For those who see an absolute decline in America's technological and economic position, America's merchandise trade deficit represents a general deterioration of the American economic position. According to this school of thought, the 1950's witnessed a gradual redistribution of global economic, and technological capabilities. By 1971, they argue, a profound shift in economic power had taken place, particularly in the direction of Western Europe and Japan. Throughout the 1950's and 1960's, Western Europe (with the exception of Great Britain) and Japan enjoyed higher rates of growth of gross national product than did the

United States. Whereas Japan was growing at 13 percent a year and Europe at 7 percent, the United States throughout this period tended to grow at 3 to 4 percent a year.

As a result, the United States, share of world GNP had fallen dramatically from nearly 40 percent in 1950 to around 30 percent in 1970, while the Common Market share had risen from 11 percent to nearly 15 percent in the same period. European competitiveness also improved; the American share of global exports shrank from 16.7 percent in 1950 to 13.7 percent in 1970, while the Common Market share rose from 15.4 percent to 28.6 percent in that period, of which nearly half was in intra-European Economic Community trade.

In the area of technological innovation the evidence suggests to acute observers like Charles Kindleberger that, outside the military and aerospace spheres, American innovation in commercial technology has become sluggish. In areas where the United States had formerly reigned supreme and in other areas as well—automobiles, steelmaking, shipbuilding—Japanese firms in particular, have been taking the lead. Japanese entrepreneurship has been more dynamic. The Japanese save and invest more: 29 percent of GNP as gainst 14 percent for the United States and 20 percent for West Germany. As a consequence, Kindleberger observes, "the balance of payments difficulties of the United States [have been] due to a slowing down of innovative capacity relative to Europe and, above all, to Japan, and to an increase in spending, relative to income, on the part of business, households, and government."

In addition to its relative rates of economic growth and innovative capacity, the composition of American imports and exports is said to reflect its decline as an industrial economy. After 1967, America's trade surplus began to decline dramatically. By 1971, the United States had a trade deficit. Although American exports in technology-intensive manufacturers (capital goods, transportation, scientific instruments, etc.) and agriculture continued to remain strong, the United States went into severe deficit with respect to fuels, consumer products, and other categories. But even in technology-intensive goods, the rate of export growth declined and imports increased. In technology-intensive goods the United States not only had a declining surplus with Western Europe, but it actually had a deficit with Japan as well.

The "technological decline position" regards these developments as indications of a secular deterioration of the American economy. There is, according to this position, a long-term trend toward lower industrial productivity, decreased innovation, and sluggishness in the American economy. For some of this persuasion, a major factor has been the export of American technology, which has accelerated the catching up of America's overseas competitors. Advocates of this position, therefore, tend to support a major program of government support for technlogical development and to advocate policy changes that would retard the export of American technology.

For the opposing position, these alarming trade and economic statistics can be explained primarily in terms of the price levels of American goods. For a number of reasons, the American dollar has been overvalued and as a consequence American goods have been noncompetitive in world markets. As they point out, the devaluations of the dollar in

1971 and 1973 have improved America's trading position. In short, according to this position, the problems of the American economy have been cyclical rather than reflecting a secular decline. Fortunately, they argue, we are now on the upswing once again, and no major policy initiatives are required.

My own view is that each position contains part of the truth. The explanation of America's declining trade position undoubtedly is some combination of the cyclical and secular positions. Our economic and technology position has declined in absolute terms, but it has not deteriorated as much as the most extreme proponents of the technological decline position suggest. The debate, however, obscures the most critical question that must be addressed: what is important is not whether we are doing as well technologically as we did in the past, nor is it whether we are falling behind our major economic competitiors, rather it is whether we are doing well enough relative to our own social, political, and economic needs.

These needs are well known to all of us. Are we creating new industries and technologies to absorb an expanding work force? Can we produce the new technologies required to solve the energy and other resource problems? These questions, however, are not the ones upon which I wish to focus. Instead I wish to discuss the role of technology and technological innovation in our overall global economic, political. and military position. This is a situation that I do not believe is well appreciated, and it is one to which we are going to have to give increased attention.

Since the end of the Second World War, the United States has become a global power. I believe this role was forced upon us, and we did not seek it. The fulfillment of this role, however, has been very costly, even in times of peace. The maintenance of large numbers of troops abroad, military aid to our allies, and economic aid to friendly countries have imposed a heavy economic burden upon us. In particular, there is a balance of payments burden.

From the point of view of economics, the costs associated with our global position are consumption expenditures and like all consumption expenditures have no direct economic return. Somehow a way must be found to cover these military and political expenses. What I propose to do is show how we have managed this problem and the relevance of this subject to the status and export of American technology.

During the first decade or so of the Cold War, we covered the cost of the struggle with the Soviet Union and the maintenance of our evolving global position by drawing down our savings and depressing our own consumption. At the end of the Cold War, for example, we owned a major fraction of the world's supply of gold. Today, our gold reserves are low. The Daughters of the American Revolution are essentially correct in fretting about the gold at Fort Knox. We gave it away. But we gave it to our own military and our allies in the effort to contain the Soviet Union. We have largely depleted over the past several decades a gold reserve that we had acquired over the better part of a century.

During the second decade of the Cold War, 1961 to 1970, we financed our global political and military position primarily by printing money. The dollar had become the basis of the world monetary system,

and we had become the world's banker. We controlled the printing presses, and we printed dollars to suit our needs: the purchase of foreign industries, the importation of goods, and the fighting of foreign wars. Under the system of fixed exchange rates, others were forced to accept and honor these dollars; they were glad to do so. But Vietnam and poor economic management destroyed the system of fixed exchange rates; and under the present system of flexible exchange rates, we have to pay in hard cash for what we buy abroad. We can no longer in effect live on credit extended by our allies.

In effect, the United States must earn from the sale of goods and services abroad enough not only to cover what we import but to cover the costs of maintaining our global political and military position. We can no longer draw upon our savings or depend upon our role as world banker in order to finance our global military and political commitments. The problem of how we can earn enough foreign exchange so that we can maintain our political-military position in Europe, the Far East, and elsewhere has become a major challenge to the United States.

The problem posed by the trade and balance of payments position of the United States was addressed in the late 1960's by a blue-ribbon Presidential Commission on international economic policy, by the President's newly appointed international economic advisor, and by a host of academic economists. The tone of the reports and studies of these experts was on the whole optimistic. The reason for this optimisim takes us to the second issue I wish to discuss, namely, the export of technology.

In brief, what I want to talk about is the role of foreign investment or more particularly the so-called multinational corporation. Nothing could be more relevant for the topic of my talk on technology and economy, particularly as this subject relates to the national security of the United States. In the first place, when one speaks of technological innovation in the American economy, he is talking principally about these gigantic corporations. These 200 or so major corporations dominate our economic life and are one of the foremost sources of our new technology. Secondly, these multnational corporations either in the areas of extractive industries or manufacturing have become critically important earners of the foreign exchange we require to import energy, maintain troops in Western Europe, and finance our world position. Thus, there is a strong connection between the technological innovativeness of these firms, their foreign investments, and our global political-military position.

What, then, is a multinational corporation? In nontechnical terms, it is any corporation in which ownership, management, production, and sales activities extend over several national jurisdictions. It is comprised of a head company with a cluster of subsidiaries throughout the world economy. The goal of the corporation is to have managerial control of foreign production units. The two most prominent types of investment are manufacturing investments in developed economies and investment in extractive industries in the underdeveloped world, especial petroleum. These corporations have a common pool of managerial talent and of financial and technical resources. Most importantly, the whole operation is run in terms of a coordinated global

strategy. The multinantional seeks to perpetuate its dominant position with respect to technology and access to capital through vertical integration and centralization of decision making. These investments create economic relations of a highly significant and lasting character, and for this reason investment of this kind is highly controversial.

The essence of multinationality and this is a point that cannot be overemphasized—is the ownership by a corporation of a particular nationality of a production unit (extractive or manufacturing industry) in another economy. It thus entails the extension of property rights across national boundaries and the guaranteeing of those rights by the host government. As such, the multinational corporation is perfectly compatible with Western views regarding the sanctity of property rights. It runs directly counter, on the other hand, to Communist notions and to the views of developing countries committed to socialism and state intervention in the economy.

Although the corporations of other industrial powers are among the oldest multinational (Royal Dutch Shell, Unilever, Nestlé), the multinational corporation today is most frequently American. Eleven of the fifteen largest multinationals are American. While European and Japanese corporations are increasingly going multinational, that is, establishing foreign production facilities through foreign direct investment, these nations still lag far behind the United States. In general, these other nations prefer trade and portfolio investment to foreign direct investment. Therefore, the term "multinational corporation" (MNC) is still largely a euphemism for the overseas expansion of America's giant oligopolistic corporations.

From an initial accumulated investment of only $7 billion in 1946, by 1972 the book value of American direct investment abroad totaled nearly $100 billion with an annual output of approximately $200 billion. Additionally, whereas prior to the Second World War, Latin America accounted for most of this investment, after the War, Canada, Western Europe, and other industrial areas absorbed the great bulk of this investment. Investment in the production of raw materials and in traditional manufacturing industries has remained strong. However, a large fraction of post-War investment has gone into advanced manufacturing industries (40 percent), where it is heavily concentrated in the so-called commanding heights of the modern industrial economy (automobiles, chemicals, and electronics). The other large segment of U.S. foreign direct investment is in petroleum (30 percent). This $20 billion investment accounts for about 40 percent of American direct investment in the lesser developed countries.

By the early 1970's, the United States had become more of a foreign investor than an exporter of domestically manufactured goods. International production by MNC's had surpassed trade as the main component of international economic exchange. Foreign production by the affiliates of American corporations was nearly four times American exports abroad. Moreover, a substantial proportion of American exports of manufactured goods were really transfers from an American branch of an MNC to an overseas branch. By 1969, the American multinationals alone produced approximately $140 billion worth of goods, more than any national economy except those of the United States and the Soviet Union, and in 1971 the MNC's accounted for 15

percent of total world output. Many of America's largest corporations have placed more than half of their total assets abroad, and more than half of their earnings come from abroad. These earnings in turn have become an important factor in America's overall balance-of-payments position. The loss of these assets and the loss of these earnings would be a severe loss to the American economy and to our world position.

As I mentioned earlier, the economic and strategic importance of these earnings began to be appreciated in the late 1960's. Projections by government officials and academic economists showed a vast surplus in our international accounts. Although we would be a net importer of merchandise, it was anticipated that the income and earnings from foreign investment would buoy the national treasury. Foreign earnings from American overseas investments in extractive industries and manufacturing would greatly exceed the costs of our imports and of our foreign political-military commitments. As a consequence, there would be no problem of importing what we needed or of financing our global military and political commitments.

For a number of reasons, these vastly optimistic projections have failed to materialize. There are several reasons, but I wish to mention only one. This is what can only be described as the energy revolution. The shift in control over the non-Communist world's supplies of petroleum from the United States to the producer countries had two profound effects on our global economic position. In the first place, it has mean a severe loss of foreign earnings. A substantal fraction of the overseas investment income we had anticipated would have come from petroleum investments in the Middle East and elsewhere. These monies now go to the members of the Organization of Petroleum Exporting Countries rather than to American oil companies and thereupon are taxed by the U.S. Treasury. Secondly, the United States is rapidly becoming a major importer of costly foreign oil. Together, these two effects of our loss of control over foreign petroleum resources have had a profoundly negative effect on our overall balance-of-payments situation.

As a consequence of the several developments I have mentioned, the United States has become heavily dependent—one might say disturbingly dependent—upon our remaining foreign investment in manufacturing. Although we earn increasing amounts from our export of food and our overall trading position has improved with the devaluation of the dollar, our earnings from foreign investment have become a very important factor in our ability to finance our global political and military position. Until, and unless, we develop an alternative foreign economic strategy, for example, one based on trade rather than on investment, the multinationals and their foreign earnings will loom large as a factor in our world position. And herein lies a developing major problem.

Until very recently, the multinationals and their operations were relatively immune from criticism. The one major exception was organized labor, which regarded them as exporting jobs; the labor-backed and extremely protectionist Burke-Hartke bill would have severely restrained the multinationals' capacity to export capital and technology. The defenders of the multinationals rose to the challenge and after a protracted conflict defeated Burke-Hartke. While Amer-

ican organized labor has by no means given up the fight, the first round in the battle was won by the multinationals.

Very recently, however, the more astute champions of the multinationals have seen a new and far more ominous opponent entering the lists. While this potential opponent does not challenge the multinationals directly, the thrust of certain policy initiatives is regarded by many leaders of the multinationals with great concern and as highly threatening.

The potential challenge to foreign investment and the multinational corporation that I have in mind is the United States Department of Defense. The policy initiative to which I allude is contained in a recent task force report of the Defense Science Board, entitled, "An Analysis of Export Control of U.S. Technology—A DOD Perspective." This so-called Bucy Report (for J. Fred Bucy, Executive Vice President of Texas instruments), issued last February, has caused considerable consternation among knowledgeable and farsighted multinational corporate executives. To understand why let us look more closely at the nature of foreign investment and at the proposals of the Bucy Report itself.

Reduced to its essence, foreign investment by American multinational corporations involves the export abroad of a package composed of American management, capital, and technology. Of the three, the export of capital is the least important. What American multinationals are doing in effect is exporting American managerial skills, know-how, and technology in order to earn a higher rate of return than they could earn by keeping the skills and technology at home. In doing so, they are acting in many cases on the assumption that the diffusion of American technology overseas to foreign competitors is inevitable. Through the overseas migration of American industry the diffused technology remains under American control. In the language of economics, American foreign investment is said to be defensive, i.e., to forestall the right of foreign competitive industry.

Behind this development is the fundamental fact that the cost of innovation has been rising rapidly at the same time that the rate of diffusion has been increasing. Improvements in communication and transportation as well as the increasingly systematic nature of technology and know-how have greatly accelerated the ease with which knowledge and innovations can be diffused to foreign competitors. In a world in which industrial and organizational techniques are based on scientific knowledge, comparative advantage has become increasingly ephemeral. Furthermore, both developed economies and certain underdeveloped ones have greatly improved their capacity to absorb scientific and technological advances. For its part, the United States appears less able to capitalize on the great advantage it has long enjoyed over its foreign competitors—the capacity to turn inventions of whatever origin into profitable innovations. Thus, the United States must work faster, and at an increased cost, to keep ahead of its competitors.

The implications of this transformation in the relative rates of technological innovation and diffusion have been profound for the United States. Despite high wages and an elevated standard of living prior to and during the quarter century following World War II, the United States has maintained its competitiveness in world markets largely because of its superior technological position and the availability of

skilled labor. However, by the mid-1970's the United States had to meet the problem of how to remain competitive in a world where comparative technological advantage had become increasingly transitory. The production of new knowledge and innovation is very expensive for the individual firm. Moreover, once such goods come into existence, they are in effect free goods. Even when the innovation is patented, a domestic or foreign competitor can utilize the new knowledge or innovation at a relatively low cost to itself. Unless a firm can capture a relatively large fraction of the benefits of its research and development efforts, it has little incentive to undertake this investment in the first place. One can argue, in fact, that unless firms are able to realize the benefits of their own research efforts, total investment in new knowledge and technology will be below what can be considered a socially optimum level. Under these circumstances the export of technology and foreign investment are regarded as important means to increase the return on research and development expenditures. This fact, however, does not solve the problem.

Although the exported technology remains within the confines of the American corporation, this fact does not prohibit the diffusion of the technical and managerial know-how to foreign nationals. The key managerial and technical personnel of an American overseas subsidiary will most likely be American. However, an increasingly large number of the executives, scientists, and technicians employed by the corporation will be foreign nationals. Through its training programs and on-the-job work experiences, these foreign nationals are gaining an expert knowledge of American managerial skills and manufacturing know-how. Many foreign nationals in fact are given training in the United States with respect to our most advanced science and engineering. As technology transfer is largely a matter of face-to-face communications, the everyday operations of the multinationals are raising the scientific and technical competence of non-American managers, scientists, and engineers.

Moreover, an important change in the overseas operations of American multinationals has taken place over the past several years. For a number of reasons, host governments have improved their bargaining positions and are making greater demands of the multinationals. Whereas in the past the multinationals had complete control over their foreign subsidiaries, they must increasingly enter a joint venture with a foreign firm; frequently the foreign firm has majority control and direct access to American technology. As foreign investment has become more difficult and risky, American corporations are building more so-called turnkey plants and licensing their technology. A major demand of the developing countries is that all foreign investment be accompanied by research and development facilities. The thrust of all of these more recent changes has been to accelerate the diffusion of American technology to other countries. It is against this background that one must see the Bucy Report.

The Bucy Report addressed a problem that is and rightly should be of concern to the Department of Defense, that is, the diffusion of American "design and manufacturing know-how" to enemies of the United States. In particular, the Committee investigated the potential hazards associated with the diffusion of American industrial know-how in four so-called "high-technology" areas: airframes, aircraft jet engines, in-

strumentation, and solid-state devices. In concluding that the rapid diffusion of American technical know-how in these strategic technological areas was undermining our military position vis a vis the Soviet Union, the Committee proposed a highly restrictive policy with respect to the export of strategic technology.

The most important finding of the Bucy Committee was that "control of design and manufacturing know-how is absolutely vital to the maintenance of U.S. technological superiority." For a variety of reasons, however, the task of keeping our technological lead over the Russians has become much more difficult. Under the umbrella of détente, American firms are selling more technological know-how to the Russians. America's allies are said to be knowingly or unknowingly violating Cocom [1] regulations in order to gain access to the Soviet and East European market. Neutral nations that gain access to American technology via foreign investment and other means are said to be re-exporting it to the Soviet and their allies. In short, through subterfuge and the playing off of potential sellers against one another, the Soviets are finding it easier to get around the Cocom barrier and thereby acquire American technological know-how.

While the Bucy Committee proposes a liberal policy regarding the export of end products to the Soviets and other Communist countries, it proposes that the Department of Defense formulate and implement policies greatly restricting the export of so-called strategic technology. Under new guidelines now being developed by the Department of Defense, certain types of industrial know-how could not be exported beyond the borders of the United States. Other types could not be exported to neutrals, lest it be re-exported to the Communists. Still other types of technology could be exported to our allies. However, if they re-exported the technology to the Communists, they would "be prohibited from receiving further strategic know-how" from the United States.

The merits and demerits of the Bucy Report are not at issue here. As I have already suggested, the problem it addresses is a serious one. What I wish to discuss is the fear that the report has generated among corporate leadership and the potential danger they see inherent in the concept of strategic technology control. While they favor the report's more liberal attitude toward the export of end products to the Soviet Union and other Communist countries, they regard a more restrictive policy toward the export of design and manufacturing know-how as a major threat to the multinational corporation and its mode of operation.

Although corporate reservations have not been articulated publicly to any extent, there are three aspects of the Bucy Committee's recommendations that disturb sensitive corporate leaders. The first is the mere fact that the Department of Defense would impose itself into the affairs of the multinationals. The DOD would presumably monitor the export of technology not merely to Communist countries but to Western Europe, Japan, and all other countries. Secondly, although the report proposes controls in only four technological areas, it holds open the possibility of extending controls to other technological areas as

[1] Cocom is an acronym for the Coordinating Committee of the Consultative Groups of Nations, comprised of NATO members (less Iceland) and Japan, which controls the shipment of strategic products to Communist countries.

well; the committee notes that it is extremely difficult to distinguish between strategic and nonstrategic technological know-how. And, thirdly, a number of corporate executives fear that implementation of the recommendations of the report would open the way to highly protectionist actions on the part of the government.

Behind the Bucy Report, a number of businessmen, rightly or wrongly, see lurking old-fashioned economic protectionism. Public statements by individuals closely associated with the report reinforce this fear. Whether it is intended or not, they fear that the policy of technological protectionism inherent in the report would encourage latent forces of protectionism in the United States. The control mechanisms and policies advocated by the report, for example, could be used to prohibit the export of technology merely because it would allegedly put Americans out of work. They note, for example, a parallel between the recommendation of the Bucy Committee and of the so-called Burke-Hartke bill advocated by organized labor, which would have restricted the export of American technology. In short, knowledgeable corporate executives fear that the implementation of the Bucy Report could cripple the operations of the American multinationals.

Corporate concern over the alleged dangers inherent in the Bucy Report are perhaps exaggerated at this time. Yet, corporate sensitivity with regard to the whole question of technology exports must be seen against the background of other developments. I have already mentioned the Burke-Hartke bill; the Jackson amendment should also be noted. In addition, a recent report of the General Accounting Office has advocated greater government monitoring of technology exports to the Soviet Union. A prominently mentioned foreign policy advisor to Jimmy Carter has endorsed the main thrust of this report and has proposed tighter controls over the export of technology, particularly to the Soviet Union. Moreover, a number of government officials, Congressional leaders, and prominent citizens have seemed to suggest that the United States should restrict the export of technology in order to maintain our competitive position, especially with respect to Japan. In short, many multinational executives sense a change in the national atmosphere from one that favored foreign investment to one that is more hostile to the export of technology and other forms of know-how by the multinationals.

All of these critics of the multinationals and of relatively unrestricted export of technology appear to argue that our competitive system puts us at a disadvantage in dealing with Communist governments and even with countries like Japan, where the government in effect does the negotiating with American corporations. As a consequence, it is argued, these foreign governments can play a divide and conquer strategy and thereby acquire technology that should not be exported. The point may best be made by a quotation from the Bucy Report:

> The natural reluctance of U.S. companies to share proprietary know-how with competing U.S. companies is sometimes cited as an effective deterrent to sharing know-how with foreign industrial organizations. However, this mechanism was found to be ineffective in three of the four industry segments studied by the subcommittees. The sole exception was the U.S. jet engine industry. Inhibiting factors in the case of jet engines are considered to be the very small base of suppliers, long product development cycle, and large capital investment rerequired for new products. However, in view of a recent incident, the inter-

national jet engine industry does not have these strong inhibiting factors, and reacts the same as the other industry segments to Communist overtures. In other industries, however, recent history shows a consistent pattern of some companies selling know-how that other companies in the same industry consider proprietary. These selling companies seem to be swayed by the allure of exclusive access to state-controlled markets and/or large cash payments important in meeting the capital needs of the particular companies.

The solution to the problem of excessive technology exports by American corporations, therefore, is for the American federal government to monitor and control the export of technology and thereby attain a more even balance.

In response to this increasingly challenging environment, the multinationals make essentially three sets of arguments. In the first place, they argue that the technology being exported does not represent the most advanced state of the technical art. In particular, corporations are said to license only technology that is being superseded by more advanced technology. The export of obsolescent technology is necessary to finance the research and development that will enable American corporations to stay ahead of their foreign competitors. Secondly, they argue that if they do not sell the technology someone else will and that technology export controls will not severely restrict Soviet military developments. And, finally, American business responds to the criticism that foreign governments are outwitting them by arguing that they can take care of themselves; they do not need government protection. No Soviet commissar or Japanese bureaucrat, they contend, can outwit a shrewd Yankee trader.

I will not attempt to assess these conflicting arguments and views. What I wish to stress is that we have here a genuine dilemma. On the one hand, the concerns of the Bucy Report and others regarding the diffusion of American technology are real; it is increasingly difficult because of foreign investment, the licensing of American technology to foreign countries, etc. to keep our technological lead over our Soviet adversaries. There is also cause for concern that the seemingly accelerating rate of technological diffusion to foreign competitors has weakened our competitive position in the international economy. On the other hand, the operations of the multinationals upon whom we as a nation have become extremely dependent could be undermined if American policy on technology exports became too restrictive. This is to say, the American dilemma appears to be the following: American corporations and the American economy as a whole have become increasingly dependent upon the export of technology; principally through the establishment of foreign production facilities and increasingly through other devices we export technology in order to earn the foreign exchange required to purchase energy and other imports as well as to finance our world position.

The consequence of this economic strategy, however, has been to accelerate the diffusion abroad of our technological skills and know-how to our economic competitors and, more ominously, to our potential military oponents as well. If, however, we were to reduce substantially the export of our technology, we might find it exceedingly difficult, under present circumstances, to earn the foreign exchange required to maintain our global economic, military, and political position. We seem to lose either way. This dilemma is one that is going to be with us for a long time to come.

The one and only solution to this dilemma, of course, is to maintain here in the United States a strong commitment to scientific research and technological development. We must maintain a strong lead over both our economic competitors and our military antagonists. The only real and long-term solution to a world in which technological leadership is increasingly transitory is to maintain a healthy climate for innovation at home rather than seek to close ourselves off from the rest of the world.

In conclusion, the two major policy issues I have discussed—the development of commercial technology and the export of this technology—raise the same question: How should we respond to a world of increasing economic and military competition? Shall we continue to rely principally upon the market mechanism, or shall we see an increased governmental role in the development of technology and a move toward technological protectionism? It is too early to feel confident regarding which way we shall move, but, for better or worse, the pressures for government intervention will increase greatly in the years ahead.

As you may sense, I have a strong reservation regarding government encroachment on the private sector in either the areas of technology development or control over technology exports. I believe our best strategy is to rely upon private initiative in order to stay ahead of our competitors rather than to retreat into protectionism, save where there is an overriding national security interest involved.

AMERICAN TECHNOLOGY: NATIONAL ISSUES IMPACTING ITS ADVANCEMENT AND INTERNATIONAL TRANSFER

DR. J. FRED BUCY

PRESIDENT, TEXAS INSTRUMENTS, DALLAS, TEXAS

The current array of U.S. Government statutory laws and regulations impacting either the advance of American technology or its international transfer are incoherent and, at times, conflicting. This condition has developed through the inclusion of technology issues as discrete actions to implement various policies, none of which focus on technology itself as an issue of high national priority. Since a policy does not exist for specific sectors of technology, there is no framework for assessing the impact of laws and regulation on technology goals.

In those few specific areas where the Federal Government has attempted such policies, it has severely restricted the private ownership of resultant technology, and therefore limited the spin-off of its commercial applications. Certainly there is justified concern that policies developed for a narrow segment of technology might eventually spread to cover more and more areas of technology. This concern, when coupled with the trend toward severe restrictions on private ownership of technology, are strong arguments for not pursuing any policy.

However, the inconsistency of Federal policies and regulations regarding technology will continue to be further aggravated in the future, as new policies are developed regarding the encouragement of technology transfers to less developed countries, and, at the same time, other policies will focus on the competitiveness of American technologies versus other industrialized nations.

The development of coherent policies for all of these areas—national security, foreign policy issues, and economic issues of trade is difficult since:

1. Technology is often misunderstood, particularly the difference between products, science, and technology;
2. Most American technology is privately owned; and
3. Most nations recognize "high" technology industries strongly influence their strategic position and economic development.

Those of us who have devoted their careers to some aspect of product and subsequent market development in technology-intensive industries understand the value of technology and the importance of both nourishing its development and guarding against untimely dissemination. For in technology-intensive industries, economic survival is dependent on timely application of technology to new products in world markets. The sale of technology to third parties not only denies participation in some segment of world markets, but also accelerates the dissemination of technology to new competitors.

Technology, products, and science are misunderstood and confused by most people and the lay media; and it is not uncommon to see the meanings of these three words used interchangeably. The specific design and manufacturing know-how required to produce products is really the issue and it is of major importance. This is what technology is all about.

Technology is not products, and it is not science. Technology is the application of science to the design and manufacturing of goods and producing services.

Technology is the specific know-how to define a product that fulfills a need, and then to design and manufacture it. Technology encompasses the thousands of detailed steps that are necessary to develop and manufacture a product, including the design and development of manufacturing processes and equipment.

As opposed to technology, science is directed to the collection and expansion of knowledge. Scientific information and data is exchanged around the world, and in so doing it adds to man's understanding, Science, alone, does not provide a capability to produce goods or services.

Products are the end result of technology, and are not technology in themselves.

With few exceptions, U.S. technology is owned by the private firms that developed it for the manufacture of commercial products, whether semiconductors, computers, or wide-bodied aircraft. Each firm develops its own specific design and manufacturing know-how, although it may be very similar to that of its competitors. Each firm attempts to protect its know-how through patents or trade secret restrictions, and it is regarded as the proprietary information of the individual firm. Such information consists not only of technical data defining the design and the manufacturing processes for the product, but also the large body of infrastructure information and skills that includes development of product requirements, computer aided design and manufacturing programs, production planning and scheduling programs, quality assurance and testing techniques, and development of specialized process equipment, instrumentation and supplies. Each advance is built upon a corporate experience base that has been accumulated over the corporation's entire history. The expense of translating scientific knowledge into a new manufacturing technology is often ten times greater than the expense of the R&D project itself.

While Federal R&D expenditures have advanced science, particularly in electronics and aerospace, and Federal procurements for weapons and space programs have advanced the translation of this scientific knowledge into products, the underlying design and manufacturing know-how, if there is any potential for commercial applications, has almost always remained the property of individual, private firms. In those instances where Federal programs have not resulted in large spin-offs of commercial products, a major factor often have been overly restrictive patents and "rights and data" clauses which do not provide any protection for the private firm in subsequent applications. In the absence of such protection, there is little incetive to take the risk of applying this technology to commercial products.

TECHNOLOGY SECTORS OF AMERICAN INDUSTRY

The relative importance and understanding of technology varies widely across American industry. Of primary concern to the development of specific national policies are the areas of "high" technology industrial segments. These segments may be characterized by:

A. Rate of technology advances continues to be elastic.

B. Resultant markets grow at rates substantially greater than national averages.

C. Requires substantially greater investment in R&D as well as continual capital investment in manufacturing equipment.

D. Product life cycles are considerably shorter than those of mature industries.

The high technology industry segments are a major contributor to: U.S. foreign exports, growth and development of domestic markets, creation of new jobs, and the superiority of weapon systems for national security. Also, it is principally these segments that have the promise to provide long-term solutions to some of the more pressing national problems. Further, it is also these technology segments that are of greatest interest to international technology transfer issues, whether East-West trade, political demands of less developed countries, or competition among industrial nations.

Of particular interest among these sectors is the electronics industry, and within it, the semiconductor industry. For it is solid-state technology that is the driving force for very low cost logic and memory which is greatly extending the capability of man's mind, and his ability to: communicate, detect and control, and compute and store information. This technology is generating a revolution in all industries and sectors of life, similar to the advent of electric power and low-cost motors, about one hundred years ago.

The American electronics and semiconductor industries are at the leading edge of this technology's development. The importance of this sector is widely recognized throughout the world, and competition among nations for this technology is intense.

DISINCENTIVES: ADVANCEMENT OF TECHNOLOGY

This distinction between "high technology" industry segments and the remainder of American industry is not recognized by various departments and agencies of the U.S. Government, when they solicit industry's viewpoints on proposed regulations. Since the number of more mature companies is much greater than the "high technology" companies, the results are weighed heavily by lesser-technology oriented companies, and the issues of technology impact are neither recognized nor assessed.

A good example of this problem are the Treasury Regulations governing the source of deductions of computing foreign tax credit limitations. One section (1.861–8) of these regulations requires an apportionment of U.S. research and development expense to foreign income. This change will result in a U.S. firm not receiving full U.S. tax credit for research and development expense.

This change in the law penalizes a U.S. firm for making large R&D expenditures in the United States and, in time, will cause these firms

to consider relocation of some R&D activities to foreign countries to avoid double taxation. The net effect is that U.S. tax regulations are providing an incentive to export the development of new technology. This is certainly counter to the national needs and implied priorities of the country.

Before January, 1977, all U.S. R&D expenditures were apportioned against the U.S. firm's foreign source income on the basis of the gross income of the U.S. company. Now, they are apportioned, through a complex formula, on a theoretical "worldwide activities" basis. This requires an amount of U.S. R&D expenditures be apportioned against foreign source income.

In effect, Regulation Sec. 1.861–8 artificially allocates a portion of a U.S. R&D expenditure against foreign source income and reduces the amount of U.S. tax credits that may be deducted for R&D expense. This may result in a decrease in the amount of foreign taxes that a U.S. firm may utilize as a credit against U.S. taxes.

The only solution to avoid this additional taxation is to physically move a portion of R & D activities to those foreign countries producing income. Since some industrialized nations already have substantially lower wages for engineers, the United Kingdom's wage rate, an extreme example, is about 50 percent of U.S. wage rate, there already exists a competitive pressure to shift R & D.

In response to industry's objections to this change, the regulation was modified so that its impact is phased over a three-year period: 50 percent of U.S. R & D is excluded from apportionment in the first year; 40 percent of U.S. R & D is excluded in the second year; and 30 percent of U.S. R & D is excluded in the third year.

Since this section was only one portion of an overall regulation regarding foreign source income, it is believed that most industries were more concerned with other aspects of the regulations, and viewed the above change as a reasonable trade off. This would be particularly true for many mature industries where technology is of secondary concern.

The significance of Section 1.861–8 is not whether it is right or wrong from a tax policy point of view. Rather, the significance is that government agencies have no way of reviewing their regulations in the light of their impact on the development of U.S. technology, in fact, the question of a regulation's impact on technology development does not even appear to be a consideration during the drafting of new regulations. Without an overall technology policy focused on specific issues, government agencies are unable to evaluate whether technology distincentives are offset by other policy considerations.

Similarly, there is no standard against which to measure the effect of other tax regulations such as the investment tax credit and accelerated depreciation for capital expenditures. We know that capital formation manifested as new design and production equipment can accelerate the development of new technology, but our government currently has no way of comparing the value of this technology development against the costs of tax incentives.

The patent laws have traditionally recognized private ownership of technology, and provide a basis for owners to obtain a return on their investment from this technology. Within the past decade, there has been a strong trend for governments, both United States and

foreign, to override private ownership of technology on issues of national policy. As protection of private investment in technology is eroded, less incentive remains to undertake the risks of applying technology to new products and markets, and alternate investments become increasingly attractive. Yet, these same governments demand that private industry assume the initiative and undertake the risks of applying the very technology that has been usurped by the government. It is my contention that government R&D procurement clauses that give the government ownership or control of patents and subsequent licensing are definite barriers to commercial innovations.

For example, in the field of energy, industrial and private concerns, who have developed over the years at private expense an expertise and technological base which is need to provide innovative solutions to the energy problems, are very reluctant to embark on Government-sponsored programs because of these patent clauses. There are many industrial and private concerns which have no investment in the technology and have not developed any particular expertise. For the most part of course, they have no hesitation about taking on Government programs even with these onerous patent provisions—because they have nothing to lose and expect the Government to provide the expertise to make it work. The other side of the coin is, of course, that their potential for contribution is not nearly as great as those industrial concerns who have an established privately funded expertise.

These restrictive patent ownership and control policies are the antithesis of U.S. concept of private ownership and technology.

In addition, there is growing concern for the protection of proprietary technology data and know-how supplied to the Government. Under the practice of the Freedom of Information Act, proprietary information is supplied upon request to competitors. The only recourse available to the owner is to obtain a court injunction, if possible, prior to release of this information.

Some laws, e.g., Environmental Protection Act, Food and Drug Act, Federal Aviation Act, and Government contracts require industry to supply the Government substantially all of the technology relating to the manufacture and/or use of a given product.

It is essential that the Freedom of Information Act be amended to eliminate the gaping loophole which has developed, whereby almost anyone—including the Soviets and Eastern Bloc countries—can obtain information from the Government which is not only competitive sensitive information, but on some occasions, may also have defense military implications.

Another disincentive is the continuance of trade barriers. American technology must have fair and equal access to foreign markets. Too often, our trade policies have been dominated by a "protectionism" climate fostered by segments of mature industries. This is a harmful and disastrous policy to pursue as it leads only to retaliation and a disruption of wide segments of trade.

In those instances when one U.S. firm has made an innovation, it is important that it quickly gain marketshare in the world markets. This is the only meaningful, long-term return on the investment required for the innovation. To pursue a strategy of concentrating on domestic markets, while selling technology to foreign firms for their

markets is a delusion that eventually leads to confrontation with foreign competition in the U.S. market, amid cries for "protectionism." Again, the most effective strategy is participation in world markets, and this requires fair and equal access to these markets.

Over the past 10 decades there has been an increased environment to assess and critique potential technology impact. However, there is a trend among the regulatory agencies for: excessive delays of 2 to 10 years for new technologies; premature standardization; and legislation of solutions rather than prioritization of problems. These delays are of major impact to innovations, which are so dependent upon timeliness in the world markets. Although regulatory agencies have had minimal impact on U.S. electronics industry in the past, the future is not promising and, I fear the timeliness of some new innovations will be lost to American companies due to unnecessary interference by regulatory agencies.

These are the major areas of government disincentives for innovations. Before closing, it is important to address one point regarding government incentives for innovations. There are those in the government who are strongly advocating more government sponsored R&D, and treat this as the only goal. They tend to be input-oriented instead of recognizing that more R&D is not a goal, but a way of traveling. It is the products generated by R&D that create jobs and growth that we seek. This requires incentives for companies to invest in both R&D and the major downstream engineering and manufacturing investments.

More government funds for R&D also imply government control. It means bureaucratic consensus and inertia in the selection of R&D programs instead of entrepreneural insight and market-driven exploration of new areas. The Department of Defense has been more successful with its R&D because it used the products of its research. It is user oriented. Few government technical establishments have this incentive or "final exam."

The advance of American technology is increasingly hampered by tax regulations, regulatory delays, erosion of private ownership of patents, the disclosure of proprietry information to competitors, both domestic and foreign, and trade barriers.

A focus only on increased R&D is not sufficient to advance American technology, as R&D is only one phase of the technology process. Incentives must be provided for downstream costs in engineering and manufacturing investment. It is only these latter investments that produce products and services, produce jobs, and increase trade.

CONTROL OF MILITARY SIGNIFICANT TECHNOLOGY TRANSFERS

In the spring of 1974, not quite five years ago, the Defense Science Board was asked by Department of Defense Research and Engineering to form a task force focusing on the control of technology transfers of military significance. Since then, the international transfer of technology has been a topic of increased attention by the Congress, Executive Branch, and media. These many discussions and articles may be developing a political consensus as a basis for action. However, today, there has not really been any noticeable change in the administration of export control policy.

One of the primary objectives of any policy for American technology of military significance is to maximize the performance of U.S. weapon systems for as long as possible, as compared to the Soviet's weapon systems. There are two principal strategies supporting this objective. First is the continued development and application of new technology to weapon system. This is being pursued, although often impeded by government regulations and bureaucratic delays. The other strategy is the export control of technologies that are critical to U.S. weapon systems. My comments are directed to this later strategy, and in particular focus on the identification and control of critical technologies more so than products as a means of meeting today's challenge of enhancing military capability through technology, while encouraging East-West trade.

There are a number of trends and events that make export control of technology a much more difficult problem today than it was five years ago. Three of the more significant ones are:

1. U.S. foreign policy toward the Soviets has emphasized an increase in commercial trade;

2. Soviets continue to place highest priority on the acquisition of Western technology, particularly electronics and aerospace; and

3. In some fields of militarily significant technologies, such as electronics, applications are now occurring three to five years in advance of military applications. For example, LSI integrated circuits were first applied to handheld calculators in the early 1970's, followed by microprocessors in the mid-1970's which have been applied to a variety of consumer and industrial products. As of today, there has been only minimal application of these LSI integrated circuits to weapon systems. Yet, LSI integrated circuits will have profound impact on electronics for weapon systems of the 1980's and beyond.

Currently, we do not have an effective export control policy that copes with the complexities of our environment and these challenges. Too many proposed technology transfer cases are still considered principally on the basis of commercial specifications of the process equipment while ignoring the accompanying flow of technical data and services. This emphasis on commercial specifications adversely impacts trade by delaying product sales, and does not protect the flow of strategic technologies.

As a consequence of private ownership, the need for controls on the export of technology should be on those commercial trade mechanisms which most effectively "transfer" know-how. The "reverse engineering" of products—engineering dissection and analysis—is not an effective technique for transferring technology.

Commercial product sales rarely include proprietary design and manufacturing information.

There are, however, gray areas. One product category that does transfer some know-how is manufacturing or process equipment. Such equipment usually conveys only the know-how for its point-of-use in the manufacturing system. Manufacturing equipment unique to critical military products, are, thus, also critical items.

Another gray area is large computers. Although they are products and not technology, their application can directly advance design and

manufacturing know-how. For these machines are as much tools for extending technology or know-how as they are end-use products.

The principal mechanisms for the transfer of design and manufacturing know-how are those based upon special and extensive communications by the donor with the objective of teaching specific know-how. Usually, such information and data are provided to the receiver so that he may achieve a stated manufacturing capability within a relatively short period of time. Thus, effective mechanisms for transferring technology to state-controlled enterprises include sales of "turnkey" product technologies, sales of manufacturing and technical data, licenses with extensive teaching, consulting agreement, and the training of technical personnel.

In addition to these formal transfer mechanisms, there are casual and clandestine transfers of technology. Both of these must be guarded against—ranging from the peer conversations with engineers from controlled countries at technical or professional gatherings, to the information disclosed to them during plant visits, and the data included in preliminary proposals and sales briefs to them.

The transfer of technology with all its data bases should be viewed as an element of long-term strategy for the corporation, and not as an opportunistic item of the immediate future. This policy is vigorously pursued by the innovators and leading producers of each industry segment.

Unfortunately, in each industry segment, there are some companies who view their technology as another commodity for sale or who are lax in its protection. These are often the imitators or marginal producers. In either case, the release of technology may significantly hurt not only themselves but their industry in the long run; and, in some instances, the security of the country.

It was with this definition of technology as the really critical issue, and its principal transfer mechanisms as just noted, that a group of senior industrial and government participants in a task force for the Defense Science Board underscored these recommendations:

1. That the emphasis on export controls should be shifted from products to critical technologies. This requires a clearer definition of critical technologies than now exists.

2. That these critical technologies must be defined by the Defense Department based upon:

A. Their use in the more significant weapon systems of present or future;

B. Whether they are principal technology drivers; along with their past rate of advance, and probable future rate of advance;

C. The principal infrastructure of support items for the technology;

D. Their current practice in controlled countries; and

E. Their commercial availability among Western nations.

3. The strategies for implementing control of critical technologies should recognize:

A. That the chief criterion for assessing the impact of a technology transfer is not whether it is obsolete by U.S. standards, but rather the degree to which it would advance an adversary's capabilities;

B. That each technology is time-dependent in its singular value to U.S. weapon systems, and therefore, the criticality of a given technology needs to be periodically reviewed; and

C. That critical products that do remain under control should be controlled on the basis of their intrinsic utility, and not on the basis of commercial specifications, end-use statements, or safeguards.

In addition to the commercial trade mechanisms for transferring technology, similar controls for critical technologies must also be applied to: weapon sales, government-to-government science and technology exchanges, and other non-commercial transfer mechanisms.

The control of critical technologies does not need to be absolute in order to be effective. Their objective is to delay their rapid acquisition by the Soviets and other controlled countries.

Although U.S. export controls and those of its allies have been less effective in the past five years, than in prior decades, they do continue to provide some measurable lead time in the practice of these critical technologies by the United States and its allies, various estimates by research institutions, industry committees, and the intelligence community continue to estimate that lead times are two to ten years for selected technologies.

As is often the case when major policy changes are proposed, objections arise either because there is uncertainty about their implementation, or because of ignorance and distortion of the need for the policy. From industry's viewpoint, a negative reaction to Federal policies affecting trade is biased on past experience. Too often Federal policy changes result in over control and a more negative rather than positive impact on industrial and commercial trade practices.

In this case the uncertainty is further increased due to a lack of specific definitions for critical technologies. This uncertainty will continue to exist until critical technologies are defined and applied to export controls by the Defense Department. Unfortunately, DOD has given minimal support to the administration of export controls over the past five years and other government departments have serious doubts about DOD's ability to carry forward and implement this policy.

The responsibility for refining critical technologies has been assigned to the Research and Advanced Technology Branch of DDR&E. Over the past few years, a start has been made at this task. It is apparent that the resources and priorities of DDR&E are aligned with the strategy of advancing military significant technologies, almost to the exclusion of support for control of critical technology. There is no argument regarding advancement of technology as being first priority. However, resource alignment should be modified so that both strategies can be pursued on a timely basis.

Without controls on the transfer of critical technologies, the effective advancement of military capabilities through R&D programs becomes an almost impossible task, as this new know-how would be transfered to ComeCom countries as quickly as they can purchase it.

Some of the objections cited by those in industry to either the current technology control practices or the Defense Science Board recommendations are:

1. The Department of Defense has too limited a knowledge base of current technology practice in the Eastern Bloc countries as well as in other Western nations; and, therefore, its assumptions regarding uniqueness of some technology items are obsolete. The charge that DOD has too limited a knowledge of current technology practice on both the Soviet Union and Western countries has merit. It can be overcome by assigning adequate intelligence resources to this area, and by interacting with industry in the review and update of critical technology elements.

2. Strategic criteria for control of technology should give recognition to the opportunity for U.S. firms to sell obsolete technology. The rate of the advance of a specific technology is predictable for evolutionary, year-to-year advances. However, revolutionary advances are not predictable, and when these occur they should be protected and weighed versus their impact on receiving nations, in order to maximize lead time. A criteria of obsolesence based on U.S. practice would limit lead time to those of U.S. product life cycles, which is less than 5–7 years for many electronics products.

3. The U.S. control list should not have unilateral listings, as compared to Cocom lists. This practice denies U.S. firms East-West trade, while allowing CoCom partners to capitalize on opportunities. Today, the administration of U.S. controls has the implicit effect of unilateral controls, due to excessive delays, as well as ambiguities in interpretation of list between United States and other CoCom countries. The actual items under control should be based on their criticality to significant weapon systems. At times, when a new technology is unique to the United States, is may be necessary to unilaterally place it on U.S. lists. Otherwise, it is desirable to approach the multilateral lists.

4. The transfer of "high" technology to the Soviets is not a significant problem, since they have limited resources or abilities to adapt technologies to new applications. While Eastern Bloc nations do tend to have serious deficiencies in defining requirements and implementing technologies for their visible commercial sectors, their military sectors are mission oriented, and have high priorities. Although only limited information is known about state-of-the-art technologies for military projects, it is known that these programs do not have the administrative and planning barriers that exist in the commercial sectors.

The analysis of proposed technology transfer is quite different from reviewing a products' commercial specifications. This task has been ineffectively performed. Design and manufacturing technology for the entire system must be evaluated apart from those of its individual components. For a "turnkey" process, the whole is greater than the sum of the individual parts. The capability of the whole system must be evaluated in the context of its industry, and then principal technology drivers need to be examined for their linkages to other military significant products of technologies. I cannot envisage this type of assessment being made effectively without close liaison with "system experts" in the industry affected or end-user industries. The current Critical Technology Evaluation Group initiated at Defense Research & Engineering's request, cannot fulfill this role due to their arm's length

relationship with DOD. They are trade association committees attempting to provide a service to DOD. However, they are too distant and lack DOD sponsorship, thus their effectivity is judged to be minimal. In this current mode of operation, there is too much overlap betwen the Critical Technology Evaluation Groups and Commerce Department's Technical Advisory Committees.

Other objections by individuals in the Federal Government to any change in emphasis of export control policy from products to critical technologies have been:

First, the present controls have been effective in controlling East-West trade, and only fine tuning is needed, rather than a major change;

Second, the principal problem in commercial trade is really West-West to East flow. However, it is not practical for the U.S. to enforce controls on reexportation of technology from either its allies or neutral nation; and

Third, there is no data base to support the control of critical technologies, and since it cannot be quantified and measured, there is no basis for formulating policy.

These arguments ignore the negative impact of present case-by-case reviews with their ambiguities, long delays, and excessive focus on product's commercial specifications, and the resulting low credibility of the process held by segments of industry and some of our allies. This practice is an unnecessary interference in the commercial trade of many products. Without a policy framework, case-by-case reviews based on the precedence of history offer no opportunity to develop a cohesive policy, and a defocused policy is no policy at all.

A clear definition of critical technologies is necessary to win support from our allies. As for neutral nations, if we cannot control reexportation of critical technologies, then there should be serious questions as to why it is transferred to them at all.

As to the last objection cited, not all logical deductions can be quantified, and where it is attempted, the data is often subjective or poorly defined. Therefore the lack of quantitative measures then place greater reliance on the judgment of senior personnel for definition and implementation.

We really do not know how much significant technology has flowed from the United States, let alone the West. We do know that over the past five years the outflow of technology has increased. Some argue the impact of technology transferred has been minimal. My concern is that the transfer of militarily significant technology has been of major proportions, and that the Soviet Union has narrowed the gap in its relative weapons capability with the United States. This change will become more evident unfortuntely, over the next five years.

Improvement in the effectiveness of these controls can only be attained by the United States clearly defining its objectives, implementing them with consistency, and communicating this information to all interested parties. The issue is effectiveness of existing control mechanisms, and not one of more or fewer laws or regulations. In other words, an intelligent approach must be taken toward the control of technology and critical products of military significance. If this can be achieved, then the United States can gain improved support from industry, its allies, and the enforcement agencies.

The challenge that we face is to implement a policy that will allow the U.S. an effective means of meeting two conflicting goals:

1. Enhancement of East-West trade, particularly in "high technology" items. While at the same time
2. Reliance on technology to provide a qualitative advantage for U.S. military systems.

The complexity of today's weapon systems and the rapid dispatch of commerce in high technology goods and services throughout the world will place our national security in jeopardy, unless we can effectively delay the acquisition of critical technologies and key products by the Soviets and her partners. The overwhelming consideration in controlling technology transfers must be U.S. national security.

This position is consistent with the national policies and need of the U.S.—only if the bureaucrats curb their appetite for controls—and really limit them to truly critical technologies of commercial trade.

Otherwise, the morass of red tape controls will force on this country the undesirable alternative of abandoning all controls on commercial trade. There are indications that the Congress, under justifiable pressures from their constituents—is moving in this direction, at least in regard to national security issues.

Philosophically, the response by individuals in the Executive Branch and industry to this proposed policy implementation encompasses two different time horizons and emphasize a divergence of viewpoints. Federal policy change and its implementation is approached by individuals in the executive Branch as a gradual and long-term adjustment—while industry is faced with near-term decisions and actions regarding commercial trade and national security issues. The former viewpoint is inconsistent with the changes that have taken place in the technology transfer environment.

The immediate task requires a realistic identification of critical technologies by DDR & E and the implementation of strategies for effectively controlling them by the United States and its allies. The resultant shift of export control emphasis from ambiguous reviews of a product's commercial specifications to the control of critical technologies has the potential to accelerate reviews and release a number of products for commercial trade.

As the private sector recognizes that the only adequate payment for "high" technology is market share derived from the long-term sale of products in world markets and that technology is basic to long-term strategies of the corporation, then this technology will be more effectively protected by its owners.

However, there remains a need for export controls of critical technologies, for I see no other answer to controlling the sale of such know-how by a marginal producer in a military segment.

CONCLUSION

In order to enhance and protect this national resource—and that is the perspective in which technology must be weighed—the nation needs both an enlightened view of its importance among the private and public sectors, and a sharply focused national policy limited to those technology segments of principal concern. The development of such a policy should have as its primary objective a set of clearly defined

goals. It must also have strategies for assessing current and proposed laws and regulations that impact technology, and for recommending changes to minimize inconsistencies.

The many disincentives to the advancement of American technology introduced by U.S. government statutes and regulations must be greatly reduced. If this is done, then the private sector can effectively regain momentum in providing jobs, expanding trade, and enhancing national security.

Proposed transfer of technology that significantly impacts national security must be effectively assessed and controlled; concurrent with less interference in the trade of products between East and West. The implementation of this policy shift can be made within existing statutes.

Policies for U.S. technology must not be allowed to become the rallying point for a whole new set of laws and regulations that would result in more Federal interference in the development of technology by private enterprises.

Instead, this policy should place in perspective the vital contribution of technology to the security and economic development of the United States, and recognize that technology is most effectively advanced through private ownership.

RESOURCES AND ENERGY

ENERGY SYSTEMS AND TECHNOLOGY DEVELOPMENT

DR. ROBERT C. SEAMANS, JR.

DEAN OF ENGINEERING, MASSACHUSETTS INSTITUTE OF TECHNOLOGY,
CAMBRIDGE, MASSACHUSETTS

INTRODUCTION

Severe fuel shortages existed in the United States during the oil embargo of 1973–74 and local shortages, mostly of natural gas, occurred more recently due to severe weather conditions in the winters of 1977 and 1978. But today, there is a surplus of oil in California and other west coast states due to Alaskan oil and in part as a consequence the United States has not adopted a national energy policy. It is my judgment that the United States needs a sound energy policy to promote conservation and to develop alternate energy sources. I believe there is only a short time to convert to new energy forms and more efficient energy consumption and that extensive research and development will be required in the process.

I find my own views closely aligned with the results of a recent comprehensive investigation which was called the "Workshop on Alternative Energy Strategies." There were participants from fifteen nations in the workshop. They concluded that the supply of oil could not satisfy world demand beyond the 1980's even if Saudi Arabia doubles its present production and it is not clear that it is in Saudi Arabia's best interest to continually increase its production rate. Admittedly, no one can be certain that cataclysmic events are going to occur in 10–15 years, but even today there is a clear redistribution of wealth taking place. We in the United States paid forty-five billion dollars last year for oil, much of this from the Middle East. Important questions arise as to the long term effect of such sizable payments both on the United States and on the world economy. Some argue that the decline in the value of the dollar is not related to this imbalance in United States world payments, but for my own part I feel that there is a definite relationship between the value of our currency and the imbalance in world trade created by our large purchases of oil.

In my discussion of energy systems and technological development I am going to discuss primarily systems used in the United States, in part of course because of my familiarity with these systems and in part because U.S. energy policy is receiving worldwide attention. Only this morning I read in the Athens News an article headlined, "Plight of Carter's Energy Proposal Causing Worry." The energy systems that are used in the United States as in all industrial nations, are complex with many interconnections between delivery systems and consumers. The first chart, Figure 1, is a functional diagram showing both the energy delivery systems and the energy consuming systems.

ENERGY DELIVERY

The basic inputs to the delivery systems include today's existing fuels, nuclear, hydro-electric, coal, oil and gas, and new possibilities, solar, shale oil and geothermal. The latter three are not extensively used today, but have promise in the relatively near term. There are three other potential energy resources, but it is not believed that any of these will have a major impact until after the year 2000. These are the nuclear breeder, fusion and solar electric. Prior to delivery to the consumer, the energy resource must be collected, converted, and transported. Some of the facilities needed for this process are shown in the diagram including mines, nuclear enrichment plants, electric generators, refineries, synthetic fuel plants, transmission lines, and fuel transportation systems. The consumer may use coal, oil and gas directly or electricity from nuclear, fossil, or hydro-electric generating plants. In the future synthetic fuels may be derived from shale oil, coal, or biomass. Energy must be delivered to the point of end use for transportation, residential and commercial buildings, and industry.

TRANSPORTATION

Transportation systems include highway traffic (automobiles, trucks and buses), trains, ships, aircraft and pipelines. With the exception of small amounts of electricity used by the railroads and metropolitan subways, transportation is fueled by oil. Transportation systems use 25 percent of our energy raw material and 31 percent of the energy actually delivered to the consumer. Since there is a relatively small energy loss in refining crude oil, the percentage of energy delivered to the transportation systems is greater than the percentage of total energy input for transportation. Transportation serves passengers and freight and its end use can be measured in passenger miles and ton miles.

RESIDENTIAL AND COMMERCIAL BUILDINGS

The next major category of energy consumption includes both residential and commercial buildings. Within each building there are space and hot water heaters, lights, and often extensive capacity for ventilation, and air conditioning. In residential buildings there will be stoves and other kitchen accessories, and all high rise buildings must have elevators. There are about 75 million buildings in the United States and the services they provide are varied, but the energy requirements can be related to the number of residential units and the square feet of commercial space. Approximately 33 percent of the total energy input to the United States is for the residential and commercial sector, but the actual energy delivery is only 27 percent of the total. The reason for the difference is that much of the energy comes in the form of electricity and there is a loss of 66 percent in the generation of electricity.

INDUSTRY

There are many different industries in the United States. The heavy energy users are aluminum, iron, steel, pulp and paper, and petrochemical. In the case of the petrochemical, the energy requirements

include the use of oil and gas as feed stock. Agriculture and food processing are other heavy users. Total energy use amounts to 42 percent of the U.S. total. In most cases, the industrial output can be measured in terms of product quantity, i.e., tons of steel, barrels of alcohol, cubic feet of paper, etc.

U.S. ENERGY REQUIREMENTS

In this paper I will attempt to address the question of whether the United States has the correct energy delivery and end use systems and, if not, what is required in the future and what new technologies should be developed. For the purposes of this paper, I am basing my estimates on the year 2000. Table 1 shows the U.S. consumer requirements for energy in quads. Quads are a measure of energy in quadrillions of British Thermal Units (10^{15} BTU). For those not familiar with quads, there is a ready conversion to equivalent barrels of oil; two quads per year is nearly equal to one million barrels per day. From Table 1 it can be seen that in 1976 the United States consumed 54 quads of energy at the point of end use. Although not shown in the table, it should be noted that U.S. production sources supplied only 40 of the 54 quads. The remaining 14 quads were imported primarily in the form of oil. It is difficult to estimate with assurance the future energy growth rate. Energy use has been recently growing in the United States at an annual rate between 4½ and 5 percent. Many feel that this is excessive and that we must find ways to decrease our growth rate drastically. In this paper I am selecting an over-all growth rate slightly in excess of 2 percent. Even this modest rate of growth clearly demonstrates the seriousness of our energy situation.

TABLE 1—U.S. CONSUMER REQUIREMENT FOR ENERGY

[In quads]

Consumers	1976	2000		
		2+ percent growth	Potential improvement in efficiency	With major conservation
Transportation	16.5	31.8	10.2	21.6
Residential and commercial sector	14.9	23.9	6.6	17.3
Industry	22.6	38.5	8.8	29.7
Total	54.0	94.2	25.6	68.6

Specific areas will be over or under 2 percent depending upon particular consumer needs. The future growth rate for air transportations is assumed to be 4 percent per year, compared to the current level of 7 percent. All other forms of transportation are assumed to grow at 2 percent per year leading to an increase in quad requirements for transportation from 16.5 to 31.8 by the year 2000. In the case of the residential and commercial sector it is assumed that the residential will grow at 1.5 percent per year, commercial at 2.2 percent per year. Since residential building account for approximately 60 percent of the energy that is used in this sector, the 1976 energy requirement of 14.9 quads becomes 23.9 in the year 2000. A growth of 4 percent per year is assumed in the aluminum industry, 2.8 percent per year

is assumed in the petrochemical industry, and all other industries are assumed to grow at 2 percent per year. These assumptions lead to an industrial energy requirement of 38.5 quads in the year 2000. A summation of the three major categories of energy use then gives a total annual requirement for energy in the United States of 94.2 quads by the year 2000, requiring an increase of 40 quads (20 million barrels of oil equivalent per day). Clearly, even with a modest energy growth of 2 percent, it is essential that ways be found to use energy more efficiently. It is believed possible to make substantial savings in energy use without at the same time reducing in any major way the services rendered.

CONSERVATION IN TRANSPORTATION

Improvements can be made in our automobiles by making them lighter and by providing more efficient propulsion. Automobiles used in the United States in 1976 were heavier by 50 percent than the models used in Europe. It appears that it will be possible by the year 2000 to have a fleet of cars that obtain 30 to 32 miles per gallon on the average compared to the present fleet average of 18 mpg. If it is assumed that all other forms of transportation can be improved by 20 percent, the savings in the year 2000 will amount to 10.2 quads so that the amount of energy delivered to the transportation system in the year 2000 can be 21.6 quads as compared with 31.8 quads based on present day efficiencies.

CONSERVATION IN RESIDENTIAL AND COMMERCIAL BUILDINGS

It is assumed in these estimates that major improvements can be made in the residential and commercial sector. Of course it is easier to make energy savings in new construction than by remodeling. As a consequence, it is assumed that on the average all existing buildings, both residential and commercial, will be improved by 20 percent in the year 2000 and all new buildings will be 40 percent more efficient than contemporary structures. On this basis a saving of 6.6 quads is obtained and the requirement for energy delivered to the residential and commercial sector becomes 17.3 in the year 2000.

CONSERVATION IN INDUSTRY

It is difficult to generalize savings that can be realized in industry since many efficiencies are peculiar to a given type of industry. However, heat is used in many industrial processes and if liberal use of heat recuperators is assumed and savings are made in recycling waste, it is possible that an over-all saving of 20–25 percent can be made by the year 2000. It should be noted that in the United States industry has already made substantial savings. Energy costs industry increased dollars since the price of oil quadrupled in 1974, and for that reason industrial investment has been made for energy conservation in the desire to improve profits. A 23 percent reduction in industrial use of energy by 2000 leads to a reduction in over-all energy use by industry from 38.5 to 29.7 quads.

TOTAL ENERGY REQUIREMENTS WITH CONSERVATION

The total requirement for energy in 2000 becomes 68.6 quads with major conservation in each of the energy categories. This energy level amounts to a one percent per year growth requirement for energy during the last quarter of the century. As already noted, the U.S. imported 14 quads of its energy in 1976. If, as a matter of policy, the United States is to become independent of foreign sources, the growth in domestic production of energy would amount to 28.6 quads, i.e., the difference between the 68.6 required in the year 2000, and the present level of domestic production, 40 quads. It can fairly be asked whether a 70 percent increase over today's domestic production can be achieved in a 24-year period. The increase is most likely to occur from an expansion in the use of existing fuels since the technology is well developed and the infrastructure already exists for its supply and use. In the next section of the paper, there is a brief discussion of the status and potential of existing fuels.

U.S. OIL SUPPLY

If we look at oil production in the United States from 1920 to the present it can be seen that annual production grew steadily for 50 years, and reached a peak in the early 1970's. Since then production has dropped by 15 per cent. U.S. consumption of oil has continued to increase in the 70's and for that reason the United States is now importing between 40 and 45 per cent of the oil that is consumed. It should be emphasized that the domestic supply of oil is not about to run out, but it is becoming increasingly expensive. The chart shows that in the future our present wells can be expected to produce less and that new oil fields must be developed if production is to be sustained.

The principal new field that has come on line recently is northern Alaska at Prudhoe Bay. In order to realize production levels of roughly 1½ million barrels per day, i.e., 3 quads per year, a private investment of 12 to 13 billion was required. If oil is discovered off the Atlantic Coast, it will similarly be more expensive to produce than in the past. Whether off shore or on the mainland, it used to be sufficient to drill wells from 8 to 10 thousand feet, now in order to find oil, exploration is required at depths of 20 to 25 thousand feet, thereby increasing costs. There is under development new technology for recovering greater amounts of oil from existing and new fields; however, it has yet to be shown how successful these techniques will prove to be. Based on these factors, it appears that U.S. oil production can probably continue at the present level for the next 25 years, but is unlikely to increase.

U.S. NATURAL GAS SUPPLY

The history of natural gas use and future estimates are similar to the pattern of oil. The use of gas, however, did not start in a major way until after World War II. Initially, gas was felt to be a nuisance and was flared at the well head. It was later recognized that natural gas was an ideal fuel that burned cleanly and could be delivered at low cost. A large network of pipelines has been installed throughout the United States and natural gas is used extensively in commercial and

residential buildings, in industry, and in the generation of electricity. Gas production will benefit from the Alaskan fields when a new trans-Canada pipeline is completed.

Future production of gas depends upon the discovery of new fields and, in addition, the possibility for enhanced recovery from existing and new fields. As in the case of oil, it is plausible, but somewhat optimistic, to assume constant annual gas production for the remainder of the century.

U.S. COAL SUPPLY

We are fortunate to have in the United States nearly a third of the known world coal reserves. In the early part of this century coal supplied nearly 80 percent of our energy and in absolute terms was mined at about the same tonnage as today. It is fair to ask why the use of coal did not grow substantially since the United States has such large deposits. The answer is that it is difficult and expensive to mine and transport coal. It is also difficult to burn coal efficiently without emitting sulphur and nitgoren oxides and other harmful substances. After burning, there are large quantities of fly ash requiring disposal. Hence, it is necessary to introduce stack scrubbers or use different methods of combustion than have been used in the past in order to maintain environmental standards and this, of course, increases the cost.

The Carter administration have as part of their energy program recommended a near doubling of coal production by the year 1985. This goal appears most unlikely; as a matter of fact, in the last year coal production has remained essentially constant. However, for the purposes of this paper, it is assumed that coal production can be tripled by the year 200. This represents a major endeavor for the United States and involves heavy investment in mining equipment and transportation systems, whether train, slurry pipe or ship, as well as a major commitment on the part of the consumers to provide facilities for using the coal.

USE OF FISSION REACTORS

Nuclear energy was proclaimed an unlimited resource in years past. Today many question the desirability of its use and much controversy surrounds the safety and environmental consequences of nuclear fuel cycle. There are 70 nuclear plants in operation today in the United States and all have operated safely with no adverse consequences. An expansion of the U.S. nuclear capacity is taking place. There are 90 plants under construction and 50 additional plants are planned and are in preliminary design. However, the ultimate growth in the use of nuclear energy is still in question. The issues rest not so much on the plants, themselves, as on the front and the back end of the nuclear fuel cycle.

Uranium, when mined, contains U_{238} and seven-tenths of 1 percent U_{235}, which must be enriched to 3 or 4 percent to operate present light water reactors. Nuclear enrichment plants exists in three locations in the United States. Additional enrichment plants, matched by increased mining capacity, is required for the growth of the nuclear industry. In addition, policies and plans for handling the spent fuel must be established. Spent fuel contains unused U_{235} and plutonium converted in the reactor from U_{238}. Both the U_{235} and the plutonium can

be reclaimed by known processing technology and can then be recycled as reactor fuel. Whether the spent fuel is reprocessed or not, provision must be made to take care of the nuclear waste. Plutonium is weapon material and nuclear waste could adversely affect the environment. The Carter administration is currently reviewing alternatives for nuclear reprocessing and storage of spent fuel. Assuming that nuclear fuel cycle issues can be adequately resolved, three hundred additional nuclear plants could be available and in operation by the year 2000. These 300 include 90 already under construction, and represent a five fold increase in the number of plants. Since the newer generating stations operate at higher power levels, the electrical output would be roughly ten times the present nuclear generating capacity.

HYDRO-ELECTRIC

Hydro-electric is often times lumped with solar energy since the flow of water in our rivers depends on solar heating, evaporation, and recirculation of water vapor in the form of rain. A variety of environmental issues have plagued the expansion of hydro-electric power. Recent examples include the Teleco Dam, on the Little Tennessee River. This dam has been completed at a cost of over 100 million dollars and is ready for operation. However, it appears that its operation will endanger a small fish called the snail darter, thereby contravening existing congressional legislation. Whether or not the dam will be allowed to go into operation is currently under debate in the U. S. Congress.

A large complex of hydro-electric plants and dams have been considered for the State of Maine and again the question arises as to whether such a system will destroy endangered flora and fauna. As a consequence, the construction of this hydro electric system is being delayed by environmental considerations and may be suspended. Hydro-electric capacity cannot be increased without forming large artificial lakes that may encroach on agricultural and forest land. Consequently, it is assumed in this paper that hydro-electric capacity will grow modestly (20 to 30 percent) during the next 25 years.

ESTIMATED ENERGY BALANCE

The measure that I have just discussed for increasing the U.S. supply of energy will provide 68.6 quads by the year 2000, and it might then be assumed that energy issues can be resolved by taking the strenuous measures discussed in this paper both for energy conservation and production. Unfortunately, this is not the case. It is not only necessary to have the right total quantity of energy, but also to have it in the appropriate form. Table 2 breaks out the energy requirements for the three principal consumers in terms of electricity, coal, oil and gas, and shows that by the year 2000 there is an excess of electricity, coal, and gas and a major deficiency in the quantity of oil even though the total requirement for 68.6 quads is met. The oil deficiency of 21.2 quads is greater than our present import of 14 quads and if this deficiency were to be resolved by increasing imports, assuming that the oil were available, it would represent an additional 22 billion dollars per year in foreign payments. Clearly this is unacceptable and the question arises as to how to bring energy supply and demand into balance for each type of fuel.

TABLE 2—U.S. CONSUMER REQUIREMENT FOR ENERGY WITH MAJOR CONSERVATION YEAR 2000

[In quads]

	Electrical	Coal	Oil	Gas
Consumers:				
Transportation	0.2	----------	21.4	----------
Residential and commercial sector	4.9	----------	4.2	8.2
Industry	4.6	5.8	12.0	7.2
Requirement	9.7	5.8	37.6	15.4
Availability [1]	13.6	20.1	16.4	18.5
Excess (deficiency)	3.9	14.3	(21.2)	3.1

[1] Assuming: Coal—production up 1300×10^6 t; oil and gas—no imports, domestic production constant; hydro—modest increase; nuclear—300 new plants.

There is insufficient data available today to provide a recommended plan for bringing about this rebalancing. However, it is possible to indicate some broad areas that need extensive development effort at this time so that decisions can be made in the future on the introduction of new technology.

SYNTHETIC FUEL

It can be seen from Table 2 that a tripling of coal production leads to a great excess of coal compared to the amount required. The Germans in World War II kept their industry and the military services in operation for several years by using synthetic fuel derived from supply of coal. The same technology for coal gasification and liquefaction could be used today; however, the cost even in today's marketplace is too high. A variety of pilot plants for low and high BTU gasification and for liquefaction are undergoing tests at this time. In addition, a design competition has been initiated for a solvent refined coal plant that, if successful, would provide a synthetic fuel in the form most needed.

Synthetic fuel can also be derived from oil shale that exists in large quantity in the U. S., particularly in the Rocky Mountain States. At temperatures of 900 to 1000 degrees Fahrenheit a kerogen is formed from shale that in many ways is similar to oil. Extensive testing has shown that this fuel can be used for transportation and all other uses for which we are currently utilizing oil.

Full scale commercial plants, whether utilizing coal or shale, are expected to deliver 40 to 50 thousand barrels per day of synthetic oil or equivalent. Today these plants are projected to cost on the order of 1 billion dollars. However, in view of the magnitude of U.S. oil deficiencies and of increasing needs for oil in the future, the generation of synthetic fuels should receive increasing emphasis in the next 25 years.

CONSUMER SUBSTITUTION

It should be noted from Table 2, possibly with some surprise, that there is an excess of gas postulated in the year 2000. In the analysis that led to the results shown in Table 2, it was assumed that neither oil, nor gas, would be used in the year 2000 as an energy source in electrical generating plants. All electric generators were assumed to utilize either coal, nuclear, or water power. Under these assumptions it might be questioned whether there is need for coal gasification plants.

However, if gas, whether natural or synthetic, could be more available, the gas could be substituted for oil to heat residential and commercial buildings, to provide heat for industrial processing and as feed stock in the petrochemical industry.

The largest U.S. energy demand on oil is in transportation systems. More than 50 percent of U.S. oil consumption will be needed to satisfy U.S. transportation needs even after major improvements have been made in redesigning the systems to improve energy efficiency. The question then arises whether transportation systems can utilize electricity or other forms of energy. It is difficult and costly to construct subways in our major cities, but as in the case of the Metro in Washington, D.C., electrified public transportation does reduce the amount of gasoline used in certain areas. However, there is a limit to the savings that can be realized by this means. The cost estimate for the D.C. Metro system has tripled and is now 8 billion dollars and it is expected that less than one-third of the commuters will utilize the system. An alternative that provides greater personal flexibility is is an electric car. An electric car can be recharged at night and can provide access to work areas or to shopping centers within a limited range. Today such cars can only travel 30 to 40 miles, but with major battery improvements this form of transportation might provide the answer to urban travel and it would be pollution free, an important added benefit.

Solar heating can substitute for oil in residential and commercial buildings. At present there are a few thousand demonstration units that utilize solar energy, either for hot water heating or for the partial heating of the buildings themselves. Solar heating today is expensive and is only economically attractive in comparison with electric heating, and of course it is oil, not electricity, that needs to be replaced. The use of solar heat depends on latitude and the percentage of annual cloud cover. It appears that for average conditions, 10 to 15 million solar houses might reduce the need for other forms of energy by about 1 quad. How much of this might be oil is problematical. Even though this is not a large saving, it is anticipated that solar heating will come into wide use throughout the United States during the next 20 to 25 years, especially for hot water. Other forms of solar energy, for example, generators driven by the wind or generators based on ocean thermal gradients will only provide energy in limited quantity by the year 2000.

CONSERVATION-IN-THE-LARGE

There remains one other broad area for reducing an oil deficiency, namely, the use of large scale energy systems for improvement in energy efficiency. The interrelationship between transportation, residential and commercial buildings and industry must be considered in community development and that is the purpose of this conference. By proper planning, more public transportation can be made available and commuting distances can be minimized. Generators can be used for developing both electricity and heat. Waste can be recycled and industrial parks can be built where the exhaust heat from one plant can be the input to another.

In the United States the solid waste generated annually is prodigious, amounting to over one billion tons. One quarter of the waste is

municipal including sewage, the remainder is industrial (10 percent), agricultural (35 percent), forest (5 percent) and animal waste (25 percent). Means can be found for converting this waste into appropriate forms of energy or in the case of metals or glass for recycling the material. Biological means exist for converting agricultural and forest waste, sewage, and manure into synthetic fuels.

Waste also occurs when the utilities generate electricity or when process heat is developed in industry. It is possible to provide a common generator for electricity and heat. Excess heat from the utility plants must now be dissipated, often creating environmental problems. This heat in the form of hot water or steam can be piped throughout a community for heating of buildings. Functionally the way such district heating might take place is with most of the formerly waste heat used for community services, and with industrial cogeneration; namely, the conversion of fuel to process heat for manufacturing and at the same time the generation of electricity. Some of the electricity may prove to be excess and can then be supplied to the utility grid. A wide variety of environmental and institutional problems exist if cogeneration is to be used widely. This is a technology that should be studied extensively in connection with community development.

In an industrial park with various types of industry, each requires energy at different temperature levels. The waste energy from aluminum remelting might be used for glass remelting, and its waste, in turn, for paper manufacturing. The waste from paper manufacturing can be used for either paint finishing or baking bread. Of course, production levels depend on the quantity of energy supplied and, hence, the production schedule of each plant is dependent on all the others if maximum efficiencies are to be obtained. Extensive study of particular plants would be required prior to incorporation in an industrial park and the actual integration of plant operations would then need some form of energy control center.

Community planning and development is an area that must receive increasing emphasis in the years ahead. Obviously, it is much easier to build more efficient community systems anew as will be the case in Sakia, Crete, but the planning for new communities can be adapted to a lesser extent into existing communities. I commend the planners of this conference for bringing greater attention to bear in this important area. Our energy supply and demand will not be brought into proper balance just by using our present systems more efficiently or by developing greater quantities of existing fuels, even though such steps are essential. New technologies are also required for synthetic fuels, fuel substitutes, and for improving energy through large scale community developments.

SUMMARY

In summary, this paper shows that even when the annual growth of U.S. consumer needs is reduced from 5 to 2 percent and even when major conservation efforts reduce the delivered energy from 2 percent to 1 percent per year, that the United States requires a 70 percent increase in energy production by the end of the century if oil imports are eliminated. Even when the use of existing fuels is increased to the maximum extent practical, there is still a requirement for a 50 percent

increase in imported oil, clearly an unsatisfactory condition. The United States must reduce its end use demands, it must make major conservation efforts, it must increase its use of present fuels, but that is not enough. New technologies are needed for synthetic fuels, electric cars, solar heating, solid waste recycling, and cogeneration. In addition, residential and industrial communities of the future must be planned differently in order to find ways for improving energy efficiency on a large scale. The research, development, and capital investment will require tremendous manpower and resource outlays.

Time is not on our side. In the United States, it took 60 years to go from a primarily wood burning society to a coal burning society, and another 60 years to convert from coal to oil and gas. We do not have 60 years to make the next transition. I believe that if we pursue the avenues that I have outlined in this paper that the future will not be exactly as we visualize it today, but it will be possible to provide the energy resources for a dynamic, healthy society and a stable world community.

ENERGY AND JOBS

DR. BARRY COMMONER

DIRECTOR, CENTER FOR THE BIOLOGY OF NATURAL SYSTEMS,
WASHINGTON UNIVERSITY, ST LOUIS, MISSOURI

The only way to meet the fundamental needs of labour—to reduce unemployment and inflation and reverse the present economic decline—is to adopt a policy that would at the same time make sense out of the energy crisis and reduce pollution. The reverse is also true: the only sound energy and environmental policy—a policy that can best give the nation a stable energy supply and a clean environment—is one that serves these needs of labour.

The place where labour works, where energy is produced and used, and where most environmental problems are created, is the same: the productive enterprise—the mine, the factory, the farm. This means that the relation between the availability of jobs, the production and use of energy and impact on the environment depends on how these productive enterprises are designed and operated—more generally, on the technology of production.

What labour requires from this system is that it should operate at its highest possible capacity; that it should provide, for all who can work, decent jobs at decent pay, in conditions that protect safety and health; that the goods which it produces should be sold at prices that labour can afford; that inflation, which erodes the standard of living, should be controlled; that labour should be free to organize and to take part in the decisions which affect its welfare.

The prices of goods that are particularly dependent on energy are hardest hit by inflation. Unfortunately, these energy-intensive goods include housing (which depends on the cost of fuel and electricity), clothing (most of which is now made from petroleum-based synthetic fabrics) and food (which now heavily depends on fertilizers and pesticides, chemicals made out of petroleum and natural gas). This puts a particularly heavy burden on the poor. In the United States, the poorest fifth of all families use about 25 percent of their budget to buy such energy-intensive items; the wealthiest fifth of the families use only five percent of their budget for this purpose. When the price of energy rises the poor suffer most.

Inescapably, whenever the limited supply of non-renewable fuel is sufficiently depleted, its price begins to rise exponentially—that is, the higher the price, the faster the price increases. (In the case of oil this is sometimes blamed on OPEC and the Arab states' embargo. But in fact two years *before the embargo*, the OPEC oil ministers got their cue from a massive and detailed report published by the U.S. National Petroleum Council. The NPC—which should know, since it is composed of the officers of the U.S. oil companies—predicted that the price

of domestic U.S. oil, which had been essentially constant for the previous 25-30 years, would, beginning in 1972-73, need to rise exponentially if the oil companies were to maintain their rate of return on investment. The OPEC oil ministers believed their American colleagues and took steps to see that they were not left behind.)

Each of the different ways of producing energy also has its own particular demand for labour. For example, in 1973 for every unit of energy yielded (trillion BTUs), oil and natural gas extraction created six jobs; strip mining, six jobs; deep coal mining, 18 jobs. As a result of these differences, and differences in capital productivity, the same amount of capital invested in different ways of producing energy can have very different effects on unemployment.

The impact of different forms of energy production on working conditions and on the general environment also vary a great deal. The physical danger of work in coal mines and the risk of diseases such as black lung are well known. In the nuclear power industry, uranium miners are exposed to particular high risks of radiation-induced cancer. The risks of radiation to other workers in the industry are still poorly understood, but some recent studies suggest that they may be higher than most earlier estimates. Shale oil production and conversion of coal to synthetic fuels produce highly carcinogenic substances; workers in a pilot coal conversion plant operated in West Virginia in the 1960s suffered 16–37 times the incidence of skin cancer as comparable workers in different jobs. There may be similar problems in tar sands operations.

The environmental impact of different energy sources closely parallels their impact on the workers' health. Coal mining, shale oil and tar sands oil production devastate the land and use large amounts of scarce water. Coal conversion operations are heavy polluters of the air. Coal-burning power plants pollute the air with nitrogen oxides, sulfur dioxides and carcinogens. The nuclear power industry has yet to solve its serious environmental problems, such as safe disposal of radioactive wastes.

Let us compare the productivities of two industries which produce competing material: leather products and the chemical industry which produces the plastics that have so heavily replaced leather and other natural materials. Of the two industries, leather production is about 4.5 times more efficient in converting capital into value added, and nearly 13 times more efficient in its use of energy. This relationship between capital and energy productivity is quite general among different industries. Five industries, petroleum products, chemicals, stone, clay and glass products, primary metals and paper, account for about 59 percent of electricity and 77 percent of the total energy used in manufacturing. They also have the lowest capital and energy productivities of all major sectors of manufacturing.

Another important feature of the relation betwen energy and the economic system is that—strange as it may seem in the light of supposed economic principles—capital and energy tend to flow toward those enterprises that use them least efficiently. Capital used in industrial production flows heavily toward those sectors which are low in both energy productivity and capital productivity. For example, the five industries cited earlier that use energy and capital least efficiently use nearly one-half of the capital invested in all manufacturing indus-

tries. In contrast, the seven most energy-efficient industries (such as leather production) use only seven per cent of the capital invested in manufacturing.

Industries which use energy inefficiently also use capital inefficiently; they also pollute the environment most heavily and are often least effective in creating jobs. In sum, the same economic tendencies—the displacement of labour by energy-driven machines—that have worsened employment carry a good deal of the responsibility for the energy crisis and the environmental crisis. The crisis in employment, energy, and the environment are, in this sense, the same crisis.

SOLAR ENERGY, ECONOMICALLY COMPETITIVE

For most methods of using solar energy the technology is already in hand, and can be introduced at once in most parts of the country, for a wide variety of uses, at economically competitive costs. . . . The most important thing about solar energy is that unlike conventional energy sources it will stabilize the price of energy, slow inflation and improve investment planning; it will create rather than destroy jobs; it can turn the country's faltering economy around. It can give us a real energy plan that solves the energy crisis rather than making it worse—the kind of energy plan that meets the needs of labour.

Unlike oil, natural gas, coal or uranium, solar energy is renewable; it will never run out (or at least not in the next few billion years). Because solar energy is renewable, it is not subject to diminishing returns—which means that its price, instead of escalating like the price of present energy sources, will be stable and even fall as the cost of devices continues to decline. By stabilizing the price of energy, solar energy reduces the threat of inflation and eases the task of planning investments in new productive enterprises, thus relieving two of today's worst economic problems.

Second, the use of solar energy does not depend on any single technique. There are different sources of solar energy, some forms more available in one place and other forms in other places. . . . Of course, the amount of sunshine varies from place to place, but not as much as most people think. The sunniest place in the United States, the Southwest, gets only twice as much sunshine as the least sunny place, the Northwest.

The most important aspect of solar energy would be its effect on employment and economic recovery, but solar energy has another unique feature—it has no economy of scale.

In conventional energy production the large economy of scale means that only very large corporations can compete (that explains why the energy corporations are such big ones). In solar energy production a small or middle-sized company (or a household) can do as well as a corporate giant. As a result, huge, centralized solar installations are unneeded. The power can be produced on a scale that matches its use, where it is used, thus eliminating the need for heavy transmission systems (although light ones will be useful to balance out production and demand). It is easy to see that the introduction of solar energy would

mean a rebuilding of not only one system of energy production, but also many of the ways in which energy is used in manufacturing, agriculture and transportation. This would mean a vast programme of new construction; it would create new jobs, and in doing so begin to control inflation.

When compared with alternative ways of producing the needed energy it becomes clear that nuclear power is not the best way to sustain the economy and to provide jobs. Here is a concrete example: The Fiat Company, in Italy, has just announced the availability of a cogeneration unit ("TOTEM") which uses natural gas, or methane produced from a solar source, to drive a converted gasoline engine, producing electricity and recapturing the normally wasted heat as a source of space heat. About 67,000 TOTEM units would produce a total of about 1,000 megawatts of power—the capacity of a typical U.S. nuclear power plant. However, whereas the nuclear plant would cost about $1 billion, the TOTEM units would cost only $191 million, and they would produce electricity at about one-fourth of the cost of electricity from the nuclear plant.

If labour is to win its fight for jobs, for reasonable prices, for decent working conditions and for a strong economy, it must accept the responsibility of deciding, for itself, which forms of energy and which ways of using it will best sustain these aims. Up to now these decisions have not been made by labour, but by management. And now that management's choices—for nonrenewable sources such as oil and capital-intensive sources such as nuclear power, rather than the solar alternative—have precipitated the energy crisis, the decisions are being made by government executives and legislators.

Labour and the nation need an approach which permits rational planning of the development, testing and introduction of solar technologies in keeping with their efficacy in the overall process of transition rather than on the basis of the narrow criterion of profitability. This approach would, of course, challenge the widely fostered notion that private profit is the sole acceptable basis for new productive investments. But this has happened before, in connection with the development of energy resources—notably in the development of hydro-electric projects, in particular the Tennessee Valley Authority, rural electrification and most recently nuclear power. In each case the creation of the system required public initiative and at least the initial investment of public funds.

An independent labour position on energy could provide a powerful remedy for some of the serious economic difficulties in U.S. and Canadian industry. Many industries—auto, steel, textiles, shoes and electronics—are being forced to cut back because they cannot compete with imports. These industries face the enormously difficult job of overcoming the economic advantages of foreign producers, achieved by their more modern productive facilities, in order to regain their share of the market. Meanwhile, plants close and people are thrown out of work. From what has been said earlier it should be evident that to cope with the energy crisis all industrial countries will need to develop new renewable sources of energy and new energy-and capital-efficient production technologies.

THE TRANSITION TO RENEWABLE RESOURCES

DR. BARRY COMMONER

DIRECTOR, CENTER FOR THE BIOLOGY OF NATURAL SYSTEMS,
WASHINGTON UNIVERSITY, ST LOUIS, MISSOURI

GLOBAL RESOURCES: PERSPECTIVES AND ALTERNATIVES

The global system in which we live is rapidly approaching a new, critical situation. For hundreds of years, societies which have differed greatly in their structure and organization have been based on the common goal of exploiting natural resources for the benefit of human beings. To varying degrees, this process has improved the conditions of human life. Now, however, the resources that have supported rising standards of living are rapidly becoming less available. As a result, developing countries cannot afford the resources essential to their development; industrialized countries face serious economic disruptions; international competition for diminishing resources threatens world peace.

While the problem derives from a basic physical fact—our present dependence on non-renewable resources—its most crucial expression is political: that the exploitation of the planet's resources has been accompanied by the enormous inequities that have divided its inhabitants into the rich and the poor. In abstract terms, the solution to the physical problem is self-evident: a gradual replacement of nonrenewable resources with renewable ones. And, as we shall see, there are practical ways of achieving this transition. However, superimposed on this monumental problem is the overriding issue created by the huge economic inequities. This issue—poverty—is enormous in its scope and brutal in its impact. It dominates the physical problem because those nations which are rich—and within them, those classes which are rich—have the power to determine the course of the transition to renewable resources. In such a transition there is the danger that the rich will use their power to maintain, and even improve, their own economic position, at the expense of poor people and poor nations.

Our task here is to find a way—despite the enormous complexities and intense political difficulties that encumber this problem—to understand it. It will not be easy. We will confront a number of tempting traps. Because the problem deals with profound questions about the human condition it is tempting to substitute philosophy for fact and submerge the discussion in a sea of aphorisms. Because the technical aspects of the problem seem to be alluring in their relative simplicity, it is tempting to reduce the more difficult social and political issues to biological ones—a process which is particularly dangerous because

it can readily cloak a partisan political aim in seeming objectivity of science.

My concern here is to outline the basic problems which arise from our present dependence on nonrenewable resources, to evaluate the possibility of achieving a transition to renewable resources, and finally to consider the relation of such a transition to the overriding problem of economic inequity.

THE BASIC FACTS ABOUT RESOURCE RENEWABILITY

The basic facts about resource renewability that we need to consider can be set forth in a series of propositions. These follow.

1. *The availability of all other resources depends on the availability of energy.*

The resources on which the production of goods and services depend can be divided into two main classes: matter and energy. Since matter cannot of course be destroyed (apart from the very limited conversion of matter by nuclear reactions to energy), it is essentially renewable. The amounts of the different elements—such as carbon, oxygen, nitrogen and the various minerals—on the earth is constant. Despite their fundamental renewability, the accessibility of many mineral resources becomes reduced as they are used. The reason is that they undergo spontaneous chemical and physical changes; for example, iron oxidizes into rust and scatters. However, these changes can be reversed: iron oxides can be smelted into metallic iron; scattered deposits can be gathered. But this can be done only by expending energy. By expending sufficient energy, all mineral resources are fundamentally renewable.

The practical example is the conservation of gold and other precious metals. Nearly all of such metals which have been mined over the course of human history are still available in useful form. Because they are highly valued, great care has been taken to avoid scattering them and where necessary (as in the case of recovering silver from chemical processes such as photographic film), considerable energy is expended to recover them. There is no reason why iron or copper cannot be handled in the same way.

This means that, at least on theoretical grounds, material resources can be renewable in practice, provided energy is available. Thus the overall problem comes down to the renewability of energy.

2. *Although energy is indestructible, its ability to do work is not.*

From the laws of thermodynamics we know that energy is useful only insofar as it yields work and that work can be obtained only when energy flows from one place to another. In the process of yielding work, the ability of energy to yield work is always reduced. The First Law of Thermodynamics tells us energy is itself indestructible, but the Second Law tells us that its ability to do work—which is its only value—is nonrenewable.

3. *Work (and therefore a work-generating source of energy) is essential to the production of all goods and services.*

From the laws of thermodynamics we know that work must always be done if we wish something to happen that will not happen by itself. Since all the goods and services that meet our needs—houses,

shoes, bread, automobiles, telephones and the messages they carry—do not happen on their own account, all of them require that work be done and therefore that energy be acquired and made to flow. Hence everything that is produced and all economic value depends on the use of energy to generate work.

4. *The availability of energy depends on its price, which in turn depends on the renewability of energy resources.*

The basic reason for the energy crisis is that nearly all of the energy sources on which modern production systems rely (in the United States 96 percent)—oil, natural gas, coal and uranium—are nonrenewable. Because these fuels were laid down only once during the earth's history, their deposits are limited in amount. Inevitably, as a nonrenewable energy source is depleted, the cost of producing it—and therefore its price—rises faster and faster as more is produced and less and less accessible deposits must be exploited. Thus, unlike the production of other goods, in which increased production is usually accompanied by a decrease in production costs, as the total amount of energy produced grows, the cost of production per unit increases.

For example, in the United States a series of studies by the National Petroleum Council and the Federal Energy Administration show clearly that production costs, and therefore prices (assuming a fixed rate of profit) of domestic oil will increase at a progressively faster rate with production. The price of domestic oil was expected to increase by $0.60/bbl in the five years between 1970 and 1975, by $1.10/bbl in the next five years and by $1.40/bbl in the five years after that. In the same way, according to a report of the Edison Electric Institute, as uranium production continues, the price of uranium fuel is expected to rise by about $2 per pound between 1985 and 1990, by $5/lb. between 1990 and 1995, and by $14/lb. in the next five years. (These prices are given in constant 1970 dollars, to eliminate the effect of general inflation.)

The reason for the exponential rise in the cost of producing a unit amount of a nonrenewable resource such as oil is that there is a strong interaction between the act of finding and producing oil and the structure of the "crop" of accessible oil fields which remain to be found. When exploitation of the U.S. oil resource began in earnest at the turn of the century the largest, best-yielding, most accessible fields were the first ones found and brought into production. Production costs were only a few cents per barrel. But soon the big, easily exploited fields were exhausted and it became more costly to find and exploit the next best ones. At first, when the costs were reckoned in pennies per barrel, their gradual rise was hardly noticeable. But now, after nearly 100 years of exploitation, the cost per barrel is reckoned in dollars, and soon in tens of dollars, and the annual increase in cost is correspondingly large.

Like the rate of growth of a 100-year-old bank deposit at compound interest, the rate of growth of oil production costs has become spectacularly fast. Thus, the nonrenewability of a resource such as oil does not mean that it will become physically, totally depleted, but that it will become too costly to produce. We will not exhaust the oil, but our ability to pay for it.

5. *There is no substitute for energy in the production system.*

Energy is a factor of production; like raw materials, labor and machines, it is an essential ingredient in the production of goods and services. But when the cost of a particular factor of production rises, it is likely to be replaced by a less costly one. Can such a substitution halt the exponential rise in the price of energy? Resources have certainly been exhausted in the past. For example, in the United States the once-vast herds of buffalo were destroyed. In this case, the expected escalation in price certainly occurred; in the ten-year period 1880–90 in which the great buffalo herds were wiped out, the price of a buffalo robe increased about ten-fold. Although as a species buffalo are of course an irreplaceable resource, viewed as a source of food and clothing they are replaceable. The exponential rise in the cost of buffalo robes was made irrelevant simply by substituting less costly sources of food and apparel, incidentally saving the species from extinction.

However, energy is different: there is no substitute for it. Whether provided by fuel-fed machines, by beasts of burden, or people, work must be done in every production process, and work is generated only by the flow of energy. There is no way to avoid this thermodynamic imperative. The labor of people or animals can substitute for inanimate forms of energy but only for certain limited production processes. Practically speaking, then, unless we are willing to forgo most of the advantages of modern industrial and agricultural production and transportation, we must use some non-living sources of energy. Unlike the buffalo, energy cannot be replaced in the economy as its price escalates.

On these grounds there is no reason to foresee an end to the present exponential rise in the price of oil and the other nonrenewable fuels on which we depend. The conventional explanation for the rising price of oil is that, angered by U.S. and European support of Israel in the war with Egypt and Syria in October 1973, OPEC, led by the Arab nations, cut back oil production, inducing a world-wide shortage that enabled the cartel to raise the price from $3.01/bbl in the summer of 1973 to $11.65/bbl on January 1, 1974. In fact, the real reason for the increased oil price originates in the United States, not in the Arab nations. In 1973, the Arab oil ministers were well aware that OPEC's largest customer, the U.S. oil companies, had announced in a report published a year earlier that the price of oil produced in the United States, which had remained essentially constant for 25 years, would need to begin rising exponentially.

In response, the OPEC oil ministers followed the normal business practice—that goods ought to be priced at what the market will bear—and raised their own price. The Arab-Israel war only provided a convenient excuse. Thus, contrary to conventional wisdom, the escalating price of energy, which is the only real evidence of an energy crisis, originates not with the greed and hostility of Arab sheiks—however real that might be—but with the inevitable economic outcome of the depletion of oil in the United States (abetted, to be sure, by the oil companies' deliberate increase in their targeted rate of profit).

6. *The rising price of energy is a powerful inflationary force.*

Because energy is used in producing all goods and services, when its price rises the cost of everything else is driven upward. Before 1973 U.S. commodity prices had been inflating at a modest rate of about 2 percent a year; after 1973 they took off, going into double-digit figures in 1974, and since then running at more than 10 percent a year. And consumer prices have not been far behind. Thus, the rising price of energy has become a driving force behind the rapid rate of inflation.

7. *Energy-driven inflation places a particularly heavy burden on the poor.*

Inflation is a notorious evil; it reduces purchasing power, lowers the demand for goods, depresses production and so leads to unemployment. The prices of goods that are particularly dependent on energy are hit hardest by the rising price of energy. These energy-intensive goods include housing (which depends on the cost of fuel and electricity), clothing (most of which is now made from petroleum-based synthetic fabrics) and food (which now heavily depends on fertilizers and pesticides, chemicals made out of petroleum and natural gas). This puts a particularly heavy burden on poor families, which use a much larger part of their budget to buy such necessary, energy-intensive items, as compared with wealthier families. According to an analysis of 1976 consumer expenditures by the Exploratory Project for Economic Alternatives the poorest 10 percent of U.S. households (with annual incomes less than $3000) spent nearly 30 percent of their income on energy purchases; average families spent 7.4 percent of their budget on energy; and the wealthiest 10 percent of U.S. families spent only 4.2 percent of their income in that way.

8. *The rising price of energy tends to hamper new industrial investments.*

Since 1973 the price of energy has been rising at a rate unprecedented in the history of the country. In the ten years before 1973 the energy price index increased at about 3.7 percent per year; in 1973–76 it has been increasing at the rate of 25 percent per year. The high rate of increase in energy costs inhibits new capital investment.

Between 1950 and 1970, when energy prices were stable, the entrepreneur could count on an accurate forceast of future energy prices, in predicting the operating costs of a new enterprise. With energy prices now rising so rapidly future prices are very uncertain, and the risk that a new investment will fail is increased. A number of business commentators have pointed to such uncertainties as a major cause of the present slow rate of investment—which means that plants are not built, and job opportunities are lost.

9. *The present energy system wastes capital.*

The availability of capital, and the willingness of investors to risk it in new productive enterprises, is essential to the economy's health. There is a close connection between the flow of energy and capital. Present forms of energy production are extraordinarily capital-intensive—that is, relative to the economic value of its output, energy production demands much more capital than other productive enterprises. As a result the energy industry is particularly vulnerable whenever it

becomes difficult to raise investment capital. This often leads to the abandonment or delay of energy projects that are especially capital-intensive, such as nuclear power plants and synthetic oil and shale oil projects.

Various ways of producing energy differ considerably in their capital productivity—that is, in the yield per dollar of capital invested. The most recent analysis of this problem by the American Gas Association shows, for example, that to deliver one quad of energy per year to residential/commercial users, an electric power plant system would require an investment which is more than twice that required for systems based on natural gas. For industrial use there is a 3 to 1 disparity between the capital required by the two types of energy systems. The production of coal is considerably more capital-intensive than the production of oil or natural gas. The production of synthetic oil from coal, or shale oil, is also particularly capital-intensive. The present emphasis on electric power, especially from nuclear plants, and on the production of coal and synthetic fuels, is wasteful of investment capital.

From these considerations it can be seen that although the energy crisis originates in the nonrenewability of present energy sources, it is expressed not in the reduced production of these sources, but in their exponential rise in price. In this sense the energy crisis is fundamentally an economic crisis, which has a particularly important effect on the gap between the rich and the poor. In an industrialized country such as the United States, the escalating price of energy places a growing burden on the poor and has become a chief reason for increasing difficulties with inflation and unemployment. In the world economy, the developing nations occupy an analogous position, relative to the rising price of energy, as poor people in the industrialized countries. In these nations the effort to develop industry, agriculture and transportation is bound to be hampered when the cost of energy—oil in particular—on which they depend escalates. The most disastrous effects of the sharply rising world price of energy which began with the 1973 embargo have been felt by poor people and poor countries.

It is ironic that this difficulty has been visited upon the developing countries because of the way in which the U.S. has developed its own sources of energy. As already pointed out, in recent years, with the continued depletion of U.S. oil resources, production costs have risen to the point where their exponential increase has powerful economic effects. And with the rising cost of U.S. oil production, oil produced from much "younger" areas, such as the Mideast, although still relatively cheap to produce, could command a price which also rises exponentially. Thus, the depletion of the world's first major oil source—in the U.S.—has triggered a disastrous escalation of world energy prices.

The resulting economic difficulties can only be resolved by a transition from the present dependence on nonrenewable energy sources to renewable sources, the cost of which will be stable with time. Such a transition must begin at once if we are to avoid the catastrophic economic effects of further escalation in energy prices. Hence the choice must be made, now, between the two possible, existing forms of renewable energy: nuclear power supported by a breeder reactor system (which would extend the availability of nuclear fuel to perhaps 1,500 to 2,000 years) and solar energy.

The nuclear/breeder alternative would have many highly undesirable consequences: imposition of enormously risky and as yet unmanageable problems of dealing with radioactive wastes; a growing danger of proliferation of nuclear weapons; the consequent military control of power installations; the huge amounts of needed capital; the resultant isolation of energy sources from control of the users of energy and the danger of economic and political dominance of society by whatever agency controls these sources.

In contrast, the solar alternative is environmentally benign and in no way endangers peace; solar energy is universally distributed and is especially available in developing countries; acquisition of solar energy usually involves no economy of scale, so that it is equally efficient in whatever size is most appropriate to the task; large units of capital are therefore not essential.

SOLAR ENERGY

The common response to the suggestion that the immediate introduction of solar energy is the solution to the energy crisis is that this is something for the distant future. But this is a tragically false perception. The fact is that for most methods of using solar energy the technology is already in hand and can be introduced at once for a variety of uses at economically competitive costs. It is useful here to summarize the basic propositons which govern the realistic introduction of solar energy. These follow.

1. *The cost of producing solar energy will not escalate, but remain stable as production expands.*

Unlike oil, natural gas, coal or uranium, solar energy is renewable; it will never run out (or at least not in the next few billion years). Because solar energy is renewable it is not subject to diminishing returns—which means that its price, instead of escalating like the price of present energy sources, will be stable and even fall as the cost of devices continues to decline. By stabilizing the price of energy, solar energy reduces the threat of inflation and eases the task of planning investments in new productive enterprises, thus relieving two of today's worst economic problems—inflation and unemployment.

2. *Solar energy is available everywhere, but the most accessible forms vary from place to place.*

The use of solar energy does not depend on any single technique. There are different sources of solar energy, some forms more available in one place and other forms in other places. Everywhere that the sun shines solar energy can be trapped in collectors and used for space heat and hot water. Of course, the amount of sunshine varies from place to place, but not as much as most people think. The sunniest place in the United States, the Southwest, gets only twice as much sunshine as the least sunny place, the Northwest. In some places the most available form of solar energy may be wind (the wind blows because the sun heats the air on the earth's surface unevenly).

In agricultural areas solar energy will be available in the form of organic matter (which is produced by plants, through photosynthesis, from sunshine): manure, plant residues, or crops grown to be converted into methane (the fuel of natural gas) or alcohol. In forested

areas, waste wood, or even wood grown for the purpose, can be converted into heat, either directly, or by being made into methane. And wherever the sun shines, photovoltaic cells can be used to convert solar energy directly into electricity.

3. *The necessary solar technologies are immediately available.*

Solar collectors are used all over the world, and about 30 years ago were common in Florida and California; small windmills used to dot the farm landscape; methane plants are in operation in hundreds of thousands of Indian and Chinese villages; alcohol produced from grain was used extensively, mixed with gasoline, to run cars and trucks during World War II, photovoltaic cells now power satellites and remote weather stations. Of course solar energy needs to be stored during the night or over cloudy periods. This can be done in batteries, in tanks of alcohol or methane, in silos full of grain, as standing timber, or for that matter in piles of manure. All these items exist.

4. *Some solar technologies are already economically competitive; all will eventually become competitive relative to nonrenewable energy sources.*

As already pointed out, the cost of conventional nonrenewable fuel is now rising exponentially and will do so indefinitely. Since it is renewable, the cost of solar energy is fixed only by the cost of the equipment, which will fall in price as experience is gained. Place these two curves on the same time scale and inevitably they will sooner or later cross. Solar energy, which a few years ago was more expensive than the conventional alternatives, will inevitably equal them in price and then each year become cheaper relative to conventional energy.

Estimates of when and how solar energy systems become economically advantageous have now been made by the Solar Energy Task Force of the Federal Energy Administration (now part of the new Department of Energy). Some examples follow:

a. Solar heating: In most of the central part of the United States, if the government would provide low-cost loans, it would today pay a householder who uses electricity or oil for space heat and hot water to replace about half of it with a solar collector system. Even borrowing all the necessary funds at 8 percent interest, with a 15-year amortization period, would cut the average annual heating bill by 19–20 percent.

b. Photovoltaic electricity: The FEA report shows that the production of electricity from photovoltaic cell systems can compete with conventional power sources and exactly how that can be accomplished. The report shows that, beginning immediately for the more expensive installations such as gasoline-driven field generators, within two years for road and parking lot lighting, and within five years for residential electricity in the Southwest, photovoltaic units can compete, economically, with conventional power. All that is required to achieve this remarkable accomplishment is to invest about $0.5 billion in the purchase of photovoltaic cells by the federal government. This would allow the government to order about 150 million watts capacity of photovoltaic cells. This order would allow the industry to expand its operations sufficiently to reduce the price of the cells from the current price of $15/watt (peak) to $2-3/watt in the first year; to

$1/watt in the second year and to $0.50/watt in the fifth year, achieving the competitive positions noted above and successfully invading the huge market for conventional electricity. At a price of $2–3/watt, photovoltaic units would be more economical than fuel-operated irrigation pumps or power stations in most developing regions of the world.

c. Methane and alcohol production from organic matter: While methods of commercializing these sources of solar energy have not yet been worked out by the FEA task force, current research already begins to show how that can be done. Public works funds can be used effectively to rebuild urban garbage and sewage-sludge disposal systems so that they generate methane, which can help meet a city's energy demand. In certain farm operations, such as a dairy with 200 or more cows or a farm raising 5,000 or more chickens, it is already economical to replace current manure-disposal systems with methane generation, using it, for example, to produce electricity to drive farm machinery and heat to warm the barns. Several Midwestern states are actively developing alcohol production from grain, as a partial substitute for gasoline in cars, trucks and tractors.

5. The economic feasibility of solar energy depends on how it is integrated into conventional energy systems.

A number of studies have shown that the economics of providing space heat can be optimized by integrating both the conventional and solar sources into a single system. The integrated solar/conventional system is more flexible than either a purely solar or a purely conventional system. When sufficient sun is available relative to the concurrent outside temperature, the system is able to derive all the needed energy from the sun. On the other hand, when sunlight is scarce and/or the temperature is low the system can operate on conventional fuel. Because of this flexibility the complex system is able in the first situation to substitute cost-free sunlight for expensive fossil fuel and in the second one to substitute fossil fuel for a costly expansion of the solar system.

The key to the economic feasibility of the combined system is that it is integrated—its solar and conventional parts are fitted together so as to use the system's dual capabilities when each of them gives the most favorable results. Naturally the relationship is not a static one: As the price of fossil fuel continues to rise exponentially it will become economically sound to give solar an increasingly larger role in the combined system.

Another example is provided by the FEA's photovoltaic commercialization plan. In this case the economic feasibility of introducing the solar technology was enhanced by integration at at least two different levels. In the first place the FEA plan recognized the importance of integrating the initial production of photovoltaic cells into the overall economic structure of the market for electricity. In the past, it was customary to dismiss the possibility of introducing photovoltaic electricity by simply comparing the high cost of such power with the much lower cost of utility power. The FEA approach was based on an understanding of the complex nature of the market for electricity, in particular that a small, but nevertheless significant, part of the mar-

ket—that supplied by gasoline- or diesel-operated generator sets—uses electricity which costs much more (10 to 50 times) than average utility power. The success of the FEA commercialization scheme is based on the discovery that the immediate market for photovoltaic systems to displace conventional generators is so large that it would enable manufacturers to bring the price of the cells down to $2–$3 per watt, in about one year.

Moreover, once production facilities are expanded to meet this initial demand, the price continues to fall (to an estimated $1/watt in the second year and $0.50/watt in the fifth year), enabling photovoltaic cells to compete in ever-larger markets. A second integrating feature of photovoltaic commercialization is described below.

6. *The economic feasibility of solar energy also depends on integration with the energy-using process of production.*

The high cost of storage is a major reason for the relatively large capital costs involved in solar technologies. This cost can be sharply reduced by incorporating the solar source into an energy-using system which itself has a built-in storage capability. Thus, if a photovoltaic system is used to provide power for an electric car, which must have a battery in order to operate (regardless of whether the electric source is conventional or solar), the high cost of storage normally needed in a photovoltaic system is eliminated. In the same way, an industry that found it useful to equip its workers with battery-operated hand tools (in place of tools which operate off the power line) in order to avoid the hazards of long electric cords would find photovoltaic electricity particularly economical. With two sets of stoarge batteries, one set could accumulate the photovoltaic power while the other set is used in the plant. Again, integration, this time between energy source and energy-using task, is the secret to successful economic introduction of solar energy.

These considerations show that to be economically successful a solar technology should not be considered as an isolated piece of equipment. It is a mistake to develop a solar technology autonomously and then judge it, with respect to its economic efficiency, against some other, equally isolated, conventional technology. Rather, the foregoing examples show that commercially successful solar energy can be introduced only if it is regarded as an integral part of an overall system of production. The advantages and disadvantages of the solar technology must be carefully matched to the capabilities and difficulties inherent in the system as a whole. Solar energy can best be introduced when it improves the economic efficiency of the production system as a whole.

7. *The present energy system must be modified to facilitate the solar transition.*

Although solar energy cannot be effectively introduced unless it is integrated into the energy and productive systems as a whole, the present systems are so faulty that fitting a new solar technology into them is often likely to fail for that very reason. In other words, we are confronted here by a "bootstrap" problem. The solar transition requires a transformation of both the energy system as a whole and of its constituent technologies.

This problem can be solved by recognizing, first, that the purpose of introducing solar energy is not to satisfy some cultural longing but to accomplish an economic purpose. Second, there are non-solar steps which can be taken to achieve this same purpose, which will so alter the overall structure of the energy system as to facilitate the introduction of solar energy. This is the strategic basis for a realistic solar transition. An essential feature of a solar transition is the replacement of existing energy-using devices which are incompatible with a solar source, with comparable devices that can be operated on either a conventional or solar energy source. An oil- or coal-burning heating system is a good example of solar incompatibility, since the production of an equivalent fuel, capable of being used in such a system, from a solar source is likely to be difficult. In contrast, a heating system that burns natural gas can operate either on that fuel or on a solar fuel—methane produced from organic wastes or crops. Such a system would be an essential bridge between the conventional energy system and its solar replacement. In the same way decentralized operation and high thermodynamic efficiency will also aid the development of the solar system.

8. *Cogeneration of heat and electricity from natural gas plays a crucial role in the solar transition.*

In conventional electric power plants at least two-thirds of the energy available from the fuel is wasted—emitted into environment as heat. Cogeneration, in which this wasted heat is put to use, is an ideal transitional process. The economic advantages of cogeneration have thus far been exploited for fairly large industrial and commercial installations. For example, a recent article describes a project, supported with initial funding from the Department of Energy, which is to build a cogenerator for downtown Trenton, New Jersey. It is expected to have an ultimate capacity of 37.5 megawatts. The unit is expected to have an overall efficiency of 63 percent, compared with 30–35 percent for conventional power plants. It is expected to save $40,000 annually, in energy production costs, and 10,202 barrels of oil, compared to a conventional power plant.

What is less well known is that cogeneration can also be used on a very small scale—down to a single house—if need be. The Fiat Company of Italy recently marketed a small cogenerator for a single-family home. It consists of a four-cylinder auto engine which drives an electric generator and supplies heat for space heating and hot water. It will run on gasoline, methane, natural gas or alcohol. The unit can convert 66 percent of the energy input into heat and 26 percent into electricity; only 8 percent is lost. (A conventional home furnace, which will convert 40 to 65 percent of input energy to space heat, with the remainder being lost.)

For producing electricity alone, it is almost as efficient as a central electric generating station, not counting the available heat, which is of course lost in central power generation. The model marketed by Fiat costs about $200 per kw (electric) installed ($2,800 per unit), versus $500 to $1,500 per kw for central electric power plants.

The massive installation of such units would not only save energy and utility costs. It would create jobs in the auto industry and in maintenance and repair work; it would decentralize energy production and

establish a base for efficiently introducing solar energy. Ideally, the size of the cogenerator should be matched, economically, to the size of the task. Thus, in rebuilding an urban neighborhood, it might pay to include a small cogenerator which would provide all the rehabilitated buildings with space heat, air conditioning and electric power—probably selling some electricity to the utility as well. In this way increased electric capacity would be automatically linked to new demand, the costly overcapacity inherent in the present, centralized systems avoided, and the introduction of solar energy would be facilitated. Here is an answer not only to rising the utility bills, but also to the feeling of helplessness that tends to overwhelm consumers when they confront the giant utilities. This too is one of the advantages of a solar transition.

Such a cogeneration system effectively facilitates the transition to solar energy. Three different sources of solar energy can be readily introduced with relatively small changes in the system itself. Solar collectors can be readily introduced by feeding the heat which they collect into the system's existing heat storage and transfer system. At the same time, panels of photovoltaic cells can be installed to provide a good part of the needed electricity. Moreover, methane from a solar source can be substituted for at least part of the natural gas that fuels the cogenerator. In the United States, based on expected availability of biomass methane, this could reduce the amount of fossil fuel now used to supply the residential/commercial sector by 87 percent.

It would pay to replace existing oil and natural gas-fired heating systems with units of this type. It would benefit the immediate consumer economically; it would achieve enormous savings of fossil fuel; it would achieve the kind of decentralization essential for the effective operation of a solar system. A comparison with nuclear power is informative. In 1987 a 1000 MW nuclear power plant will probably cost $1 billion. The same electric capacity could be achieved by installing some 67,000 15 kw cogenerators at a total cost of $191 million. The nuclear power plant would produce electricity at a cost of $0.091/kwh, while the cogenerators would product electricity at $0.23/kwh, and heat at the cost of the fuel used (all of the above sums are in 1975 dollars). Clearly it would pay to install cogeneration units in place of a nuclear power plant. Such a program would also begin to decentralize electricity production and so pave the way for localized photovoltaic systems.

Fundamental to such schemes is the crucial importance of natural gas. Because cogenerators must be close enough to residential and commercial consumers to efficiently supply them with heat, cogenerators must be compatible with an urban environment. Only a cogenerator fueled by natural gas, which releases only carbon dioxide and water when it is burned, can meet this requirement. Natural gas is also the only fossil fuel which can be replaced by a solar fuel—methane generated from organic matter—with no change in the energy-using equipment. It therefore facilitates the gradual introduction of solar energy without excessive disruptions and costs. (It is worth noting that this process is already under way in Chicago, where the gas utility is buying methane produced from manure at a cattle feedlot in Oklahoma at $1.97 per 1,000 cubic feet. The solar methane is being pumped into the Texas-Chicago natural gas pipeline and delivered to Chicago con-

sumers as a very small proportion of the gas that they are now burning in their furnaces and kitchen stoves.) For these reasons natural gas is the essential "bridging fuel" in the solar transition.

9. *There are sufficient resources of fossil fuel in the U.S. to sustain a gradual transition to solar energy.*

Taking the foregoing propositions into account, it is evident that the United States could in time accomplish a gradual transition from our present nearly total dependence on nonrenewable fuels to a nearly total use of solar energy. Recent analyses show that the process could probably be largely completed over a 50-year period. But this can be accomplished only if the available supplies of conventional fuels—and natural gas in particular—are sufficient to sustain this transition.

In such a transition the present use of coal, oil and nuclear power could be gradually reduced to zero over the 50-year period, and oil imports could be eliminated in 20 years. But the present annual consumption of natural gas (about 20 TCF) would need to be increased to about 35 TCF over the first 25 years. It could then be reduced, over the next 25 years, to about 5 TCF. It is important to note that no national system could be completely solar until it had enough excess capacity to allow for storage. Like all processes that depend on sunlight (such as farming), the output of a national solar system would depend on the weather. We could not afford to run out of energy in a bad year, so that a standby energy source is essential. Again, natural gas is the leading candidate since it could be quickly produced from capped-off wells, distributed in the pipelines used for solar methane, and burned in the equipment that uses the latter with no change.

These ideas seem strange when viewed against the common conception—so dramatically expounded by Mr. Carter when he introduced the National Energy Plan last year—that we are "running out" of oil and natural gas. Of course we are "running out" of these fuels; this has been true ever since the first barrel of domestic oil was taken out of the ground in 1859. The relevant question is how much remains to be produced, and at what price. In the context of the above considerations the crucial question is whether there are remaining supplies sufficient to sustain the transition to solar energy.

This is a complex and often confusing area, in which it is easy to get the wrong answer by the simple expedient of asking the wrong question. For our purposes the relevant question is not how long the known, already-found resources of fuel will last, but rather how long the much larger findable resources will last. While answers to this last question are necessarily uncertain, the most recent data available from the U.S. Geological Survey indicate that the potential resources of domestic oil in the U.S. could supply the nation's needs (at the present rate of consumption) for about 70 years. Similarly, a recent report from the Petroleum Industry Resource Foundation indicates that the world supply of oil is probably enough to meet present world demand for about 80 years. Thus oil supplies are quite sufficient to sustain a 50-year transition to solar energy, in which the present rate of oil consumption would be gradually reduced to zero.

For the reasons already cited, the most crucial question is whether the potential supply of natural gas is sufficient to serve as the "bridging fuel" in a solar transition. The potential supply in the U.S. was

evaluated by industry experts at a recent seminar conducted at the Aspen Institute. Taking into account existing conventional resources and natural gas available from newly developed deep sources, it was estimated that annual production would rise from the present level of 20 trillion cubic feet (TCF) to 35 TCF by the year 2000. The total size of the resource is estimated at 1,500–2,000 TCF from conventional sources and 10,000 TCF from the new, deeper sources.

The newer gas can be produced at a price of about $5/thousand cubic feet—a price which conventional gas is expected to reach within 10 years. Clearly there is enough of this crucial fuel available to support a 50-year solar transition in which annual consumption would rise to 35 TCF in the first 25 years and then fall to 5 TCF in the next 25 years. A great deal of natural gas would then remain, to serve as a standby fuel for many years, or until production of solar methane is large enough to produce a surplus for storage.

The foregoing consideration describes, at least in part, some of the factual background to the vexatious problems that are being generated by the decreasing accessibility of the nonrenewable resources on which we depend. Although these observations are largely based on the U.S. situation, they are relevant to the world situation as well. The chief reason is that the real impact of the energy crisis—the escalating cost of oil and other fuels—although it affects the world, has its origin in the status of the U.S. oil resources. Once the United States remedies its present dependence on oil, there will be no reason why the world price of oil should be determined by the cost of producing the oldest, most heavily exploited, and therefore expensive resource—U.S. domestic oil. Thus, as the United States undertakes the solar transition, the world price of oil could be governed, more reasonably, by the lower costs of producing it from the much newer fields in the Mideast and elsewhere. The escalating world price of oil and other fuels could then be checked, facilitating the solar transition everywhere in the world.

It should be recalled, also, that the sun shines everywhere on the earth and that developing countries, which are largely in the tropics, are particularly well blessed with this renewable resource. All of the sensible forms of solar energy—solar collectors, windmills, fuels from organic matter, and even photovoltaic cells—can be applied in developing countries almost as readily as they can in industrial ones. All of these forms can be efficiently applied at whatever scale matches the need. No huge capital investments, which are not readily available to developing countries, are needed. There are, of course, unreasonable forms of solar applications which imitate the huge, centralized design of present conventional sources, such as centralized solar electric power stations, or even the proposed huge (and hugely unrealistic) solar satellite. These forms are unreasonable because they ignore one of the crucial differences between conventional and solar energy sources. The former have a large economy of scale, so that the efficiency of a large centralized plant can support the extra cost of the necessary transmission network. But solar installations have no economy of scale (that is, since solar energy is horizontally distributed, large energy-catching units are achieved by adding together numerous smaller ones, so that efficiency is independent of overall size) and do not produce savings that can support the network needed in connection with centralized plants.

Thus, applied sensibly, solar energy can be efficiently used on whatever scale is appropriate—from a solar water heater in a single dwelling, to a solar-powered irrigation pump in the villages of developing countries, to a neighborhood power plant in an industrialized city.

Finally we must return to the overriding economic, social and political issue of poverty. How does this relate to the foregoing considerations?

First, we must take note of the melancholy fact that some advocates of solar energy—among them Mr. Carter—believe that the only way to encourage the introduction of solar energy is to raise the price of conventional energy even faster than at present. The reasoning is that the sooner the cost of conventional energy overtakes the high cost of a solar installation, the more people will be encouraged to make the solar investment. The trouble is that this inducement will work only with those people who possess the capital needed to meet the high initial cost of a solar installation (which is about $15,000 to heat a typical one-family home)—that is, the rich. Meanwhile, the poor, who cannot afford to go solar, would be burdened by an unnecessary increase in the already high cost of conventional energy. This scheme is Robin Hood in reverse; it would take from the poor and give to the rich. It would force both the poor people in a single country such as the United States, and the poor countries of the world, to bear the economic burden of a solar transition.

The answer, I believe, lies in social action that would govern the production and pricing of energy in the interest of carrying out the solar transition in an equitable manner. Here I reflect a political point of view which will not be shared by every participant in this symposium. I believe that the great global transformation which must end our present, catastrophic dependence on nonrenewable resources—the solar transition—ought to be designed not only to achieve this purpose, but also to end poverty, within nations and among them.

There is a contrary view, which will be voiced here, that poverty in the overpopulated developing countries ought to be treated with "benign neglect" (to cite one of the least harsh proposals) on the grounds that the world's resources cannot support its growing population which must be reduced by attrition among those with the least sufficient access to resources—the poor, developing nations.

However, it is simply not true that the poverty of developing nations means that the earth has insufficient resources to support its present population. It is a fact, for example, that the present annual world production of food is enough to provide an adequate diet for 8 billion people—more than twice the world population. Some people in the world are poor and suffer from the hunger, disease and despair that is the price of poverty—because other people are rich.

Some people believe that the root cause of the world's problems with depleting resources is the rising population. But this is a simplistic notion that attempts to reduce world politics to the more tractable form of biology. We know from a number of factual analyses of this problem that the dynamics of human populations (as distinct from animal populations) is governed by forces that are peculiar to people—in particular, that people desire (and produce) fewer children when living standards are high enough to ensure that their chil-

dren will live long enough, and society will be sufficiently wealthy, to provide them with a secure old age.

The world has enough wealth to support its entire population at a level that appears to convince most people that they need not have excessive numbers of children. The trouble is that the world's wealth is not evenly distributed, but sharply divided among moderately well-off and rich countries on the one hand and a much larger number of people and countries that are very poor. The poor countries have high birthrates because they are extremely poor, and they are extremely poor because other countries are extremely rich. The answer is, I believe, not to reduce the number of poor people, so that their needs will no longer threaten the security of the rich, but to redistribute the world's resources, so that the poor have the incentive, and the means, of improving their own lives.

This, I believe, ought to be the great purpose of transforming the economy of the world from its present, catastrophic dependence on nonrenewable resources, to the balance and stability that is endowed by the endlessly renewable global resource—the sun.

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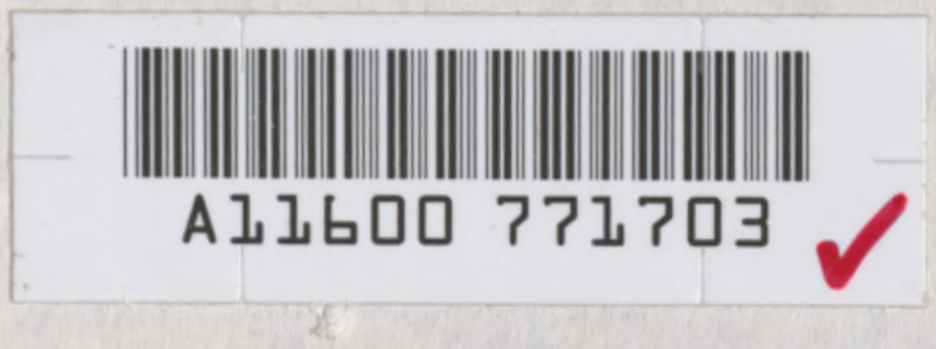
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