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Congress Session	COMMITTEE PRINT

THE SEARCH FOR A LOW-EMISSION VEHICLE

STAFF REPORT

PREPARED FOR THE

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FOREWORD

This report marks another step in Congress' search for an antidote to the continuing epidemic of vehicular air pollution. The Senate Commerce Committee, and Senator Muskie's Subcommittee on Air and Water Pollution of the Public Works Committee, have been exploring the potential of low-emission vehicles for the past several years. We have held hearings to consider the potential of both the electric and steam vehicles. The Commerce Committee staff has now charted new waters in the search for a low-emission vehicle, using the hearings as a point of embarkation.

The report should serve as a useful document for understanding the vehicular air pollution problem, the shortcomings of present pollution control efforts, and the possibility of undertaking a new approach which involves the development of a low-emission vehicle. The reader will learn about the Rankine vehicle and its potential role in solving the country's air pollution problems; and he will appreciate the obstacles to innovation in the automotive field. Finally, the reader will confront several provocative recommendations.

Not all people will agree with the report's conclusion, nor will they choose to follow its recommendations. To my mind, however, the report is extremely useful because it forces us to consider seriously transportation's impact on the environment and to evaluate one possible solution. I am personally convinced that we must look for such new approaches in solving the air pollution epidemic.

Again, I wish to commend the staff for its significant contribution. I urge all concerned to give the matters discussed in the report thoughtful attention; and I earnestly invite them to comment on the conclusions and recommendations.

WARREN G. MAGNUSON,
Chairman, Senate Commerce Committee.

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THE SEARCH FOR A LOW-EMISSION VEHICLE [1]

THE AIR POLLUTION EPIDEMIC

> Like a dirty gray blanket flung across the city, a dense eye-stinging layer of smog dimmed the sun here yesterday. The fumes hung unmoving in the still air, rousing tears and sniffles in thousands of Angelenos.—Los Angeles Times, 1946.

Air pollution significantly degrades the quality of living for all Americans, but the citizen of the city is air pollution's most desperate victim.[2] For decades urban dwellers have experienced the telltale symptoms of air pollution. The flecks of soot they smear from their faces, the persistent throat irritation they accept, and the urban vistas they watch disappear behind opaque curtains of smog testify to the existence of polluted air. But today people are beginning to realize that simply by living in their polluted environments they are exposing themselves to serious health hazards.[3] Doctors in Los Angeles in a single year advised more than 10,000 people to move away because of air pollution's harmful effects on them.[4]

Air pollution is a significant contributing factor to the rising incidence of chronic respiratory diseases—lung cancer,[5] emphysema,[6]

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[1] This Commerce Committee staff report was prepared at the urging of Chairman Warren G. Magnuson after the Commerce Committee held joint hearings on the steam automobile with the Subcommittee on Air and Water Pollution of the Public Works Committee chaired by Senator Edmund S. Muskie. See "Automobile Steam Engine and Other External Combustion Engines," joint hearings before the Committee on Commerce and the Subcommittee on Air and Water Pollution of the Public Works Committee of the U.S. Senate, 90th Cong., second sess. (May 27, 28, 1968), serial No. 90–82, hereinafter cited as "Hearings."

[2] The number of people affected by urban air pollution will dramatically increase in the next several years. See the following table:

ANTICIPATED URBAN POPULATION DISTRIBUTION

	Major metropolitan areas (over 5,000)		All urban areas (over 2,500)—percent of population
	Number	Percent of population	
1960	78	48.3	67
1980	117	59.4	75
2000	145	65.9	85

Source: Jerome P. Pickard, "Metropolitization of the United States," Urban Land Institute, Washington, D.C., 1959. U.S. Department of Commerce, Bureau of the Census data.

[3] For a general discussion of the health significance of air pollution see "The Automobile and Air Pollution: A Program for Progress (Part II)," U.S. Department of Commerce (December 1967) at pp. 2–4.

[4] See the Washington Post, Jan. 26, 1969, p. B–3.

[5] See "Air Pollution, 1968 (pt. 2)" hearings before the Subcommittee on Air and Water Pollution of the Committee on Public Works, U.S. Senate, 90th Cong., second sess. (July 1968) at 609, for a review of information relating air pollution to lung cancer.

[6] See id. at p. 680 for a study of emphysema in metropolitan areas.

chronic bronchitis [7] and asthma.[8] Recent investigations disclose that deaths from lung cancer are greater in urban areas than they are in rural areas.[9] Figures standardized by taking into account the different smoking patterns of urban and rural inhabitants demonstrate that the death rate from lung cancer is still 25 percent higher in the cities.[10] Empirical evidence is beginning to suggest a strong interrelationship between harmful effects of smoking and air pollution. "Smoking has been shown to inhibit ciliary action in the respiratory tract, and thus may make the lungs more vulnerable to the harmful effects of air pollution. But air pollution, too, inhibits ciliary action and may in turn make the lungs more vulnerable to the effects of smoking." [11]

The automobile is the primary villain in air pollution.[12] It accounts for at least 60 percent of the total air pollution in the United States—85 percent of the pollution in some of our sprawling urban areas.[13] Nationwide, the automobile produces 90 percent of all carbon monoxide pollution.[14] The automobile is responsible for dumping into the atmosphere each year more than 90 million tons of pollutants; this is twice as much as any other single contributor.[15] If air pollution is to be curtailed, dangerous emissions from automobiles must be substantially reduced.

Carbon monoxide, hydrocarbons, oxides of nitrogen, lead, and oxidants are the primary components of vehicular air pollution.[16] Each

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[7] See New Yorker, Apr. 13, 1968, at p. 51:

"In each human lung, there are three hundred million alveoli, and the classic saw in medical schools is that the combined surface of the alveoli would cover a tennis court. The walls of the air sacs are diaphanous membranes, thinner than paper. When these walls progressively break down, making breathing more of an effort, the unhappy owner is suffering from a disease called emphysema. Or, in other cases, the walls of the bronchial tubes may become chronically inflamed, causing an increased flow of mucous and coughing; this is bronchitis. Either way, the lungs have *ceased to be an efficient breathing machine.*" [Emphasis added.]

[8] Hearings before a Subcommittee on Air and Water Pollution of the Committee on Public Works of the U.S. Senate, on S. 3112 and S. 3400, 89th Cong., second sess. (1966) at p. 22. Hereinafter cited as "Air pollution hearings."

[9] Id. at p. 25.

[10] The figures were also standardized for age differences between urban and rural inhabitants. Id. at p. 25. These figures do not, however, take into account any differences in the death rate from cancer between urban and rural smokers.

[11] Id. at p. 26.

[12] Nationally the automobile is said to account for 91 percent of all carbon monoxide, 63 percent of unburned hydrocarbons, 48 percent of oxides of nitrogen, as well as 8 percent of particulate matter and 4 percent of sulfur oxides. "Sources of Air Pollution and Their Control," U.S. Dept. HEW, Public Health Service, Washington, D.C., U.S. Government Printing Office, 1966.

[13] See "Air Pollution—Present and Future," City of Livermore Air Pollution Control Study Committee, March 1968. See also hearings at p. 155.

[14] See "Automobile and Air Pollution Report (II)", supra note 3.

[15] See "Automobile and Air Pollution Report (II)", supra note 3 at p. 1. The 90 million tons from automobiles compares with manufacturing's contribution of 30 million tons, electric, coal and power generation's 15 million tons, space heatings 8 million tons, and refuse burning's 3 million. (See id.)

[16] Id. at pp. 2–4. Asbestos may become another serious component of vehicular air pollution. Current information indicates that asbestos is a very toxic pollutant which, even in small quantity, contributes significantly to the production of certain types of cancer. See Air Pollution hearings, 1968, supra note 8, at pp. 685–686. See also "Biological Effects of Asbestos," 132 Annals of the New York Academy of Sciences (1965). Because asbestos is used in brake linings, each time the brakes are applied some virtually indestructible asbestos particles wear off and enter the atmosphere. See New Yorker, Apr. 4, 1968, p. 107. Available information indicates that asbestos pollution from automobiles is not yet a serious health problem. See Lynch, "Brake Lining Decomposition Products," Journal of the Air Pollution Control Association, pp. 824–826 (1968):

"Only a very small proportion of the asbestos worn from brake linings is released as free fiber; the remainder is converted into some other mineral as a result of the extreme temperatures generated at small spots on the lining surface. Thus, although urban air contains a few free fibers as a result of brake lining wear, they represent a very small proportion of the total asbestos used in manufacture of brakes. Many sources of respirable fibers not associated with asbestos products have been identified, and free fibers from brake lining wear seem to be an inconsequential health factor in urban air pollution."

Even though asbestos pollution from automobiles is not yet a serious health problem, it is important for officials controlling air pollution to examine the total pollution potential of the vehicle. Exhaust emission is not the only vehicular contaminant source. In fact,

has different deleterious effects on human physiology. The toxicity of carbon monoxide is relatively well understood. "By combining with hemoglobin in the same manner as oxygen, but with far greater affinity, the inhaled carbon monoxide interferes with the capacity of blood to transport and release oxygen to the tissues." [17] This interference can impair vision and psychomotor performance, and thus may interfere with a driver's ability to respond to certain traffic situations. Concentrations above 30 p.p.m. (parts per million) for short periods of time are not advisable and a limit of 10 p.p.m. for an 8-hour period appears reasonable from the public health standpoint,[18] but present concentrations in certain areas have reached levels as high as 65 p.p.m. for extended periods and 100 p.p.m. during peak traffic hours.[19]

The precise effects of hydrocarbon pollutants are not as well understood as the effects of carbon monoxide. It would seem that they have little direct effect at existing concentration levels, but they do have negative indirect effects. Some hydrocarbons interact with oxides of nitrogen in sunlight, producing odorous smog, eye irritation, and vegetation damage.[20]

Nitrogen dioxide, one of the oxides of nitrogen, is directly toxic to man and animals.[21] The gas is mildly irritant and may be deeply inhaled. Death and chronic respiratory diseases have resulted from exposure to nitrogen dioxide; and pulmonary damage in animals has occurred with concentrations of less than 5 parts per million.[22] In addition to its toxic effect on man, nitrogen dioxide is responsible for most of the atmospheric coloration problems, and in the Los Angeles area alone plant damage caused by nitrogen dioxide is estimated to be between $6 million and $10 million per year.[23]

Although there is a dearth of knowledge about atmospheric lead inhalation,[24] the toxic effects of ingested lead are well known. Lead poisoning can attack the central nervous system, peripheral nerves, smooth muscle, and reproductive organs. Current recommendations call for a 10-percent reduction of lead content per year in order to assure reduction of the public health hazard of atmospheric lead compounds.[25]

The final major vehicular pollutants, oxidants and ozone, are irritating to exposed mucous membranes. Eye and respiratory irritation has occurred in sensitive subjects at oxidant levels as low at 0.1 to 0.15 parts per million.[26]

Twentieth century man can proudly point to partial mastery of his environment. He has developed his technology to a point where he can physically explore the moon, previously reachable only through the imagination of the poet and novelist. But 20th century man has not yet confronted his potential for self-destruction. While accepting

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some people have suggested that rubber particulate matter from tires should be examined to see if it is a potentially dangerous source of pollution. Vigilance in these matters is required.

See note 55 infra for a discussion of how a steam-propelled vehicle might help alleviate asbestos pollution in automobiles should it become a critical problem.

[17] Id. at p. 2.

[18] Id. See also air pollution hearings, supra note 8, at pp. 42–43.

[19] See Livermore study, supra note 13, at p. 24.

[20] See "Automobile and Air Pollution Report (II)" supra note 3, at p. 2.

[21] Air pollution hearings, supra note 8, at pp. 47–50.

[22] See "Automobile and Air Pollution Report (II)" supra note 3, at p. 3.

[23] Id. (pt. I) at p. 15.

[24] See app. B, "Leaded Gasoline Presents Hazards to Health."

[25] See "Automobile and Air Pollution Report (II)," supra note 3, at p. 3. See also app. B, "Leaded Gasoline Presents Hazards to Health."

[26] Id. at p. 4.

the benefits modern technology bestows upon him, he often refuses to confront its attendant detriments. Air pollution is one of technology's unpleasant byproducts for which the price of ignorance and inaction may be the very destruction of man's primary resource—the air he breathes. There is no other known alternative to reducing air pollution than to attack it at its source.

THE FAILURE OF THE PRESENT APPROACH

To meet the problem of vehicular air pollution, Government is issuing emission-control standards.[27] Following the lead of California, the Federal Government has adopted nationwide hydrocarbon and carbon monoxide emission standards for all automobiles and light trucks.[28] But the present approach is inadequate for a number of reasons.

The present emission standards will not stabilize, much less reduce, vehicular air pollution.[29] Studies indicate that, under existing controls, automobile air pollution in the United States will more than double in the next 30 years because of the projected increase in both the number of vehicles and miles driven by each vehicle.[30] Ironically, under

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[27] Federal standards regulate the emission levels of new cars purchased after Jan. 1, 1968.
[28] See the following table:

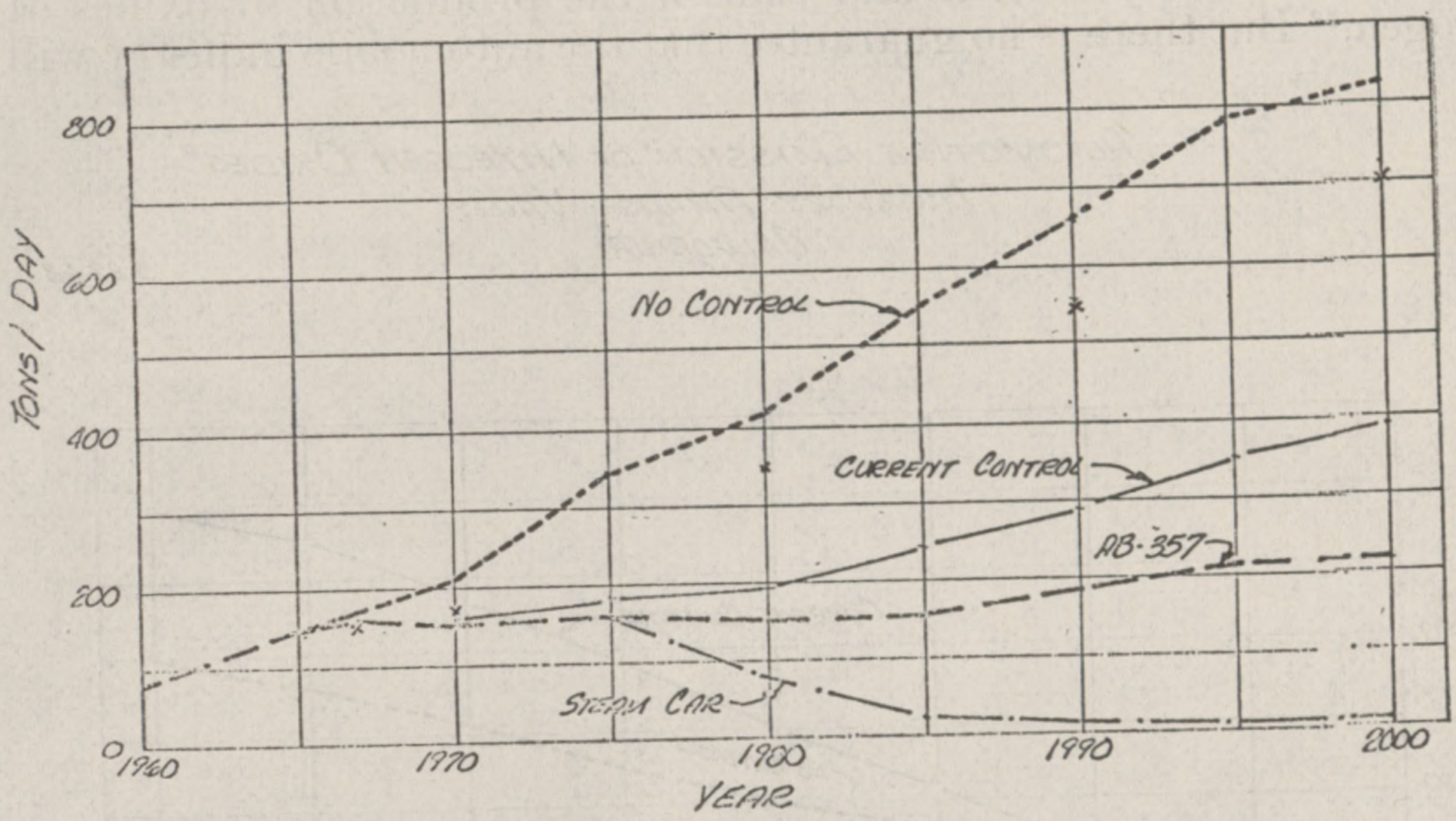
ALLOWABLE EMISSION CONCENTRATION

Engine displacement (cubic inches)	Hydrocarbons (parts per million)	Carbon monoxide (percent by volume)
50 to 100	410	2.3
100 to 140	350	2.0
Greater than 140	275	1.5

Fuel evaporative emissions are not to exceed 2 grams per "test." A "test" is an average 20-minute trip. These regulations become effective in 1970.
[29] These standards do not even regulate nitrogen oxide emission.
[30] The charts on pp. 5 and 6 illustrate the rate of growth of vehicular air pollution under existing emission control (hearings, 231, 232).

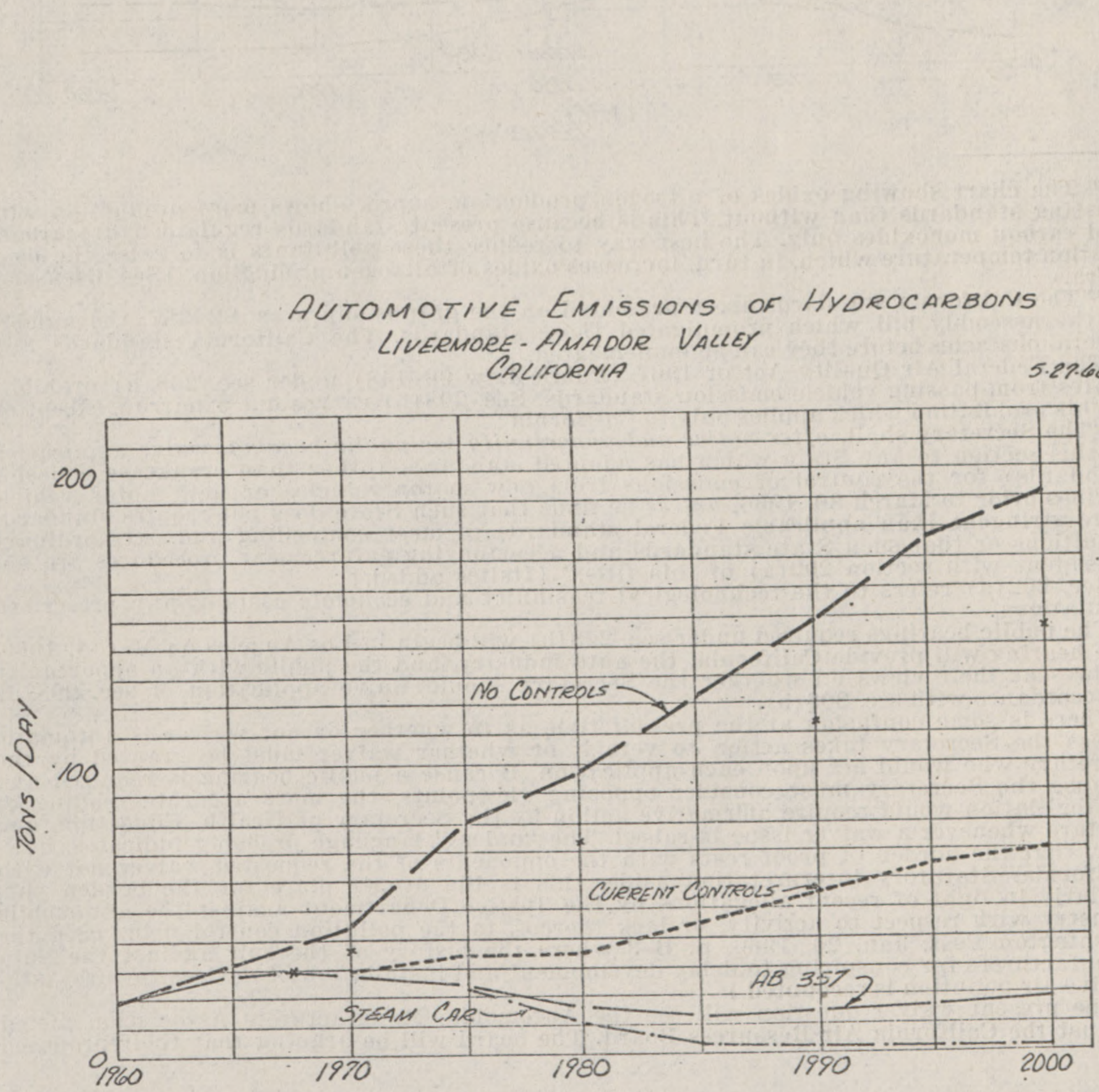
AUTOMOTIVE EMISSIONS OF CARBON MONOXIDE
LIVERMORE-AMADOR VALLEY
CALIFORNIA

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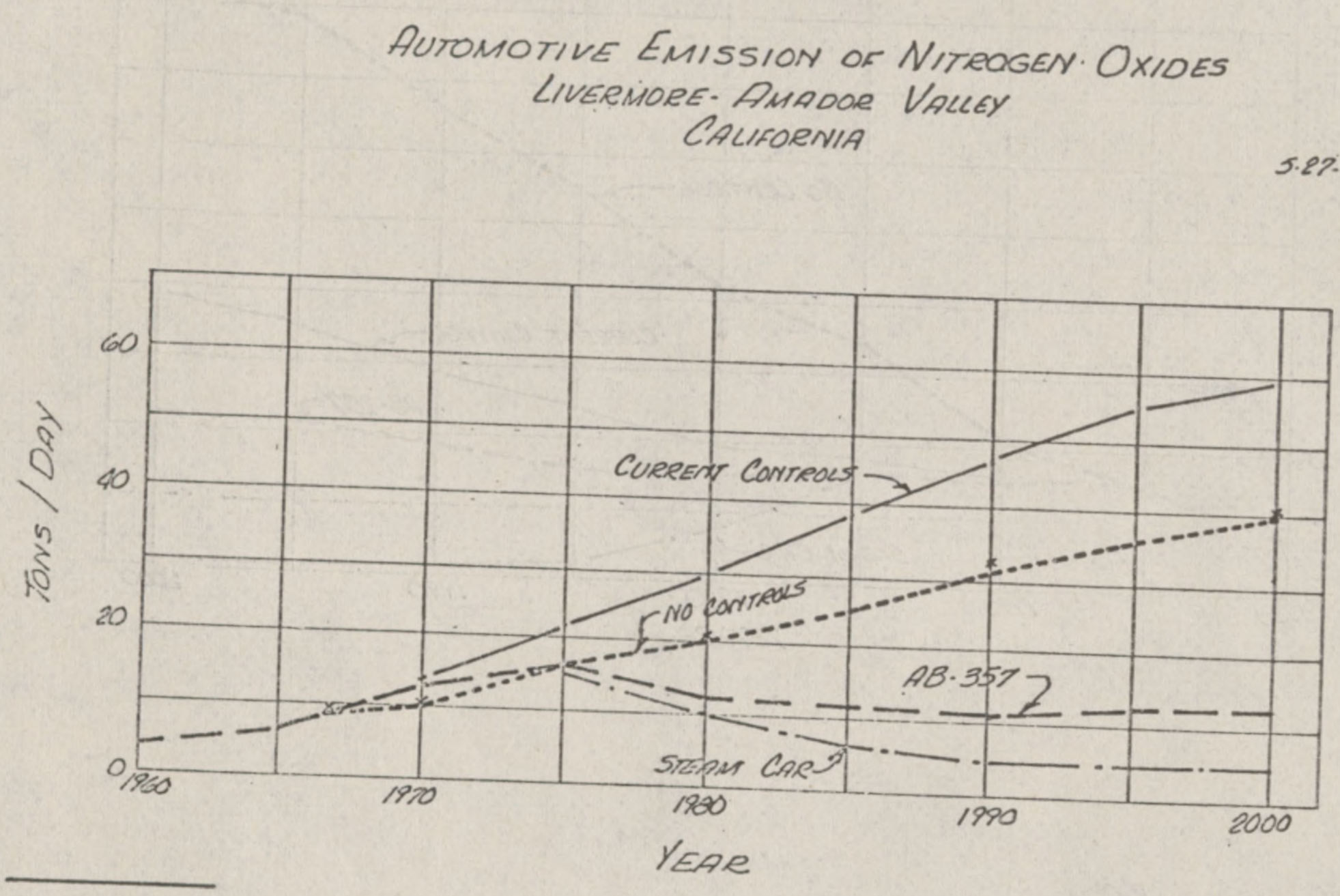
AUTOMOTIVE EMISSIONS OF HYDROCARBONS
LIVERMORE-AMADOR VALLEY
CALIFORNIA

5-27-68



present emission standards, oxides of nitrogen emissions, the main villains in photochemical smog production, will be higher than they would be if no standards existed.[31]

Only California has adopted emission standards for the 1970's which will stabilize air pollution and control the production of oxides of nitrogen.[32] But there is no guarantee that the automobile industry will



[31] The chart showing oxides of nitrogen production, supra, shows more production with existing standards than without. This is because present standards regulate hydrocarbons and carbon monoxides only. The best way to reduce these pollutants is to raise the combustion temperature which, in turn, increases oxides of nitrogen production. (See discussion infra.)

[32] The California standards are represented on the graphs supra as AB–357, the number of the assembly bill which promulgated those standards. The California standards face several obstacles before they can be implemented.

The Federal Air Quality Act of 1967 (Public Law 90–148) under sec. 208(a) prohibits States from passing vehicle emission standards. Sec. 208(b) carves out a narrow exception to this prohibition which applies only to California:

"The Secretary shall, *after notice and opportunity for public hearing,* waive application of this section to any State which has adopted standards (other than crankcase emission standards) for the control of emissions from new motor vehicles or new motor vehicle engines prior to March 30, 1966, *unless* he finds that such State does not require standards more stringent than applicable Federal standards to meet compelling and extraordinary conditions or that such State standards and accompnying enforcement procedures are not consistent with section 202(a) of this title." [Italics added.]

Sec. 202(a) refers to the technological feasibility and economic costs of any prescribed regulations.

The public hearings required under sec. 208(b) will begin in Los Angeles on Mar. 4, 1969. The hearing will provide California, the auto industry, and the public with an opportunity to present their views on whether the Secretary should waive application of sec. 208(a) in accordance with sec. 208(b).

There is some confusion at the present time as to whether or not waiver is automatic unless the Secretary takes action to veto it or whether waiver must be granted by the Secretary who would act upon each application. Because a public hearing is required and because the Secretary must consider opposing viewpoints, the more accurate reading of the legislation would require affirmative action by the Secretary of Health, Education, and Welfare whenever a waiver issue is raised. The "unless" language probably indicates, however, that the burden of proof rests with the opponents of the requested waiver not with California. Statutory interpretation aside. this is the proper place for the burden particularly in light of recent allegations by the Justice Department against the automobile industry with respect to activity, or lack thereof, in the pollution control field. (See the Washington Post, Jan. 26, 1969, p. B–3 where the history of the suit against the auto manufacturers for conspiring to delay development and installation of devices to curb automotive air pollution is recounted.)

The present waiver question will see the Automobile Manufacturers Association pitted against the California Air Resources Board. The board will be arguing that their proposed

produce cars that will meet the proposed California standards.[33] Manufacturers presently control hydrocarbon and carbon monoxide emission by combusting fuels at high temperatures. This high-temperature combustion reduces hydrocarbon and carbon monoxide pollution but increases oxides of nitrogen emission.[34]

The automobile industry is investigating new pollution control methods, but there is no assurance that they will develop satisfactory control systems. Nitrogen oxides pose a particularly difficult control problem.[35] Ford Motor Co., in a recent letter to the Commerce Committee, suggests that some sort of catalyst bed might be used to control emissions. But because these catalysts burn up at high speeds, Ford suggests a possible bypass system under high-speed conditions, arguing that raw emissions at turnpike speeds are low.[36] The Ford approach is indicative of problems associated with internal combustion engine emission control. Control technology is lacking and, in developing technology, automobile companies are prone to overlook pollution details. Ford, for example, incorrectly assumes that emissions at high speeds are low. Almost twice as many oxides of nitrogen are produced at speeds of 50 miles per hour than at speeds of 30 miles

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standards are absolutely necessary for the health and safety of the citizens of California and that such standards are within the technical capacity of automobile manufacturers. The AMA will probably argue that California has not offered enough data to support their contention that the emission standards are required. Losing that argument, the association will probably lobby with the National Air Pollution Control Administration in order to convince them that: (1) the standards exceed existing technology; and (2) the costs of developing control devices are too great. The association will make these arguments at the same time they are saying publicly that the ICE will be able to meet any required emission standards that are needed. (See app. A (Ford, General Motors, and Chrysler letters.)

It is absolutely essential that any determination by the Secretary as to the waiver issue consider emission control characteristics of Rankine and other low-emission vehicles. As subsequent text and notes disclose, there are serious technological problems facing the control of oxides of nitrogen in ICE's. But these problems should not override the more important considerations of public health and safety, particularly when Rankine cycle-propelled vehicles will be available to meet automotive needs and can meet the required pollution standards proposed by California.

[33] Those standards for oxides of nitrogen are:

For cars and light trucks:

1971 models: 4.0 grams per mile of nitrogen oxides.
1972 models: 3.0 grams per mile of nitrogen oxides.
1974 models: 1.3 grams per mile of nitrogen oxides.

[34] This problem was alluded to in the electric vehicle hearings, 90th Cong., first sess. (1967) at p. 97: "* * * by reason of increased combustion efficiency in the engines, and the higher temperatures associated therewith, [ICE's] will produce an increase in oxides of nitrogen." See also "Reduction of Nitrogen Oxides in Automobile Exhaust," SAE Paper No. 690019 (Jan. 13–17, 1969).

[35] See "Problems Ahead on Nitrogen Oxide," Automotive News, Jan. 13, 1969, at pp. 1, 6:

"A progress report on General Motors efforts to reduce nitrogen oxide (NOx) emissions in auto exhausts, indicates that both the engineers and the Nation's motorists have real problems ahead with these devices * * *.

"NOx reduction is difficult for the engineers because it is formed by the chemical reaction of nitrogen and oxygen at high-temperature combustion in the engine. Most measures that reduce the nitrogen oxides either increase the emission of unburned hydrocarbons (HC) and carbon monoxide (CO) or reduce engine performance and economy or both."

[36] App. A (Ford letter).

per hour.[37] Any control device with a bypass system would have detrimental effects on the total emission picture.

There is a final problem associated with present emission control efforts. Even if the automobile industry is able to bring automobile emissions down to a satisfactory level through elaborate emission control devices,[38] there is no assurance that such devices will maintain their effectiveness. Emission control in the internal combustion engine is external to the combustion system. Increases in control add to its initial cost, maintenance, and reliability. The control system impedes the efficiency of the engine, and drivers may be prone to disconnect the emission control device. If the device is built into the engine so that disconnection is difficult, then the system is still prone to deteriorate with age.[39] This deterioration obviously jeopardizes any long-range air pollution gains. Emission control devices must be able to last for the life of the car if any significant inroads into the vehicular air pollution problem are to be made.

The present approach to vehicular emission control is better than no approach at all. Current controls reduce pollutants in new cars, at least for a time, by 60 percent.[40] But the present approach will not solve the air pollution epidemic. A new approach is needed.

A NEW APPROACH

Perhaps the best long-range method of solving the vehicular air pollution problem is to substitute for present propulsion systems a new

[37] See the following table:

OXIDES OF NITROGEN CONCENTRATIONS BY MODE OF OPERATION

[Parts per million NO_2]

Car number	Type of transmission	15 to 30 miles per hour acceleration	0 to 25 miles per hour acceleration	15 miles per hour cruise	30 miles per hour cruise	50 miles per hour cruise
27	Manual	1,512	1,526	70	616	1,405
28	do	2,179	1,576	95	1,108	2,379
1005	do	1,068	646	45	296	339
1021	do	2,198	1,279	88	807	2,190
29	Automatic	2,724	2,200	1,378	1,834	2,712
1001	do	617	801	53	332	664
1002	do	1,217	448	37	747	2,132
1003	do	1,353	314	48	248	1,071
1004	do	2,276	2,040	199	815	1,167
1006	do	2,368	1,730	174	1,831	2,050
1018	do	1,129	1,157	260	1,146	1,279
Average		1,694	1,247	204	889	1,581

Source: "Oxides of Nitrogen in Air Pollution," California State Department of Public Health (July 1967). Verified by National Air Pollution Control Administration, Department of Health, Education, and Welfare.

[38] See "A Progress Report on the Development of Exhaust Manifold Reactors," SAE Paper No. 690139 (Jan. 13–17, 1969) at p. 31:

"Well-designed exhaust manifold reactor systems can achieve very low-emission levels—below 50 p.p.m. hydrocarbon and 0.5-percent carbon monoxide.

"The reactors can be built to be durable enough to last the lifetime of the vehicle under normal consumer operations * * *.

"Some of the unsolved problems which limit immediate application of reactors are: there are many vehicle engine combinations produced which do not have sufficient space * * *.

"*Durability.*— * * * The durability remains to be proven under the wide variety of tests employed by vehicle manufacturers to assure trouble free operation.

"*Cost.*—Reactors are expensive * * * ; furthermore, the only materials of proven durability are expensive * * *.

"*Fuel economy.*—Economy is decreased."

[39] Id.

[40] Hearings at p. 43.

system which produces few pollutants and performs as well or better than the present powerplant. Such a system should have good emission qualities, be reliable, and when mass produced cost no more than present propulsion systems.[41] Any new approach to the vehicular air-pollution problem should be directed toward the development of a low-emission propulsion system.

In the spring of 1967 the Committee on Commerce, and the Subcommittee on Air and Water Pollution of the Committee on Public Works, held hearings designed to explore the potential and to encourage a new approach.[42] Reasoning that self-interest in the automobile industry should lead to further refinement of the internal combustion engine,[43] the two committees began exploring alternative vehicular-propulsion systems.

The first hearings were primarily devoted to electric vehicles and had as their focal point two bills which would have provided Federal research and development funds for electric automobiles.[44] The hearings disclosed that because of lack of research and development expenditures the electric vehicle had not yet reached a point where it could be considered as a feasible alternative to the present internal combustion engine (ICE) passenger car.[45] Their batteries were too bulky, too expensive, and might present a safety hazard. Since the cars also had a limited range and limited speed, they probably would be unacceptable to the majority of Americans as a general-purpose vehicle, although they might have some immediate application as a second car for urban commuting and shopping. Even though refinements were being made on electric vehicle propulsion systems, it appeared that more progress was necessary before the electric car would be able to offer the same performance advantages as an ICE automobile.[46]

In May of 1968, after publication of a report commenting favorably on automotive steam engines,[47] the Commerce Committee and the Subcommittee on Air and Water Pollution held steam car hearings.[48] The purpose of the hearings, as Chairman Magnuson explained, was "to learn whether some of the earlier problems with steam propulsion systems had been overcome and whether there were specific advantages which steam engines might offer—both in the emission of fewer pollutants and in improved performance and maintenance." [49] The hearings accomplished their objectives.

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[41] Present cost projections indicate that the Rankine propulsion system will probably cost less when mass produced than present ICE propulsion systems. See discussion accompanying notes 68–72 infra. The cost factor is important only from the standpoint of customer acceptance. The air-pollution problem is so great that as a society we should be willing to pay more for clean air. Differential taxing policies could be used to equalize costs between polluting and nonpolluting vehicles in order to negate any cost competitive advantages that the polluting ICE's may enjoy. But such measures will probably not be necessary.

[42] "Electric Vehicles," hearings before the Committee on Commerce and the Subcommittee on Air and Water Pollution of the Public Works Committee of the U.S. Senate, 90th Cong., 1st sess. (1967). Hereinafter cited as "Electric Vehicle Hearings."

[43] The committees were also of the opinion that their investigation into alternative propulsion systems would give impetus to industry development of further ICE controls.

[44] S. 451 and S. 453, 90th Cong., 1st sess. (1967).

[45] Electric Vehicle hearings at p. 347. See also, "Prospects for Electric Vehicles," Department of Health, Education, and Welfare, National Center for Air Pollution Control (May 15, 1968), at pp. 78–82.

[46] But see Ideas, February 1969, p. 34, where Dr. Victor Wouk, director, Electronics Research, Gulton Industries, Inc., disputes the performance limitations of electric vehicles and states that the only "operational failure" at present of the electric vehicle is range.

[47] "Automobile Air Pollution Report (II)," supra note 3.

[48] "Automobile Steam Engine and Other External Combustion Engines," joint hearings before the Committee on Commerce and the Subcommittee on Air and Water Pollution of the Committee on Public Works of the U.S. Senate, 90th Cong., 2d sess., 1968, hereinafter cited as "Hearings."

[49] Hearings at p. 1.

This report reviews the hearings and discusses present external combustion, low-emission, engine development, and the potential outlook for successfully marketing such an engine. The report concludes that the external combustion engine is a satisfactory alternative to the present internal combustion engine in terms of performance and that it is a dramatically superior alternative in terms of emissions.[50] The report ends by making specific recommendations for further action designed to facilitate the development of low emission vehicles.

THE RANKINE PROPULSION SYSTEM

Introduction

In the Rankine or vapor cycle propulsion system,[51] the ignition of the fuel takes place without explosion outside the engine in the burner.[52] The heat produced by the burning of the fuel in the burner is used to heat up a working fluid—water or some other neutral fluid. When the fluid is heated, it converts to vapor. This conversion takes place in a monotube steam generator. The vaporized fluid becomes the power source for the engine. It is conducted to the engine, where it is used to drive the pistons or turbines which turn the shaft and drive the wheels. Valves control the entry and exit of the vaporized fluid. Instead of an explosion within the piston chamber, as occurs in the internal combustion engine, there is simply the entry and exit of a vaporized fluid. In a closed Rankine cycle system, the exhausted vapor is captured, run through a condenser resembling a radiator, cooled, and returned to its liquid state where it is ready to be heated again in the generator.

A Rankine propulsion system does not utilize a transmission. The car can accelerate from a dead stop without a transmission because the engine delivers high torque at low speeds. Its high-torque qualities may, however, require a simple system to gear down the drive train in order to prevent wheel spin.[53]

When the vehicle is at a standstill, the vapor source to the engine is cut off, and the engine does not run. The vehicle is put in motion by simply opening a valve. Acceleration is very good. An engine with an engine rating of 168 horsepower will accelerate from 0 to 60 miles per hour in 9.5 seconds. An ICE with a rating of 250 horsepower propelling the same load takes 10 seconds to accelerate from 0 to 60

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[50] See infra, p. 18.

[51] This report does not attempt to discuss in specific detail the various kinds of external combustion engines. The main focus in the hearings was upon the Rankine cycle engine. The report will primarily discuss that propulsion system.

There are two systems, however, which should briefly be discussed. General Motors testified that the Stirling engine was perhaps the best external combustion alternative to the internal combustion engine. Hearings at p. 44. The Stirling engine uses hydrogen or helium as the working fluid, and because of very high temperatures and pressures requires rather exotic and expensive alloys. It has excellent emission qualities, is more efficient than the steam engine (about 35 percent thermal efficiency), but is not economically competitive except in large vehicles such as trucks or buses. Hearings at p. 13.

A Stirling engine has been used in an external engine-battery hybrid propulsion system. Id. at pp. 44–45. The low-emission engine is used to charge the electric batteries which serve as the power source for the drive train. Such hybrid systems could employ controlled internal combustion engines and might lead to reduction of air pollution. See hearings at pp. 242–244 for a discussion of these hybrid systems and their potential pollution advantages. See also, app. B for a recent article on GM's hybrid car ("GM Builds No-Smog Car").

[52] For a glossary of terms relating to external combustion engines see hearings at pp. 12–13.

[53] Professor Gouse testified that such gearing could serve to control acceleration, but such control might not meet with consumer acceptance. Hearings at p. 74.

miles per hour.[54] Smaller horsepowered Rankine engines accelerate at rates equivalent to larger horsepowered ICE's because the Rankine engine loses less power between the engine and the wheels since there is no complicated transmission.

Braking for a Rankine-powered vehicle can be accomplished by conventional means, or else the engine, by means of reverse torque, can brake the car. Reverse torque can be employed in emergency situations only or in each braking maneuver.[55]

The Rankine propulsion system is adaptable to present automobiles. The burner, generator, and condenser can fit within the existing space under the front hood.[56] The engine can be placed in the present transmission casing or further back under the car near the differential. Existing auxiliaries can be run off power provided by a small Rankine turbine engine which operates even when the main engine does not; thus heat or air conditioning can be provided at all times.[57]

Emission characteristics

Unlike an ICE, combustion of fuel in the burner of a Rankine cycle system is almost complete. This means that under normal operating conditions, without attempts at emission control, a steamcar produces almost no pollution. In emissions tests conducted on the 8-year-old Williams Steamcar the following results were obtained:[58]

Hydrocarbons	20 p.p.m.
Carbon monoxide	0.05 percent.
Nitrogen oxides (no lead)	40 p.p.m.
Lead	None.

[54] App. B (Critical Comparison Report):

TABLE 1.—PERFORMANCE OF AUTOMOBILES WITH VARIOUS 150-HP. POWER SYSTEMS

[Weight of auto plus load, 3,500 lbs.; tire pressure=28 p.s.i.; tire diameter=2 ft.; standard air conditions; frontal area=22.4 ft.; CD=0.4; coefficient of friction between tires and road=0.6]

	Otto [a] cycle (engine rating≈250 hp.) [b]	Vapor [c] reciprocator (engine rating≈168 hp.) [d]	Vapor [e] turbine (engine rating≈150 hp.) [f]
Top speed	117 m.p.h	121 m.p.h	117 m.p.h.
0 to 60 m.p.h. acceleration	10 seconds	9.5 seconds	10 seconds. [g]
30 to 60 m.p.h. acceleration	5½	5 seconds	6½.
Grade at 60 m.p.h	20 percent	22½ percent	20 percent.

[a] Transmission efficiency taken as 90 percent.
[b] 150 hp. corresponds to maximum torque condition, assumed to occur at 60 percent of maximum power. Engine assume to operate at constant 3000 r.p.m. during all calculated maneuvers.
[c] Transmission efficiency taken as 98 percent.
[d] 150 hp. corresponds to normal maximum power at maximum engine r.p.m. (6,000 r.p.m.) Engine operates with fixed gear ratio; rotates at 3,000 r.p.m. at 60 m.p.h. Cutoff held wide open during acceleration to 60 m.p.h.; at 60 m.p.h. the engine develops 168 hp., and reaches 150 hp. at 7.5 seconds (50 m.p.h.). Engine could be designed never to exceed 150 hp. at slight penalty to acceleration time.
[e] Transmission efficiency taken as 98 percent for acceleration; 90 percent for other conditions.
[f] 150 hp. corresponds to normal peak power at 30,000 r.p.m. turbine speed. Fixed gear ratio assumed during acceleration from 0 to 60 m.p.h. (30,000 r.p.m.); turbine operates at 30,000 r.p.m. at all power levels once having reached 30,000 r.p.m.
[g] Traction limited. Turbine supplies more torque at start than traction can transfer.

[55] The ability of the Rankine engine to perform the braking maneuver may have some important pollution control effects. Investigations are currently underway to determine the amount of asbestos pollution caused by vehicles whose brake linings are composed of asbestos. (See supra note 10.) If asbestos from automobile brakes is found to be a serious health hazard, the Rankine vehicle could significantly reduce this danger by utilizing the engine in each braking maneuver, thus reducing wear on brakes—wear which throws small asbestos particles into the air.

[56] See app. A (Lear letter).

Testimony in the hearings as to the size and weight of a steam engine was somewhat conflicting. Dr. Robert Ayres stated at the hearings that "a closed-cycle steam engine weighs approximately 4 pounds per horsepower compared to the ICE's 3 pounds" (hearings at p. 4). "General Motors Co. suggested that the steam engine would weigh three times as much as the ICE" (id. at p. 48). "Ford Motor Co., in a chart comparing engine installation, indicated that the ECE and ICE would be of comparable size and pictured the engines occupying the same space within the vehicle" (id. at p. 30).

[57] See app. A (Lear letter). See also discussion in text accompanying note 99 infra.

[58] Hearings at 113. These results are well below the projected 1975 emission goals. The suggested national goals for 1975 are: Hydrocarbons, 50 p.p.m.; carbon monoxide, 0.5%; nitrogen oxide, 250 p.p.m.

Compare these results with the uncontrolled ICE:[59]

Hydrocarbons	900 p.p.m.
Carbon monoxides	3.5 percent.
Nitrogen oxides	1,500 p.p.m.
Lead	(?)

The low-emission characteristics of the external combustion engine (ECE) are built in. This is an important feature. There are no emission controls to maintain or repair. Deterioration is virtually nonexistent. As long as the engine functions, it will function with low-emission characteristics. Compared to the controlled ICE, then, the Rankine system's emission characteristics are far superior.[60]

Noise characteristics

The Rankine system not only helps eliminate air pollution, it also greatly alleviates noise pollution. A Rankine vehicle cuts perceived vehicular noise by a factor of 4 at peakloads which is equivalent to multiplying the distance between sound and person by 10.[61] Trucks and buses gearing up and gearing down are the greatest generators of surface vehicle noise. By operating under steampower, the need for a transmission in trucks and buses is eliminated; and their roar can be reduced to a tolerable whirring sound. Again, noise pollution control like air pollution control is a built-in quality of the steam engine. No practical amount of muffling of the ICE can replicate the inherent, relative silence of the ECE.

Fuel requirements

The Rankine vehicle operates on a variety of fuels.[62] It can burn gasoline from the pump of any service station, or it can operate equally as well, perhaps better, on low-grade white kerosene. The steamcar does not require leaded gasoline with high octane ratings. Rankine fuel, then, is less refined, less costly, and less polluting than ICE fuel.

Fuel consumption tests on existing steam vehicles and consumption projections for future Rankine vehicles indicate that such vehicles get, or will get, better fuel mileage than their ICE counterparts.[63] The Williams steamcar averaged 20 miles per gallon on kerosene in a conventional gasoline mileage test.[64] Comparable ICE vehicles get only 15 miles per gallon. Representatives of General Motors testified that the steam engine consumed 0.70 pounds of fuel per horsepower hour compared to the ICE's consumption rate of 0.50.[65] Further examination of those figures revealed, however, that the loss of horsepower in the drive train was not represented in the ICE figures.[66] It is fair to conclude that steam engine mileage will be as good as the ICE mile-

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[59] "Automobile and Air Pollution Report (II)," supra note 3 at p. 23.

[60] See App. A (Smith and Peterson letter) where current Rankine engine emission statistics are presented:

Total grams per mile of hydrocarbons, carbon monoxide, and oxides of nitrogen

California standards, 1970	27.2 g.
California standards, 1972	25.9 g.
California low emission vehicle, AB 356	12.25 g.
1967 Smith and Peterson test	4.8 g.
1968 Smith and Peterson capability	2.8 g.

[61] Hearings at pp. 8 and 99.

[62] Hearings at p. 99. Of course, an engine will probably be designed to run on one particular type of fuel and be most efficient with that fuel.

[63] See app. B, "Critical Comparison of Otto and Rankine Cycle Engines," at p. 14.

[64] Hearings at p. 115. The test was the seven-mode California cycle test.

[65] Id. at p. 48.

[66] Id. at p. 55.

age—probably better—and that it will consume less expensive fuels which do not have lead and other additives that add to air pollution.[67]

Cost

Vintage steamcars were quite expensive compared to their ICE competitor, but this was primarily due to low-volume, nonassembly line, production.[68] Dr. Robert Ayres maintains that a steam-powered vehicle would cost less to produce on the same scale, and the same amount to produce on a smaller scale, than a comparable present ICE vehicle.[69] Dr. Morse estimates that the steam engine will cost 1.5 times as much as the present ICE; and General Motors Co. boosts that to three times as much.[70] It is possible that the GM figures take into account only the comparative engine costs, not total drive train costs.[71] The Battelle research report properly concluded:[72]

> It is impossible to fix a specific cost figure based on current data because no figures are available which reflect volume-production quantity. The best available evidence indicates that the specific cost will be less than that of a comparable diesel engine and about equal to that of an equivalent V–8 engine with automatic transmission. *The additional cost of a transmission will be eliminated with steam power.*

Maintenance and reliability

Testimony relating to the maintenance and reliability characteristics of the Rankine propulsion system was conflicting. Ford Motor Co. in the hearings considered the Rankine engine to be more complex than the present ICE.[73] On the other hand, Professor Gouse thought that the Rankine engine was simpler, particularly when compared with an ICE with emission control:

> If you look under the hood of a new car, the number of valves and devices added for exhaust emission control are not negligible, and the next year or two may bring more.[74]

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[67] See app. B ("Leaded Gasoline Presents Hazards to Health").
[68] Id. at p. 8.
[69] Id.
[70] Id. at p. 48.
[71] See the graphs submitted by General Motors (app. A) which still show a differential in price of about 2 to 1 even when exhaust reactors are added to the ICE. Again, it is possible that the figures do not include transmission cost comparisons.
[72] See research report for HEW (National Center for Air Pollution Control), "Study of Low-Pollution Potential Power Sources for Urban Vehicles," Battelle Memorial Institute (March 15, 1968) at 61–62.
See also app. B, "Critical Comparison Report."

TABLE 3.—RELATIVE COST COMPARISON OF OTTO AND RANKINE SYSTEM

	Otto cycle	Steam reciprocator	Steam turbine	Organic reciprocator	Organic turbine
Engine [1]	$0.42	$0.40	$0.20	$0.40	$0.16
Heat addition		.20	.18	.18	.10
Heat rejection	.04	.10	.10	.10	.18
Transmission	.35	.15	.40	.15	.3
Accessories [2]	.13	.13	.11	.10	.10
Emission control	.06				
Total	1.00	.98	.99	.93	.93

[1] Engine cost includes fuel-injection system and ignition system.
[2] Accessories exclude air conditioning, power steering, power brakes, power seats, power windows.

[73] Hearings at p. 29. But see id. at p. 165, where the Ford data is challenged. Ford has been severely taken to task for its complexity ratings which testimony disclosed were based on guesses. See also id. at p. 163. A survey conducted in July by Industrial Research found that of the more than 400 scientists and engineers, 87 percent disagreed with Ford's claim that steam engines are more complex. See Ideas, "Information on Developments in Electricity and Steam," November 1968, at p. 15.
[74] Hearings at p. 82.

A recent study has compared the reliability and maintenance characteristics of the ICE and Rankine systems. The following tables illustrate the better maintenance and reliability of the Rankine system: [75]

Other characteristics

1. Safety

In his testimony, Mr. Hafstad of General Motors stated that the high-pressure steam used to propel steam engines created a consider-

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[75] See app. B, "Critical Comparison," at pp. 12 and 15:
"The Rankine engine has the potential of having these major advantages over the Otto cycle engine for automobile use: *maintenance* and *reliability,* fuel, economy, low emissions." [Emphasis added.]

TABLE 4.—RELIABILITY COMPARISON OF OTTO AND RANKINE ENGINES

	(V–8) Otto cycle	Steam reciprocator (4 cycle)	Organic reciprocator (4 cycle)	Steam turbine	Organic turbine
Main bearings	5	5	5	2	2.
Connecting rod and wristpin bearings.	16	8	8	0	0.
Camshaft and rocker arm and pump bearings.	22	13	13	2	2.
Set of rings or equivalent.	8	4	4	0	0.
Valves	2 per cycle, cam operated.	1 per cycle mechanically operated, 1 sleeve. seal.	Same as steam reciprocator.	Variable nozzle reciprocator.	Variable nozzle.
Controls	Throttle control on carburetor (plus automatic control on carburetor, coolant temperature).	Valve cutoff, fuel flow pump speed (plus automatic temperature and pressure control).	ditto	ditto	Do.
Seals	2 major oil seals	1 major fluid seal.	ditto	Same as steam reciprocator.	Same as steam reciprocator.
Transmissions	Multigear, hydraulically controlled system.	Simple gears	Simple gears	Multigear, hydraulically controlled system.	Do.
Peak metal temperature.	1,200° F. plus	1,000° F	700° F	1,000° F	700° F.
Minimum internal steady-state temperature.	180° F	212° F	150° F	212° F	150° F.

TABLE 5.—PARTS NEEDING ADJUSTMENTS OR SERVICING

	Otto cycle	Steam reciprocator	Organic reciprocator	Steam turbine	Organic turbine
Prime mover	Valve life	Cutoff valve	Gate valve	Cut off valve	Gate valve
	Valve surfaces				
	Bearings				
Heat addition	Ignition system	Fuel flow control.	Same as steam	Fuel flow control	Same as steam.
	Carburetor	Valves	Reciprocator	Fluid flow valve	Turbine.
	Carbon cleanout	Igniter	do	Igniter	Do.
	Fuel pump and filter.	Safety valve	do	Safety valve	Do.
Heat rejection	Fan belt	Fan motor	Fan motor	Fan motor	Fan motor.
	Clean radiator	Clean condenser	Clean condenser	Clean condenser	Clean condenser.
	Coolant				
	Water pump				
Transmission	Fluid			Fluid	Fluid.
	Bands			Bands	Bands.
Auxiliaries	Voltage	Voltage	Voltage		
	Lube system	Deaerator	Deaerator	Deaerator	Deaerator.
	Filter	Lube system			
	Oil	Oil			
	Pump	Pump			
	Belt drive	Condensate and boiler feed pump.	Condensate and boiler feed pump.	Condensate and boiler feed pump.	Condensate and boiler feed pump.

able safety hazard.[76] In older steamcars the danger of boiler explosions may have been real.[77] Today, however, steampower is certainly safe.[78] Mr. Williams discussed this point as follows: [79]

> Let me state exactly what is likely to happen and what might happen if a steamcar is involved in a collision. The modern monotube boiler is totally different from the kind alluded to by Detroit. It is composed of a long length of high-strength steel tubing—of ⅜- to ½-inch diameter—coiled tightly in a spiral and helical shape. It is nothing like a storage boiler used in factories and homes. The monotube steam generator has only a very small amount of steam in it at one time. In a collision, this strong coil would be deformed or distorted—nothing more.
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> Suppose it ruptures—what happens? First, a small piece of tubing, three-eights of an inch in diameter, breaks. The result is that the very small amount of steam contained within the coil is dissipated in a matter of seconds, doing virtually no damage.
>
> There is no large vessel to disintegrate like a huge grenade. In short, the danger of scalding is very slight, and the likelihood of serious danger is not remotely comparable to what happens when 20 or so gallons of high-octane fuel are ignited in a pileup. Here you have an explosion.

There is no danger of boiler explosion in modern monotube steam boilers that would be used in the today's steamcar.[80]

2. Possibility of freezeup

The problem of freezeup does not present serious obstacles.[81] Traditional antifreezes may not work in systems which operate at 1,000° F.—but other antifreezes probably can be developed. Ford Motor Co. assumes that such freezing is a solvable engineering problem.[82]

Mr. Pritchard, in his testimony, suggested alternative solutions to the freezing problem.[83] First, the water tank could be constructed with sloping sides so that freezeups would do no damage and the burner could thaw out the frozen water supply rather quickly. Second, a small pilot light within the burner could keep the water source from freezing—a solution employed in several contemporary steamcars.

Another solution to the freezing problem is to use a working fluid with a low freezing point. Freon, for example, is being tested by some steamcar builders.[84] When freon is used in the closed-cycle Rankine system, the problem of freezeup is virtually eliminated.[85]

3. Water consumption

In older steamcars, water consumption was a problem. The steam cycle was not completely closed; therefore, steam escaped from the vehicle and caused appreciable water loss. Today a hermetically sealed closed-cycle Rankine engine consumes at most 1 gallon of working fluid per 1,000 miles.[86] Water consumption is no longer a problem.

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[76] Hearings at p. 46.

[77] There have been no cases of vintage steamcar explosions reported, however.

[78] See app. A (Lear letter), where it is reported that the latent energy in the generator at any time is equivalent to a few ounces of gasoline only.

[79] Hearings at p. 112.

[80] See app. A (Lear letter).

[81] For a general discussion see Dr. Ayres testimony hearings at p. 9. But see app. A (Chrysler letter) where this problem is put forth as a main obstacle to Rankine cycle development.

[82] Hearings at p. 28.

[83] Id. at p. 153.

[84] See, e.g., Product Engineering, Nov. 4, 1968, where Wallace L. Minto's freon "steam" engine is discussed (app. B).

[85] Freon has a freezing point of —68° F., hearings at p. 9. Minto's freon engine will be used in the Dallas steam bus demonstration project funded in part by the DOT. See discussion in text accompanying notes 102 and 103 infra.

[86] Id. at p. 9.

4. Lubrication and its effects on boiler and condenser life

Lubrication of the steam engine can be accomplished in a variety of ways. In some systems the lubricant is placed directly in the working fluid. Some testimony in the hearings suggested that impurities in the water and the presence of lubricants would have a detrimental effect on boiler and condenser life.[87] On the basis of experiences with the Williams steamcar there does not seem to be a problem; high-velocity flow through the boiler tube prevents scale from accumulating.[88]

Thermo Electron uses solid fluorocarbon lubricants in the working fluid system. By placing this type of lubricant in the system, the seals between the cylinder and the crankcase can be eliminated. This allows a simpler piston setup. There is no need for a cross-head piston and a unit similar to the single-power piston in the ICE is possible.[89]

5. Startup time

Older steam automobiles with large water supply in their boilers took as long as 30 minutes to start. Slow startup, then, is associated with steamcars. Today, with the modern steam engine and its monotube boiler, initial startup time should take less than 20 seconds.[90] After the initial startup and for about a 3-hour period after shutdown, the startup would be instantaneous. Today, startup time is not appreciably longer than for an ICE.

Recent developments

Appendix A contains correspondence from individuals or business enterprises working on the development of low-emission vehicles. Appendix B contains information from secondary sources on low-emission vehicle development. This section will not attempt to discuss all recent developments in this area but will merely highlight some of the major activities. For complete details on important new developments in the low-emission field the reader should consult the appendices.

California has recently given impetus to the development of Rankine cycle propulsion systems.[91] By resolution the California Legislature has asked the California Highway Patrol to test Rankine cycle patrol vehicles in six different geographical regions of the State.[92]

The California Highway Patrol demonstration project initially was to be funded by General Motors Corp., which had agreed to pay a selected vendor $20,000 toward the cost of developing an engine, and up to $100,000 for outfitting six operational patrol vehicles.[93] Because of problems of proprietary disclosure of information and hardware,[94] the Rankine engine manufacturers rejected the General

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[87] Id. at p. 46.
[88] Id. at p. 79.
[89] See diagram id. at p. 129.
[90] Mr. Minto claims a 3–6 second startup time for his Freon "steam" engine. Product Engineering. Nov. 4, 1968. at p. 56 (app. B).
[91] In the first place California has passed emission standards that will severely test the emission control potential of the internal combustion engine. (AB 357 (1968)). Secondly, the California Highway Patrol will undertake a testing program of Rankine cycle patrol vehicles. See text infra. Third, the California Assembly will supervise a steam bus demonstration project financed in part by the U.S. Department of Transportation. See text infra. Finally, California by legislative mandate will purchase low-emission vehicles for State use. (AB 356 (1968)). See text infra under "Recommendations."
[92] See app. B for copy of California Assembly Resolution No. 111 (1968).
[93] See Ideas, October 1968, p. 5.
[94] See Ideas, February 1969, p. 33 (corroborated by phone conversation with William P. Lear, Feb. 19, 1969).

Motors offer. After several false starts,[95] the California Highway Patrol has accepted letters of understanding from two firms which will each furnish a highway patrol vehicle to the patrol for testing within the next 6 months.[96] Thermodynamics Systems, Inc., has been given a late model Oldsmobile by the California Highway Patrol; it will convert the vehicle to steam and return it to the patrol for testing.[97] No specific details about Thermodynamics' powerplant are presently available.

Lear Motors Corp. of Reno, Nev., will provide the California Highway Patrol with a test vehicle by August 1, 1969. William Lear has purchased a 1969 Dodge Polara, the vehicle presently used by the patrol, and is converting that vehicle to steam.[98] Lear reports that the Rankine system he is installing will fit within the present space under the front hood. The engine will have a horsepower rating of at least 300 and will meet all necessary acceleration and speed requirements of the patrol. Lear reports significant advances related to the auxiliary system:[99]

> I have enclosed for your interest a diagrammatic representation of our basic power system. You will see that an auxiliary package is in operation whenever the system is used. This auxiliary unit provides support for the system proper and, in addition, powers the various services required by the vehicle, such as the air conditioner, power steering pump, alternator, et cetera. Under this arrangement, even though the vehicle were parked with the motor not running, full accessory usage is guaranteed. This has direct application to our highway patrol vehicle where there is a heavy demand for auxiliary power (rotating lights, power supplies, transceivers, etc.) under static conditions. In a passenger automobile, the car could be heated or cooled under "parked" conditions.

California is also undertaking a Rankine engine demonstration project financed by the Department of Transportation.[100] This project involves the installation and testing of Rankine systems in buses in the San Francisco area. The objective of the project is "to demonstrate the complete operational feasibility and superiority and public understanding and acceptance of an external combustion engine-based propulsion system for urban mass transit bus use."[101] Lear Motor Corp. has announced it plans to bid on the engine contract for this project.

The Department of Transportation has recently announced the award of a second steam bus demonstration contract.[102] The city of Dallas will soon have buses powered by Rankine engines using freon as the working fluid. The Department of Transportation selected the

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[95] Initial bidding did not produce satisfactory results and a new request for proposal was distributed to Rankine cycle propulsion system manufacturers. There were four respondents to the second request: Lear Motor Corp.; Thermodynamics Systems, Inc.; Paxve, Inc.; and Mr. Berry W. Foster. (See app. B for complete information on the California Highway Patrol's request for proposal.)

[96] Phone conversation with Inspector David S. Luethje, California Highway Patrol, Feb. 25, 1969.

[97] Id.

[98] Id.

[99] See app. A (Lear letter).

[100] The demonstration project is supported under the Department of Transportation's program of research, development, and demonstrations of the Urban Mass Transportation Administration which is aimed at improving mass transportation in all cities across the Nation through the application of new technology. The total cost of the program for 3 years is estimated at $610,000 of which the Federal share will be $450,000. The initial Federal grant is for $244,250 to aid in the purchase, installation, and testing of the engine. The State of California, AC Transit, and San Francisco MUNI will contribute the remaining funds. (See app. B (California steambus proposal.))

[101] Id.

[102] The Dallas project will cost $464,684 of which the Federal grant from the Urban Mass Transportation Administration will be $309,789. The city of Dallas will pay $114,895 of the project's cost with the balance to be provided by LTV Aeronautics Division in services.

This project was not formally presented to the Department of Transportation in the way the California project was, but the Department is to be commended for allocating funds to both these necessary demonstration projects.

freon engine for testing in the Dallas project because it appears to reduce difficulties with freezing, lubricating, and starting.[103] The engine will be furnished by Kinetics Corp. of Sarasota, Fla.; engineering work on the project will be done by Vought Aeronautics Division of Ling-Temco-Vought aerospace industry.

The most publicized activity in recent months in the field of Rankine propulsion system development is Lear Motor Corp.'s announced plans to enter a steam-powered racer in the 1969 Indianapolis 500. There are several interesting accounts of Mr. Lear's plans. (See app. B.) Assuming that race officials allow the steam racer to compete,[104] it will be interesting to watch its performance when competing with traditional power plants. Mr. Lear is not alone in his steam racer plans; Mr. W. D. Thompson of San Diego, Calif., also has announced plans to enter a steam racer in a future Indianapolis 500.[105]

In summary, there has been considerable activity in the Rankine cycle field in recent months. This activity has already produced results which reinforce the optimism of Rankine cycle proponents. On the basis of current developments and existing technological capability,[106] there is but one inescapable conclusion.

CONCLUSION

The Rankine Cycle Propulsion System Is a Satisfactory Alternative to the Present Internal Combustion Engine in Terms of Performance and a Far Superior Engine in Terms of Emissions.

This conclusion is based upon the above discussion. The Rankine vehicle is more economical to operate because it gets better gasoline mileage using less expensive fuels,[107] and because it has better maintenance and reliability potential.[108] Its acceleration, auxiliary operation, and braking characteristics are superior to those of the ICE. Alleged "problems" in applying Rankine cycle systems to automotive use have been or are being solved. The Rankine cycle engine is as safe as the ICE;[109] it consumes no more water;[110] freezeup can be avoided;[111] and startup time is satisfactory.[112] In terms of the all-important exhaust emission characteristics, the Rankine cycle system is far superior to the ICE,[113] and if the ICE becomes more competitive in this area, it will become less competitive in terms of gas mileage, maintenance, and reliability.[114] These assertions have been confirmed in a recent report, entitled "Critical Comparison of Low-Emission Otto and Rankine Engine for Automotive Use," delivered at the International Automotive Engineering Congress in Detroit, Mich., on January 13, 1969.[115] The authors of this report conclude:[116]

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[103] See app. B ("Product Engineering—Minto") for a description of Minto's activities in developing engines using Freon.

[104] Any attempt to keep the Rankine vehicle out of competition will be viewed by critics as another automotive industry attempt to stifle progress and perpetuate the status quo. Such an exclusion may, in fact, prompt a congressional inquiry.

[105] See app. A (W. D. Thompson letter).

[106] See app. B, "Critical Comparison Report."

[107] See discussion in text accompanying footnotes 62–67 supra.

[108] See discussion in text accompanying footnotes 73–75 supra.

[109] See discussion in text accompanying footnotes 76–80 supra.

[110] See discussion in text accompanying footnote 86 supra.

[111] See discussion in text accompanying footnotes 81–85 supra.

[112] See discussion in text accompanying footnote 90 supra.

[113] See discussion in text accompanying footnotes 58–60 supra.

[114] See supra, footnote 38.

[115] See app. B ("Critical Comparison Report").

[116] Id.

The Rankine engine has the potential of being better than the Otto cycle engine in maintainability and reliability, fuel economy, and exhaust emissions. Also, the Rankine engine should be at least comparable in initial cost and safety in case of accident * * *.

It is, therefore, recommended that the automotive industry seriously consider the Rankine engine as the future powerplant and that the chemical and petrochemical companies concentrate on the development of the "ideal" fluid.

Opponents of change may dispute the conclusion reached in this report. But their previous attacks on the feasibility of the Rankine cycle engines are no longer viable; they will have to find new criticisms. For example, Chrysler Corp. can no longer say that the problem of cold weather operation is "a real impediment to the successful application of steampower to automotive vehicles." (See Chrysler letter, Feb. 18, 1969, app. A). It presents no such impediment.[117] Ford Motor Co., in face of the evidence, can no longer argue that complexity is a disadvantage for the Rankine vehicle.[118] Finally, General Motors should reevaluate its emission-reduction economics charts.[119] In terms of cost, General Motors lumps Stirling, gas turbine, and steam engines in the same category and concludes they are twice as expensive as controlled ICE's. This is simply not the case: All other cost estimates place controlled ICE's and Rankine systems in comparable categories. General Motors probably neglected to include in its comparisons the substantial cost of the ICE transmission—a transmission not required in the Rankine cycle system.[120]

Opponents of the Rankine system will be hard put to find new criticisms. Although Lear Motor Corp. has been in operation only 6 months, it has put together a research, development, and production program that will place a racing vehicle in the Indianapolis 500 and will deliver an operational highway patrol vehicle to the State of California.[121] Progress in other areas has been as rapid.[122] This progress has taken place without a massive infusion of research and development money; existing technology has been applied. Any critic of the Rankine system will have to confront the fact that Rankine system development is in an embryonic state; the potential for improvement far outstrips any potential for improvement of the ICE upon which immense amounts of capital have already been expended without producing startling improvements in emission or other characteristics.[123]

Finally, it should be pointed out that the Rankine propulsion system that is being developed today is not new in the sense that it has just come within our technological reach. Without the myopic persistence of the automobile industry in devoting most of its research funds to the ICE, a reliable, low-polluting Rankine cycle engine could probably have been developed 20 years ago.

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[117] See discussion in text accompanying footnotes 81–85 supra.
[118] See footnote 73 supra.
[119] See app. A (General Motors letter).
[120] See footnote 71 supra.
[121] See footnote 98 supra.
[122] Thermodynics Systems, Inc., and Kinetics Corp. are among those about to provide operational equipment within a very short time.
[123] Ford Motor Co. will spend a reported $7 million for one emission control research program designed to improve the ICE. A comparable expenditure in the Rankine field would have far greater pollution control impact. (See footnote 130 infra.)

OBSTACLES TO RANKINE CYCLE DEVELOPMENT

(1) Inertia of automobile industry

The auto industry is committed to emission control of the ICE rather than development of a low-emission external combustion system.[124] At the hearings General Motors stated that "we continue to believe that clean air quality objectives can be achieved most quickly and at a lower price through further development of the internal combustion engine."[125] In a recent letter to the Senate Commerce Committee General Motors stated:[126]

> To summarize, we are actively investigating a number of energy conversion methods, including steam engines, which offer potential for satisfying automotive power requirements. However, present technology indicates that the gasoline engine still offers the best compromise as to cost, durability, reliability, economy, performance, efficiency, and the control of pollutants.

To substantiate the above claims General Motors has prepared several charts showing pollution-reduction economics.[127] In every case their charts purport to show that in the 1970's the internal combustion engine will match the pollution performances of the alternative powerplants at an expenditure of at least a third less.[128]

Ford Motor Co. stresses that it is "aggressively pursuing all avenues leading to the ultimate goal of clean air."[129] The main thrust of the Ford emission control program has been the development of control systems for the internal combustion engine. Ford has been a leader in a reported $7 million automobile and petroleum interindustry emission control program (IIEC) based on a systems approach concept for solving the common problem of emissions.[130] Ford announced:

> We have not met all our emission objectives as yet, but we are quite gratified with the results achieved to date. The second vital phase of the engineering problem—proving the durability of these hardware systems—is also underway but the major efforts in this area lies ahead.[131]

Ford also reports engineering and research work with alternate power sources, particularly the gas turbine, which is powering Ford trucks carrying cargo from Michigan to plants in Ohio.[132]

Without disparaging their efforts at ICE emission control, it would seem that neither Ford nor General Motors plans to work toward the development of what appears to be a more promising Rankine cycle propulsion system. A response from Chrysler Corp. indicates they are of like mind.[133]

None of the "Big Three" automobile manufacturers are working toward developing a Rankine cycle vehicle. Only American Motors Corp. reports an interest in Rankine propulsion development:[134]

> We are pursuing a program to develop the application of steam as a result of a suggestion by a highly regarded potential supplier of this type of equipment. We have only begun to consider this latter alternative but are presently optimistic about its mechanical possibilities.

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[124] Hearings at pp. 24, 33, and 48.
[125] Hearings at p. 53.
[126] App. A (General Motors letter).
[127] App. A (General Motors letter).
[128] See discussion accompanying footnotes 70 and 71 supra.
[129] App. A (Ford letter).
[130] See hearings at p. 27; see also App. A (Ford letter).
[131] See app. A (Ford letter).
[132] See app. A (Ford letter) and app. B ("Turbine Era Dawns," Automotive News, Feb. 10, 1969, p. 8).
[133] See app. A (Chrysler letter).
[134] See app. A (American Motors letter).

As you might imagine, American Motors is highly interested in developing a low-emission, mass-produced automobile. Not only would this have advantages from a social point of view, but we look upon it as a rare opportunity for our company.

The present juxtaposition of the approach to Rankine cycle development by the "Big Three" and American Motors is interesting. In the hearings, Ford Motor Co. said that "* * * it is often assumed that our industry would resist any radical change in automotive power systems because of our tremendous investment in existing production facilities. On the contrary, one of the reasons we are continually examining new power sources is that we must periodically update our designs, plants, and equipment *to meet the ever-changing demands of our customers*." [135] The Big Three must not see a customer demand for a low-emission, reliable Rankine cycle vehicle ;American Motors, without a large stake in the existing market, at this time does see such a demand.

Senator Muskie's concern that "the momentum of the status quo may run counter to the public interest" is well founded.[136] There is no assurance that the present course set by the major automobile manufacturers will lead to the development of a low-emission, reliable internal combustion engine.[137] Their present course does seem to assure, however, that low-emission Rankine cycle propulsion units will not be developed by one of the major automobile manufacturers.

Ironically, Government, as the protector of the public interest, also may very well be pursuing a course contrary to the public's long-range interest. For example, in fiscal year 1967 the Department of Health, Education, and Welfare spent $3.2 million on automobile emission research.[138] Only $115,000 was spent for researching ICE alternatives; the rest went to refining the ICE.[139]

The inertia of the automobile industry toward the development of the Rankine cycle propulsion system is perfectly understandable. The auto industry has large sums committed to the present internal combustion engine in terms of development man-hours and production capabilities.

There are several other reasons why the auto industry is dragging its feet in the development of a Rankine propulsion system. As Ford Motor Co. has stated, the automobile industry changes its designs, plants, and equipment "to meet the ever-changing demand of our customers." [140] There is as yet no customer demand for a Rankine propulsion system. The public is simply not aware of the advantages of the Rankine system as a power source for general-use vehicles. Not until a vehicle powered by a Rankine system is developed and widely

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[135] Hearings at p. 25.

[136] Hearings at p. 33 :

"Senator MUSKIE. You [Mr. Misch, Ford Motor Co.] make the point, which is very legitimate, that the internal combustion engine has benefited from the contributions of thousands of engineers, scientists, and manufacturing experts over many years. In addition, there is a commitment to the internal combustion engine in terms of investment, and consumer acceptance, and consumer familiarity.

"Doesn't all this, however, add to the momentum of the status quo in a way that may run counter to the public interest?

"Mr. MISCH. Well, it would only run counter to the public interest if we pursued the internal combustion engine and failed to arrive at the satisfactory final position with regard to pollutants."

[137] See discussion in test accompanying footnotes 33–35 supra.

[138] "The Automobile and Air Pollution : A Program for Progress (Part II)," U.S. Department of Commerce (December 1967) at p. 25.

[139] Id.

[140] Hearings at p. 25.

publicized will there be even a limited customer demand for the Rankine-powered vehicle.

Not only is there no customer demand for a Rankine cycle vehicle, there is not even a general customer demand for a low-emission vehicle. When purchasing an automobile the individual consumer does not use emission control as one of his influencing criteria.[141] Although he may be opposed to air pollution in general, he does not normally shop for a low-polluting vehicle himself. In fact, he may shop for the highest allowable polluting vehicle because present pollution control devices interfere with the efficient operation of the engine and require constant adjustment. Because there is no consumer demand, the automobile industry's present posture toward Rankine systems specifically, and pollution control in general (especially before Federal emission standards), is understandable even though it may not be commendable.

Of course, there is presently customer demand for some of the benefits that the Rankine vehicle would offer. For example, the customer presently looks for good gas mileage and low-noise qualities. In addition the Rankine system has better maintenance and reliability characteristics than its elaborately controlled ICE counterpart. Finally, automobile manufacturers do not have to wait for customer demand before they act. How often have they created new customer demands through saturation advertising? As auto critic Ralph Nader once said: "Who wanted fins?"

(2) The petroleum industry

The petroleum industry is engaged in a joint auto-gas industry study of ICE emission control and will spend an estimated $19 to $25 million for research between 1967 and 1969.[142] It is probable that the petroleum industry and automobile industry are firmly wedded to each other in their approach to the problems of vehicular air pollution.

However, on January 30, 1968, the Wall Street Journal reported that "the automobile industry, in an apparent effort to simplify its own efforts to reduce auto-caused air pollution is now trying to shift part of the blame for dirty air to gasoline * * *. The oil industry, needless to say, is not pleased by the indictment of its products. 'They're just looking for someone to join them on the hot seat,' complains a research executive for one major oil company." The present rift between the automobile industry and petroleum industry may cause the petroleum industry to review its assumed present negative posture toward Rankine cycle systems.

In such a review the oil industry would have to balance the costs of producing "clean" gas against the costs of converting to lower grade fuels. It has been reported that the cost of "clean" gasoline would result in extra costs of 1 cent to 2.3 cents per gallon and an added investment of $1 to $3 billion.[143] There are no available cost estimates on the conversion of refineries from high-octane petroleum to kerosene, but such conversion would necessitate phaseout of existing refinery facil-

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[141] Very few individuals are aware enough or public spirited enough to choose an automobile merely on its pollution qualities. The steam vehicle will have to be competitive in every other way if it is ever to gain wide public acceptance. But competition does not require limitation. The steam vehicle may offer an unusual opportunity to adopt innovative and safer, but still competitive, design characteristics that complement the novel propulsion spstem. (See e.g., app. A (Lear letter).)

[142] "Automobile and Air Pollution Report (II)," footnote 138 supra at p. 28.

[143] Ideas, February 1969, p. 35. The figures were based on an American Petroleum Institute report.

ities and cause disruptions which no established industry favors. In addition to refining changes there would be per mile consumption changes downward and some changes associated with auto servicing and supply operations. Certainly the Rankine vehicle is preferable from the oil industry's standpoint to electric vehicles, but on balance the recent rift between the auto and petroleum industry is not likely to cause the petroleum industry to divorce itself from the automobile industry and come out in favor of a Rankine cycle system. Profitwise there is probably "nothing in it for them."

(3) Costs of introducing Rankine propulsion system in face of industry inertia

Because the major automobile manufacturers apparently are not going to develop and market the Rankine propulsion system, such development and marketing will have to be undertaken independently. The obstacles to such an independent undertaking are enormous.

The price of direct entry into the passenger vehicle market has been estimated to be $300 to $400 million.[144] This price includes the money necessary to set up nationwide dealerships and nationwide service facilities as well as a cost increment because of anticipated subcontracting problems. In addition, it includes money necessary to sustain a fairly high rate of production in order to produce the vehicle at minimum cost so that it is economically competitive with its ICE counterpart. The extremely high price of entry will undoubtedly prevent any independent steam automobile manufacturer from directly entering the automotive market.

Such large capital expenditure is all the more unlikely, given the risks of such an undertaking. Assuming the innovator meets with initial success, such success is likely to be short lived. The automobile industry is capable of responding to any innovative competitive threat by producing a Rankine vehicle of their own.

> The steam innovator is faced with some very difficult problems. His vehicle is general purpose and will probably require a fairly substantial dealer organization for initial success. A fairly high rate of production will probably be required for minimum cost. The possibilities of subcontracting for large quantities of components he will need are limited. Thus his capital and organizational requirements are heavier than for the electric car innovator. If he overcomes these difficulties and markets an attractive product, success is likely to be short lived. The automobile industry could readily adapt its production and service complex to steam-power if forced by serious competitive threat. Unless the steam innovator is much better, or luckier than most, he will be eliminated. What innovator will challenge the automobile industry in an area where the advantages accruing to him are small and the disadvantages overwhelming?[145]

Any development and marketing of a Rankine propulsion system will take place only when an entrepreneur overcomes the anticipated costs of direct entry. He must figure a way to reduce the cost of establishing nationwide dealerships and service centers and to reduce the cost of manufacturing his own nonpropulsion system automotive component parts. Ideally, he must also figure a way to market a price competitive product at a low initial production rate.

One way to accomplish these goals is to contract with an existing automobile manufacturer to provide Rankine propulsion units for some of its vehicles. By marketing Rankine propulsion system units

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[144] Hearings at p. 10.
[145] Hearings at pp. 65–66.

through an organization with existing dealer and service networks, initial capitalization costs in those areas would be considerably reduced. A new propulsion system would require some service investments, but these could be developed in conjunction with existing facilities. The cost of nonpropulsion unit parts would be eliminated because the automobile manufacturer would supply those parts. The remaining problem of manufacturing a price-competitive product during initial production could be overcome if the Rankine system manufacturer and auto company were willing to accept temporarily an after-tax profit margin lower than the existing one. Any such effort could be countered, however, by a corresponding profit reduction by industry members not producing Rankine-powered vehicles.

Another way to reduce entry costs is to sell Rankine vehicles in specialized markets until production is raised to a level where a company can offer vehicles generally at competitive prices. Such markets exist where vehicles such as buses, taxis, or trucks are used in fleet operations within a limited geographic area.[146] Such fleet sales would not require extensive dealer networks. The servicing costs would be minimal because fleet operations usually have their own central servicing facilities. Unless the Rankine vehicle producer worked in concert with an existing automobile company, the costs associated with nonpropulsion automotive part procurement and low-volume production would still have to be sustained. Too, such an approach would not lead immediately to widespread development and marketing, but as an initial approach to Rankine development it may be the only practicable method available.

A final speculative approach, used alone or in conjunction with one of the others, might be to try to create a consumer demand for Rankine cycle vehicles by building prototype cars and publicizing their advantages. Once a customer demand has been created, then the automobile industry might respond by developing an innovative propulsion system. Ford Motor Co. suggests that customer demand guides innovative development. A successful race car, for example, built at a cost far below the $300 million direct-entry cost, might generate consumer demand for Rankine-powered cars, and Detroit might respond to this demand.

RECOMMENDATIONS

Federal, State, and local governments have an immediate and pressing duty to protect the health of the American people by curbing dangerous vehicular air pollution. It is clear that present efforts to curb pollution by regulating new car emission levels are wholly unsatisfactory. Therefore, Federal, State, and local governments should take immediate and comprehensive steps to encourage the development of low-emission vehicles.

Congress Should Pass Legislation Requiring Government Procurement of Low-Emission Vehicles

Legislation requiring Federal procurement of low-emission vehicles will foster low-emission vehicle development. Such legislation will

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[146] "The potential business in the bus and truck field alone is tremendous. If only one-tenth of 1 percent of the 16½ million buses and trucks in this country could be converted to steam within the next 10 years, the volume of sales would exceed $90 million, and this is in only one of the potential market areas" (hearings at p. 255).

make feasible independent innovative development of low-emission vehicles. By offering legislatively guaranteed markets, a reasonable rate of initial production is possible.[147] Initial costs of low-emission vehicles can thereby be made more competitive with existing vehicles. Large capitalization for nationwide dealerships and servicing centers is unnecessary. Sales of these vehicles can be arranged centrally with the purchasing agents of the various departments thereby reducing marketing costs, and many Government vehicles are centrally serviced thereby reducing investment costs for service centers. The legislatively guaranteed market also provides impetus for an existing automobile manufacturer to close ranks with any low-emission engine producer, thereby minimizing the cost of nonpropulsion automotive parts to the innovator.

Secondly, the procurement legislation creates a consumer demand for low-emission vehicles. This demand might prompt Detroit auto manufacturers to accelerate their development work in the low-emission field.

What form might this legislation take?

Federal procurement finds precedent in California, the acknowledged leader in the air pollution field. Federal legislation should be modeled after California's Low Emission Motor Vehicle Act.[148] The California act defines a low-emission vehicle as one which "does not have exhaust emissions of more than 0.5 grams per mile of hydrocarbons, 11 grams per mile of carbon monoxide, and 0.75 grams per mile of oxides of nitrogen."[149] After the Air Resources Board certifies the emission levels, the Department of General Services in consultation with the Board determines if the low-emission vehicle meets all the following requirements:[150]

(*a*) Such vehicle can be manufactured in sufficient numbers for the purpose of proper evaluation.

(*b*) Such vehicle meets the performance needs for State vehicles.

(*c*) If such vehicle is purchased by the State there would be a sufficient number of servicing and maintenance outlets.

(*d*) The average servicing and maintenance costs for a low-emission vehicle are comparable to the average servicing and maintenance costs for all other State passenger vehicles, but in no event shall the average servicing and maintenance costs for low-emission vehicle exceed the average costs of servicing and maintaining all other State passenger cars by more than 50 percent.

(*e*) The cost of such vehicle does not exceed by more than 100 percent the average cost of State passenger vehicles purchased in the preceding fiscal year.

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[147] Total net fleet inventory for all Federal agencies (civilian and military, not including troop training or tactical vehicles) amounted to 380,758 vehicles as of June 30, 1968. This included 68,065 sedans, 13,560 station wagons, 3,763 ambulances, 12,488 buses, and 282,882 trucks. Total Government agency purchases for passenger-carrying vehicles amounted to $26,047,272 for 15,706 vehicles. Total expenditures for buses, ambulances, and trucks in fiscal year 1968 amounted to $128,736,562 for 46,360 vehicles. (See "Annual Motor Vehicle Report—Fiscal Year Ending June 30, 1968," GSA (February 1969).)

The Post Office alone on Sept. 10, 1968, put out to bid an order for 24,000 quarter-ton delivery vehicles for use by urban letter carriers.

[148] This bill added ch. 5 (commencing with sec. 39200) to pt. I of division 26 of the Health and Safety Code, and to add sec. 14808.5 to the Government Code, relating to low-emission motor vehicles.

[149] Sec. 39201.

[150] Sec. 39203.

Vehicles meeting these requirements will be purchased in quantities determined by the Department of General Services, but in quantities no less than 25 percent of all motor vehicles purchased by the State the previous year.

Federal procurement legislation should follow the California model. The cost and required purchase percentage, however, might be revised. Federal legislation might set a lower price per vehicle. Such price might be determined after considering the required purchase percentage. A sliding scale based on the year purchased and the quantity of purchase might be worked out so that more money per unit is available for initial purchases, of fewer vehicles, but as production increases and per unit costs decrease less money per unit is available.[151] But the problem of vehicular air pollution is so great, and a solution so urgently needed, that cost should not impede a broad-scale Federal procurement program.

It should be noted that proposed legislation would initially create a market only for Rankine or electric propulsion systems because ICE's have not reached the required emission levels. But the legislation itself would be written in terms of emission goals, not types of propulsion systems. If modified ICE's can meet the requirements of the act, they would also be eligible for purchase.

Prior to passage of Federal low-emission procurement legislation, the various agencies should undertake voluntarily to purchase a limited number of low-emission vehicles. For example, last year in response to a letter from Senator Magnuson, the Assistant Postmaster General explained Post Office procurement practices:

> When, and if, industry offers a propulsion system which can effectively perform in our rigorous service, the Research and Engineering Appropriation is available for purchase of experimental units.[152]

The Post Office should be encouraged to devote such funds to Rankine propulsion systems. If experimental models prove satisfactory, then plant and equipment appropriations should be used to purchase sizable quantities of those low-emission vehicles.

State and Local Governments Should Adopt Low-Emission Vehicle Procurement Policies

By adopting low-emission procurement practices at the State and local level, the advantages discussed above are reinforced.

The Department of Transportation Should Finance Demonstration Projects Which Test Various Transportation Applications of Low-Emission Propulsion Systems

The Department of Transportation is charged with the responsibility of planning for the transportation needs of the country. In exercising its responsibility it should continue to study, test, and develop low-emission propulsion systems, particularly the Rankine cycle system. In this connection the Department of Transportation should support Rankine-cycle experimentation in urban transportation systems. Continuing support should be given to the steam bus demonstration projects.[153]

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[151] California provides for purchasing low-emission vehicles even if they cost up to 100 percent of the normal purchase price for that type vehicle. The potential California market is about 700 vehicles at the minimum 25 percent level. If the Federal Government adopts procurement, it probably could reduce the cost differential to 50 percent or less because of savings associated with a larger production rate.

[152] App. B (postal letter).

[153] See discussion in text accompanying footnotes 100–103 supra.

The Department of Transportation should also research, develop, test, and evaluate low-emission propulsion systems in terms of their overall transportation characteristics. For example, there is some talk these days about open automobile-carrying pallet systems for conducting interurban and intraurban peak traffic loads. Low-emission propulsion systems for automobiles may have peculiar advantages in future integrated transportation systems. Indications are that the Rankine cycle has many potential advantages because it can provide auxiliary service to the automobile on the pallet or conveyor— e.g., heat and air conditioning—for extended periods of time without idling and ruining the engine The intercity and urban transportation divisions of the Department of Transportation should coordinate the study, development, and testing of low-emission propulsion systems and evaluate their integrative capabilities

The Department of Health, Education, and Welfare Should Devote a Greater Portion of Its Research Funds to Inherently Low-Polluting Propulsion Systems

Present automobile air pollution control research expenditures are concentrated in areas designed to improve the emission characteristics of the ICE.[154] Government research and development expenditures on inherently low-polluting propulsion systems should be increased because such systems may offer the only practical solution to the automotive air pollution problem and because such expenditures will not ultimately detract from ICE emission control—industry will merely increase its efforts in the ICE control area when research in a competitive field is intensified.

State Licensing and Taxing Authorities Should Consider Creating Economic Incentives for Private Ownership of Low-Emission Vehicles

State and local governments should consider imposing an additional registration fee on all motor vehicles, with the amount of the fee determined by the emission characteristics of the vehicle. Those with high emissions would be severely taxed; those with low emissions would escape the tax. To provide for proper assessment and to insure that appropriate emphasis is placed on maintaining the effectiveness of emission control devices, where used, such a program could require that each vehicle be tested for its emission characteristics when given a periodic inspection as required under the Federal highway safety program.[155] Such a tax scheme and inspection system could create a private customer incentive for purchasing low-emission vehicles which retain their favorable emission characteristics over a period of years. The proceeds of such a tax which fairly allocates burden could be used to meet the escalating social costs of vehicular air pollution.

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[154] See discussion in text accompanying footnote 139 supra.

[155] See app. A (Clayton's letter) where a procedure for testing vehicle emissions is presented.

APPENDIX A

Letters were sent to—
American Motors Corp.
Mr. Robert Barber, Barber Nichols Engineering Co., 6325 West 55th Avenue, Arvada, Colo.
Mr. William J. Besler, Besler Systems, Inc., 4053 Harlan Street, Oakland, Calif.
Clayton Manufacturing Co., 4213 Temple City Boulevard, El Monte, Calif.
Chrysler Motor Corp.
Comstock & Wescott, 765 Concord Avenue, Cambridge, Mass.
General Motors Corp.
Day-Land Pattern & Manufacturing Co., 1160 Airport Drive, Upland, Calif.
Empirical Engineering, 8591 Pyle Way, Midway City, Calif. (Attention Mr. Smith).
Ford Motor Co.
Mr. Richard S. Morse, Energy Systems Inc., 141 California Street, Newton, Mass.
Mr. Roy R. Ferrier, Roy R. Ferrier Co., 5737 Venice Boulevard, Los Angeles, Calif.
Mr. Thomas A. Hosick, Mr. R. A. Gibbs, Gibbs-Hosick Trust, 2110 Rocky Knoll Road, Greensboro, N.C.
Mr. William Lear, Lear Motor Co., Reno, Nev.
Mr. Wallace Minto, Kinetics, Inc., 1242 North Palm Avenue, Sarasota, Fla.
Paxve Inc., 426 31st Street, Newport Beach, Calif.
Mr. Edward Pritchard, Pritchard Steam Power Pty., Ltd., 339 Balaclava Road, Caulfield, Victoria, Australia.
Semple Engine Oil Co., Inc., Post Office Box 2937, St. Louis, Mo.
Shaw Machinery Co., 1164 Market Street, San Francisco, Calif.
Mr. Simon MacKay, Somac Ltd., 62 Addison Road, London W14, England.
Mr. Don Johnson, Mr. R. G. Smith, Thermal Dynamic Systems, Inc., 3800 Campus Drive, Newport Beach, Calif.
Thermo-Electron Engineering Co., 85 First Avenue, Waltham, Mass.
Mr. W. D. Thompson, 5200 Marlborough Drive, San Diego, Calif.
Mr. Calvin Williams, Mr. Charles Williams, Williams Engine Co., Post Office Box 4, Ambler, Pa.
San Diego Gas & Electric Co., San Diego, Calif.

[Copy of letter of inquiry sent]

Mr. W. V. LUNEBURG,
President, American Motors Corp.
Detroit, Mich.

JANUARY 16, 1969.

DEAR MR. LUNEBURG: The staff of the Senate Commerce Committee is currently preparing a report on the steam vehicle hearings held last May. (Joint hearings before the Committee on Commerce and the Subcommittee on Air and Water Pollution of the Committee on Public Works, U.S. Senate, 90th Congress, 2d sess. (1968).) In the report we will consider the vehicular air pollution problem and discuss the role of the low-emission vehicle in reducing or even eliminating this problem.

Since the May hearings many important advances in the low-emission field have occurred. We would like in this report to bring the hearings up to date by discussing the recent developments. Therefore, we would appreciate receiving any information which you can send us describing the progress your company has been making in developing a low-emission engine.

Our mid-February target date for final publication of the report is fast approaching. We would appreciate a speedy response to this inquiry. If you have any questions, please do not hesitate to write or call us.

Sincerely,

S. L. SUTCLIFFE,
Staff Counsel, Committee on Commerce.

AMERICAN MOTORS CORP.,
Detroit, Mich., January 24, 1969.

Mr. S. L. SUTCLIFFE,
Staff Counsel, Committee on Commerce,
U.S. Senate, Washington, D.C.

DEAR MR. SUTCLIFFE: In response to your inquiry of January 16, 1969, on the subject of advances in the low-emission field, I am pleased to make this report.

American Motors has continued to pursue its interest in this field and has since the time of the hearings engaged in an intensified examination of both a steam- and electric-type vehicle. We have seriously undertaken indepth reviews of hybrid electric devices to see what application might make sense in our future product programs. Additionally, we are pursuing a program to develop the application of steam as a result of a suggestion by a highly regarded potential supplier of this type equipment. We have only begun to consider this latter alternative but are presently optimistic about its mechanical possibilities.

As you might imagine, American Motors is highly interested in developing a low-emission, mass-produced automobile. Not only would this have advantages from a social point of view, but we look upon it as a rare opportunity for our company.

Sincerely,

GERALD C. MEYERS.

CHRYSLER CORP.,
Detroit, Mich., February 18, 1969.

Mr. S. L. SUTCLIFFE,
Staff Counsel, Committee on Commerce,
U.S. Senate, Washington, D.C.

DEAR MR. SUTCLIFFE: This is in reply to your letter of January 16, addressed to Mr. V. E. Boyd, president, Chrysler Corp., in which you were checking supplementary information for your report on the steam vehicle hearings.

Chrysler Corp. has maintained an active interest in steam powerplant development and have had several investigative programs over the last three decades. Our investigations have concerned themselves not only with the basic powerplant, and its control problems, but also with the working fluid.

Based on the premise that any satisfactory automotive powerplant must be able to start at subzero temperatures, the development of a low-freezing point working fluid has been one of the real impediments in the successful application of steam power to automotive vehicles. A steam powerplant of reasonable size and high efficiency requires extremes of both temperature and pressure. This imposes severe limitations on the working fluid and, to date, we have found nothing that even approaches the heat transfer characteristics, low cost, and ready availability of water. Again, we are back to the unsolved problem of cold weather operations with water as the working fluid.

Despite the lack of a satisfactory low-freezing-point fluid, work has continued at Chrysler on cycle analysis, design, and refinement of automotive steam powerplants using water. This work indicates, so far, that a steam powerplant may be unduly complicated and expensive despite its much-discussed characteristic of not requiring a transmission.

With regard to emissions, it should be pointed out that the steam engine is probably no better than other possible automotive powerplants. Further, our research efforts over the last 20 years, which are continuing at an ever-accelerating rate, assure us that eventually it will be possible to limit the exhaust emissions from the internal combustion engine to the point where they should be as low as that to be expected from the steam engine.

We are pleased at this opportunity to establish our position in this important field.

Yours very truly,

L. B. BORNHAUSER.

CLAYTON MANUFACTURING CO.,
El Monte, Calif., January 21, 1969.

Mr. S. L. SUTCLIFFE,
Staff Counsel, Committee on Commerce,
U.S. Senate, Washington, D.C.

DEAR MR. SUTCLIFFE: Thank you for your letter of January 15, 1969, regarding progress reports on developments in the low-emission engine field. The Clayton Manufacturing Co. has not addressed itself to what appears to be an extremely long-range development program in the form of replacement powerplants for the spark ignition automobile type engine. Rather, we have spent considerable in-house development funds on the problem of monitoring current in-use or newly produced engines, with the belief that this is a field in which we are well versed and perhaps we can contribute to the current-day problem of reducing emission levels.

It is possible this work may be of interest to you and we are, therefore, enclosing two copies of a semitechnical paper dealing with this activity. A short abstract precedes the paper to give you an insight of the intent and scope.

Please do not hesitate to communicate with us further should any of our activities on the above lines be of interest to the committee. We would like to contribute to the solution of this perplexing air pollution problem.

Sincerely,

E. L. CLINE,
Vice President, Dynamometer Division.

[Enclosure]

A REALISTIC VEHICLE EMISSION INSPECTION SYSTEM

(E. L. Cline, Vice President, Dynamometer Division, and Lee Tinkham, Chief Development Engineer, Dynamometer Division, Clayton Manufacturing Co., El Monte, Calif.)

ABSTRACT

A 1-minute mass vehicle exhaust emission inspection system is described to aid those seeking to establish an appropriate effort in compliance with the Air Quality Act of 1967.

This proposed inspection system is suitable for both emission controlled and preemission controlled automobiles. It is oriented to appropriate auto service industry corrective measures since it provides guidelines as to probable cause of unnecessarily high emissions for each rejected vehcle. This capability is essential to avoid abnormal corrective expense due to excessive repairs or continued high emissions due to inadequate repairs.

Low skill levels may be used during the inspection process, yet results are repeatable and consistent in a plurality of inspection stations.

The net gain in lower emissions through inspection of inuse vehicles is large because the point of rejection is no longer dictated by the inherently high emission vehicles.

Not more than two rejection standards are required for emission controlled vehicles, and only one for preemission controlled vehicles. This includes all domestic and foreign makes. These standards are flexible in that they may be initially liberal and gradually tightened as circumstances warrant. Such policy changes or future spark ignition engine designs will not significantly obsolete the hardware required to perform this inspection.

The fundamental techniques employed permit the use of greatly simplified equipment and instrumentation with resultant lower initial cost and increased reliability than previously envisioned meaningful inspection methods.

A study of nearly 1,000 automobiles over a 1-year period evolved and documented this proposed inspection system. Qualified persons may study this work to any depth desired by contacting the authors.

ORIENTATION

We have been asked to present information relative a 1-minute mass vehicle exhaust emission inspection system to aid those seeking to establish an appropriate effort in compliance with the Air Quality Act of 1967. Time will not permit a full verbal disclosure of the development work which involved nearly 1,000 emission controlled and preemission controlled automobiles. Nor will it let us

acquaint you with our qualifications to bring such a system into reality. Over 28 years of experience in prescribing the technology for inuse vehicle and aircraft inspection and diagnosis does afford us a background of practical experience. Nor will time permit more than an acknowledgment of the library of foreground material relative to spark ignition engine emission control that our engineers digested, or the months of data analysis that was necessary to the creation of a realistic vehicle emission inspection system.

Time requires the almost flagrant use of flat statements with but meager explanation. However, our entire files are open and equipment and instrumentation is demonstratable in the event qualified persons wish to pursue this matter in depth. Be assured that a realistic mass vehicle inspection method is here. It will serve emission and preemission controlled "inuse" or "newly produced" vehicles.

The automobile industry is building vehicles today that are basically capable of polluting the atmosphere at a rate far less than that of their predecessors. Engines with low potential emissions are truly a reality. The task before us is to see that their potential is exploited during usage. To do so simply requires a reasonable basic engine maintenance.

Owner neglect and/or inept maintenance practices cause degradation of any mechanical device. Even with their great inbuilt reliability, the automobile engine is no exception. A large number of engine malfunctions or maladjustments adversely affect exhaust pollutants. Yet, any car can seemingly run very well and still be pouring dangerous pollutants into the air. "Exhaust pipe halitosis" is like human halitosis—few people know when they have it. This is one reason why voluntary maintenance is phychologically unsound. Compulsory maintenance must be minimal and, therefore, it is technically inadequate, particularly as vehicle mileage accumulates. Furthermore, the captive market, resulting from compulsory maintenance, will swell the ranks of incompetent repairing agencies.

Visual inspection can detect obvious defects like burned out light bulbs, etc. Unfortunately, the engine malfunctions that cause unnecessarily high emissions (in both emission controlled and preemission controlled vehicles) are not obvious either through casual or deliberate visual inspection. It is necessary to "look" almost directly at the engine internals to know if it is operating at or near its basic minimum emission capability.

In the interest of safety, no one debates being required to replace light bulbs. Is it so different to be asked to keep our engines in reasonable repair so that each vehicle only contributes its share rather than the equivalent of several, to the pollutants reaching the air we all breath? There is little question of equity to the individual if he is shown when a malfunction exists, that, it left uncorrected, is indeed a menace to himself and the public interest.

Adequate periodic inspection is the implement to greatly reduce emissions now. Further, it can assist the motorist in the attainment of a high degree of vehicle reliability, safety and economy. However, there have been many technical difficulties associated with emission inspection. Experts are aware of these, which probably accounts for suggests alternates, including compulsory vehicle maintenance. We believe it is apropos to outline the hazards of inspection before suggesting a solution.

THE HAZARDS OF INSPECTION

To assure uniformity of vehicle protoype tests, the U.S. Government has adopted the "seven mode" driving cycle. This cycle subjects the automobile engine to several modes of operation indoors, typical of popular urban driving outdoors. Carbon monoxide (CO) and unburned Hydrocarbon (HC) content in the vehicle exhaust is monitored as the vehicle is operated through these several modes. The "weighted" values of CO and HC for the total seven mode test is subject to Government regulation. The seven mode cycle and the prescribed gas analysis methods operating together as a system has proven to be most useful for the development and certification of new vehicles. It, however, is too sophisticated and time consuming to be employed for mass vehicle inspection. The testing of millions of vehicles require a quick test cycle of 1½ minutes or less.

Several States have legislation or are seriously considering testing exhaust emissions of all "inservice" vehicles. Various quick cycles have been proposed that consider combining the weighted values of gases sampled during two or more modes of engine operation and correlating the results with those of the seven mode cycle. While the "average correlation" of a group of vehicles may be excellent, true vehicle-by-vehicle correlation of such test methods is poor. Vehicles are designed to meet regulations on the seven mode cycle. Such quick inspection

methods actually test them with a different yardstick. For example, some vehicles indicate 50 to 250 percent more HC on a quick cycle than they actually produce on the seven mode test. What is a State to do with such vehicles? Conversely, just think how lucky the motorists will be whose vehicles only test at 50 or 60 percent of their true seven mode value. What is to be done for older vehicles who have no seven mode standards? Actually, if results on a quick cycle correlated with results on the seven mode cycle, the longer seven mode cycle could be eliminated even for laboratory testing. Furthermore, mass inspection facilities built to match the then used certification test methods can become obsolete. For example, how long will the seven mode cycle be used for research and certification testing?

Vehicle individuality is such that identical models have different "weighted" values of emissions even when in perfect condition. Figure 1 is a plot of HC against vehicle population. Curve A shows the HC emission level expected when properly tuned emission controlled vehicles are tested on the seven mode cycle. The slope of curve A shows that some vehicles are inherently "low emitters" and some are inherently "high emitters." A similar characteristic exists for CO. A single value HC reject baseline, such as B, would reject approximately 20 percent of these cars, yet they have no malfunction. A higher reject baseline such as C permits the acceptance of most vehicles even though they would be pouring unnecessarily high emissions into the air. Yet, with this high and relatively wasteful reject baseline, 1 percent of the total vehicle population cannot be improved by a repairing agency because they are already up to manufacturer's mechanical specifications. These are typical characteristics for all cars. Even 1 percent of a 100 million vehicle population is 1 million cars. The lack of correlation between the seven mode and quick cycles can even more alarmingly swell this volume of potentially rejected cars even though they are at their best emission capability.

The retest of rejected vehicles after repair, to determine if the repair has, in fact, been made and made properly, will again reject the inherently high emitter regardless of any improvement in emission resulting from competent repairs. This is why it has been said that thousands of motorists will be "bouncing back and forth between inspection and repair facilities like a ping pong ball," with no hope for reprieve. We submit that the relationship between this kind of inspection—the car owner—and the repairing agencies would become uneasy indeed.

These problems, and more, had to be overcome in the development of a realistic mass inspection system. A more fundamental approach was indicated.

A NEW LOGIC FOR MASS INSPECTION METHODS

When any vehicle exceeds its basic emissions capability, it is because of maladjustment or malfunction. Why, then, not employ an inspection method that simply exposes the engine faults that cause unnecessarily high emissions? Conversely, when no pertinent faults exist, each engine is as good as repairing agencies can keep it and should be regarded as acceptable.

DEVELOPMENT OF A FAULTFINDING TECHNIQUE

Being oriented toward total engine performance diagnosis, our engineers could efficiency address themselves to the easier task of developing engine "faultfinding" techniques. Data by others (1)[1] as well as our own earlier studies, indicated that CO and HC levels in engine exhaust are indexes of abnormal operation. For this reason, and because CO and HC are the legislated culprits, we elected to retain instrumentation that would measure these gases. The monitoring of thousands of inservice vehicles to develop total diagnostic techniques had taught us the kinds of engine operating modes that most reliably cause all engine malfunctions to occur (2). The job at hand was to learn the minimum number and variety of operating modes required by all standard vehicles to expose the engine malfunctions responsible for unnecessarily high emissions. The first work involved both preemission controlled and emission controlled vehicles representative of all U.S. engine types, displacements, and carburetor and transmission options.

This work did define the operating modes. Those which most reliably exposed engine faults were labeled "key" modes. The resultant three mode steady-state inspection cycle requires 1 minute and is known as the Clayton key mode cycle. Our studies to date include nearly 1,000 vehicles. Each added group of vehicles merely confirms the reliability of the key mode test method.

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[1] Numbers in parentheses designate bibliography at end of paper.

To many motorists, the vehicle engine is only a monster under the hood that demands gasoline, water, and oil periodically. If it responds to his satisfaction when the throttle is depressed—nothing is wrong.

At the other end of the spectrum is the design engineer and the manufacturer whose refinements have made possible the simplicity of operation and reliability of today's engine.

In between is the mechanic who must understand the basic simplicity of the engine if he is to maintain the design performance as well as the new parameter of low emissions.

The engine consists of three main systems:

1. The main body is a 4-cycle air pump of special design. The amount of air pumped is dependent on engine speed and the opening of the throttle valve at the air inlet. Thus, air flow is infinitely variable as the throttle is opened and speed is allowed to change.

2. Economy, performance, and low emissions are highly dependent on the ability of the carburetor to meter an optimum amount of fuel throughout the entire range of engine operating conditions. Fuel flow variation responds automatically to the signals of velocity and/or pressure resulting from changes in air flow.

3. Ignition timing is also infinitely variable within its specified range and responds automatically to signals resulting from changes in speed and throttle opening.

Operation of these systems is not haphazard. The manufacturer has designed automatic coordination so that they function in a predictable pattern if there is no malfunction or adjustment. All of these variations result from just opening the throttle as the motorist demands an increase in speed or power.

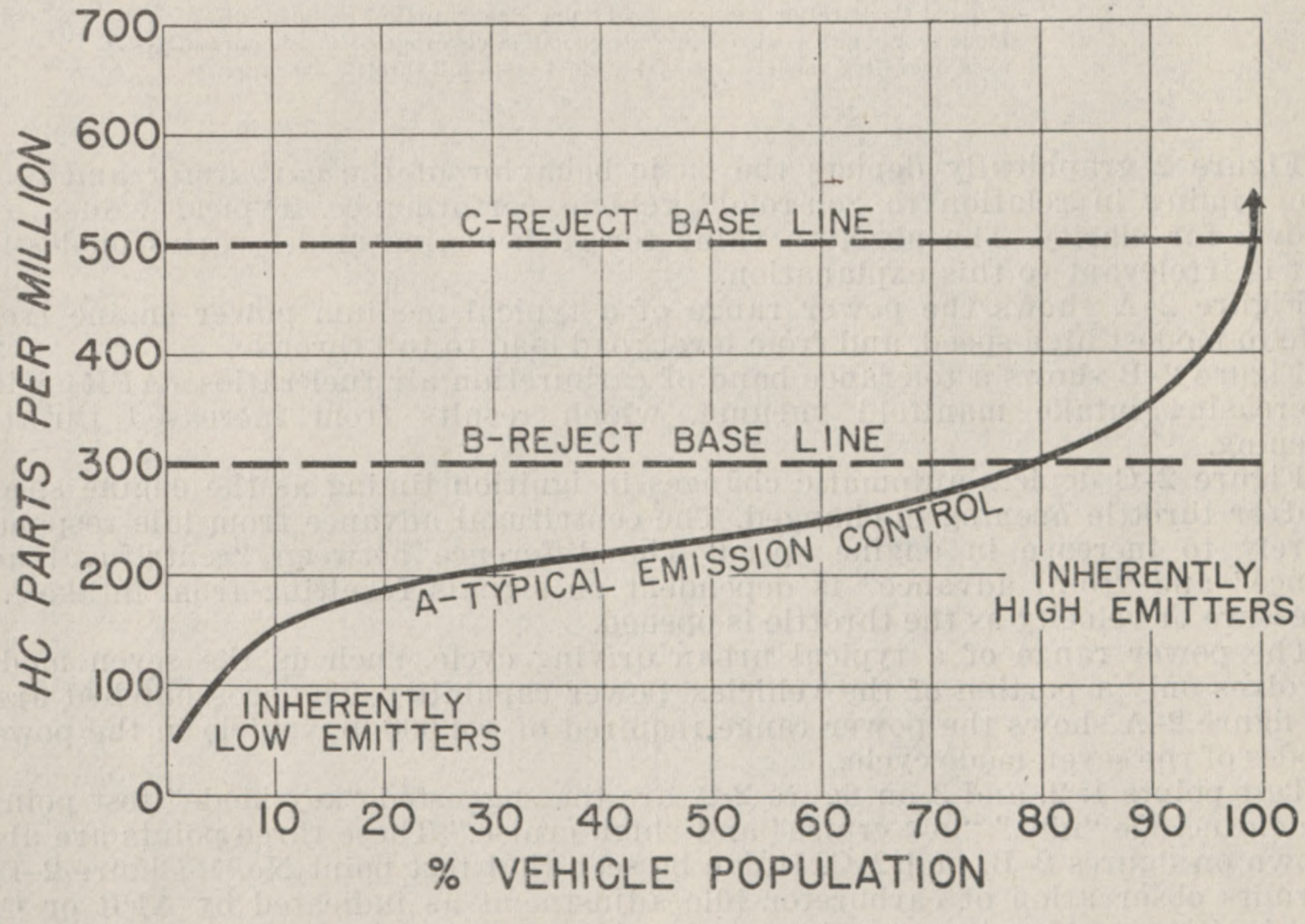
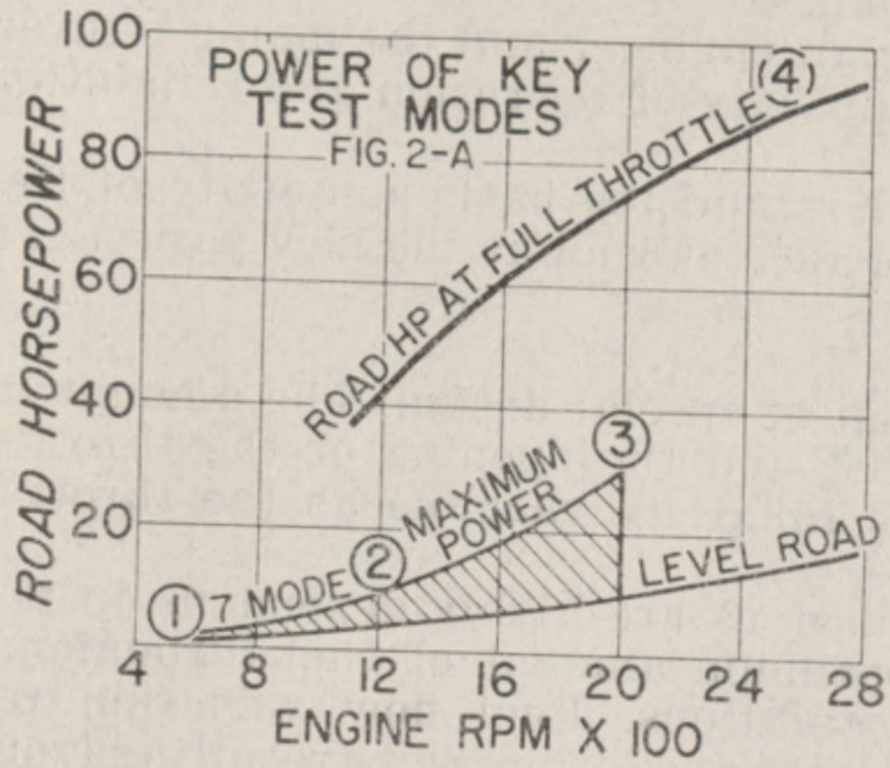
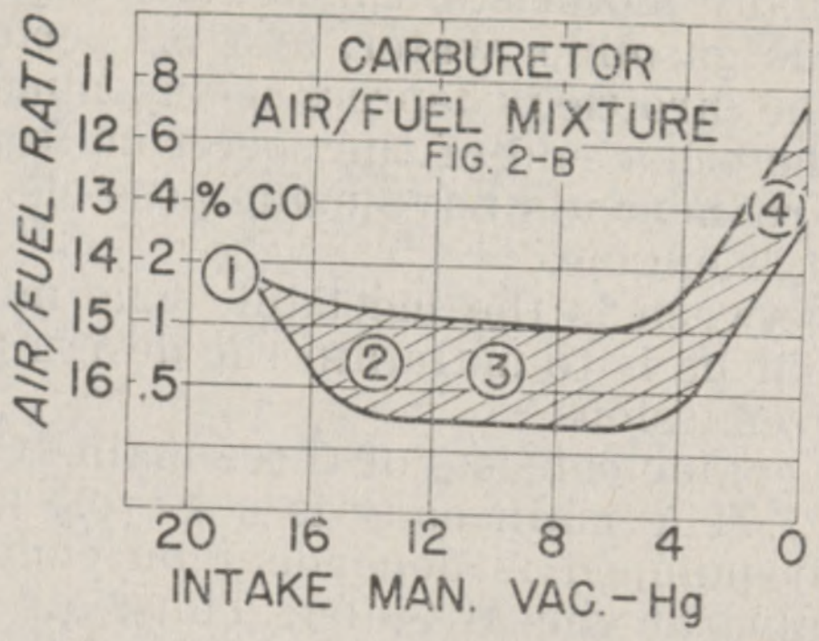


FIG. 1 - Hydrocarbon versus Vehicle Population. Seven Mode Cycle. Vehicles in good condition and set to factory standards.





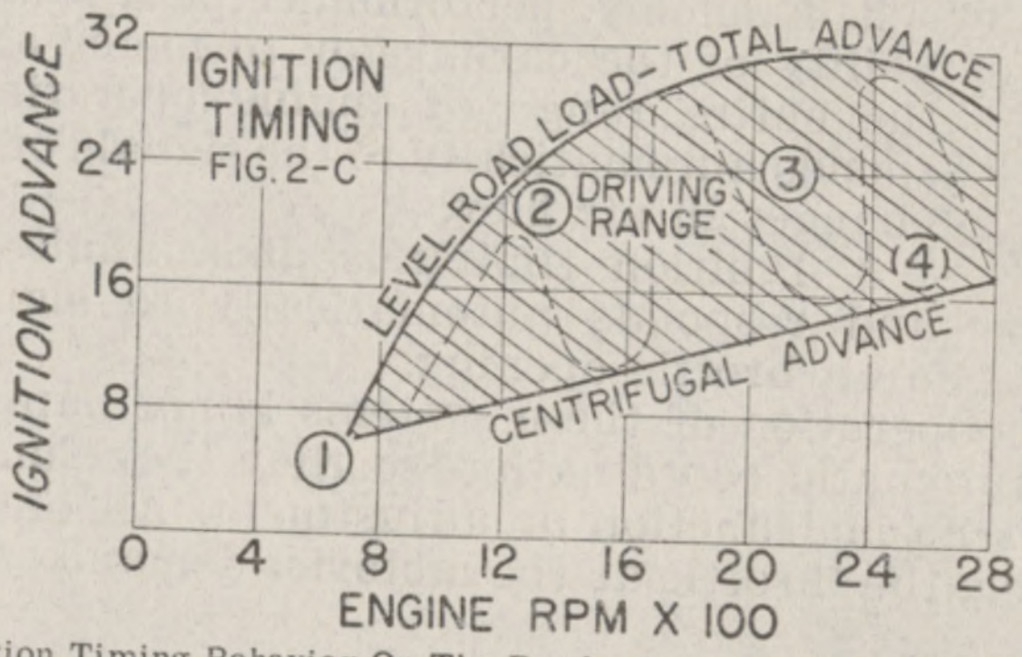


FIG. 2 - Typical Carburetion and Ignition Timing Behavior On The Road. Key Mode test points 1 - 2 - 3 provide good test coverage of engine normally used operating range. Optional mode 4 tests full throttle operation.

Figure 2 graphically depicts the basic behavior of the carburetor and ignition timing in relation to "on-road" vehicle performance. Typical values are shown for clarity. The absolute value for each engine model varies modestly, but is irrelevant to this explanation.

Figure 2–A shows the power range of a typical medium power engine from idle to modest high speed, and from level road load to full throttle.

Figure 2–B shows a tolerance band of carburetion air fuel ratios (AFR) with decreasing intake manifold vacuum, which results from increased throttle opening.

Figure 2–C depicts automatic changes in ignition timing as the engine speed and/or throttle opening is changed. The centrifugal advance from idle responds purely to increase in engine speed. The difference between "centrifugal advance" and "total advance" is dependent on signals resulting from intake air pressure or velocity as the throttle is opened.

The power range of a typical urban driving cycle, such as the seven mode, involves only a portion of the vehicles' power capability. The crosshatched area on figure 2–A shows the power range required of a 4,000-lb. vehicle in the power modes of the seven-mode cycle.

Test points 1, 2, and 3 on figure 2–A are the suggested "key mode" test points which include "idle," "low cruise" and "high cruise." These three points are also shown on figures 2–B, and 2–C. It can be seen that test point No. 1 (figure 2–B) permits observation of carburetor idle adjustment as indicated by AFR or CO and ignition malfunction or other combustion problems causing abnormally high HC. Test point No. 2 is in the transition range between idle and the maximum acceleration power of the seven-mode cycle. Test point No. 3 is at a power approximating maximum of the seven-mode tests.

As far as emission inspection in concerned, the purpose is to detect an engine that emits unnecessarily high CO or HC within the power range of a legislated driving cycle. These test points will expose carburetor problems at idle (point No. 1) and in the intermediate system (point No. 3), as well as point No. 2 which is in the transition range between these two phases of carburetor operation.

Normal CO but abnormally high HC at any of the three test points, is an indication that fuel is escaping without being subjected to combustion. HC can rise in excess of 10 times normal due to ignition misfire of one cylinder. Intermittent misfire, leaking exhaust valves, and gross ignition timing error, will cause substantial rise in HC.

Key mode test points Nos. 1, 2, and 3 provide good test coverage of the engine normally used operating range. The purpose of optional mode 4 is covered later.

INSPECTION DESCRIPTION

A simplified chassis dynamometer is used as an indoor road (figure 3). It imposes a load through the vehicle driving wheels for the engine to work against. The dynamometer is so designed that it automatically imposes an increasing engine load as vehicle speed is increased. This is also what occurs on an actual road. The dynamometer requires no operator control whatsoever, regardless of the make, size, or weight of the automobile to be tested. Thus, a constant "indoor road" of the operator, is created upon which the test vehicle is operated.

NOTE.—The dynomometer must simply be capable of absorbing horsepower as nearly a cube of the speed change and reach 30 horsepower at 50 miles per hour. Although repeatability of the speed horsepower curve is important, this need not be expensive with current dynamometer technology.

It is only necessary to open the vehicle throttle to a predetermined miles per hour at high cruise and log the CO and HC on a preprinted report card. (The logging can optionally be done automatically.) The throttle is then closed to obtain prescribed miles per hour at low cruise and log CO and HC followed by the same readings at idle. The only technique required is to depress the throttle to a given miles per hour and read the stead state instruments. The procedure is applicable to both domestic and foreign automobiles. It is quick and reliably repeatable by thousands of inspection personnel.

No connection is made to any part of the vehicle under test. Therefore, there is no need for an assortment of devices to permit connection to various vehicle configurations. Nothing need be disturbed on the vehicle. As schematically shown in Fig. 4, a tube is simply inserted in the vehicle tail pipe to permit a sample of exhaust gas to be drawn off and presented to a carbon monoxide and unburned hydrocarbon gas analyzer.

NOTE.—Properly so, there is concern regarding the suitability of CO and HC analyzers to perform reliably under continuous duty and in the hands of unskilled personnel. The key mode cycle is one which permits direct sampling and the use of low-response rate instruments. This significantly contributes to lower cost, rugged analyzer design.

The simplest equipment and instrumentation are employed.

The test is completed in 1 minute and can be readily performed with relatively low-skill-level personnel.

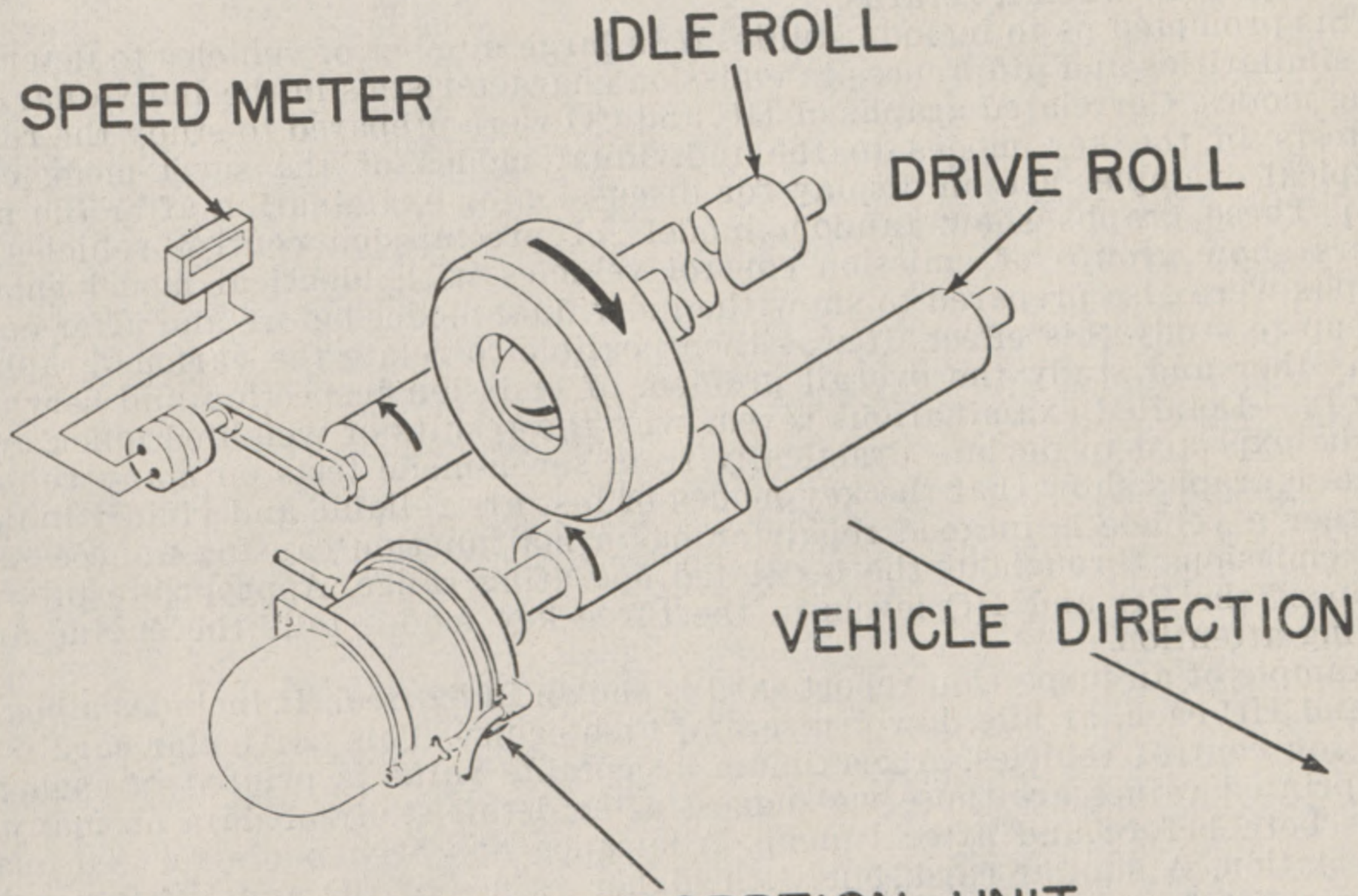


FIG. 3 - Schematic - Simple Dynamometer. Rolls support vehicle driving wheels like a treadmill. Power absorption unit loads engine to automatically obtain proper Key Mode test powers.

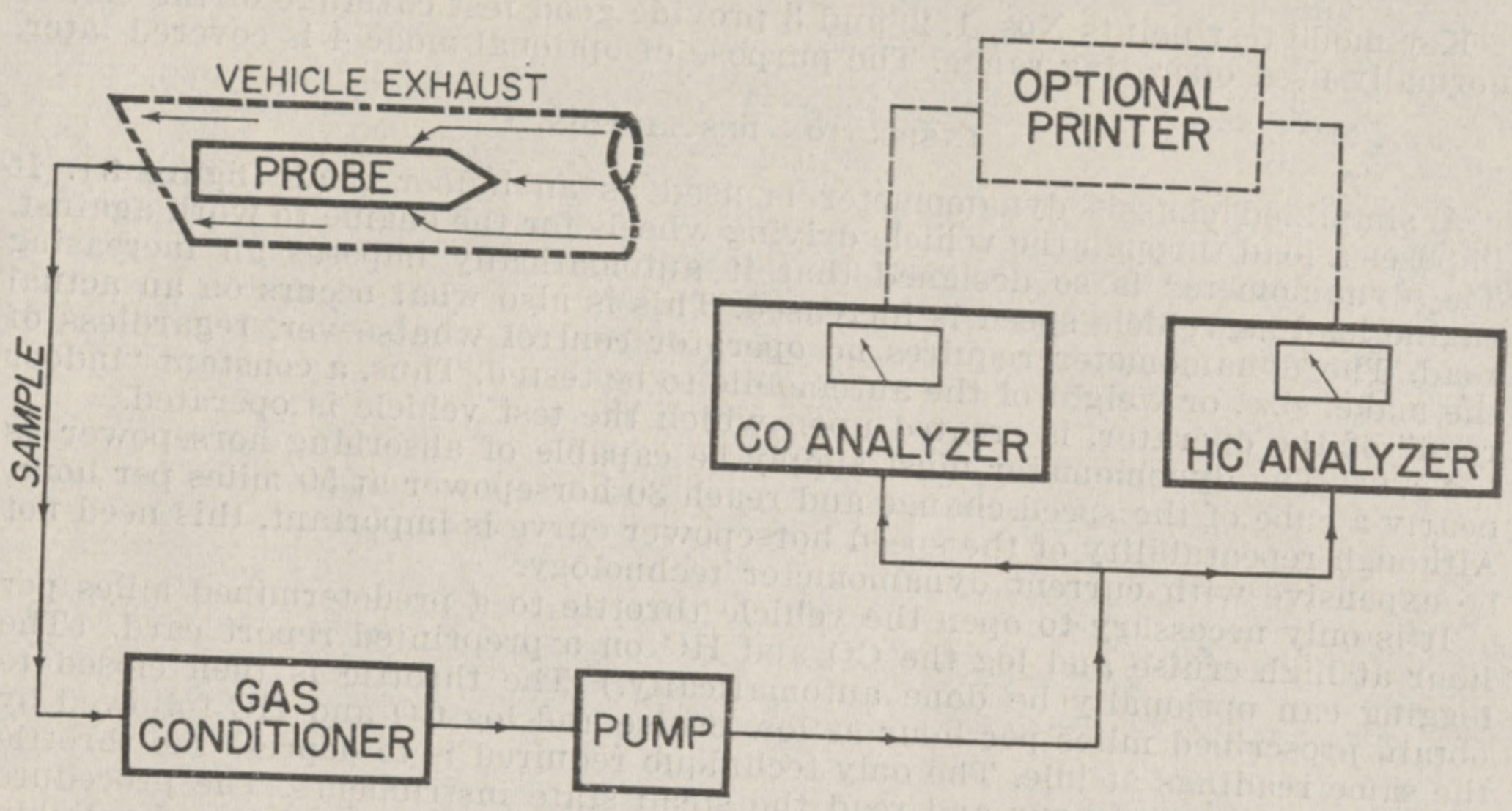


FIG. 4 - Block Flow Diagram of Simple Exhaust Gas Sampling and CO/HC Readout Instrumentation. Conditioner cleans gas sample.

REPAIR AIDS

Success in obtaining maximum overall emission reduction involves problems of the manufacturer, the service industry, the motorist, and reliability of inspection methods. They should not be considered as isolated from each other.

Inspection without the capability of adequate repair will probably spell failure to the intent of the inspection. It seems reasonable that there should be correlation between inspection and service test methods to prevent the motorists from being caught in an exasperating and costly "squeeze." If, without added time or cost, inspection can provide guidelines that indicate the type of malfunction, the mode of operation, and the severity of the existing engine problem, there is a better probability that the vehicle will be repaired at a lower average cost and pass inspection when it returns.

This prompted us to include studies on a large number of vehicles to determine the similarities and differences in emission characteristics in the individual operating modes. Correlated graphs of HC and CO were prepared to study the results of tests in the key modes to the individual modes of the seven-mode cycle. (Typical examples are on display for discussion or examination after the meeting.) These graphs show random models of preemission control vehicles and others show groups of emission control vehicles with identical model engines. Graphs were also prepared to show the individual modes before and after engine tuneup to study this effect. It was then possible to relate the various graphs to each other and study the overall problem of emission inspection and service.

NOTE.—Detailed examinations reveal why the results of weighted quick cycles can be expected to deviate drastically from seven-mode tests on many vehicles. These graphs show that the key modes of test are reliable and vividly indicate whether a vehicle is in good repair or has a malfunction causing unnecessarily high emissions throughout the legislated operating range. Appropriate interpretation of the CO and HC levels in the three key modes tells the engine areas needing attention.

Example of an inspection report card is shown in figure 5. It includes a box for CO and HC each, at idle, low cruise and high cruise. This particular card is for emission control vehicles. A maximum acceptable value is printed in each box. The printed values are those we suggest after detail study of data on many vehicles both before and after tuneup. Allowance has been made for reasonable depreciation. A similar card, but with higher values of CO and HC is required for preemission control vehicles.

NAME: John Doe VEHICLE: 1920 Hupmobile

VEHICLE & OWNER STATISTICS

	IDLE	LOW CRUISE	HIGH CRUISE	FULL THROTTLE
-CO- CARBON MONOXIDE	MAX. 3%	MAX. 2.5%	MAX. 2%	
-HC- UNBURNED HYDROCARBON	MAX. 290 PPM	MAX. 240 PPM	MAX. 220 PPM	

OPTIONAL MODE

✓ = REJECT

NOTE: VALUES ARE THOSE WE SUGGEST AFTER DETAIL STUDY OF DATA ON MANY VEHICLES BOTH BEFORE AND AFTER TUNE-UP.

FIG. 5 - Example - Inspection Report Card.

It can be broadly stated that—

1. CO is a result of incomplete combustion and is reliable as a "go no go" indicator of air fuel ratio supplied by the carburetor. Abnormally high percentages of CO is an indication of unnecessarily rich air fuel mixture. High CO in the idle key mode only, shows the need for an idle adjustment only. High CO in the cruise modes shows need for carburetor overhaul. These are examples of distinct guidelines for the correct repair. It is not a detailed diagnosis because the trouble could also be a restricted air cleaner or choke not opening completely. These, however, can be revealed through visual inspection by the repairing agency.

2. Normal CO with abnormally high HC in one or more test modes, indicates that gas is escaping from the combustion chamber into the exhaust without being properly subjected to combustion. If the ignition timing is within reasonable tolerance, this is usually due to either ignition misfire or valve problems. For example, complete misfires of one cylinder of an eight cylinder engine can increase the exhaust MC more than 10 times normal. Obviously, an incipient ignition misfire or valve leakage will have less effect, but there is always a dramatic rise in HC level.

Abnormally high values can occur in any one or a plurality of the report card boxes. Recognition of what these reject patterns say by the repairing agencies is accomplished with a "truth chart."

NOTE No. 1.—In this case, a "truth chart" is defined as a procedural outline telling the recommended corrective measures to be taken for each possible single or combination reject pattern found on the individual report card. It should be prepared by the vehicle manufacturer.

NOTE. No. 2.—Cooperative interest is already so high that the Independent Garage Owners Association and one major motor car manufacturer have volunteered to publish and distribute the "truth charts."

The inspection card and the "truth chart" together constitute a kind of computer that guides the repairing agency to correct only what is necessary with reasonable assurance of success. There are many more mechanics capable of performing satisfactory repair than are capable of reliable diagnosis. The "paper computer" technique greatly reduces the need for diagnostic skill and judgment. It is a

method requiring no added cost to the inspection effort, yet will help immensely in bringing about appropriate repair.

A "motorist aid" is included in the appendix. It is suggested that such a printed form be given with each rejection to explain the effect of abnormally high CO and HC on the motorist's safety, and potential life, performance, and economy of his engine. Such informative material is a simple act of sensible public relations and service.

Examples of malfunctions that cause unnecessarily high emissions are shown in figure 6.

Figure 6–A shows one type of maladjustment prevalent in many vehicles. The "Motorist Aid" explains the dangers, the waste of fuel, and the excessive carbon residue in the engine that is indicated by the high CO at idle speed. The mechanic with his "truth chart" will know that only an idle adjustment is required. He can correct this one condition and feel confident the vehicle will pass inspection. Without such an inspection report, he would have to check every phase of engine operation and hope he found the problem that caused rejection.

Figure 6–B shows another type of carburetion problem indicated by abnormally high CO at cruise. The "truth chart" instructs the mechanic to visually see that the choke is not stuck partially closed or that the air cleaner is not restricting. If these are satisfactory, a carburetor overhaul is necessary. In this instance, a carburetor overhaul was required because the power jets were stuck open.

Figure 6–C reports excessive HC and normal CO. The "Motorist Aid" explains the general condition indicated by high HC and the owner's reward after repair in the form of economy and reliability. With knowledge that carburetion is not at fault, the mechanic's "truth chart" will tell him to check for ignition misfire first, and then for abnormal compression loss. This particular problem was caused

REPORT CARDS INDICATING FOUR TYPICAL MALFUNCTIONS

NAME: John Doe VEHICLE: 1920 Hupmobile

VEHICLE & OWNER STATISTICS

	IDLE	LOW CRUISE	HIGH CRUISE
-CO- CARBON MONOXIDE	MAX. 3% 5.9 ✓	MAX. 2.5% .5	MAX. 2% .25
-HC- UNBURNED HYDROCARBON	MAX. 290 PPM 315	MAX. 240 PPM 210	MAX. 220 PPM 135

✓ = REJECT

6-A

NAME: John Henry VEHICLE: 1919 Maxwell

VEHICLE & OWNER STATISTICS

	IDLE	LOW CRUISE	HIGH CRUISE
-CO- CARBON MONOXIDE	MAX. 3% 2.1	MAX. 2.5% 3.8 ✓	MAX. 2% 5.6 ✓
-HC- UNBURNED HYDROCARBON	MAX. 290 PPM 190	MAX. 240 PPM 335	MAX. 220 PPM 295

✓ = REJECT

6-B

NAME: Pete Poor VEHICLE: 1930 Hudson

VEHICLE & OWNER STATISTICS

	IDLE	LOW CRUISE	HIGH CRUISE
-CO- CARBON MONOXIDE	MAX. 3% 2.0	MAX. 2.5% 1.5	MAX. 2% .8
-HC- UNBURNED HYDROCARBON	MAX. 290 PPM 490 ✓	MAX. 240 PPM 380 ✓	MAX. 220 PPM 305 ✓

✓ = REJECT

6-C

NAME: Ken Kent VEHICLE: 1932 Cord

VEHICLE & OWNER STATISTICS

	IDLE	LOW CRUISE	HIGH CRUISE
-CO- CARBON MONOXIDE	MAX. 3% 2.4	MAX. 2.5% 1.6	MAX. 2% .75
-HC- UNBURNED HYDROCARBON	MAX. 290 PPM 395 ✓	MAX. 240 PPM 180	MAX. 220 PPM 950 ✓

✓ = REJECT

6-D

FIG. 6 - Examples of Completed Report Cards, indicating Four Typical Malfunctions.

by an exhaust valve that was not seating properly, thus causing abnormally high HC in all modes of operation.

Figure 6–D shows another problem. It was caused by intermittent ignition misfire. The resultant engine surge was "damped out" by the fluid drive of the automatic transmission and, therefore, not known to the owner. This might be any one of several ignition problems, but turned out to be bad spark plugs.

The "truth chart" will include routine instructions, found by experience to be good maintenance practice. For example, if a vehicle has been rejected for high idle CO, this does not necessarily mean that only an idle adjustment is recommended. If upon removal of the air cleaner the carburetor is found to be "varnished up," it should be cleaned. Otherwise idle may not remain in adjustment. It also seems reasonable that, all vehicles rejected should routinely have the basic timing, idle speed, and mixture adjustment set to factory specifications.

NOTE.—The appendix includes the above four examples showing both the "as received CO and HC levels" and "the resultant levels after corrective repair."

MEANINGFUL AND EQUITABLE REJECTION STANDARDS

Figure 7 is a distribution graph showing vehicle population in percent plotted against Seven Mode HC emissions on three groups of vehicles when they are in good repair and set to factory standards. Curve "A" is for preemission with manual transmission; curve "B" for preemission with automatic transmission, and curve "C" for emission control vehicles. The three baselines (one for each vehicle category) are the type of acceptance standards that have been proposed for combined mode quick cycle tests. Let's consider the problems involved even if there was correlation between the quick cycle and Seven Mode.

As explained in conjunction with Figure 1, the baselines will have to be set high so that too many vehicles in good repair will not be rejected for excessive emissions. Secondly, combined mode testing provides no way of telling whether the vehicle at the point marked "X," for example, is in good repair or is actually a vehicle capable of 150 PPM that has a gross malfunction. The biggest "piece of the emission reduction pie" that can be obtained economically, lies to the left of the intersection of the distribution (curves "A"–"B"–"C") and the baselines. Note the shaded area for each vehicle category.

It seems logical that maximum overall emission reduction will result from placing responsibility for proper engine maintenance on all motorists, not just those unfortunate enough to own a vehicle that is inherently in the higher emission group. These fall to the right of the intersection of curves "A"–"B"–"C" and their corresponding baselines. Raising the baselines reduces the net gain from the inspection effort. Lowering the baselines rejects more and more vehicles that inherently cannot be improved by the service industry.

The key mode inspection system totally overcomes this dilemma because it reports the emission levels during operation in each of the three prescribed operating modes. If, then, there is a malfunction or adjustment that causes emission above the basic capability of the specific vehicle under test, it is detected. Since malfunctions cause large increases in emissions in the individual key modes of test, reject standards are not critical nor are they required for each model vehicle.

Unlike other quick cycles, the key modes can be repeated on any dynamometer capable of varying speed and power absorption. Hundreds of these are used today by the service industry. Garages that do not have such dynamic test equipment at least are given guidelines on the inspection report so they do not have to make "shotgun repairs" of everything and anything that might contribute to excessive emissions.

PREDICTING PROBABILITY OF MALFUNCTION BEFORE NEXT INSPECTION

The key mode system just described does not exceed the power output required to perform the Seven Mode test. It, therefore, looks for malfunctions in the legislated vehicle operating range. At option (fig. 2) a fourth mode performed at nearly full throttle will so stress ignition, carburetion, and compression that incipient faults will usually appear. Such faults worsen as mileage accumulates until they will cause malfunction in the lower throttle openings of the Seven Mode or normal key mode cycle. This can occur between annual inspection periods. The optional fourth key mode is a reasonable implement for predicting future emissions performance. The fourth mode can be performed in an added 15 seconds.

Common examples of such faults are—

1. It is not uncommon for components of the ignition system, such as spark plugs, to break down at high power as they begin to depreciate. Such conditions may only have a modest or no effect on idle and cruise HC at the time of test. However, it is common for such deterioration to progress rapidly and affect part throttle modes of engine operation at a point in time after inspection.
2. Statistics indicate that power enrichening does not occur on well over 10 percent of all vehicles tested. If this malfunction is left uncorrected, it usually causes serious engine depreciation with eventual costly repairs as well as a premature rise in emissions. A service will be performed if the motorist is advised of such malfunctions.

CONCLUSIONS

1. A reliable 1 minute mass vehicle inspection system is a reality.
2. It overcomes the technical and public relations hazards of inspection.
3. Its results are repeatable from station to station.
4. Low inspector skill levels are practical.
5. It is suitable for both emission controlled and preemission controlled vehicles.
6. It overcomes the problem of the inherently "high emitter." Yet requires not more than three reject standards to cover the range of all standard domestic and foreign automobiles.
7. The net gain in lower emissions is large because the point of rejection is not dictated by the inherently high emission vehicles.
8. This test method provides guidelines to the service industry so that economical repairs or adjustments can be undertaken.
9. Truth charts can be provided to the service industry that correlate with the inspection card and aid in educating the mechanic in a problem that is totally new to him.
10. Inspection can provide the vehicle owner with a simple explanation. The "Motorist Aid" can be designated to promote his confidence in both inspection and the service industry. Such an inspection is actually a service to the motorist; just as inspection is an economic necessity to operators of vehicular fleets.
11. The fundamental techniques employed permit the use of simple equipment and instrumentation. This assures exceptional reliability and lower initial cost than previously envisioned meaningful inspection methods.
12. The reject standards are flexible in that they may be initially liberal and gradually tightened as circumstances warrant. Such policy changes or future spark ignition engine designs or changes in the certification test modes, will not sigificantly obsolete the hardware required to perform this inspection.

ACKNOWLEDGEMENTS

There is a wealth of test data in the emission laboratories of motor car manufacturers and of the California Air Resources Board. We appreciate their prompt cooperation in supplying us with all data we requested.

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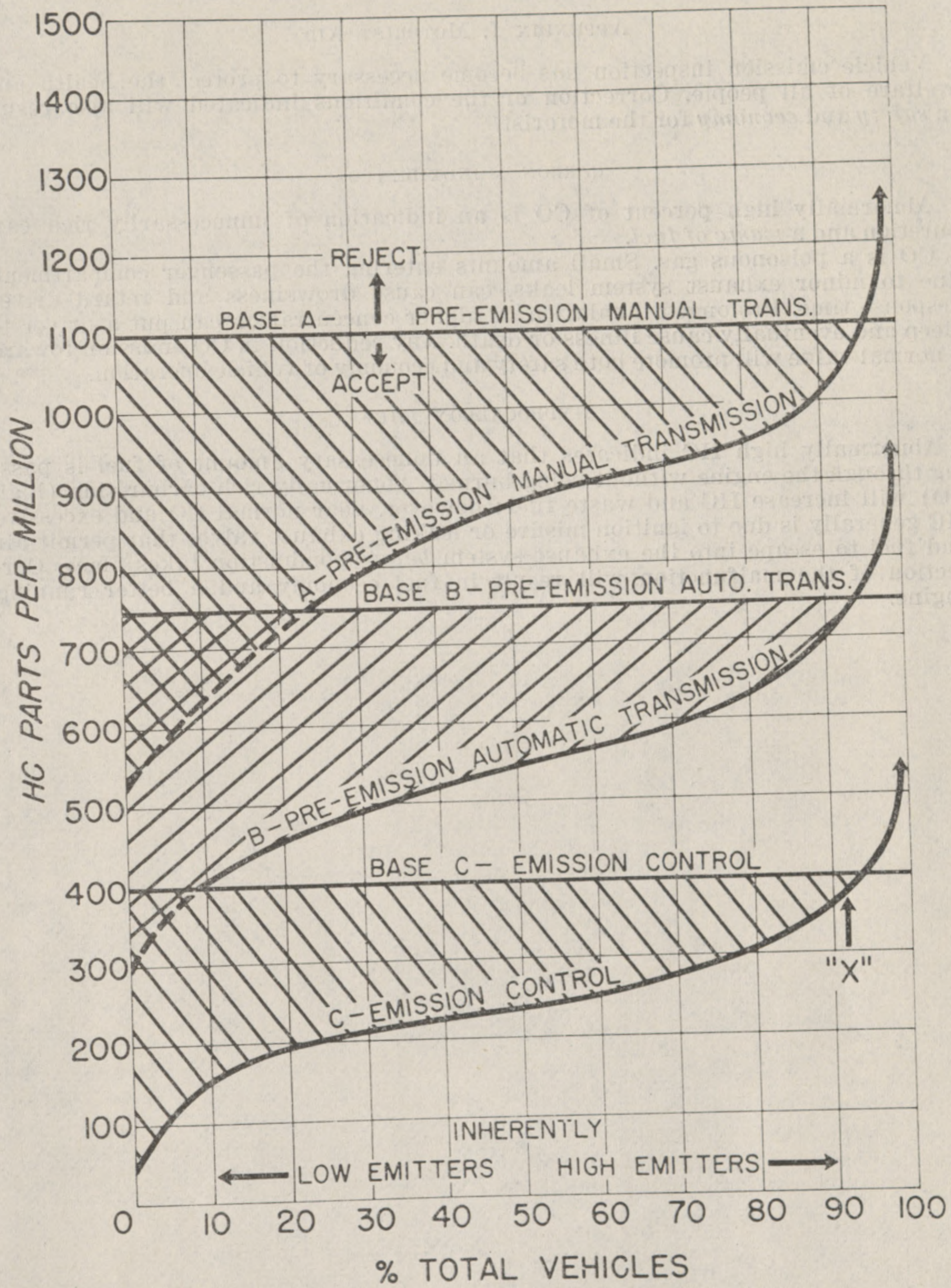


FIG. 7 - Weighted Hydrocarbon - Seven Mode Cycle versus Vehicle Population. Three vehicle groups all in good repair and set to factory standards.

Appendix I. Motorist Aid

Vehicle emission inspection has become necessary to protect the health and welfare of all people. Correction of the conditions indicated will also result in *safety* and *economy* for the motorist.

CARBON MONOXIDE (CO)

Abnormally high percent of CO is an indication of unnecessarily rich carburetion and a *waste of fuel.*

CO is a poisonous gas. Small amounts entering the passenger compartment, due to minor exhaust system leaks, can cause drowsiness and retard driver response time. Prolonged inhalation or higher concentration can put a driver to sleep and eventually cause illness or death. Any reduction in CO emission toward a normal value will promote both safety and economy of vehicle operation.

HYDROCARBON (HC)

Abnormally high HC indicates that an unnecessary amount of fuel is passing through the engine without being burned. Abnormally rich carburetion (high CO) will increase HC and waste fuel; however, near normal CO and excessive HC generally is due to ignition misfire or leaking exhaust valves that permit air and fuel to escape into the exhaust system *before* combustion takes place. Correction of the malfunction will result in fuel economy and a better running engine.

THESE FOUR SHEETS SHOW THE "AS RECEIVED" AND "AFTER REPAIR" EMISSIONS FOR THE FOUR CARS SHOWN IN FIG. 6.

Reference Fig. 6-A

AS RECEIVED

	IDLE	LOW CRUISE	HIGH CRUISE
- CO - CARBON MONOXIDE	MAX. 3% 5.9 ✓	MAX. 2-1/2% .5	MAX. 2% .25
- HC - UNBURNED HYDROCARBON	MAX. 290 PPM 315	MAX. 240 PPM 210	MAX. 220 PPM 135

✓ = REJECT

AFTER ADJUSTING IDLE CO

	IDLE	LOW CRUISE	HIGH CRUISE
- CO - CARBON MONOXIDE	MAX. 3% 1.0	MAX. 2-1/2% .2	MAX. 2% .3
- HC - UNBURNED HYDROCARBON	MAX. 290 PPM 180	MAX. 240 PPM 195	MAX. 220 PPM 145

26-248—69——4

Reference Fig. 6-B

AS RECEIVED

	IDLE	LOW CRUISE	HIGH CRUISE
- CO - CARBON MONOXIDE	MAX. 3% 2.1	MAX. 2-1/2% 3.8 ✓	MAX. 2% 5.6 ✓
- HC - UNBURNED HYDROCARBON	MAX. 290 PPM 190	MAX. 240 PPM 335	MAX. 220 PPM 295

✓ = REJECT

AFTER CARBURETOR OVERHAUL

	IDLE	LOW CRUISE	HIGH CRUISE
- CO - CARBON MONOXIDE	MAX. 3% .6	MAX. 2-1/2% .8	MAX. 2% .75
- HC - UNBURNED HYDROCARBON	MAX. 290 PPM 165	MAX. 240 PPM 205	MAX. 220 PPM 165

Reference Fig. 6-C

AS RECEIVED

	IDLE	LOW CRUISE	HIGH CRUISE
- CO - CARBON MONOXIDE	MAX. 3% 2.0	MAX. 2-1/2% 1.5	MAX. 2% .8
- HC - UNBURNED HYDROCARBON	MAX. 290 PPM 490 ✓	MAX. 240 PPM 380 ✓	MAX. 220 PPM 305 ✓

✓ = REJECT

AFTER VALVE REPAIR

	IDLE	LOW CRUISE	HIGH CRUISE
- CO - CARBON MONOXIDE	MAX. 3% 2.0	MAX. 2-1/2% 1.3	MAX. 2% .9
- HC - UNBURNED HYDROCARBON	MAX. 290 PPM 220	MAX. 240 PPM 170	MAX. 220 PPM 160

Reference Fig. 6-D

AS RECEIVED

	IDLE	LOW CRUISE	HIGH CRUISE
- CO - CARBON MONOXIDE	MAX. 3% 2.4	MAX. 2-1/2% 1.6	MAX. 2% .75
- HC - UNBURNED HYDROCARBON	MAX. 290 PPM 395 ✓	MAX. 240 PPM 180	MAX. 220 PPM 950 ✓

✓ = REJECT

AFTER REPLACING PLUGS

	IDLE	LOW CRUISE	HIGH CRUISE
- CO - CARBON MONOXIDE	MAX. 3% 2.0	MAX. 2-1/2% 1.3	MAX. 2% .3
- HC - UNBURNED HYDROCARBON	MAX. 290 PPM 95	MAX. 240 PPM 95	MAX. 220 PPM 125

ENERGY SYSTEMS INC.,
Newton, Mass., January 25, 1969.

Mr. S. L. SUTCLIFFE,
Staff Counsel, Committee on Commerce,
U.S. Senate, Washington, D.C.

DEAR MR. SUTCLIFFE: In response to your letter of January 15, Energy Systems, Inc. is continuing its development program with emphasis upon the application of new technology to—

(*a*) Small, compact burners.
(*b*) Steam generator systems.
(*c*) Study of high-temperature lubricants.
(*d*) Control systems.
(*e*) Piston-type Rankine cycle engines.

We now have a complete operating system and are studying markets prior to design and development of our first preproduction, prototype unit which will probably be in the 100- to 250-horsepower range. The system has been privately financed, and our company neither has nor has sought any Government support for our project, at least to date. We are more convinced than ever that there are some commercial projects for use of steam and/or vapor cycle engines where questions of pollution, speed-torque characteristics, and noise are important.

Very truly yours,

RICHARD S. MORSE.

ROY R. FERRIAR CO.,
Los Angeles, Calif., January 28, 1969.

Mr. S. L. SUTCLIFFE,
Staff Counsel, U.S. Senate Committee on Commerce,
Washington, D.C.

DEAR MR. SUTCLIFFE: Thank you for your letter of January 15, 1969, regarding the report the Senate Commerce Committee is preparing on the steam vehicle hearings held in May 1968.

Enclosed is a copy of a statement I was invited to make to the California Assembly Committee on Transportation and Commerce on December 6, 1967. It gives a very brief summary of what I have been doing, and am planning to do in the field of steam research and development. Expanding on one part of this statement—about the need for a large research grant for steam—I believe this is where the Federal Government and private enterprise could well get together. The untapped potential use for steam power in all phases of our country's future development—and that of all other countries, too—is practically limitless. This is something to which I am deeply committed and vitally interested. I only wish it were more widely known and understood what steampower can really do and accomplish.

I am also enclosing a copy of the Steam Power Quarterly, vol. 1, No. 4, 1967, with an article on pages 8 and 9 about the total energy package (TEP) which I developed for the Southern California and Southern Counties Gas Companies. This unit was built to illustrate the idea of producing light, heat, power, and refrigeration from one source of heat—in this instance, natural gas. Any other fuel could be used. Here, too, the future use for this steampowered unit is unlimited.

At the present time I am building a steam unit for an automobile, with special emphasis on the burner with a low pollutant. I regret that I am unable to furnish full details on this project at the prseent time, because we have not yet completed all of our tests.

If you have any questions on any of the above, please do not hesitate to let me know.

Sincerely yours,

ROY R. FERRIER.

STATEMENT BEFORE THE CALIFORNIA ASSEMBLY COMMITTEE ON TRANSPORTATION AND COMMERCE, SACRAMENTO, CALIF., DECEMBER 6, 1967

Mr. Chairman, ladies and gentlemen: Thank you.

I am in Sacramento today to speak on behalf of steam. As a possible prime mover for automobiles, steam can be the force to alleviate smog.

For the past 10 years I have been working in Los Angeles doing research and development with steam engines, boilers, and burners.

A steam system for modern automobiles and trucks, I am convinced, can be produced to meet all the demands of modern traffic—and with much less pollution to the air than the present internal combustion engines. A small compact engine I built for the Marquardt Corp. is an ideal type for such automotive use.

Another form of steampower is the total energy package that I developed and built for the Southern California and Southern Counties Gas Companies. It is a part of their permanent energy exhibit just opened at our California State Museum of Science and Industry, in Exposition Park, Los Angeles. Such production of five forms of energy from natural gas—heat, light, electricity, mechanical motion, and sound—would emit considerably less smog than gasoline or diesel-driven units.

This steampowered unit is adaptable for use in both urban and remote areas. It has practical application in all types of commercial and private buildings. In the event of power failure, it could serve as a standby unit.

Burners for steam systems consume the fuel much more completely than internal combustion engines. However, much still remains to be done in improving these burners—and that is why I am concentrating research and development efforts in that direction.

In 1967, a group of natural gas utilities, in cooperation with Pratt & Whitney Aircraft and the Institute of Gas Technology, launched a $20 million, 3-year program aimed at building a natural gas fuel cell which would be capable of supplying all the energy requirements of an average American home.

I wish some company or group of companies and the technical association representing them would come through with even half that amount for research and development in steampower. I firmly believe that at the end of 3 years we conceivably could make a major contribution toward solving the smog problem.

Attached is a copy of the energy exhibit brochure and the Marquardt Corp. report, MR 20345, entitled "An Experimental Evaluation of a Modern, High Speed Steam Engine."

Thank you for giving me this opportunity to appear before you. I will be happy to answer any questions on steam.

FORD MOTOR CO.,
Dearborn, Mich., January 23, 1969.

Mr. S. L. SUTCLIFFE,
Staff Counsel, Committee on Commerce,
U.S. Senate, Washington, D.C.

DEAR MR. SUTCLIFFE: Your letter requesting information on steam vehicle developments at Ford Motor Co. has been received and referred to the appropriate people. I have asked them to provide you directly with any information that they would consider helpful.

Sincerely,

S. E. KNUDSEN, *President.*

FORD MOTOR CO.,
Dearborn, Mich., January 30, 1969.

Mr. S. L. SUTCLIFFE,
Staff Counsel, Committee on Commerce,
U.S. Senate, Washington, D.C.

DEAR MR. SUTCLIFFE: I have been asked by Mr. Knudsen to respond to your recent letter to him requesting any additional information concerning emission control activities since my testimony before your committee last May.

I believe that our emissions research work with the interindustry emission control program, which I referred to in my testimony, is worth reporting to you at this time. The IIEC, you may recall, is a joint industry program that Ford Motor Co. launched in April 1967, with the Mobil Oil Corp. It has expanded to include five other American oil companies: The American Oil Co., Atlantic Richfield Corp., Marathon Oil Co., Standard Oil of Ohio, and the Sun Oil Co. Recently the IIEC became an international venture with the addition of four foreign car manufacturers—Fiat of Italy, and Mitsubishi Heavy Industries, Nissan Motor Co., and Toyo Kogyo Limited, all of Japan.

The program is based on a systems approach concept for solving the common problem of emissions by these auto and petroleum companies.

The systems approach involves the development of both hardware and fuel modifications to meet emission objectives we established and to which I referred in my testimony. These, in brief, were levels of 65 parts per million hydrocarbons, 0.3 mol percent carbon monoxide, and 175 parts per million oxides of nitrogen.

At a meeting of the chief executive officers of the companies participating in the IIEC program (Ford Motor Co. is the project manager), held in Chicago on November 19, 1968, the following examples of equipment developed by the joint research group in the first 18 months of IIEC activity were exhibited:

DUAL CATALYST CONCEPT CAR

Main features of the car included—

1. A pressurized gas tank containing a modified fuel to minimize evaporation losses.
2. A programed by-pass system which controls the flow of exhaust gases in the concept car.
3. A catalytic converter in a reducing atmosphere to minimize the oxides of nitrogen in the exhaust.
4. An air injector which injects air into the system before exhaust gases pass into the hydrocarbon and carbon monoxide catalyst.
5. A second catalytic converter which reduces the hydrocarbon and carbon monoxide content of the exhaust.

This type of vehicle would require fuel modification including the absence of lead compounds.

IIEC TANGENTIAL THERMAL REACTOR

The IIEC-developed tangential thermal reactor was shown and represented a new design approach to the problem of injecting air into the vehicle's exhaust to promote more complete combustion of gases.

The reactor incorporates a cast iron outer housing and four separate high-temperature alloy sheet metal inner chambers that generate a swirl effect caused by the tangential entry of exhaust gases. This type of entry should allow for better mixing, prolong the time the exhaust-air mixture is in the reactor, and result in significantly lower hydrocarbon and carbon monoxide emissions.

Secondary air will be circulated between the inner and outer shells to preheat the air before it is injected into the inner parts of the reactor.

MATH MODELING FOR CATALYST AND CONVERTER DEVELOPMENT

The objective of this project is to obtain engineering design data and construct a predictive mathematical model for optimizing the design of catalyst and converter exhaust emission control systems.

It was reported that mathematical models of catalyst and converter systems, incorporating known data, are being developed to—

1. Accelerate development of the best catalyst/converter/vehicle system.
2. Optimize data interchange between experimental and computer simulation studies.
3. Identify the important engine, catalyst, and other vehicle/fuel variables.
4. Examine such items as—
   - (*a*) Catalyst specific heat.
   - (*b*) Catalyst chemical activity.
   - (*c*) Catalyst density and size.
   - (*d*) Converter flow pattern and size.
   - (*e*) Urban driving flows and temperature patterns.

PROGRAMED BYPASS SYSTEM

This is the "logic system" that controls the use of the catalyst converter in the first IIEC concept car. The purpose is to prolong the life of the converter by protecting the catalysts from long-term exposure to high-temperature exhaust gases at turnpike speeds, when raw emissions are normally low.

Using sensors measuring catalyst temperature, engine water temperature, vehicle speed, and engine intake vacuum, the logic system is programed to switch vehicle exhaust flow around the converter during low-emission driving conditions.

FAST WARMUP CATALYST CONVERTER

It was reported that a converter had been developed which would contain a high-activity, low-temperature catalyst. It is located near the engine and helps reduce exhaust emissions during the vehicle's warmup period.

After warmup, the unit would be bypassed out of the exhaust system by a programed control, to protect the catalyst and restore a more acceptable vehicle exhaust back pressure.

NITROGEN OXIDE PULSE GENERATOR

A laboratory simulation was shown which produced oxides of nitrogen and carbon monoxide equivalent to that of an automobile engine. This is a necessary first step in the study af catalysts to break down these gases to oxygen and nitrogen.

The device employs an intermittent flashing flame, similar to the firing of pistons in an automobile engine.

Several of these units have been used to determine how various air-fuel mixtures, fuel additives, and combustion temperatures affect the formation of nitrogen oxides. Exhaust gases produced by a generator have also been used to survey several catalysts for their effectiveness in controlling oxides of nitrogen.

These were reported as illustrations of our systems approach. One of the reasons this approach is working is because of the talent pool that becomes available when we combine the expertise of two major industries. By combining the proven prowess of the oil industry in the fields of chemical, catalytic and steady state math model process control, with the engineering talent of the auto industry for designing hardware systems to work in a variety of climates and under transient operation, we feel we have greatly accelerated the progress and the definition of significant problems requiring further solution. In our opinion, neither group working in isolation of the other could have achieved results of comparable quality or quantity in so short a period of time.

On November 19, 1968 we stated, "We have not met all of our emission objectives as yet," but that we were "quite gratified with the results achieved to date. The second vital phase of the engineering problem—proving the durability of these hardware systems— is also underway but the major effort in this area lies ahead."

We also are continuing our own engineering and research work with alternate power sources, such as the gas turbine engine, in addition to concerted efforts to further reduce emissions from the internal combustion engines.

As a matter of fact, we announced on January 28, 1969, that Ford Motor Co.'s gas turbine activities are being expanded significantly this year, including a 20-percent increase in engineering and technical personnel, accelerated testing programs, process development, and manufacturing planning.

You perhaps have learned that since last summer, we have been running gas turbine powered trucks in our company fleet, hauling parts from Michigan to our plants in Ohio. Performance results, including very low emissions, have been most encouraging and we are pursuing this program aggressively. As I stated in part in my testimony before your committee on May 27, 1968: "* * * Ford Motor Co. is aggressively pursuing all avenues leading to the ultimate goal of clean air."

This letter is another indication of the validity of that assurance. If you wish further information, please feel free to call upon me.

H. L. MISCH,
Vice President, Engineering.

GENERAL MOTORS CORP.,
Detroit, January 31, 1969.

Mr. S. L. SUTCLIFFE,
Staff Counsel,
Committee on Commerce,
U.S. Senate, Washington, D.C.

DEAR MR. SUTCLIFFE: This is in reply to your letter of January 16 relative to the report on the low-emission powerplant hearings of last May. As we indicated at that time, our work in this area is continuing and we are pleased to report to you on the progress that has been made.

On the steam engine approach we have stepped up our efforts to give this a thorough evaluation. As was reported last May, we hoped that by helping the

California Highway Patrol to acquire steamcars to test we would by this time have some operating experience regarding the various versions which were presumably ready for installation. We were disappointed to learn that none of the potential vendors were able to meet the initial performance requirements set by the highway patrol.

The vendors were then invited to make proposals to the highway patrol of performance standards which they, themselves, felt that they might be able to attain. According to our information six potential vendors responded, but of these only two really seemed to qualify for even these reduced performance standards. We assume negotiations between the highway patrol and these two potential vendors are still continuing. Since to permit complete objectivity General Motors has deliberately disassociated itself from any technical interaction in connection with this demonstration project, any more detailed information will have to be obtained directly from the California authorities.

As we also reported last May, to insure that there would be at least one recently developed operating steamcar available to us for testing, we contracted with Besler Developments, Inc., of Oakland, Calif., to build one of their modernized Doble units for installation in a Chevrolet Chevelle. This project is on schedule and delivery is expected in April or May.

When the delays in the California highway project began to be apparent, and it appeared that there might be no steamplant of truly modern design available in the immediate future, a new project toward this end was initiated in the GM research laboratories. This is a major project involving an upgrading and modernization of each of the many engine components involved. Completion of testing of our GM engine is probably a year or more away. In particular because of the Ayres testimony last May, the possible use of working fluids other than water was carefully considered. Further to eliminate any undue local bias, a parallel-design study was contracted for from the very competent and experienced British firm of Ricardo & Co. Their conclusions agreed closely with our own, and work is now underway on the design and fabrication of parts. It is interesting and significant that, according to oral reports at the January SAE meeting in Detroit regarding the Lear approach, the three groups making the most serious investigations of vapor-cycle powerplants—namely, Lear, Ricardo, and GM—have all returned to the use of water as the working fluid. This supports the testimony given by GM a year ago.

On another matter which led to considerable interest and discussion following the hearings last May, considerably more detailed information has become available. This is in connection with the matter of licensing and inspection. You will recall that GM testimony called attention to the fact that there has long been in existence the ASME (American Society of Mechanical Engineers) boiler code covering the use of pressure vessels of all kinds. We have now had time to explore to some extent the degree to which this code, and regulations based on it, would apply to steam boilers in automobiles. Examples of exchange of correspondence between our Mr. Underwood and authorities in Michigan, and our Dr. Hafstad and the authorities in Washington, D.C., are representative and are attached for your information.

With regard to work on other continuous combustion heat engines, our projects on both turbines and Stirling engines are continuing. As has been reported, the problems here are principally in getting reduced cost. While steady progress is being made we can report nothing to change the relative cost estimates we made a year ago.

Our work is also continuing in the effort to reduce the emissions from the conventional internal combustion engine. Here good progress is being made as indicated by the charts attached. These charts illustrate the control of the three principal automotive emissions on a cost-benefit basis. Controls already on our vehicles are shown, as well as projections based upon our research work to establish the technical feasibility of still more effective controls.

From these charts it is seen that hydrocarbon and carbon monoxide emissions have been already reduced by about two-thirds, and modified systems on 1970 cars will reduce these emissions even more. These gains have been made at low expense to the consumer.

It is apparent that it is technically feasible to achieve very low pollution levels with internal combustion engines—levels at least as low as known ambient air quality needs. More importantly, of the various approaches to controlling vehicular pollution, the gasoline engine seems to offer a better cost-benefit relationship than the unconventional powerplants in the lower right-hand corner of these charts.

To summarize, we are actively investigating a number of energy conversion methods, including steam engines, which offer potential for satisfying automotive power requirements. However, present technology indicates that the gasoline engine still offers the best compromise as to cost, durability, reliability, economy, performance, efficiency, and the control of pollutants.

Sincerely,

E. N. COLE.

HYDROCARBON REDUCTION ECONOMICS

California Vehicles

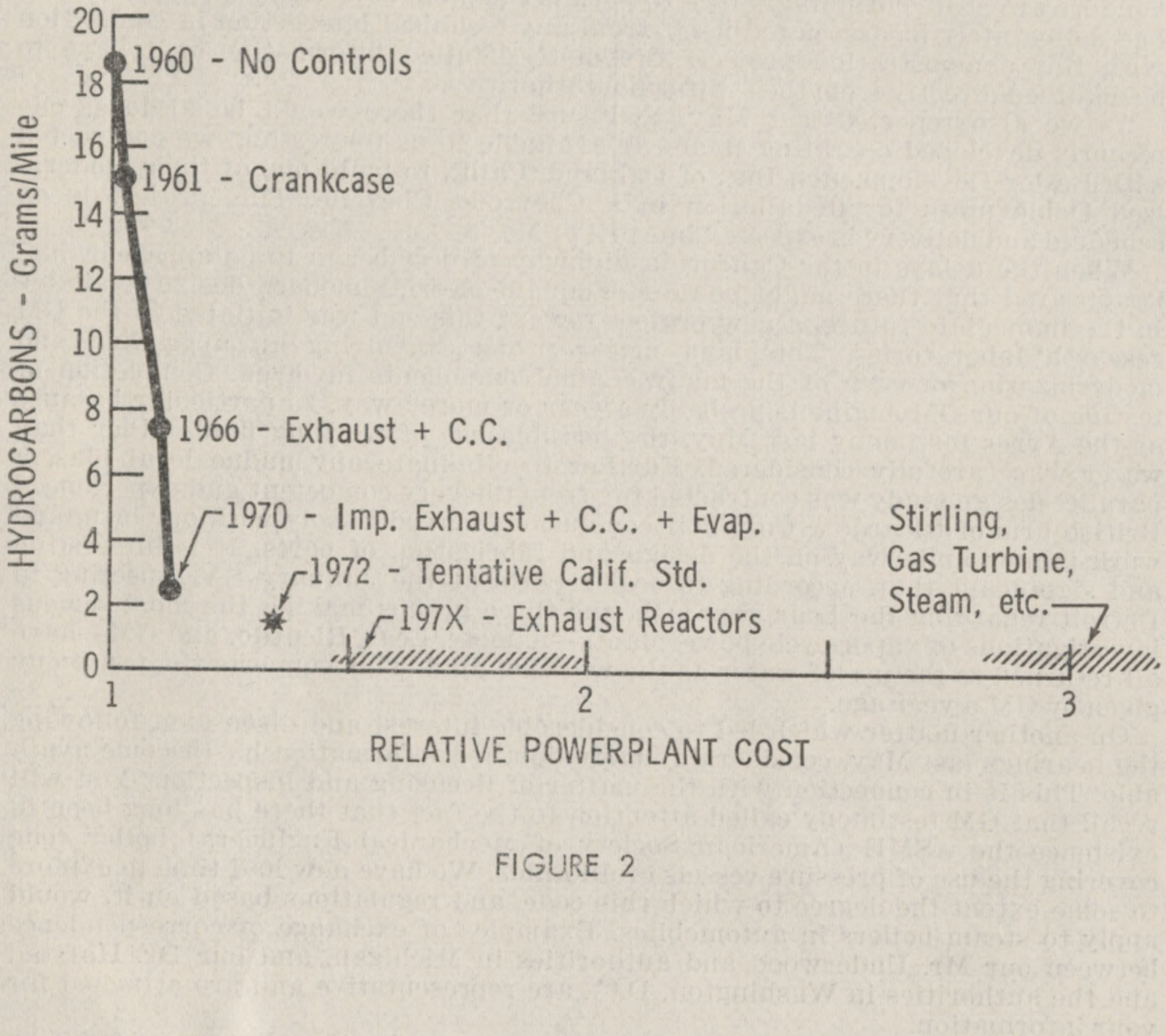


FIGURE 2

CARBON MONOXIDE REDUCTION ECONOMICS

California Vehicles

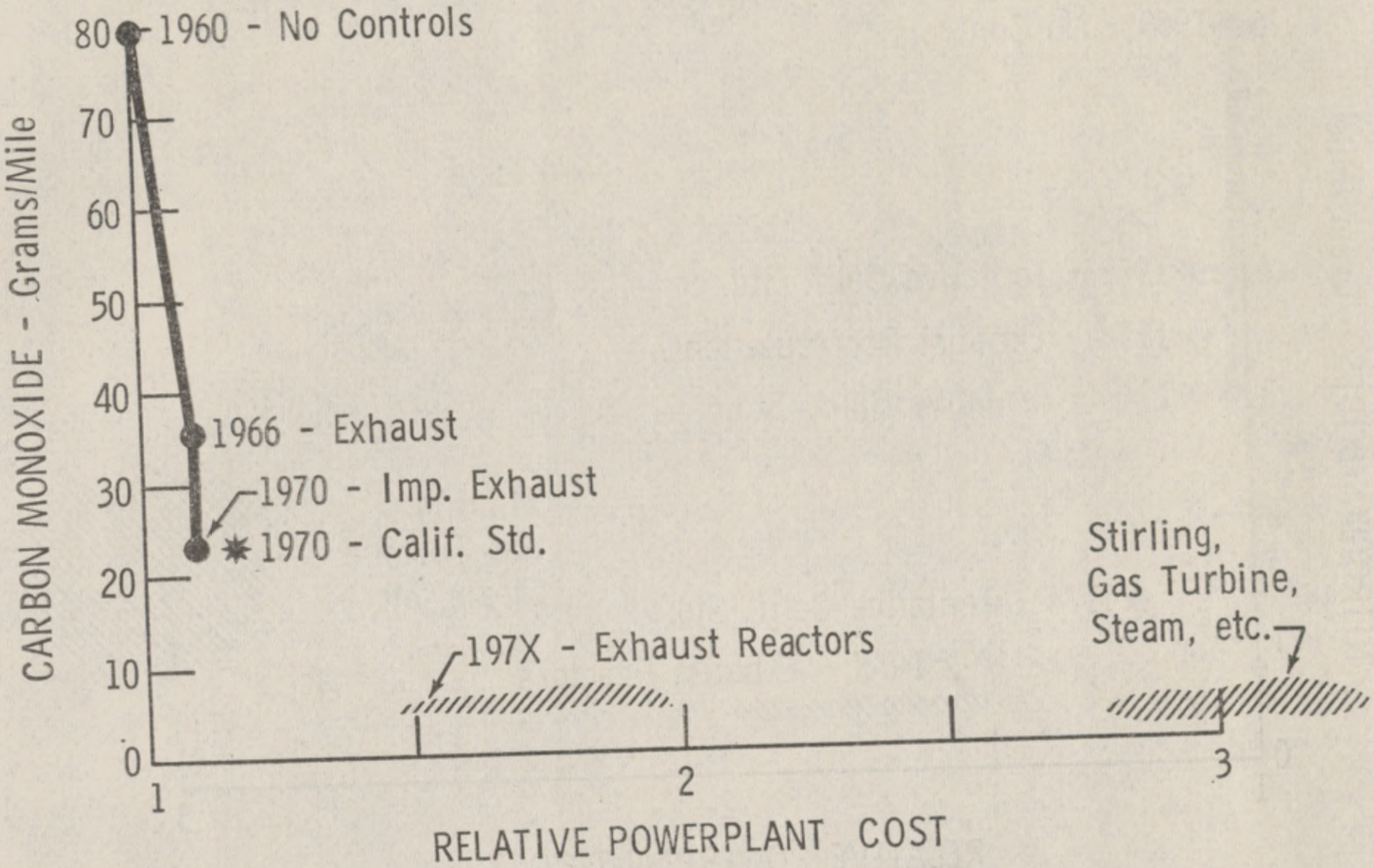
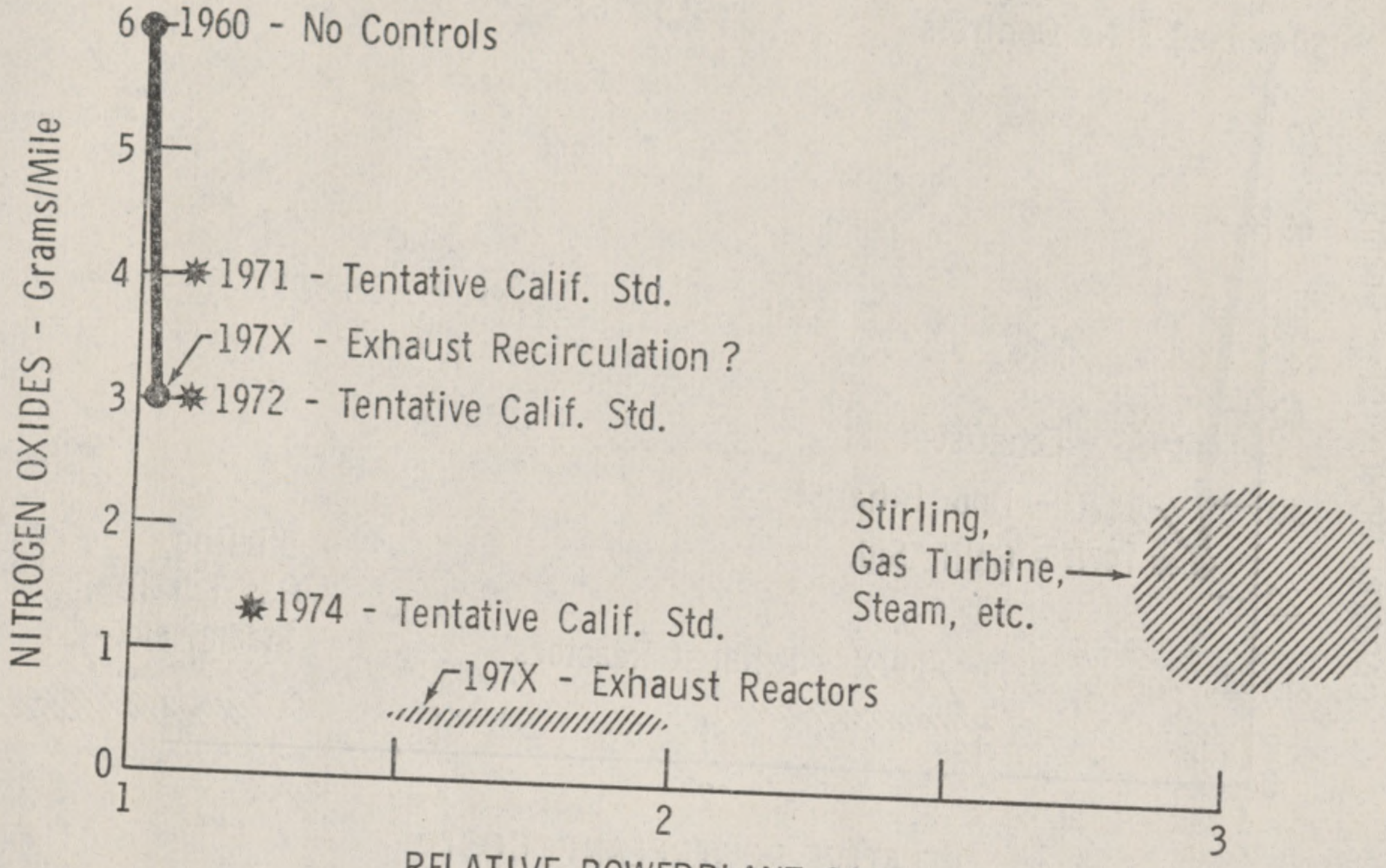


FIGURE 3



NITROGEN OXIDES REDUCTION ECONOMICS
California Vehicles

FIGURE 4

GIBBS-HOSICK TRUST,
January 18, 1969.

Mr. S. L. SUTCLIFFE,
Staff Council, Committee on Commerce,
U.S. Senate,
Washington, D,C.

DEAR MR. SUTCLIFFE: We are in receipt of your letter of January 15 requesting up-to-date information on our development project for a "smogless" automotive powerplant based upon our elliptocline steam engine.

In our program, emphasis has been placed upon the development of an engine which will produce a horsepower-hour of work on less pounds of steam than was possible with earlier automotive steam engines which were in production. This economy of steam use will go a long way toward solving any problems of steam generator and condenser size. We have preferred to believe that adequate steam generators for powering our elliptocline engines would be available from other sources, such as Richard Smith in Midway City, Calif. California tests of the Smith steam generator showed results in line with those of the well-known tests of the Williams system in regard to levels of pollutant emissions much more favorable than projections for cleaning up the gasoline engine made far into the future—levels which can be had now. The steam generator component of the automotive steampower system, incidentally, is the only source of possible pollutant emissions; our elliptocline steam engine component of the system has no emissions of any kind. Therefore, only if we get into steam generator development, will we be concerned with pollutants. As protection against the remote possibility that indeed we will not be able to procure suitable steam generators from other sources, we do have designs on paper for such a unit with an adequate automatic control system. Work has started on the actual production of one such unit.

Since the Senate joint hearings, we have emphasized studies concerning modification of the elliptocline engine for operation on heavy organic vapors, such as one of the fluorocarbons, in place of steam. The advantages of fluorocarbons as a working medium are (1) winter freezeup problem eliminated, (2) superior thermodynamic properties for higher thermal efficiencies within given temperature limits within the system, (3) self-lubricating properties, especially in specially formulated mixtures, and (4) they are odorless, tasteless, nontoxic, and nonflammable. The elliptocline modifications consist mainly of minor valving and porting alterations. Actually, the lubrication system for the engine will be made simpler by use of self-lubricating fluorocarbons. In addition, when fluorocarbons are substituted for water in a vapor power system, other modifications of the system must be made, mainly alterations of heat exchanger design. So far, our alternate fluid studies have been mainly on paper, although we are modifying an older type steam engine for preliminary tests. Our progress in recent months has been delayed due to the decreased funding available.

We would like to emphasize that our elliptocline steam engine design demonstrates a number of advantages over the more conventional steam engine configurations. Since all reciprocating components of its motion are balanced by similar opposed motions, the engine is inherently balanced, giving a very smooth and quiet operation. Only one engine valve is required to time steam admission and auxiliary exhaust events, both in the "forward" and "reverse" modes of operation, and this valve can handle any number of cylinders one wishes to design into the machine. Basic simplicity of even a multicylinder engine leads to economy of manufacture. Ability to function at very high ratios of steam expansion permits the engine to be very economical of steam usage and the multiplicity of cylinders permits the engine to have good starting ability at all power-shaft angles for economical operation at greatly varying torque outputs. In comparison to the gasoline engine, the elliptocline shares with all other automotive steam engines the large number of characteristics that make it vastly superior for powering automobiles. We need to find a way to expedite the development of an elliptocline-powered automotive steam or vapor system for the elimination of smog, coupled with a vast improvement of the nature of an automotive powerplant. One does not have to suffer performance deterioration to eliminate the automotive smog problem.

We hope the newly elected group in Washington will be strongly cognizant of the fact that the automotive smog problem can be virtually eliminated by a program that will start giving immediate results, if sufficient encouragement is given.

Sincerely yours,

THOMAS A. HOSICK.
R. A. GIBBS.

[From Product Engineering, Nov. 4, 1968]

ENGINE USING FREON "STEAM" ENTERS THE AUTO POWER RACE

By the end of this month, a car powered by Freon—a fluid normally used as a refrigerant—may be undergoing public tests on Florida roads. The car, an invention of Wallace L. Minto, of Sarasota, is far from production or even prototype form. But it represents one more effort to find a pollution-free substitute for internal combustion.

Minto is president of Sarasota Research & Development Corp., parent company of Kinetics Corp., which holds the patents on the Freon-powered car. His car works on essentially the same principle as the old Stanley Steamer, yet the two can hardly be compared.

FAST START

The steam engine was a relatively slow starter, besides wasting a good deal of energy. It also had winter freezing problems. The so-called Sarasota engine uses a refrigerant fluid that freezes at —168° F. Minto claims the flash burner in his car can generate enough power in 3 seconds to move it from a driveway or parking spot. And, he says, full power is generated 6 seconds from the time the ignition key is turned.

According to the inventor, the rear-mounted engine is almost soundless. And the propane used to heat the liquid burns in an open, high-oxygen flame, so it causes little or no air contamination.

COMPUTER-CONTROLLED

According to Minto, a computer is the key to the car's operation. When the key is turned, the computer is turned on, and the ignition system kicks the single spark plug through a 10-second time cycle. The burner is ignited. Then the computer senses low pressure in the Freon boiler and automatically turns the propane burner full on. Minto claims 1 million B.t.u./hour are generated.

The driver is alerted by the flashing of a green light that the car is ready to go. There is no sound.

There are three lights on the panel facing the driver. Green means normal operation; amber means increased power is needed, as for freeway passing or climbing a steep hill, and a red "idiot light" coupled with a buzzer stops the car and warns the driver of an undesirable condition in the engine.

For winter driving, hot vapor from the boiler warms the car in seconds, says Minto. For summer, air conditioning would be standard because Freon is the coolant used in air-conditioning systems.

PERFORMANCE

If the car ever goes into production, it will have a top speed of 120 miles per hour, according to the designer. Cruise speed of 70 miles per hour would be maintained at 750 revolutions per minute, compared with about 3,000 revolutions per minute for a conventional automobile.

Because the internal parts move slowly, Minto says his car will last a long time. There are only about 3 dozen moving parts, including the wheels.

Weight of a commercial version of the engine, according to Minto, will be 150 pounds. The tank, burner, and control systems—including 100 pounds of Freon—will weigh 250 pounds.

SAFETY FEATURES

Minto has designed a revolution per minute-sensor for the drive shaft that is correlated to throttle demand. The sensor is set with a key to limit maximum speed.

Another safety feature would enable the driver to decelerate rapidly without brake fade, according to the designer. If the driver presses hard on the brakes, the computer senses the speed of the vehicle at the time. If the car is traveling at high speed, it automatically reverses torque on the rear wheels at the maximum rate that doesn't cause the vehicle to spin. The torque reverser is applied only in proportion to forward speed; jamming on the brakes at under 25 miles per hour, for example, would not activate this safety mechanism, Minto says.

COMMERCIAL PROSPECTS

There are no plans yet to build the car. However, earlier this year Minto obtained estimates from Rowan Industries, Inc. (owners of the Italian automobile designers, Ghia) for building a prototype based on his power-train configuration.

One of the first commercial uses Minto foresees for his car is in mass-transit vehicles such as city buses. A Freon engine, he says, would reduce their noise and provide smooth and rapid acceleration, besides reducing chemical pollution.

LEAR MOTORS CORP.,
Reno, Nev., February 19, 1969.

Mr. S. L. SUTCLIFFE,
Staff Counsel, U.S. Senate,
Committee on Commerce, Washington, D.C.

DEAR MR. SUTCLIFFE: Mr. Lear has asked me to reply in detail to your letter of February 4. Although at this time we do not have an "off the shelf" progress report for release, I will do my best to acquaint you of our progress and expectations in the area of steam power.

For your convenience I have submitted the requested information in the form of the enclosed attachment, and trust it will meet the requirements for your report.

Regarding a visit to Reno, it is our pleasure to have any of your staff or Senators visit our facilities. In development to date we have achieved 100 percent combustion efficiency, and a complete power system will be operational shortly. In the near future we will be able to pinpoint a date for you to examine a fully operating street vehicle.

Thank you for your consideration and action in the field of steam power. I look forward to talking to you soon about your visit.

Very truly yours,

KEN WALLIS, *General Manager.*

LEAR MOTORS CORP. VAPOR CYCLE POWERPLANT DEVELOPMENT

GENERAL DESCRIPTION

Lear Motors' present program is concerned with the development of a powerplant range from 30 to 1,000 horsepower embracing both reciprocating and turbine machinery and adaptable to practically every power requirement presently served by the internal combustion (IC) engine. It is our belief that not only is the IC engine unsuitable because of its inherent exhaust pollution but that its basic characteristics are totally unsuited to the propulsion of a vehicle. The present acceptance and use of the IC engine says much for the half century of development and ingenuity largely by the transmission industry.

The Lear Motors power system is essentially a modified Rankine cycle and, of course, is entirely closed. Our contribution has been largely in the application of modern aerospace technology to the old science of steam engineering. This contribution is apparent in many areas, principally :

1. Vapor generator,
2. Condenser,
3. Control System,
4. Thermodynamics.

Our vapor generator, for example, utilizes relatively high pressure and high temperature to reduce size and to improve efficiency over early steam machines. Yet all parts of the powerplant are cool enough to be comfortable to the human touch. Concerning the high pressure, there is no such possibility as a "boiler explosion." Total latent energy at maximum capacity in the vapor generator of our California Highway Patrol unit is the equivalent of a few ounces of gasoline. When it is understood that this cumulative energy is contained in a monotube construction generator, possibility of a so-called "explosion" is nonexistent. Under extensive burst testing in our laboratory we have established tube failure to occur at about 400 percent of full operating pressure.

Similar significant advances relate to other parts of the total system.

I have enclosed for your interest a diagrammatic representation of our basic power system. You will see that an auxiliary package is in operation whenever the system is used. This auxiliary unit provides support for the system proper and, in addition, powers the various services required by the vehicle, such as the air conditioner, power steering pump, alternator, etc. Under this arrangement, even though the vehicle were parked with the motor not running, full accessory usage is guaranteed. This has direct application to our Highway Patrol vehicle where there is a heavy demand for auxiliary power (rotating lights, power supplies, transceivers, etc.) under static conditions. In a passenger automobile, the car could be heated or cooled under "parked" conditions.

THERMAL EFFICIENCY

Because of the operating mode of the system and the wide variation in duty cycle, it is difficult to quote a general thermal efficiency for our system. However, our studies and tests indicate that for all forms of operating we can expect improved fuel economy over the present gasoline powered vehicles. This by our early units with obvious development potential.

SHAFT HORSEPOWER

Power available from our system in vehicular applications can be from 200 to 700 horsepower. To satisfy the performance requirements of the California Highway Patrol we are required to install approximately 300 horsepower in the patrol car. This power package can readily be accommodated under the hood. Considering the modern IC engine and transmission, the steam power system is obviously less complex. There is no requirement for carburetor, pollution control equipment, afterburners, clutch-torque converter, or shifting transmission.

COST

Cost of a vapor cycle powerplant falls naturally into two categories: cost of construction, and cost of operation.

Production units being constant, cost of construction is a function of material cost and machine complexity. We require no more "exotic" materials in our engines than those now being used in high performance IC engines, and as an overall system the vapor cycle will prove to be no more complex than current IC engines, some individual parts being much simpler. We project competitive volume production cost.

Concerning operating cost, fuel economy will be improved over present IC engines. Furthermore, since our units will burn clean kerosene or heating oil without the need for expensive and toxic additives such as lead, we expect to show appreciable operating cost advantages in cents per ton-mile in addition to the reduction in health and fire hazard associated with highly refined gasolines.

SIZE

Our total power generating system fits under the hood of a 1969 highway patrol vehicle. The actual motor is much smaller than one of comparable power in IC engines, but our vapor generator somewhat compensates for this obvious advantage.

At the present state of the art, we are building "bolt-in" items compatible with today's motor vehicles. Were a vehicle to be designed around a vapor powerplant, it could utilize space much more efficiently, however, and there would be significant decreases in the area required for the powerplant and drive train. The advantages inherent in this are obvious.

COMPLEXITY

Complexity is ofttimes equated with unfamiliarity, regardless of how invalid this assumption may be. The most complex power train component in our system is the valve for controlling steam admission to the engine, and a sophisticated development program is presently being conducted. The vapor generator control system is comparable in complexity with the transistorized ignition system used on some gasoline-powered vehicles. No new techniques are involved in this electronic package and high reliability is confidently expected.

LUBRICATION SYSTEM

We are presently engaged in a comprehensive lubrication program, and although we have many solutions to the obvious lubrication problem it will be some little time before we make a final selection of lubrication philosophy.

STARTUP TIME

Startup time, cold from 0° F., is of the order of 20 seconds.

PAXVE, INC.,
Newport Beach, Calif., January 17, 1969.

Hon. WARREN J. MAGNUSON,
Committee on Commerce,
U.S. Senate, Washington, D.C.

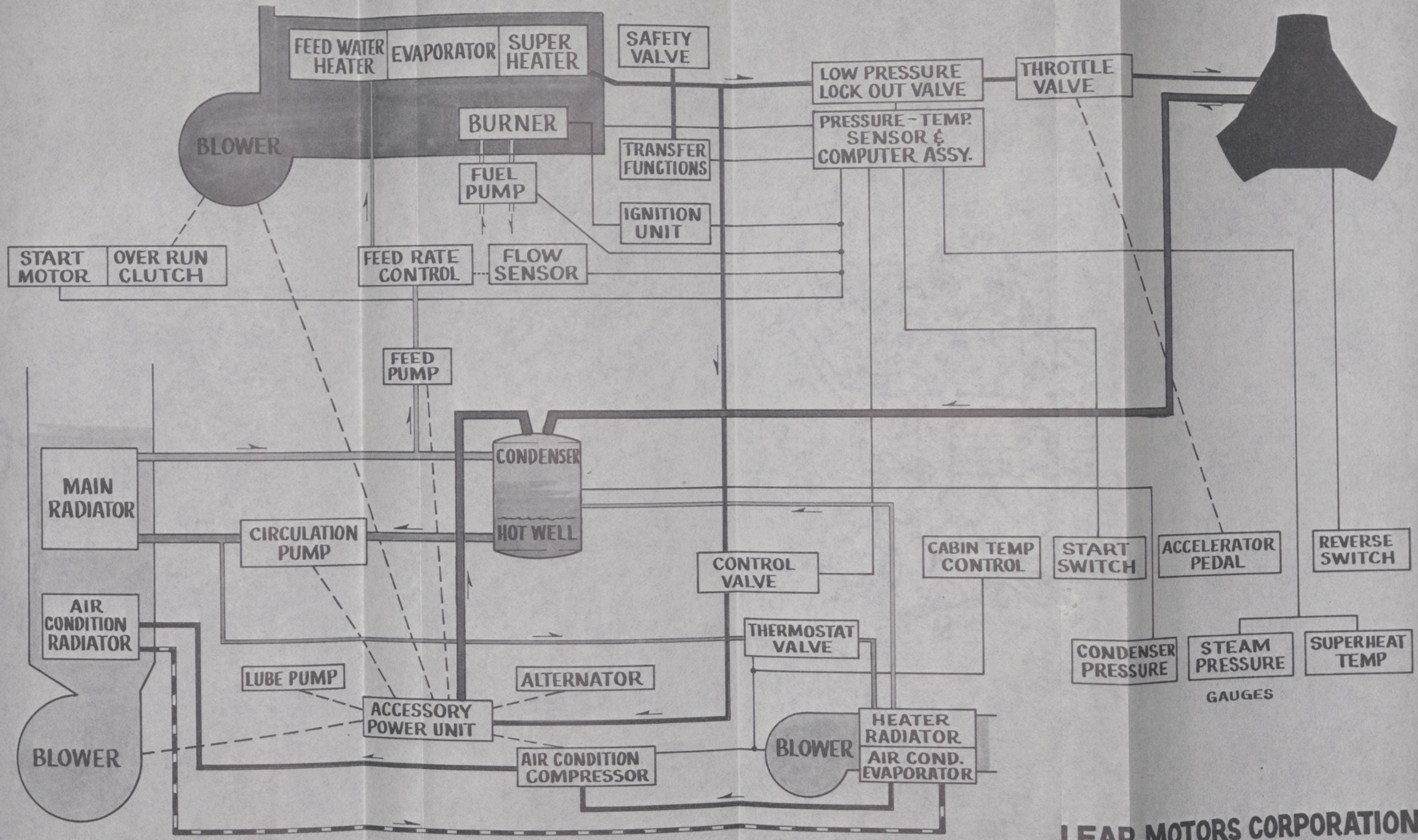
DEAR SIR: We enclose herewith a description of the Paxton vapor engine we will soon demonstrate. We hope to have manufacturing prototype No. 1 operating in March 1969.

The first engine we will operate will be somewhat too large, too powerful, and too costly for an economy car. We intend to demonstrate its excellence in a large motorcar, in a bus, highway truck, and a tractor.

The work of your committee is very much in the public interest and we are very pleased to see evidence of your continuing activity.

Yours very truly,

JOSEPH M. HAUGHEY, *President.*
NOVEMBER 26, 1968.

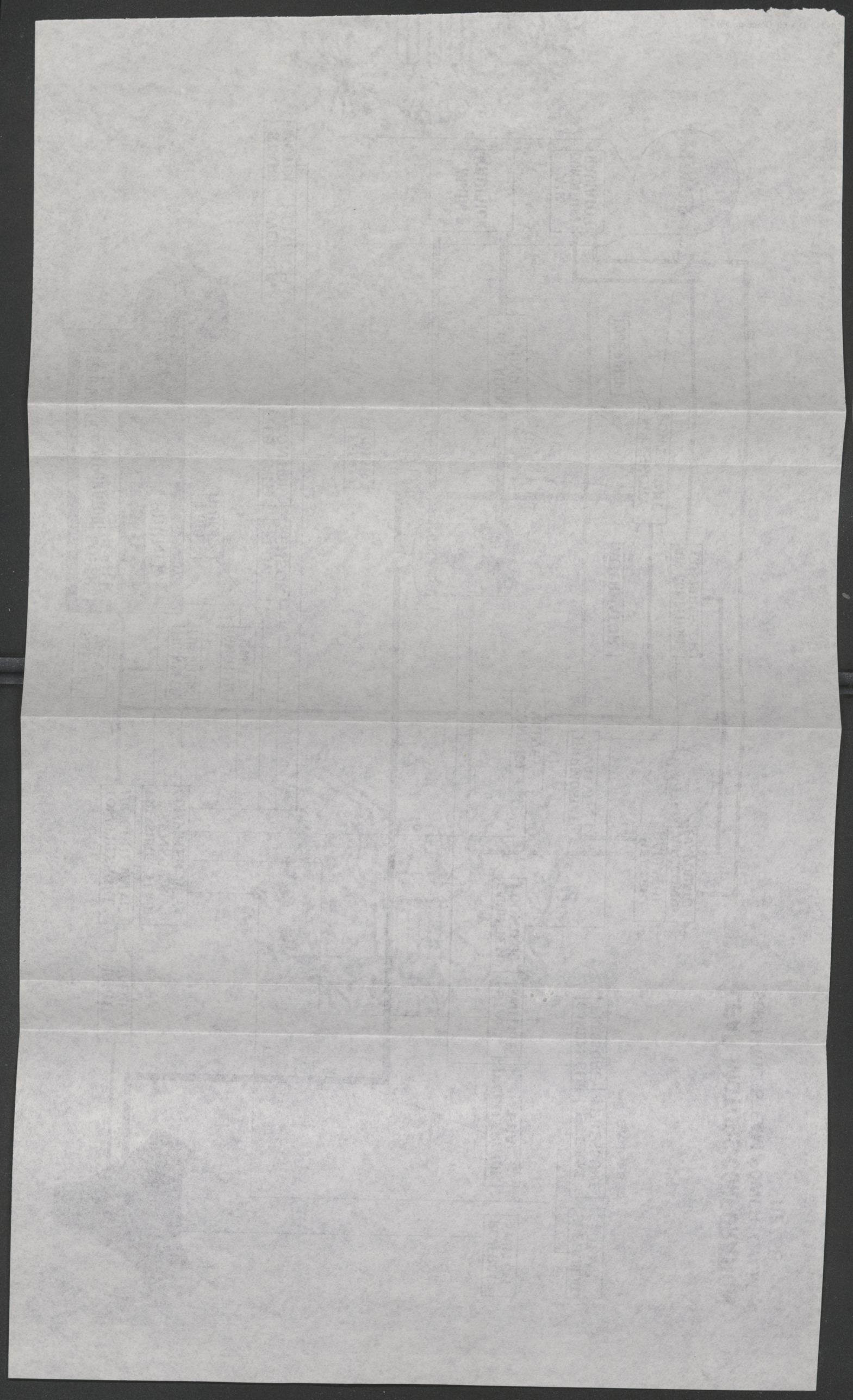


LEAR MOTORS CORPORATION

SCHEMATIC-STEAM POWER CYCLE

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Introduction

The Paxton vapor engine is based on the Paxton heat engine thermal cycle, as conceived by Mr. Douglas Paxton after several years of research, seeking a practical means to develop an engine capable of very high torque output. During this period of initial research and development, three engines were constructed by Mr. Paxton. Two were "breadboards"—built only to test theory. The third, using components of the other two, was a prototype of an engine designed for racing, which combined extremely high torque with very low weight. Although not designed to operate continuously under maximum output, this engine (after 14 months testing in a truck) was field tested under full load for 3 weeks of continuous operation until it was destroyed, as a result of bearing failure.

Early in 1968 Paxve, Inc., was formed and incorporated in the State of California, to continue the development of the Paxve engine and to construct another prototype to demonstrate its capabilities. Both of these objectives are being met and, since the demonstration model is designed and packaged as a complete power unit, it is anticipated that it will be the production prototype of a marketable engine.

A number of patents are pending. Applications for others are in process. Among those pending are some which have wide application in other types of engines and for other types of technical usage. Of major importance in this category—and discussed below—are those for the thermochemical heat generation process and for the Torqane, one of the two working media in the thermal cycle.

General Description of the Paxve Engine

The Paxve engine is an externally heated, closed cycle, chemical vapor engine that utilizes both liquid and gaseous compression in its thermal cycle. Two working media of different densities are used. The first is hydroxylated fuel; the second a dense, organic fluid (Torqane), which has as one of its many desirable properties, the ability to absorb and store large amounts of heat energy. Inasmuch as the thermal cycle of the engine is both regenerative and recuperative, heat is not dissipated from the system during liquid compression of the Torqane.

The engine is physically composed of four functional sections: (a) The heat generation and storage section; (b) the reciprocating drive section; (c) the turbine drive and auxiliary power section; and (d) the heat recovery section. The function of each is described below:

(a) Heat generation and storage section

In this section, the chemical energy of the fuel is converted into heat energy and transferred to the Torqane, where it is stored until released to perform work. A unique feature of the heat generation section is that the energy conversion takes place through a thermochemical reaction process, rather than combustion. By so doing, all the available fuel energy is converted, thus increasing the thermal efficiency of the engine and significantly reducing any residual pollutants. This permits the selection of fuels based on energy content or other criteria without the constraints imposed by smog control.

(b) Reciprocating drive section

The reciprocating drive section consists of two cylinders, each containing a single double-acting piston actuating the driveshaft through a scotch-yoke type linkage. Both ends of each cylinder contain inlet and exhaust valves which are operated mechanically, and programed functionally, by driveshaft rotation. The engine speed and direction of rotation are controlled by altering the programing of these valves. As no throttle valve is required, throttling losses are avoided.

(c) Turbine drive and auxiliary section

A drive turbine is directly coupled to the driveshaft adjacent to each cylinder and a free turbine is mounted concentrically with one of the drive turbines. Since it is not possible to convert all of the available heat energy to mechanical energy in one expansion through the reciprocating drive section, these turbines make use of the heat energy exhausting from that section; the fixed turbines giving additional torque to the driveshaft, and the free turbine driving the pumps and other auxiliary equipments.

(d) Heat recovery section

In this section, any heat not converted into mechanical energy in the two power stages described above is recovered and returned to the heat generation and storage section for recycling.

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Operational Characteristics

Recalling that the Paxve engine is primarily a torque producing engine, it functions most effectively where normal operating conditions dictate frequent changes in output loading. Such changes may result from variations in the load itself as in the case of an electric generator where the load varies with electrical demand; or, as in the case with a motor vehicle, the load remains constant but must be continuously accelerated or decelerated. Regardless of the use, however, the engine operates quietly, vibrationless, and smog free, and is capable of equal output in either rotational direction.

Being in the category of an external combustion engine, the Paxve engine is not limited to the type of fuel used, but will operate on any high B.t.u. fluid or gaseous fuel. Further, it consumes this fuel only when a load is applied. There is no fuel consumption when the load is removed. Because of this, and the higher efficiency of its thermal cycle, fuel consumption per operating hour is greatly reduced from that of other type engines of comparable output. As no noxious gases are produced in the heat-generation process, the engine can be operated in a closed environment without endangering life.

Also, the Paxve engine eliminates the need for many of the high-cost, low-reliability functional assemblies required by the internal combustion type engine. These include the starter, muffler, distributor, high voltage ignition system, cooling system, and carburetor or fuel injection system. For automotive use, the transmission, clutch, and differential may also be eliminated. Battery loads are reduced and, with the capability for full power reversal, wheel brakes need be used for emergency and parking only. Finally, the engine has the inherent capability to provide for climatic temperature control and for other powered accessories without the use of additional pumps and compressors:

Paxve Model 4100

The Paxve engine under construction is model 4100, designed to meet the following criteria:

Dimensions: 34x35x20 inches.
Displacement: 100 cubic inches.
Weight: 725 pounds.
Fuel: No. 2 grade fuel oil (most efficiency).

PERFORMANCE

	Torque	Horsepower
Revolutions per minute:		
0		
500	5,600	0
1,000	3,000	250
2,000	1,920	370
3,000	1,150	450
	750	440

The last completed prototype (No. 3) emitted 2.5 lbs./sec. of exhaust when operating at maximum load. The following ratio of gases were contained therein: CO_2, 13 percent; 0_2, 2.1 percent; N_2, 73.9 percent; H_2O, 10 percent; plus miscellaneous gases entering with air.

W. P. Nichols,
Executive Vice President.

Notice is hereby given that Paxve, Inc. of Newport Beach, Calif., owns valuable proprietary rights to this data.

Pritchard Steam Power PTY., LTD.,
Caulfield, Victoria, Australia, January 2, 1969.

Mr. S. L. Sutcliffe,
Staff Counsel, Committee on Commerce,
U.S. Senate, Washington, D.C.

Dear Sir: Thank you for your letter of January 15 in which you ask for news on the progress we are making with our low emission automotive steam engine.

Since I reported to the U.S. Senate steam vehicle hearings held last May, 1968, my company has proceeded with the development and testing of our compact steampower unit. The rate of progress is somewhat limited, owing to the small size of our company.

However, I am pleased to be able to report that the first main road tests of our prototype car power unit were carried out during November and December, 1968. A series of eight short road tests were made. Reults are encouraging.

Although our new (car) unit features a number of improvements over our earlier (truck) prototype, some faults in the new design have been shown up by the above tests. Work is being done now to eliminate these faults before the next series of road tests is carried out.

The Australian Senate Select Committee on Air Pollution held hearings on air pollution during December 1968. In Melbourne, witnesses invited to attend included representatives from the Chamber of Manufacturers, the State Electricity Authority, Australian Carbon Black Pty Ytd., myself, Clean Air Council of Victoria, the Ford Motor Co., and some others.

Some interest has been shown in our project by a large U.S.A. car company. Recently some Australian companies have shown good interest. We hope this will lead to an accelerated rate of progress with the development of a practical low emission steam automotive power unit.

Yours faithfully,

E. PRITCHARD.

SAN DIEGO GAS & ELECTRIC CO.,
San Diego, Calif., January 31, 1969.

Mr. S. L. SUTCLIFFE,
Staff Counsel, Committee on Commerce,
U.S. Senate, Washington, D.C.

DEAR SIR: Naturally, we are pleased that the work of San Diego Gas & Electric Co. in the field of vehicular air pollution has come to your attention.

However, we have no experience with the steam engines proposed for use in automobiles. Our efforts have been directed toward reduction of exhaust emissions from the internal combustion engines now used by conventional passenger vehicles and trucks.

Tests over the last 3 years have demonstrated that excellent results can be attained when liquid natural gas is used as the fuel for these vehicles.

Should you decide to study a more immediate approach to the solution of the air pollution problem, the enclosed press releases should interest you.

We regret that we have nothing to contribute to your present investigation.

Sincerely,

MARTIN R. ENGLER, Jr.

[From the News Bureau]

Liquefied natural gas (LNG), a supercold, high-energy fuel, is a hot performer in the fight against automotive smog. This has been clearly demonstrated in 2 years of LNG testing by the San Diego Gas & Electric Co.

Joseph F. Sinnott, company president, reports that latest test results confirm that LNG vehicles emit less than half as much smog-producing pollutants as the average for gasoline-fueled cars equipped with smog control devices.

The LNG cars were equipped with smog control devices too, but other tests with the device disconnected showed the same low percentage of smog-producing emissions.

While contributing significantly to smog control, the LNG vehicles give power performance comparable with that of gasoline-fueled vehicles and can be operated at a comparable cost, Sinnott said.

One of four "Smog Cutter" fleet vehicles used by the San Diego Gas & Electric Co. in the test program is on a 21-city, cross-country tour to demonstrate the operational characteristics of LNG to officials of natural gas companies, automobile manufacturing companies, air pollution control agencies and other Government agencies.

The LNG demonstration car is a slightly modified 1968-model Ford sedan. It recently completed 42,000 miles of a 50,000-mile road test that began last June.

Exhaust emission tests conducted on the car by the California Air Resources Board before the start of the 50,000 miles showed that hydrocarbon emissions amounted to 118 parts per million, compared with an average of 225 parts per

million for 1968 automobiles operating on gasoline and equipped with smog control devices.

At the completion of 42,000 miles, hydrocarbon emissions from the LNG car amounted to 93 parts per million compared with an average of 240 parts per million for the gasoline vehicles with smog control equipment.

Carbon monoxide emissions from the LNG car amounted to 0.17 percent at the beginning of the 50,000 miles and 0.21 percent after 42,000 miles. The average for 1968 vehicles operating on gasoline and equipped with smog control devices was 1.0 percent at the start and 1.2 percent after 42,000 miles.

Present California exhaust standards for air pollution control allow 275 parts per million hydrocarbons and 1.5 percent carbon monoxide.

The LNG fuel is a compact form of the same kind of gas that is used for cooking and heating. The natural gas is liquefied by chilling it to a minus 258 degrees Fahrenheit, a temperature so cold that ice is boiling hot by comparison. LNG is a clear, odorless and clean-burning fuel.

Conversion of the test vehicle to use LNG included installation of an insulated fuel tank to maintain the extremely cold temperature required to keep the gas liquid, a coil of copper tubing that acts as a vaporizer to change the liquid back into a gas, a gas regulator, and a natural gas carburetor.

The engine cylinder head was milled to increase the compression ratio. Because LNG is a slower burning fuel than gasoline, a new camshaft was installed. It keeps the exhaust valve closed longer and permits more complete combustion. Ignition timing also was altered slightly.

When the vehicle is in operation, LNG flows from the insulated tank into the copper coil. The air surrounding the coil adds heat to the LNG, turning it back into a gas.

The regulator controls the flow of natural gas into the carburetor where it is mixed with the proper proportion of air to make it combustible. This mixture is then fed into the engine.

San Diego Gas & Electric Co. officials believe that the use of LNG as a motor vehicle fuel is particularly suitable in fleet operations where vehicles are in constant use and where there is a central location for servicing them.

[From the News Bureau]

Liquefied Natural Gas Test Vehicle Fact Sheet

Type of vehicle: A 1968 model 8-cylinder Ford passenger car.

Modifications: Vehicle is fitted with a 21-gallon cryogenic fuel tank, a coil of copper tubing that acts as a vaporizer to change the LNG back to a gas, a gas regulator, and a natural gas carburetor.

Fuel: Liquified natural gas (LNG), a liquid form of natural gas such as is used for cooking and heating. LNG should not be confused with LPG, which is a different product with different characteristics.

Purpose of the test program: To determine whether smog-producing exhaust emissions from motor vehicles can be substantially reduced by using liquefied natural gas as a fuel instead of gasoline. Also to determine the operational performance of LNG-fueled vehicles.

Duration of test program: The San Diego Gas & Electric Co. has been conducting this development test program for approximately 2 years. Since June 6 1968, two 1968-model passenger cars have been used in a 50,000-mile test to determine what changes occur in exhaust emissions as a result of engine wear. The vehicles have completed 42,000 miles.

Testing agency and procedures: The exhaust-emission tests are conducted by the California Air Resources Board in accordance with procedures set by California.

Performance of test vehicle:

Power performance.—Comparable to similar vehicle operating on gasoline.

Fuel consumption (average).—Fourteen miles per gallon at 40 miles per hour.

Oil.—One test vehicle has operated for the entire 42,000 miles without a change of oil. Laboratory analysis confirmed that the oil was good for continued use.

Cost of operation: Comparable to gasoline-fueled vehicles.

Exhaust emissions:

COMPARISON WITH AVERAGE FOR 1968 MODEL GASOLINE-POWERED AUTOMOBILES EQUIPPED WITH SMOG CONTROL DEVICES

HYDROCARBONS

[In parts per million]

	Start of 50,000-mile test	After 42,000 miles
Average for 1968 gasoline automobiles	225	240
LNG automobile	118	93

Note: Maximum allowable under present California exhaust standards, 275 parts per million.

CARBON MONOXIDE

[In percent]

	Start of 50,000-mile test	After 42,000 miles
Average for 1968 gasoline automobiles	1.0	1.2
LNG automobile	.17	.21

Note: Maximum allowable under present California exhaust standards: 1.5 percent.

Suitability of LNG for motor vehicle use:

Tests show that LNG is well-suited to vehicular use. It is clean-burning. It emits few smog-producing contaminants. It is portable. It is safe. The most practical application appears to be for vehicles in fleet operations.

[From the News Bureau]

LIQUEFIED NATURAL GAS FACT SHEET

WHAT IS LNG?

It is a liquid form of regular natural gas like that which is used for cooking and heating. The gas is changed to a liquid by reducing its temperature to a minus 258 degrees Fahrenheit. The liquid is clear, clean, and odorless. It weighs 29.3 pounds per cubic foot or less than half as much as water.

WHY LIQUEFY NATURAL GAS?

By liquefaction, natural gas is reduced in volume by a ratio of 600 to 1. This permits the storage of large quantities of gas in a compact space. LNG also is portable, which makes this high-energy fuel available for a variety of new applications.

IS IT SAFE?

Yes. It is nontoxic. It is safe both to store and to handle. It is stored at near atmospheric pressure. When exposed to the atmosphere, it absorbs heat, and as the liquid becomes warmer, it changes back into a lighter-than-air gas and dissipates quickly. When released to the atmosphere, the presence of the LNG is readily identified by a cold vapor cloud created by the cold gas coming in contact with moisture in the air.

HOW IS LNG STORED?

It is stored in specially constructed, double-walled metal tanks that maintain the minus 258 degrees Fahrenheit temperature required to keep the product liquid. Like Thermos bottles, some of these tanks have a vacuum between the inner and outer walls. This insulates the inner vessel to minimize the flow of heat from the outside. Other tanks have insulating material between the walls to arrest the heat flow.

HOW IS IT TRANSPORTED?

The San Diego Gas & Electric Co., uses an insulated highway tanker like those used to transport liquid oxygen, liquid nitrogen, or other cryogenic fluids.

WHERE DOES THE SAN DIEGO GAS & ELECTRIC CO. GET ITS LNG?

The company manufactures it at its liquefied natural gas plant in Chula Vista, south of San Diego.

HOW IS LNG USED?

LNG has many uses. The primary one is to meet cold weather peak requirements for natural gas. When needed for this purpose, the LNG is drawn from the storage tank, changed back into a gas, and fed into the gas main.

Another major use is to provide regular natural gas service in remote areas where the cost of extending existing gas lines would be prohibitive. LNG is being used to provide this kind of beyond-the-main service to the 144-unit Borrego Road Runner Mobile Home Park in Borrego Springs, 90 miles east of San Diego, and to a 2,600-man tent camp at the U.S. Marine Corps's Camp Pendleton. Similar service is expected to be started in a third area in the near future.

The San Diego Gas & Electric Co. also has used a small trailer-load of LNG to supply regular service to a community of 1,700 customers while the normal gas supply to the area was interrupted during pipeline construction work.

Several tanker loads of LNG have been sold for use in Canada, 1,500 miles away. Additional tanker loads have been transported to a customer in West Palm Beach, Fla., 2,500 miles away, for use in jet aircraft engine development.

LNG also is being used experimentally by the San Diego Gas & Electric Co. as a low, air-pollutant motor vehicle fuel. Results of nearly 2 years of testing show that smog-producing emissions from automobile exhausts can be cut in half by using LNG instead of gasoline.

San Diego Gas & Electric Co's Liquefied Natural Gas Plant

WHERE IS IT LOCATED?

The LNG plant—the first in the West—is located adjacent to the San Diego Gas & Electric Co's South Bay powerplant in Chula Vista, 8 miles south of San Diego.

WHAT IS THE FUNCTION OF THE PLANT?

It liquefies and stores natural gas at a rate of up to 2.5 million cubic feet per day during warm weather when customer use is low. The storage tank has a capacity of 175,000 barrels, the equivalent of 620 million cubic feet of gas. When required to meet cold weather peak loads, the LNG is changed back into a gas and is fed back into the gas pipeline system. The plant can regasify up to 60 million cubic feet per day.

HOW DOES THIS PLANT BENEFIT THE COMPANY?

The LNG facility provides the most modern method of storing large quantities of gas in a minimum amount of space. By being able to store these large amounts of gas at off-peak times, the company is able to keep to a minimum the amount of gas it must contract to purchase from its supplier to meet winter peak demands. This results in a substantial saving to the company and its customers.

HOW IS NATURAL GAS LIQUEFIED?

The San Diego LNG plant employs a unique split-stream turboexpander cycle using the energy of the pressurized pipeline gas in the liquefaction process.

As the gas flows from the pipeline into the plant, it passes through a cleanup section where water, carbon dioxide, and other undesirable constituents are removed.

After cleanup, the gas stream splits. One portion, about 85 percent, becomes the refrigeration stream. The remaining 15 percent becomes the liquefaction stream, which is the gas that will be liquefied.

The refrigeration stream flows through the turboexpander where the gas pressure is reduced from 300 to 60 pounds per square inch. This process cools the refrigeration stream to about minus 175° Fahrenheit. This stream then passes through heat exchangers to cool the liquefaction stream and afterward is compressed to about 70 pounds per square inch pressure and sent to the South Bay powerplant to be used as boiler fuel.

After being chilled in the heat exchanger, the liquefaction stream passes through an expansion valve which reduces its pressure from 300 to 70 pounds per square inch. This further cools the stream and liquefies a portion of it. The liquid goes to storage. The vapor goes into the refrigeration stream and eventually to the powerplant.

IS A SPECIAL TANK USED FOR STORAGE?

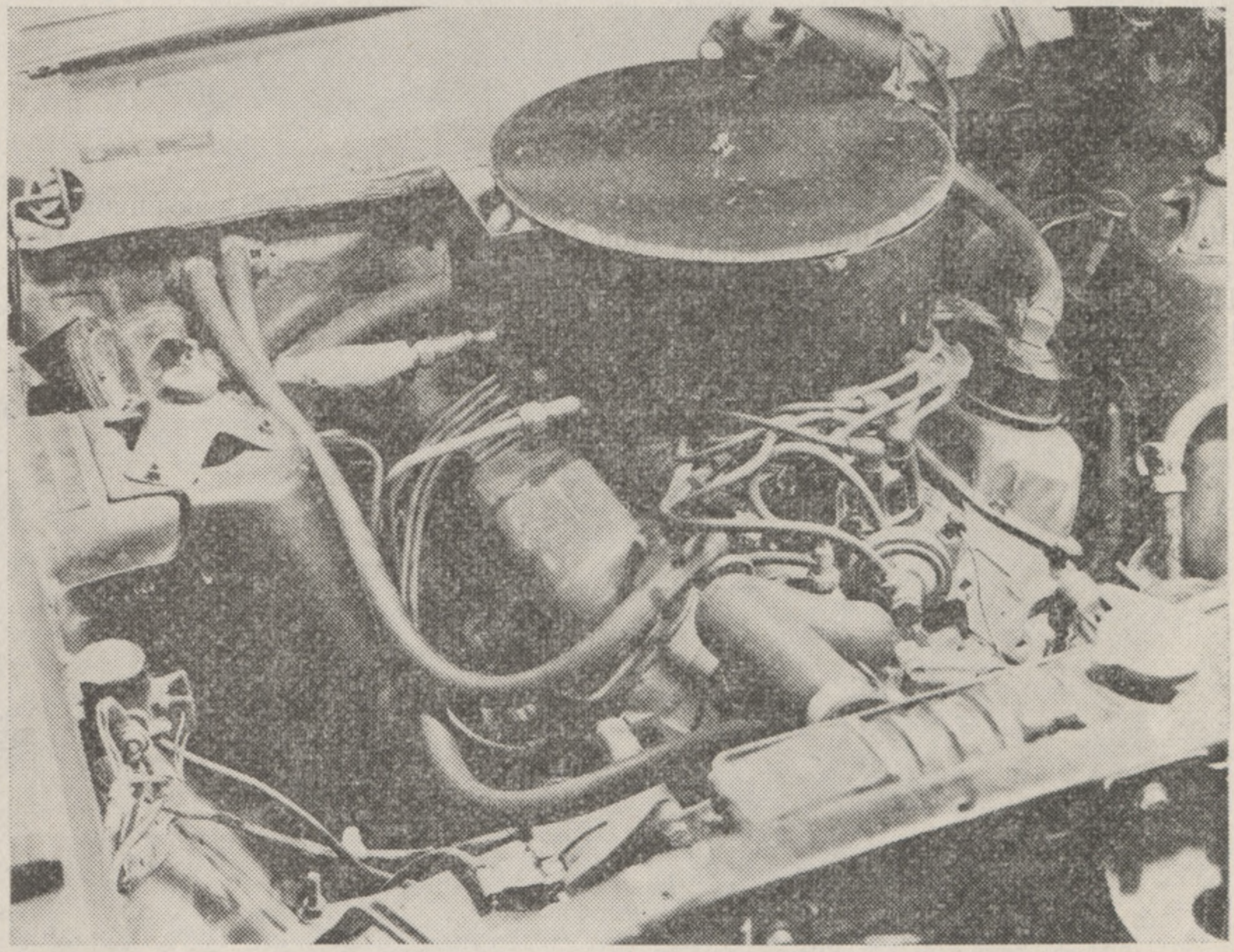
Yes. The storage tank is a double-walled cylindrical vessel with a flat bottom and a domed roof. The inner tank is made of tough, strong 9-percent nickel steel, which is suitable for storing liquids at temperatures down to —320° Fahrenheit. The outer vessel is made of carbon steel. A 3-foot insulation space between the two tank walls is filled with expanded, fireproof Perlite. Nitrogen also is used within the insulating space to keep out moisture and maintain effective insulation.

The tank sits on top of a 20-inch-thick concrete cap that rests on 325 concrete piles driven to a depth of 40 feet. The pile cap is designed to provide uniform load distribution. An airspace of 18 inches between the surface of the ground and the bottom of the pile cap prevent cold migration, which might tend to cause frost heaving of the soil.

HOW IS THE LNG REGASIFIED?

When the LNG is needed to meet peakloads, it is pumped to 460 pounds per square inch pressure. It then flows to a gas-fired hot water vaporizer. There it passes through a bundle of tubes submerged in the hot water. The heat from the water raises the temperature of the LNG sufficiently to change it back into a gas. This gas flows through an odorizer and into the pipeline for use.

[From the News Bureau]



A cool performer.—Simple modifications have converted the engine of this 1968 model Ford passenger car to operate on supercold liquefied natural gas (LNG). Added equipment includes a natural gas regulator (upper left), a copper coil vaporizer (installed in the drumlike air filter container), and a natural gas carburetor (located beneath the vaporizer). The San Diego Gas & Electric Co. has been testing LNG as a motor vehicle fuel for nearly 2 years. Results show it to be a high-performance, low-smog-producing fuel.

[From the News Bureau]

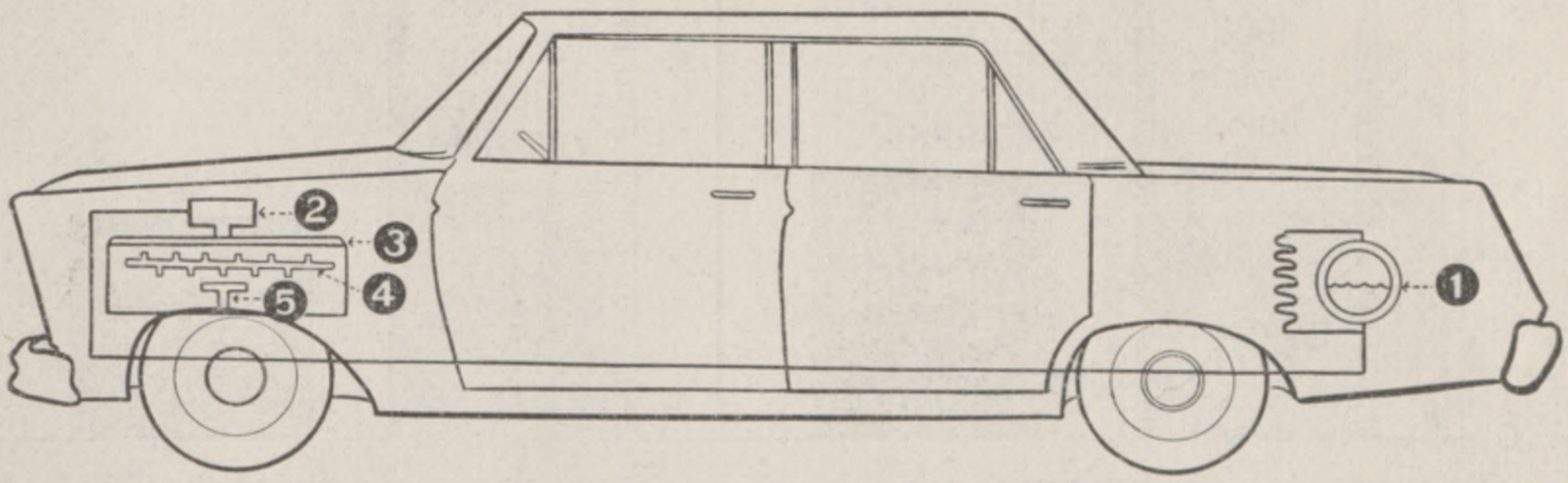


Tankful of frigid "go" power.—Installed in the trunk of a 1968 passenger car, this double-walled, vacuum-insulated tank carries liquefied natural gas (LNG), a fuel so cold that ice is boiling hot by comparison. Tests conducted by the San Diego Gas & Electric Co. for the past 2 years show that LNG-fueled cars are low producers of smog-forming contaminants.

[From the News Bureau]



LNG Modifications



① TANK

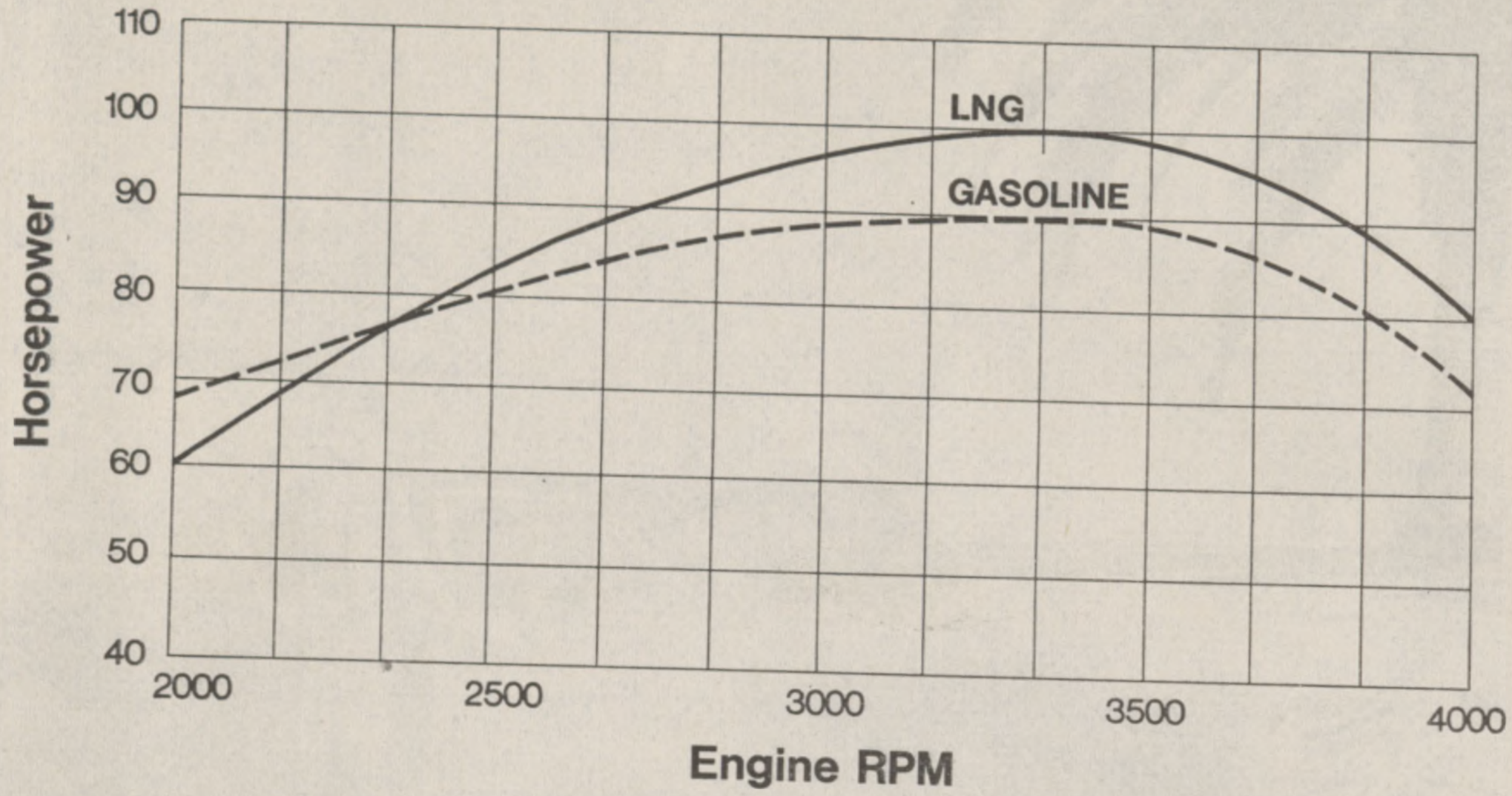
② VAPORIZER—CARBURETOR

③ INCREASE COMPRESSION RATIO

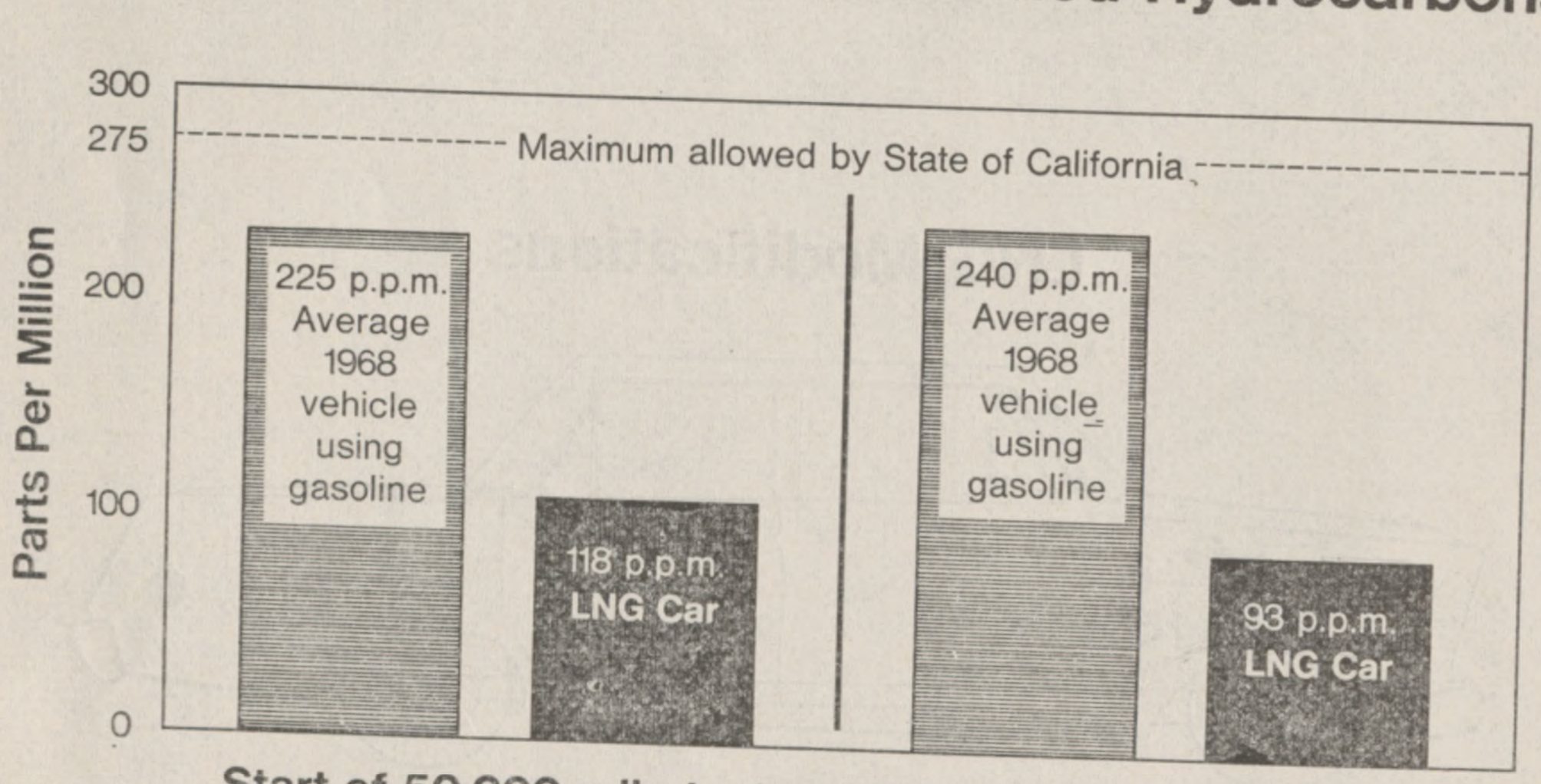
④ NEW CAM SHAFT

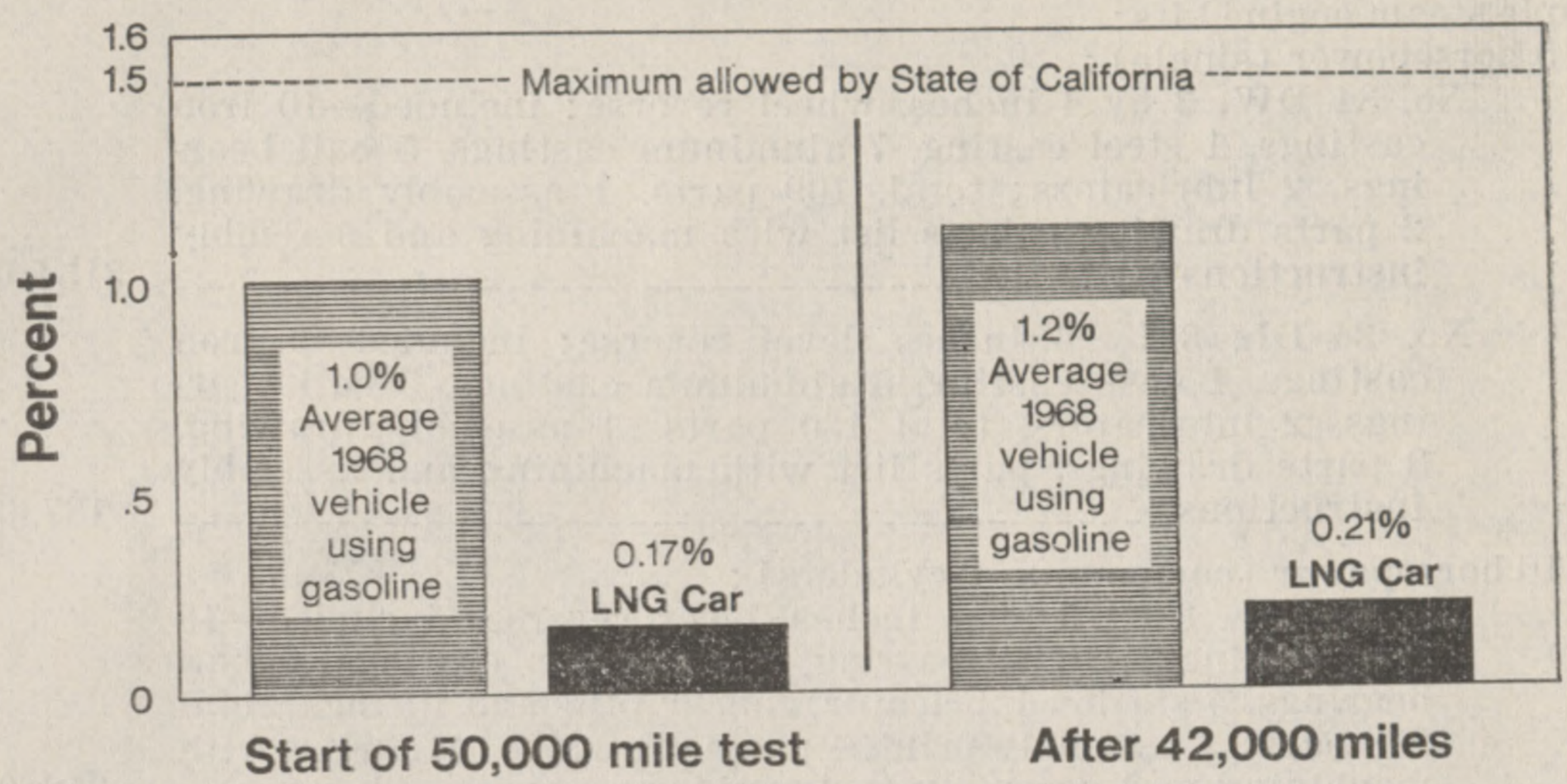
⑤ TIMING, IGNITION

Power Development Comparison
(1968 Ford Fairlane)



Exhaust Emission Test Unburned Hydrocarbons





Big car comfort with fresh air fuel.—This 1968 model Ford passenger car operates on super-cold liquefied natural gas (LNG). The San Diego Gas & Electric Co. has been testing LNG as a motor vehicle fuel for nearly 2 years. Results show conclusively that automobiles using this high energy fuel emit a substantially smaller amount of smog-producing exhaust contaminants than do gasoline fueled automobiles equipped with smog control devices.

SEMPLE ENGINE CO., INC.,
St. Louis, Mo., January 21, 1969.

Mr. S. L. SUTCLIFFE,
U.S. Senate,
Washington, D.C.

DEAR MR. SUTCLIFFE: Thank you for your letter of January 15 regarding the steampower equipment we manufacture.

We have been building this machinery for the past 13 years; research began 10 years before. These units are adapted chiefly for marine service, mostly in pleasure boats. Some are used in areas restricting internal combustion engines; others in remote places where liquid fuels are hard to get.

The enclosed pretty much describes our small engines and boilers. We are, at present, building very much larger machinery to be used on a 100-foot (200-ton) excursion boat on Lake George. This will be launched in the spring.

We have no tests on pollution gases emitted from our boilers. Many fuels have been employed with varying conditions in firing. There are thousands of small boilers of our type in stationary service. I am sure combustion tests would be available.

I might add that we completely eliminate the water pollution such as the underwater discharge of outboard motors.

Yours very truly,

FREDERICK H. SEMPLE.

Semple steampower

(Complete price list, effective June 1, 1968)

Semple steam engine kits:	
5 horsepower (single):	
No. 34–DW, 3 by 4 inches, wheel reverse: included—10 iron castings, 1 steel casting, 7 aluminum castings, 5 ball bearings, 2 lubricators; total, 109 parts. 1 assembly drawing, 2 parts drawings, parts list with machining and assembly instructions	$154.00
No. 34–DL, 3 by 4 inches, level reverse: included—9 iron castings, 1 steel casting, 5 aluminum castings, 5 ball bearings, 2 lubricators, total 130 parts. 1 assembly drawing, 3 parts drawings, parts list with machining and assembly instructions	187.00
10 horsepower (compound—2 cylnders):	
No. 354–DL, 3 by 5 by 4 inches, lever reverse: included—18 iron castings, 1 steel casting, 8 aluminum castings, 9 ball bearings, 4 station lubricator, copper pipe and fittings, total 278 parts. I assembly print, 4 parts drawings, parts list with machining and assembly instructions	352.00
Semple steam boiler: FT–40 (vertical tubular), with jacket and insulation, smoke hood, doors, and gates—complete; tested 500 pounds	572.00
Semple marine power units:	
5 horsepower standard: Included—34–DW engine kit, FT–40 boiler complete, accessory group, prints and instructions	1,023.00
5 Horspower special: Included—34–DL engine kit, FT–40 boiler complete, accessory group, water pump and heater group, prints and instructions	1,106.00
10 horsepower special: Included—354–DL engine kit, FT–40 boiler complete, accessory group, water pump and heater group, vacuum pump group, all copper condenser (welded), prints and instructions	1,464.00
Keel condenser (optional for 5-h.p. marine units)	79.00
Bilge pump (steam jet with piping)	41.00
Prints and instructions (separately):	
5 horsepower: No. 34–DW—assembly and 2 parts drawing, parts list and instructions	4.40
5 horsepower: No. 34–DL—assembly and 3 parts drawings, parts list and instructions	5.60
10 horsepower: No. 354–DL—assembly and 4 parts drawings, parts list and instructions	7.20
Semple boiler: FT–40—1 print with parts list	1.50
Marine instruction book: Installation, operation, and maintenance	2.00

Semple steam engines are now being offered in kit form only. This gives you the enjoyment, knowledge, and satisfaction of building your own. Moreover, you save 60 percent.

Kits are complete; you need nothing else. Drawings are thorough to the finest detail. All tolerances are carefully indicated. However, should a problem arise, our engineering department is always at your service.

About 95 percent of the machine work can be done on a 12-inch lathe and drill press. The balance on a mill. There are two parts that are tricky to machine, requiring elaborate setups: The base containing ball bearing pockets and the spiral reverse cam. Should these offer a problem, we will mill and bore the base for an extra $21 and bore and machine the spiral for $10.

Terms: All prices shown are f.o.b. St. Louis. No discounts or commissions are allowed. We have no dealers. Amounts may be paid in full in advance, or 20 percent in advance with the balance c.o.d. All prices and specifications are subject to change without notice.

SHAW MACHINERY CO.,
Concord, Calif., January 25, 1969.

Mr. S. L. SUTCLIFFE,
Staff Counsel, Committee on Commerce,
U.S. Senate, Washington, D.C.

DEAR MR. SUTCLIFFE: Thank you for your letter of January 15, 1969, regarding progress we have made in eliminating vehicular pollution.

As ours is the one and only steam engine under U.S. Patent No. 718,722, we also use a totally efficient U.S. patent liquid petroleum gas burner which achieves complete combustion and thereby eliminates the above-stated problem entirely.

Sincerely,

RICHARD F. SCHULTZ.

MIDWAY CITY, CALIF., *January 28, 1969.*

Mr. S. L. SUTCLIFFE,
Staff Counsel, Committee on Commerce,
U.S. Senate, Washington, D.C.

DEAR MR. SUTCLIFFE: Mr. Richard J. Smith and myself, Karl A. Petersen, are individuals working in steampower consulting and no longer use the trade style, "Empirical Engineering," as you address us.

As you know, we have achieved an unprecedented low level of exhaust emission pollutants in ouf steampower systems for automotive use. I list the 1970 and 1972 California standards, their "low-emission vehicle" levels—considered "smog free," and our California Vehicle Pollution Laboratory test of October 1967 with our present capability.

[In grams per mile]

Item	Required levels in California		California low-emission vehicle	Our 1967 tests	Our present capability
	1970	1972			
HC	2.2	1.6	0.5	0.7	0.4
CO	23.0	23.0	11.0	3.7	2.0
NO_x	2.0	1.3	.75	.4	.3
Total	27.2	25.9	12.25	4.8	2.8

The systems we have developed have been licensed to two concerns, here and abroad, for manufacture. Compared to present internal combustion systems, these cost, on the outside, less to build for equal performance and life in equal quantities.

Internal combustion oriented engineers continue to doubt this. As author John Phillifent put it, "They are quite right in this belief * * * it can't be done, by them. But it can be done, per se. What is lacking is the approach. What is needed is the combined knowledge, skill, understanding, and application of logic."

Recently the automotive industry has begun to realize that these low-emission systems are useful in some ways. The electric car concepts have been used to obtain publicity showing that the industry is supposedly trying to make low-pollutant cars, while the industry's executives admit that they "have no hope for the electric car's success within my lifetime."—Henry Ford II.

With today's electric power being largely generated by fossil-fueled power stations, even if the electric plants burn their fuel as cleanly as we can in a steamcar, the pollutants evolved from making enough electricity to drive an electric car on batteries is five times that of the steamcar in equal service. This is due to the electric's maximum of 4 percent fuel-to-wheels efficiency compared to about 20 percent in the steamcar.

Our recent developments in other heat engines may bypass the need for a vapor cycle system altogether while still using low-emission combustion of fossil fuels. Naturally if a superior heat source is available which may produce no exhaust emissions, that would be most readily adaptable to a heat engine of the types we have developed.

As ever, we offer these systems to any industrial concern who may wish to manufacture them, and we hope that manufacturers will have the foresight to

produce these low-emission vehicles on their own before they are forced to do so for their own future health and that of their neighbors.

If we can be of any further service to you or the Senate Commerce Committee, please inform us. Our telephone number is area code (714) 892–5639. Please phone after 1 p.m., your time, to be sure we are in.

We would appreciate receiving a copy of your report and hope it includes some information on our developments. I enclose some information.

You may be interested to note that we are the only ones in the country who have been delivering and are now delivering steam automotive systems and components to our clients. Others may suggest that they are developing systems, or may put development capital into projects, but our systems function as we specify or better, and are most certainly available.

Yours,

KARL A. PETERSEN.

[Reprinted from Los Angeles Times, Oct. 13, 1968]

STEAMCAR INTEREST COMING TO A BOIL

(By Bob Thomas)

The bumper sticker on a Volkswagen bus parked in the driveway was the tipoff: "Steamcars Are Smogless."

It had been a difficult address to find * * * hidden away in an Orange County community I had never heard of, Midway City. But the steamcar business has been somewhat out of sight and mostly out of mind for four decades.

However, it isn't dead.

And the more our atmosphere becomes strewn with garbage, the more intense are proposals that the steam-powered automobile be revived.

There are those, in fact, who are stoutly confident that a steamcar has a definite and prominent place in the future.

Like Richard J. Smith.

It was his address that I sought. Smith, who is 40 years old, is in the automotive steam engine and generator business. It's a modest business, at best, confined to a small backyard garage. But he and his associate, a 25-year-old industrial engineer from the East named Karl Petersen, purport to be the only people in the country presently delivering steam systems and components.

Theirs was not quite the grand operation I expected it to be. My mind, of course, was no doubt influenced by the recent announcement by industrialist William P. Lear that he was launching a $10 million steamcar project near Reno.

Smith and Petersen are working with something less than that kind of investment.

Smith has dedicated much of the past 18 years working toward a practical steamcar, departing in that effort "from antique ideas of the past."

"I don't just think they're coming," he said. "I believe it. Within the next 15 to 20 years most if not all our automobiles will be steam powered."

Smith is not a crackpot, but an engineer who turned his full-time attention to steam in the early 1960's "when I figured how to do it," he said, referring to a realistic application of steampower to the modern passenger car.

1961 BREAKTHROUGH

The breakthrough, he said, came to him in 1961 and involved mainly controls for the steam generator and kicking aside outmoded ideas.

"Over 120 different makes of steam vehicles have been produced since the 1840's," Smith said. "They all had one thing in comon: They borrowed technology from railroad trains and steamships. There was no real auto technology developed of itself."

He did note one exception, the Doble brothers who started building steamers in the twenties. Doble production ceased early in the depression, however, and, while their work still related mainly to 50-year-old concepts, they did attempt new things, he said. Their cars had two major drawbacks—high price and complexity.

Smith feels steamcars can be both simple and practical.

"It is well recognized, even by Detroit, that steampower per se is ideal for automobiles," Smith continued, alluding specifically to performance. "The inter-

nal combustion engine, as applied, is really inappropriate because it lacks flexibility. That's why an automobile needs a transmission."

A steam-powered car, he pointed out, doesn't need a clutch or a transmission "because the engine is able to turn out maximum torque (turning power) at any speed." It is connected directly to the drive line.

Smith said the compression effect is the same as the internal combustion engine. It is able to run forward or backward with a simple switch of a lever, which can be used as an assist in braking.

"It works like a rubber band," Petersen explained about braking with the engine in reverse. "You simply stretch it out slowly to a point where you start being pulled backward."

OTHER PLUSES

Longevity and durability apparently are other "pluses" for steam engines. "There are antiques still going strong with over 600,000 miles of use on them," Smith said.

The drawbacks have been financing new development, need for improved controls and discarding antiquated techniques, according to the modern steamer.

"I saw means of getting away from the antique, the unsafe and absurdly complex," Smith said of his research. "I sought a simple, practical way to get the right exhaust (for recirculation of the steam back into the generator) and a new prime mover (the engine) to replace the old steam engine.

"The really big problem, though, is the control system. What has been clearly needed is a rational approach to controls," he said.

Smith feels he has found it.

He has patents pending on controls which determine temperature, pressure and quantity requirements. His system also comes up to full pressure and temperature in 10 seconds. In the past, the gap between starting and actually moving has been as long as 20 minutes.

SUITABLE ENGINES

A suitable engine, he found, seems to be the two-cycle marine type, such as the popular Mercury outboard. A four-cylinder installation in a converted Volkswagen was operated by Smith for 1½ years successfully with acceptable performance characteristics and fuel mileage of 36 miles per gallon. Any fossil fuel can be used, including such things as paint solvent, which is considerably cheaper than gasoline.

Smith showed me a six-cylinder adaptation from his shop. Steam is admitted through the sparkplug holes to drive conventional pistons turning the crankshaft. It weighs only 65 pounds.

"Using a 60-cubic-inch displacement engine," he explained, "we can expect 250 horsepower and in excess of 600 foot-pounds of torque."

That would be more than adequate to power the conventional automobile. Picking a domestic six-cylinder engine of 225 cubic inches at random, the comparable figures show 145 horsepower and 215 foot-pounds of torque.

Cost factors are favorable, too, Smith said. On a production basis, it would be less expensive to install a steam powerplant than the conventional internal combustion engine and transmission. Weightwise, the comparison is about 1 to 3 in favor of steam, using Smith's components.

In placement, the engine would supplant the transmission and the steam generator would sit in place of the conventional engine and air cleaner * * * "with room left over."

Retained would be the battery, radiator and regular fuel tank.

The fight against air pollution, particularly the contribution from internal combustion engine exhaust emissions, has gathered new audiences for steam who until now have mainly been talking to themselves.

California has authorized the California Highway Patrol to test a half dozen steamcars, chiefly to see if claims about them are justified. General Motors has offered six new Oldsmobile chassis and $120,000 for the cost of installation and testing. Nothing has yet materialized.

TESTS PROMISING

Emission tests conducted by the State motor vehicle pollution control board with Smith's VW were promising—less than 50 parts per million of hydrocarbons, 0.08 percent carbon monoxide level and less than 60 parts per million of oxides

of nitrogen in the exhaust flow. All these figures are far below current or even projected standards.

Combustion under controlled conditions, involving longer firing time and constant heat, are said to account for this efficiency in contrast to the admittedly wasteful internal combustion engine.

The water supply necessary in Smith's system amounts to 5 to 10 gallons. "It really doesn't lose water," Petersen said. A condenser recirculates the water to the steam generator. "You might use a bathtubful in a cross-country trip."

Special water? "Anything you would drink," he said.

LESS REPAIRS

Freezing apparently is no longer a problem. Modern sealed systems retain antifreeze or freon as well as today's car radiator, steamers claim.

Maintenance was listed as another major advantage over internal combustion power since the steam engine has very few moving parts. New lubricants and synthetic products, it is said, overcome emulsification and water contamination.

Smith discounted the existence of a serious explosion hazard despite the high temperatures and 1,000-pounds-per-square-inch pressure necessary in superheating steam. Containment of the pressure is no problem, he said.

"About the only thing that could happen if a tube ruptured," he said, "would be a loss of power. It would act like a fast leak because it would still be contained in a shell.

"As an analogy, it would be several orders of magnitude safer than the average housewife's kitchen pressure cooker."

Smith and Petersen don't plan to manufacture a steamcar themselves. At present, they are merely supplying systems and serving as consultants to hobbyists and companies that actually are working on such projects.

It all sounds too easy. But listening to them makes one feel that the steam automobile business once again is getting up a head of steam.

THERMODYNAMIC SYSTEMS, INC.,
Newport Beach, Calif., January 22, 1969.

Mr. S. L. SUTCLIFFE,
Staff Counsel, Committee on Commerce, U.S. Senate, Washington, D.C.

DEAR MR. SUTCLIFFE: In answer to your letter of January 15, 1969, we are submitting the following report.

Our company has been engaged in the research and development of steam systems since February 1966. The steampower systems which we are currently testing, embody the developments that are a result of several thousand man-hours of concentrated effort in this field. Although we have not publicized our accomplishments to any great extent, we have allowed certain agencies of the Government and personnel from industrial companies to preview some of our prototypes designed for various applications. You will find enclosed with the written material contained herein, a list of the personnel of various companies and Government agencies to which demonstrations of our prototype steam systems have been presented. I hope this information will be of use in your report to be published in mid-February. We would appreciate a copy of this report, if possible.

I would suggest, for your edification, that you or members of the staff of the Senate Commerce Committee make an appointment with our company for a demonstration of the steam systems which we are currently working on.

We cordially invite you to do this at your earliest convenience, and I am certain that while you are in the area, you will want to see the work which William P. Lear is engaged in at Reno, Nev.; so your trip to the west coast could be quite useful.

Yours sincerely,

R. G. SMITH,
Vice President.

THERMO ELECTRON CORP.,
Waltham, Mass., January 24, 1969.

S. L. SUTCLIFFE,
Staff Counsel, Comittee on Commerce, U.S. Senate, Washington, D.C.

DEAR MR. SUTCLIFFE: Thank you for your letter of January 15.

During the past few months we have been continuing our development efforts in the Rankine cycle powerplant area. Progress has ben made toward a useful, practical powerplant in accordance with the expectations set forth in our testimony before the Senate committee. At this time, we have nothing specific to add to that testimony.

Very truly yours,

SOTIRIS S. KITRILAKIS,
Vice President.

[From the Automotive News, Jan. 6, 1969]

STEAM RACER DESIGNED FOR "500"—250 LUXURY MODEL ALSO PLANNED

(By William C. Miller)

SAN DIEGO.—William D. Thompson, 69-year-old retired automotive engineer and production executive, has completed designs of a steamcar of his invention to race in the Indianapolis 500.

He is also following through on plans to manufacture and sell a limited production—250 to be exact—of his luxury steam-powered passenger cars at $35,000 each.

Thompson plans to license his steam powerplant for other uses, such as for generating electricity in utility plants, and he may grant licenses to other auto manufacturers.

"We've been negotiating with the Japanese industry," he said, "but so far nothing has come of it."

Thompson designed the racing car, to be equipped with a Thompson steam plant, for three men, who hope to drive in the 500-mile classic next Memorial Day.

Thompson said he thinks they are overly optimistic, and that 1970 is a more realistic date.

Thompson gave these sketches of the trio:

"K. B. Wright, Laguna Beach, Calif., a man of wide experience in the automotive field, particularly in sports cars and racing machines.

"Roy Burslem, Chicago, an engineer and manufacturer, also with an extensive background in automotive production both in this country and in Europe.

"Len Terry, London, England, one of the world's top designers of racing cars and whose cars are well known in the racing world."

Thompson said that Terry will refine the body design and create the chassis for the racing cars. The group plans to have four cars produced, two for Indianapolis and two for LeMans. A manufacturer in Philadelphia is building the Thompson powerplants.

Thompson said the racing group had made a complete study and evaluation of his powerplant for use in their racing machines.

His design was completed, he said, "to determine the feasibility of fitting this powerplant (which was designed for a 5,000-pound car of 136-inch wheelbase) into a car of 106-inch wheelbase, with a total weight of under 1,800 pounds."

"Much of these powerplants are aluminum, so weight posed no problem," Thompson continued, "but compressing the components into 106 inches of wheelbase did present some problems, all of which have been resolved."

Thompson said the powerplant is "strictly stock" adding: "No changes of any kind have been made except the rear axle ratio. The car will achieve the maximum speed (we estimated top speed at 220 miles per hour) with a very moderate number of engine revolutions per minute compared with the engine speeds of other racing cars.

"There is no loss of water. Fuel consumption is far below that of competing cars."

Such does not hold true with the conventional steam generator, which he said could not meet the demands for sustained speeds up to 150 miles per hour and yet be compact enough to fit into a racing car.

"Even more critical," he went on, "is the condensing of this large volume of steam. Any attempt to exhaust the steam and not condense it would require such

frequent stops for water as to make any chance of winning a race completely hopeless.

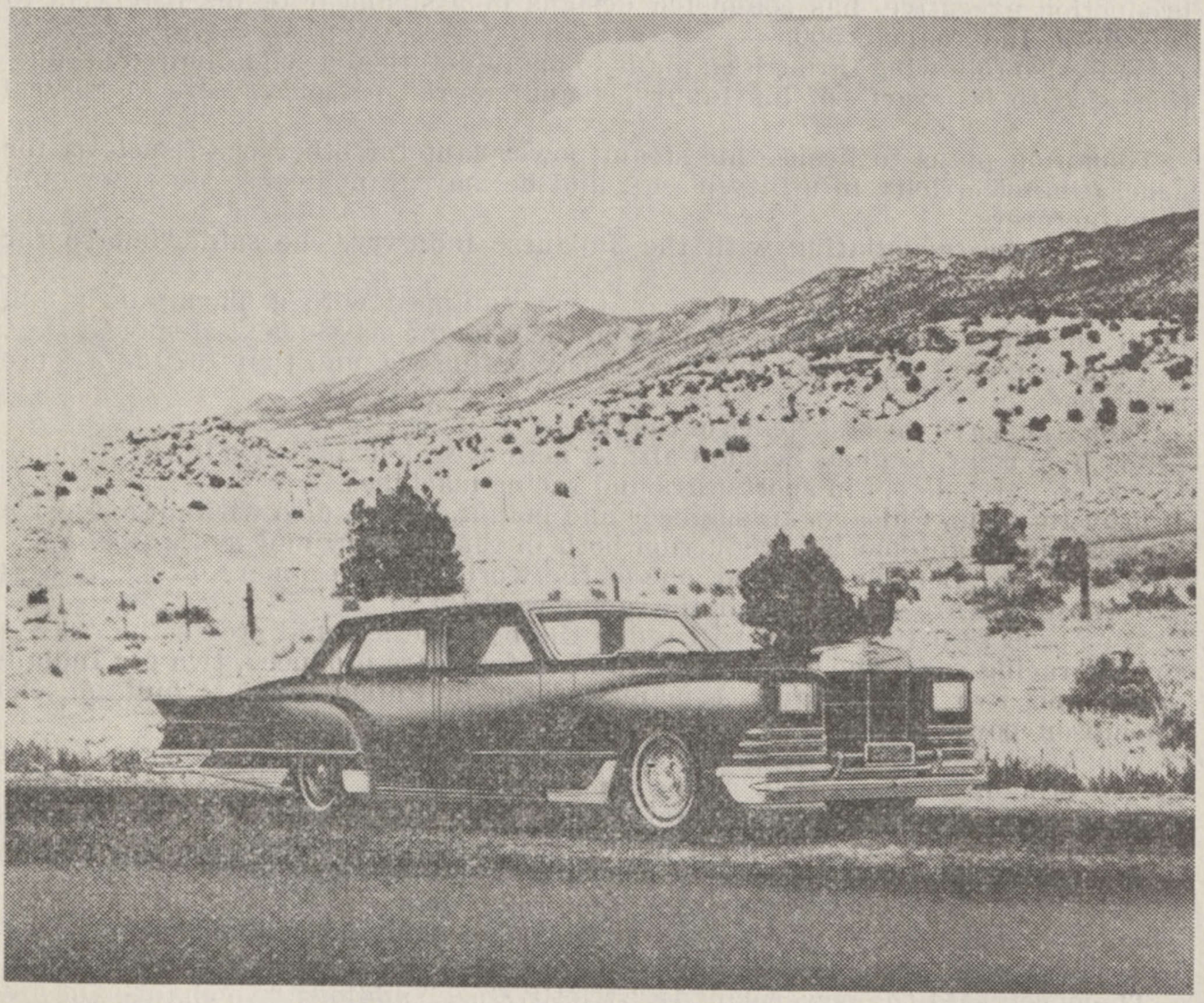
"Pumping more fuel into a standard type of small generator can be effective only up to a point. Beyond that, it becomes self-defeating, as there is not enough oxygen to completely burn this additional fuel which would therefore be wasted.

"The Thompson-Sterling G.E.S. (gasoline, steam, electricity) powerplant is, however, perfectly suited for any type of racing machine as well as for many other applications.

"The steam engine is very simple in design, but is a highly sophisticated machine that is rugged, dependable, and extremely powerful. This also applies to the steam generator. These units bear little, if any, resemblance to steam powerplants of the past or to those now being developed for automotive applications.

"Incorporated in these units is another element which provides the additional heartbeat necessary to compete successfully as a racing machine (an electric generating set which excites a reactor that provides the steam, and a small internal combustion engine, unlike those in ICE cars).

"These powerplants were not originally designed for this purpose, but were intended to power a large, heavy, superluxury motorcar, but they have the capacity to go far beyond that. A racing machine will clearly demonstrate this.



STEAMCAR SLATED FOR RUN AT INDY

This is a drawing of the steamcar designed by William D. Thompson to race in the Indianapolis 500. The three men who plan to drive the car are hopeful of competing in the classic next Memorial Day, but Thompson said he considers 1970 a more realistic date. The racer will be equipped with Thompson's steam powerplant. The plant was designed for a 5,000-pound car with 136-inch wheelbase, but had to be compressed into a 1,800-pound vehicle with 106-inch wheelbase.

"They can also go to the other extreme and be scaled down to vest pocket size for powering the very smallest of cars, down to a golf cart. The air pollution level of these vehicles is zero."

The Thompson racer would be the first steamcar ever to compete in the Indianapolis 500, though Thompson has driven the 2½-mile oval many times, back in the days when the track was brick and Stutz and Duesenberg were in their heyday.

Thompson drove a Stutz 100 miles per hour (then a tremendous speed)' in a test while working as a consultant for the company. Before going into consultant work and later retiring, he was operational vice president at Elkhart Carriage & Motor Co.

Thompson said he hopes to be ready to deliver his 250 superdeluxe steam passenger cars by next spring. The car will have a 136-inch wheelbase and weigh just under 5,000 pounds. It will have wood paneling, air conditioning, and two brake systems, hydraulic and dynamic.

"Nearly all of the production of 250 is spoken for," he said. Requests to buy them have come from all over the country, he added.

SAN DIEGO, CALIF., *January 20, 1969.*

Mr. S. L. SUTCLIFFE,
Staff Counsel, Committee on Commerce, U.S. Senate, Washington, D.C.

DEAR MR. SUTCLIFFE: In reply to your letter of January 15, let me begin by saying that our research and development program was begun in 1960 and has continued with few interruptions to date and is now completed and ready to be translated into hardware.

From our point of view racing provides a means of bringing this about and the enclosed clipping will give you some idea of our involvement in this at the moment.

I should tell you that our steam powerplants bears no resemblance to past designs, or to any that are being experimented with by others at this time. They will operate efficiently in any climate, operate in complete silence. They are extremely powerful, require no tuneups or adjustment, are rugged and completely dependable and have a very long service life. They are extremely simple, easy, and cheap to manufacture. They can be produced in many sizes from golf carts and minicars, standard size cars, big cars, all sizes of trucks and marine applications and locomotives. They use less fuel than I.C. engines or turbines and produce no air pollutants.

Mr. Lawrence V. Julihn, consulting engineer, has made a thorough study and evaluation for use of these powerplants as pumping and generating applications for use in remote areas. You might be interested in his opinions as he would likely be more objective than I would be. His address is 11678 Altoona Drive, El Cajon, Calif. Mr. Julihn is a retired admiral of the U.S. Submarine Service.

I can only add that a crash program could have a high performance, silent, completely smog-free car on the road in 12 to 18 months and at a competitive price.

Thank you for your interest.

Sincerely,

W. D. THOMPSON.

APPENDIX B

SOCIETY OF AUTOMOTIVE ENGINEERS,
New York, N.Y.

[International Automotive Engineering Congress, Detroit, Mich., Jan. 13–17, 1969]

CRITICAL COMPARISON OF LOW-EMISSION OTTO AND RANKINE ENGINE FOR AUTOMOTIVE USE

(By J. W. Bjerklie and B. Sternlicht, Mechanical Technology, Inc.)

ABSTRACT

The paper deals with reciprocating and rotary Rankine cycle engines using steam and organic fluids. It compares these theoretical engines to the present existing Otto cycle. The comparison considers size, torque, economy, emissions, response, maintenance, and reliability. Advantages and disadvantages of the various power systems are discussed and problem areas are identified.

Development of the internal combustion engine as an effective automotive powerplant involved several phases. The first concerned itself with making the engine work. The next step involved improvement of efficiency and performance. Today, with our affluent society, we are concerned with such aspects as comfort, reliability, maintainability, safety, and air pollution. Some of these objectives are justifiable; however, it should be recognized that much effort can be wasted when political pressures outweigh technical, economic, and educational factors. The technical and, to some extent, the economic considerations have motivated the authors to write this paper and try to place the Otto cycle engine in proper perspective with other low-emission engines now in the limelight. It is important to point out, however, that the Otto cycle engine is in existence and therefore actual while the Rankine cycle engines are theoretical.

Since the outcry for low-emission automotive engines has been publicized, there have been numerous ideas proposed. In the present climate, however, it is difficult to discard any ideas. At the same time, it is extremely expensive and time consuming to evaluate all of the ideas proposed.

It should be recognized that the Otto engine has had a good performance record. In addition, it is the lowest cost powerplant in the world, it sells for less than $3 per horsepower. This is a major achievement largely attributable to years of development and to mass production. In addition, there is tremendous investment in tooling and know-how for producing and maintaining the present day automotive engine. The various gas stations and service stations have mechanics that can effectively repair and maintain the engine. It is, therefore, not surprising that considerable effort is expended in modifying the present engine to meet future pollution regulations. At the same time, one should be objective and look at other potential engines that could be better or equal in performance and simultaneously minimize the pollution problem.

We do not wish to imply that the Otto engine cannot be modified to meet the low-emission requirements. In fact, the use of afterburners or catalytic reaction beds in exhaust manifold have long been considered and actually can be made to work well. Sacrifice in fuel economy is another technique that can be used to reduce pollution.

It is well recognized that powerplants which use external combustion have considerably lower emission characteristics than the present day internal combustion engines. The gas turbine is a good example of this feature. Other low-emission power systems include the electric drive and the Rankine engines.

It is also important to point out that the efficiency of a Rankine cycle utility powerplant is somewhere between 35 percent and 40 percent (based on lower heating value of fuel). While the efficiency of an Otto engine at 25 m.p.h. on level road is only about 12 to 14 percent; at 65 m.p.h. on level road it is 18 to 20 per-

cent. It is apparent that the actual operating efficiency of the Otto engine, even under ideal conditions, is considerably lower than that of the utility powerplants. In addition, the Otto engine uses highly refined fuel of higher price than the utility powerplants. In Rankine engines the combustion can be external, therefore the same fuel that is burned in utility powerplants can be used. This would reduce the fuel cost. In addition, the theoretical efficiency of the automotive Rankine engine can be several points higher than the Otto engine. This advantage can be maintained over a wide power range, thus achieving high average efficiencies well above the Otto engine. The use of external combustion therefore reduces the fuel cost and inherently produces lower emissions; hence it justifies the reasons for Rankine engine consideration. In addition, there are indications that a hermetically sealed Rankine engine of the turbine type can be developed to be highly reliable and will require very little maintenance.

The Otto engine cited in this paper represents actual performance and is used as a datum for comparison with theoretical Rankine engines. Both reciprocating and rotating engines are considered using conventional fluids such as steam and also some of the organic fluids. A 150-horsepower engine was chosen for quantitative comparison. This corresponds to the power level that fits a medium-sized, low-priced automobile (for example, Fairlane), and was also chosen because the McCullough and Williams reciprocating steam engines were of the same rating. The comparison is made on the basis of efficiency, size, cost, and performance characteristics. Problems associated with the development of Rankine engines are also identified.

In comparisons consideration was given to: horsepower requirements; torque requirements; system efficiency; system components (size and type); general control scheme; operating characteristics (startup time, acceleration, response time, starting methods; and working fluid characteristics). Because of space limitations, only highlights of the investigation are presented here.

SYSTEM CONSIDERATIONS

Figures 1 to 5 are block diagrams of the five systems compared. Figure 1 is the Otto cycle as presently used in the automobile, but with a block for "emission control" indicated. The nature of this block is not important at this time except to indicate that it probably will be required. Figure 2 is similar to the Williams (1)[1] reciprocating steam engine. Figure 4 is the same except that it uses a low temperature fluid instead of steam. Figures 3 and 5 are turbine versions of Figures 2 and 4.

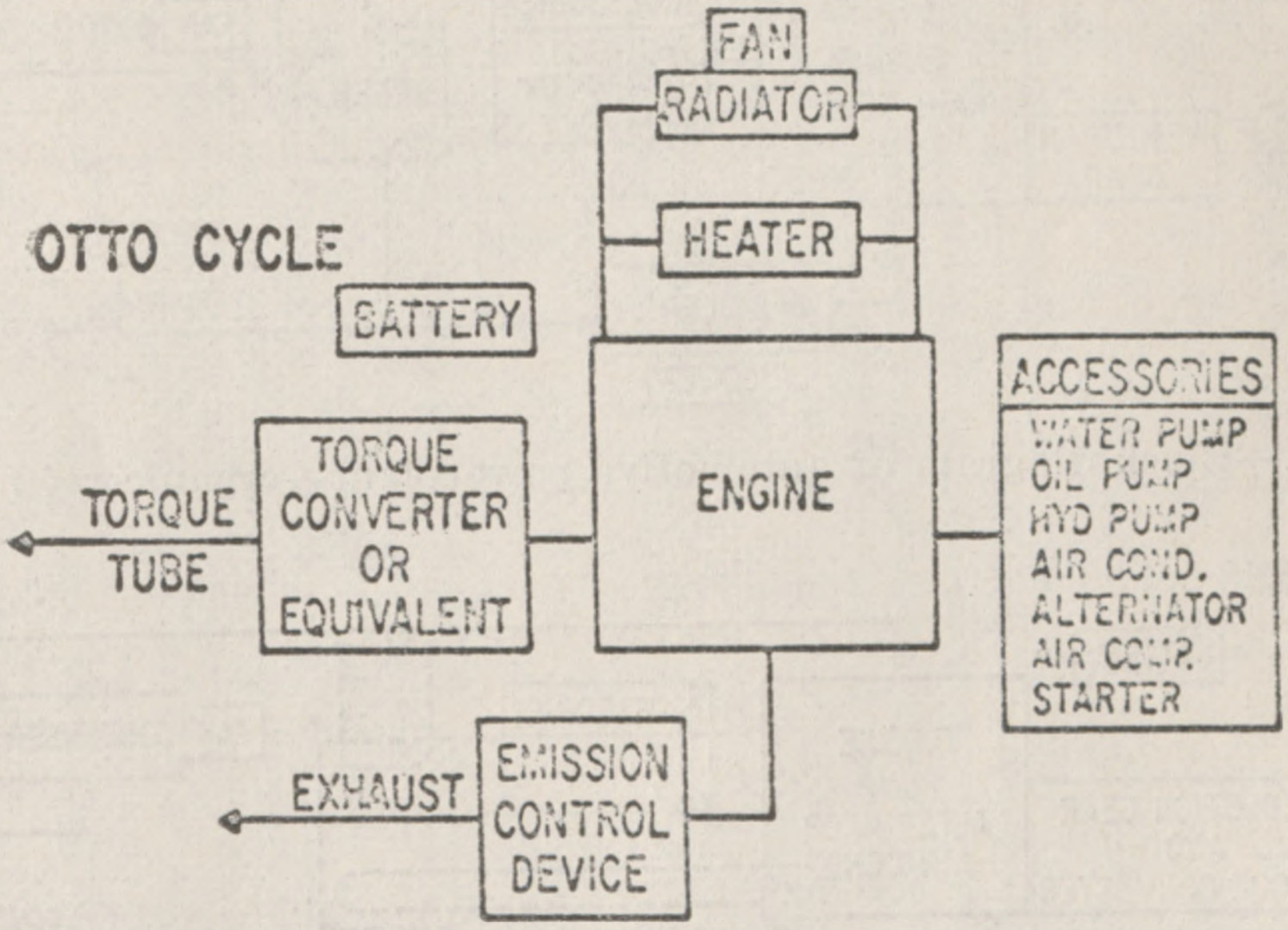


FIGURE 1.—Block diagram of automotive powerplant—Otto cycle.

[1] Numbers in parentheses designate references at end of paper.

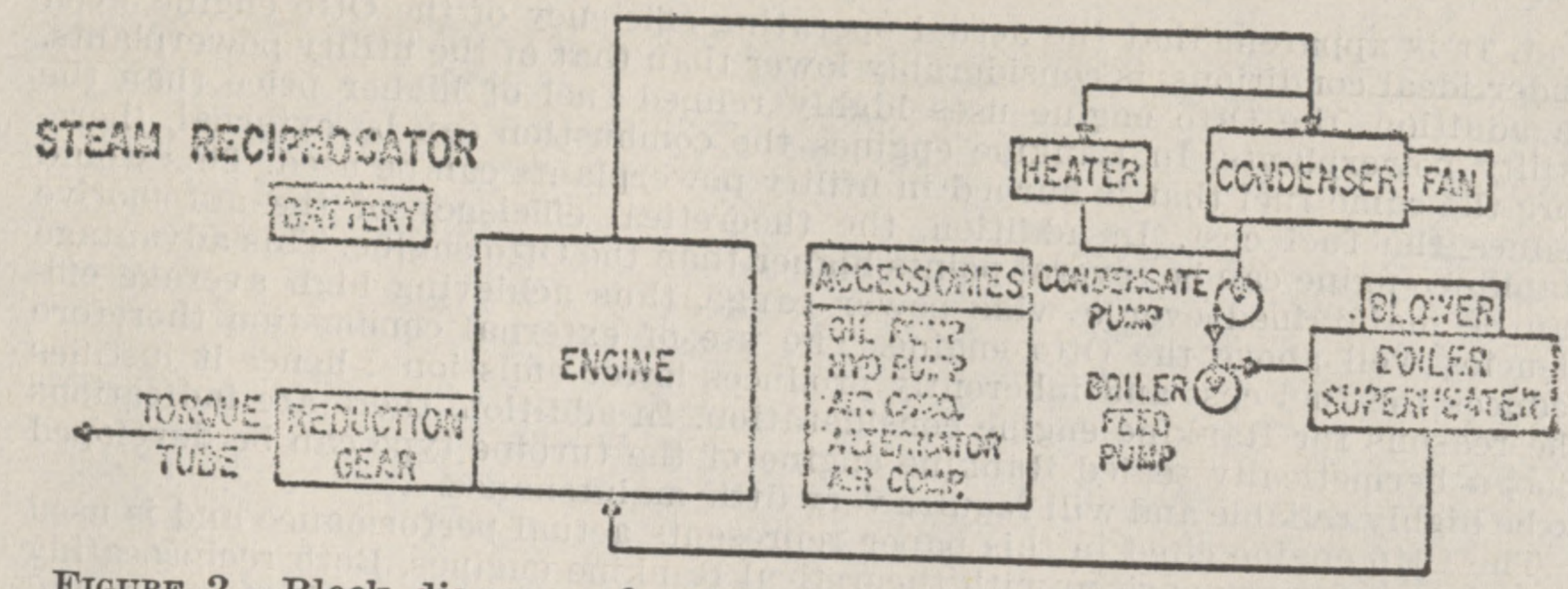


FIGURE 2.—Block diagram of automotive powerplant—steam reciprocator.

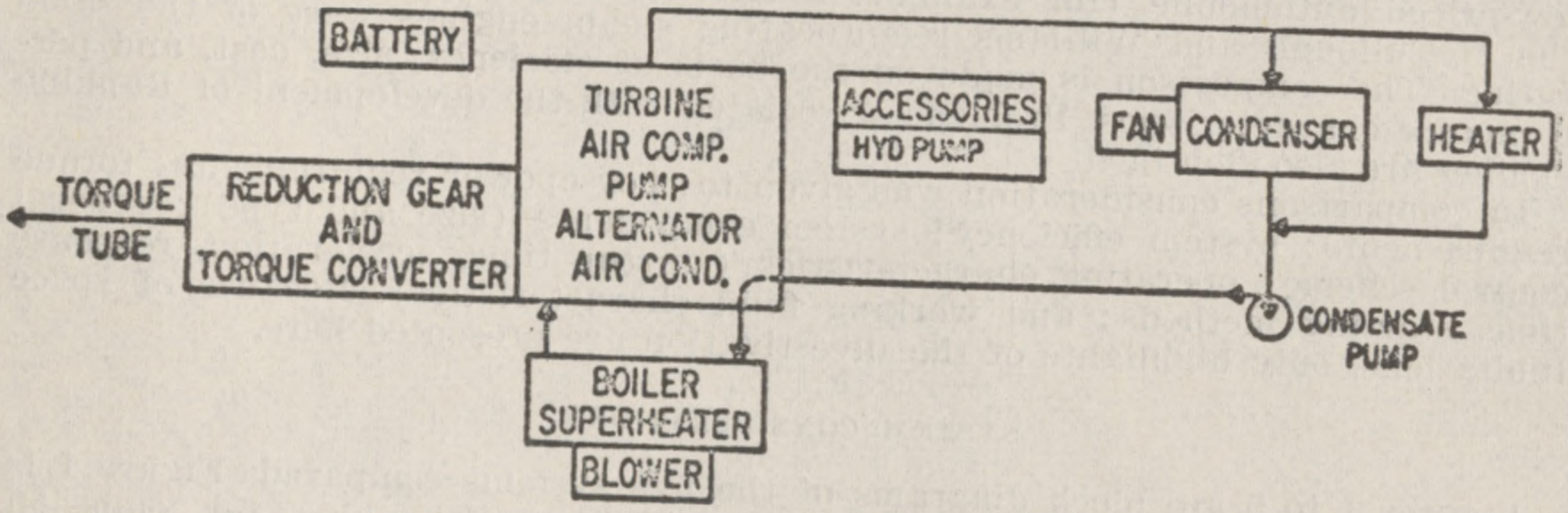


FIGURE 3.—Block diagram of automotive powerplant—steam turbo.

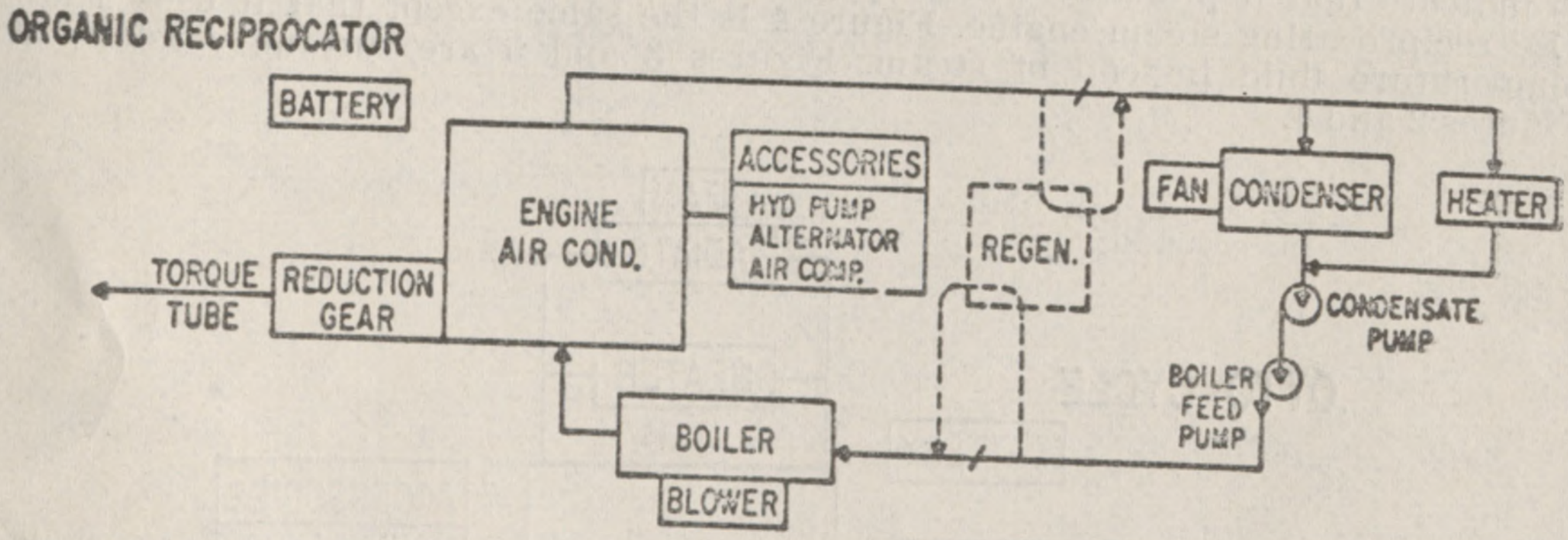


FIGURE 4.—Block diagram of automotive powerplant—organic reciprocator.

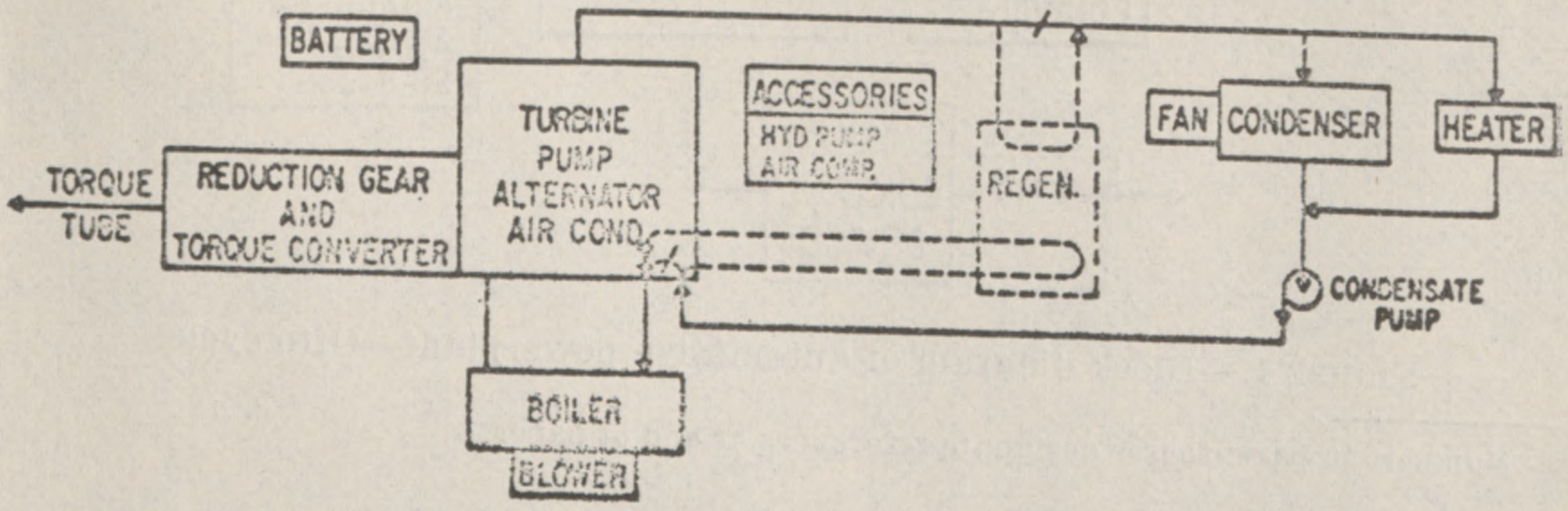


FIGURE 5.—Block diagram of automotive powerplant—organic turbo.

Only the Otto cycle requires a large starter motor. All the others require only a motor-driven pump to pressurize the boiler. This is indicated as a separate boiler feed pump for the case of the turbine and reciprocator. Fast response at initial startup is achieved with the separately powered boiler feed pump.

Separate lubrication systems are required for the Otto cycle and the steam reciprocating engine. The others might be able to use liquid or vapor "process fluid" lubrication.

The transmission used depends greatly on the powerplant. The Otto cycle requires a system of gears or other torque converter which ideally allows the engine speed to remain approximately constant at all conditions except idle and when starting from a dead stop. The transmission has to allow the engine to be rotating at a finite speed so as to develop torque at a standstill.

The turbine engines on the other hand, have the advantage of developing their maximum torque when standing still. This represents ideal condition for starting, so its torque converter should provide for a constant gear ratio drive system up to about 70 percent turbine speed. Thereafter, the requirement is for the turbine to remain near design speed for best efficiency.

Thus, both the Otto cycle and turbine engines require a torque converter that allows the prime mover to operate near constant speed once the vehicle is in motion. From a stop and during acceleration, the Otto cycle engine requires a slipping torque converter, and the turbine engine requires a locked torque converter.

The reciprocating vapor engines can develop very high torque merely by feeding high pressure vapor to the cylinder. This is ideal for starting since the engine does not have to be rotating to develop the torque. Consequently, the drive for these engines requires only a gear box to allow for the different peak rotating speeds of the engine (which depends on starting torque and size requirements) and drive shaft (which depends on wheel size and vehicle speed). Reverse can be accomplished by a gear system or be part of the control system.

ENGINE REQUIREMENTS

Performance of a medium-sized, low-priced auto was calculated for the three basic engines, all with a nominal 150 horsepower at the shaft design speed. This is comparable to several automotive steam engines that have been built and used. It is the same as the Williams engine (1) and is similar to a bread-board vapor engine tested in England (2) and has sufficient power to run a high performance automobile. It should be pointed out that a 150-horsepower vapor engine is equivalent to an Otto cycle engine rated at about 250 horsepower. This is because the maximum Otto cycle torque occurs at about 60 percent of maximum power. The maximum torque is the limiting factor in normal high power demand conditions, but its engine power is rated at its maximum. For this comparison it was assumed that the Otto cycle and the turbine drives were 90 percent efficient (except during initial acceleration for which 98 percent efficiency was assumed for the turbine drive), and the direct drives were 98 percent efficient. These figures are consistent with a hydraulic torque converter (90 percent) or with two stages of gearing (98 percent). It was further assumed that the vehicle had a frontal area of 24.3 square feet, an aerodynamic drag coefficient of 0.4, weight of 3,500 pounds, tire pressure of 28 p.s.i.g., tire diameter of 2 feet, and standard air conditions. It was sufficient at this point in the analysis to use turbine speeds of 30,000 r.p.m., and reciprocating engine speeds (all kinds) of 3,000 r.p.m. for evaluating torque. The Otto cycle, reciprocating vapor, and turbine engines can achieve the performance indicated in table 1. The acceleration figures were calculated with the assumption that traction can be maintained with a friction coefficient of 0.6.

TABLE 1.—PERFORMANCE OF AUTOMOBILES WITH VARIOUS 150-HP POWER SYSTEMS

[Weight of auto plus load, 3,500 lb.; tire pressure, 28 p.s.i.; tire diameter, 2 ft.; standard air conditions, frontal area, 22.4 ft.; C_D, 0.4; coefficient of friction between tires and road, 0.6]

	Otto[1] cycle (engine rating≈250 hp.)[2]	Vapor[3] reciprocator (engine rating≈168 hp.)[4]	Vapor[5] turbine (engine rating≈150 hp.)[6]
Top speed (miles per hour)	117	121	117
0 to 60 m.p.h. acceleration (seconds)	10	9.5	[7] 10
30 to 60 m.p.h. acceleration (seconds)	5½	5	6½
Grade at 60 m.p.h. (percent)	20	22½	20

[1] Transmission efficiency taken as 90 percent.
[2] 150 hp. corresponds to maximum torque condition, assumed to occur at 60 percent of maximum power. Engine assume to operate at constant 3,000 r.p.m. during all calculated maneuvers.
[3] Transmission efficiency taken as 98 percent.
[4] 150 hp. corresponds to normal maximum power at maximum engine r.p.m. (6,000 r.p.m.) engine operates with fixed gear ratio; rotates at 3,000 r.p.m. at 60 m.p.h. Cut off held wide open during acceleration to 60 m.p.h. at 60 m.p.h. the engine develops 168 hp., and reaches 150 hp. at 7.5 sec. (50 m.p.h.). Engine could be designed never to exceed 150 hp. at slight penalty to acceleration time.
[5] Transmission efficiency taken as 98 percent for acceleration; 90 percent for other conditions.
[6] 150 hp. corresponds to normal peak power at 30,000 r.p.m. turbine speed. Fixed gear ratio assumed during acceleration from 0 to 60 m.p.h. (30,000 r.p.m.); turbine operates at 30,000 r.p.m. at all power levels once having reached 30,000 r.p.m.
[7] Traction limited. Turbine supplies more torque at start than traction can transfer.

The reciprocator r.p.m. was chosen by selecting the maximum sliding velocity, and the number of cylinders. This in turn fixes the piston diameter and r.p.m. for a given mean effective pressure and horsepower. With well-lubricated cylinder walls such as is possible with the low temperature working fluids or oil, the sliding velocity, can approach 3,000 f.p.m. This, in turn, leads to shaft speeds of 2,000 to 3,000 r.p.m. In the interest of comparing the smallest practical engines, all reciprocators were evaluated at 3,000 r.p.m.

Table 1 shows top speed, time to accelerate to 60 m.p.h. time to accelerate from 30–60 m.p.h. and the maximum grade that can be climbed at 60 m.p.h. The notes on table 1 explain the normal engine modes assumed for the calculations.

RANKINE CYCLE WORKING FLUIDS

The thermodynamics of Rankine cycles and fluids is fundamental to any discussion of the merits of Rankine engines.

Several recent papers discuss the fluids and their application (2–5).

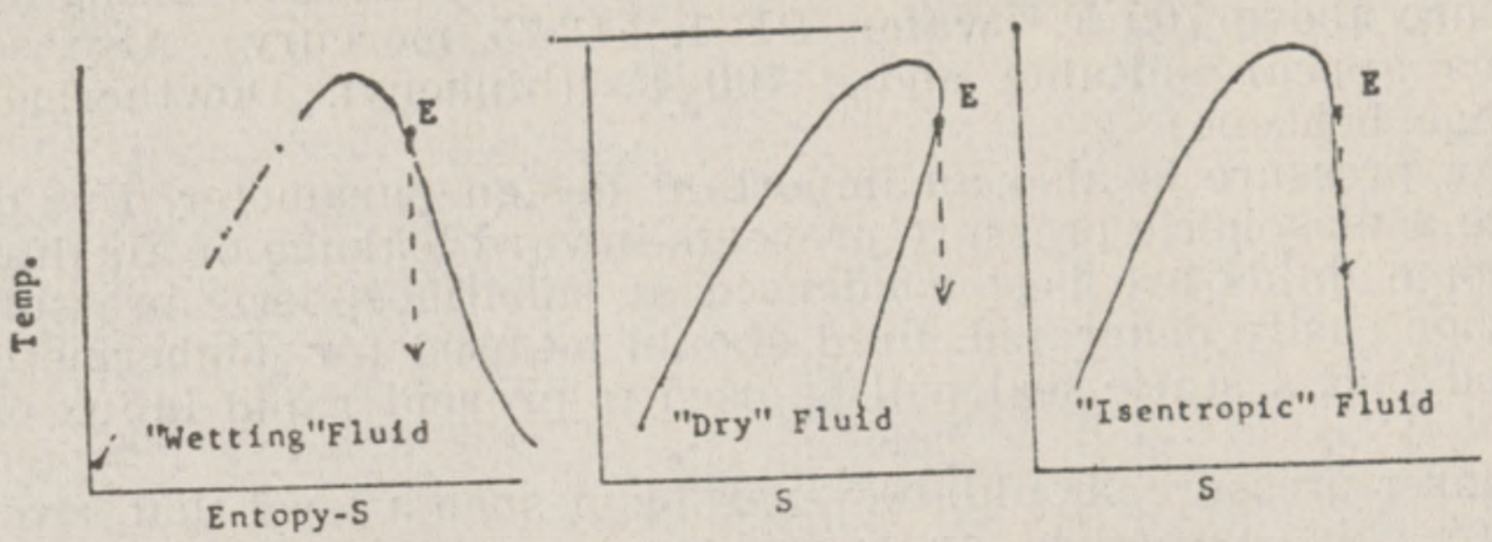
The thermodynamc consideration largely involves three factors which are interrelated: cycle efficiency, condensing temperature, and heat recovery by means of a regenerator. The cycle efficiency can, for simplicity, be represented as a fraction of the Carnot efficiency:

$$\eta_{Carnot} = \frac{T_{peak} - T_{min}}{T_{peak}} \text{ and } \eta = f\eta_{Carnot}$$

where f is the fraction of Carnot efficiency (nearly constant for a given fluid) that can be achieved. It is readily seen that the minimum temperature (condensing temperature for Rankine cycles) has a strong effect on system efficiency. It is also evident that the temperature difference between the condenser and the cooling medium (air for automotive engines), has a strong effect on condenser size. The opposing effects lead to an optimum temperature for smallest condenser size. Condenser size and cost are important for automotive applications, but so is cycle efficiency if fuel consumption is to remain acceptable. The most economic design (including the fan cost and fuel consumption) will occur in a condensing temperature range between 150 and 250 F. for a peak temperature of about 700 F. For higher peak temperatures the most eonomical system has a condensing temperature band somewhat higher. The temperature spread of the condenser is quite wide for only a small variation in condenser size. This assures a wide latitude in choosing a compromise between efficiency (fuel consumption), and condenser size (cost and package size).

Major design and usage considerations arise from the shape of the vapor dome of the Rankine fluid. The point E on the sketches below indicates a typical point on the saturated vapor curve for the start of isentropic expansion through a prime mover. The fluids have three classifications identified by the expansion

process. These are moist (wetting fluid), superheated (dry fluid), and saturated (isentropic fluid). The thermodynamic implications of the three shapes are as follows:



Wetting: High fraction of Carnot efficiency achievable if liquid specific heat is low. Water is a good example of a practical wetting fluid, but suffers from high liquid specific heat. Mercury is a good example of a theoretically excellent fluid.

Dry: High fraction of Carnot efficiency can be achieved if a regenerator is used. The regenerator recovers the superheat left in the fluid after the end of expansion. The heat is transferred from low pressure vapor to high pressure liquid just before the latter enters the preheater-boiler. Most hydrocarbons are of this type.

Isentropic: High fraction of Carnot efficiency achieveable if liquid specific heated is low. No regenerator is needed. A few fluids approximately approach these properties (for example, PF–1 and CP–34 (the former being an MTI designation, and the latter being a Monsanto Chemical Company designation)).

The design implications of these T-S diagrams are as follows:

Wetting: Danger of erosion in turbine blades if expansion is carried very far into the vapor dome. Collection of moisture usually detracts from efficiency of both turbines and reciprocators and introduces design complexities.

Dry: Requires the use of desuperheater or a regenerator for the exhaust from the expander. The desuperheater can be combined with the condenser, in this case the exhaust superheat is wasted and requires large heat exchanger volume because of poor heat transfer (gas-to-gas exchanger). With the use of a regenerator the wasted heat is recovered by the cycle, thereby improving efficiency and saving on external heating. The regenerator can be about half the size of a corresponding desuperheater because of better heat transfer (gas-to-liquid exchanger). Thus, with the use of dry fluid, for an automotive power plant, a regenerator is preferable to a desuperheater, for it results in better efficiency and keeps the heat exchanger size down.

Isentropic: Ideal.

Other thermodynamic and design features become important as other factors are considered. For example, it can be shown that a cycle having its start of expansion at the saturated vapor line will always achieve higher fraction of Carnot efficiency than if it starts either unsaturated or superheated (6). This is very important when the peak attainable temperature is limited by heat source, materials, or fluid limitations. A separating chamber should be used to assure that the vapor leaving the heat addition components is saturated. Also a superheater should be avoided, if possible, by the selection of a fluid not requiring superheat to achieve a high enough peak temperature for sufficient cycle efficiency.

It can also be shown that for a given condenser temperature the best cycle efficiency of a dry or isentropic fluid occurs when expansion starts between the critical temperature and the tip of the bulge in the saturated vapor line (6). This effect is small and only becomes important when dealing with fluids near their critical temperature. Use of a fluid with a very high critical temperature would by no means be precluded by this criterion.

As shown in Ref. 7 the head drop (enthalpy change) and volume flow upon expansion through turbines has a strong effect on both efficiency and turbine size. A low head drop (usually corresponding to high molecular weight) usually leads to lower tip speed turbines. The high molecular weight usually leads to low sonic speeds, and to low volume flow at a given temperature and pressure. These compensating factors usually end up with a high molecular weight fluid being most suitable for low power turbines.

Of major importance is the thermal stability and materials compatibility of the working fluid. Halogenated refrigerants are typically unstable above 300–400 F. It is highly desirable from a thermodynamic viewpoint to go to considerably high temperatures. There are some nonflammable working fluids stable to temperature above 700 F. (water, PF–1, FC–75, mercury). Also, some of the hydrocarbons appear suitable above 700 F. (biphenyl, Dowtherm A, CP–63, CP–27, toluene, benzene).

Condensing pressure is also an important design parameter. Use of the condenser above atmospheric pressure prevents inward leakage of air during operation. But, some fluids are best condensed at subatmospheric pressure. Then a nonreactive, or easily deaerated, fluid should be used for nonhermetic systems. It is assumed that a static seal will be used to prevent rapid influx of air upon shut down.

The condenser pressure should, however, be of such a level that several design parameters prevail (assuming condensing temperature can be satisfied by proper choice of fluid):

1. Volume flow through expander is correct for small reciprocators or high efficiency turbines. This implies low pressure for low power turbines so that high turbine efficiency can be achieved (7). For reciprocators the volume flow dictates the size of the engine, and the volume expansion ratio dictates the number of stages.

2. Pressure drop due to condensing and to flow friction should be only a small fraction of the absolute inlet pressure. This implies that the condenser pressure normally should be above 1 p.s.i.a. Pressures near 2–3 p.s.i.a. may be preferable (8).

For turbine systems this leads to usable pressures as low as 1 to 3 p.s.i.a. For reciprocators the minimum pressures will normally be above one-half atmosphere (and preferably above one atmosphere) if machinery is to be of about present automotive engine sizes. This usually leads to slightly poorer thermodynamic efficiency than for equivalent turbine systems because the last portion of expansion is not possible if the reciprocators are to remain reasonable in size.

All of the above-discussed fluid parameters can be represented on a single fluid selection chart as shown in Fig. 6. Vertical lines are used to represent maximum usable temperatures and minimum usable temperatures. Horizontal lines are used to represent minimum usable pressures and maximum usable pressure (usually selected to be <1,000 p.s.i.a. merely to prevent having to design for difficult containment).

The most suitable fluids are represented as diagonal lines on figure 6 extending all the way across the temperature belt, while staying between the maximum usable pressure and the minimum usable pressure. A slightly less workable fluid may require a slight degree of superheat. This condition is easily detectable on the chart when the vapor pressure line exceeds the maximum pressure before intersecting the maximum usable temperature line, or by the critical temperature being lower than the maximum usable temperature.

The further the deviations from the ideal, normally the worse the fluid will be from a thermodynamic standpoint. Since specific heats and exact variations in heats of vaporization also affect efficiency, a complete fluid selection chart (one with all fluids on it) can be used only to pick a number of potentially usable fluids. Hence, a more practical approach was used for figure 6 in which only the better fluids are shown. Thus, any fluid shown on figure 6 achieves ideal thermodynamic efficiency in the nonsuperheated condition above 75 degrees of Carnot efficiency (except for water).

A number of other obvious considerations enter into the selection of fluids. These are:

Cost.—Any leakage must eventually be replaced. Even hermetically sealed systems may (depending on thermal stability) require periodic replacement of the fluid.

Safety.—This reflects reaction with air and water vapor; effects on surroundings in case of spills; reaction to personnel if spilled on skin, swallowed, or breathed; toxicity; flammability; flash point; and explosion hazard.

Freezing point.—A low-freezing point enables the pure fluid to be used without having to introduce heat at startup or antifreeze which may prevent proper cycle operation.

With the aid of the studies (2–5), it is possible to make meaningful comparison between steam, presently available low-temperature fluids, and an "ideal" Rankine cycle working fluid in table 2. CP–27 has been selected in this study since it represents one of the more universally applicable low-temperature fluids.

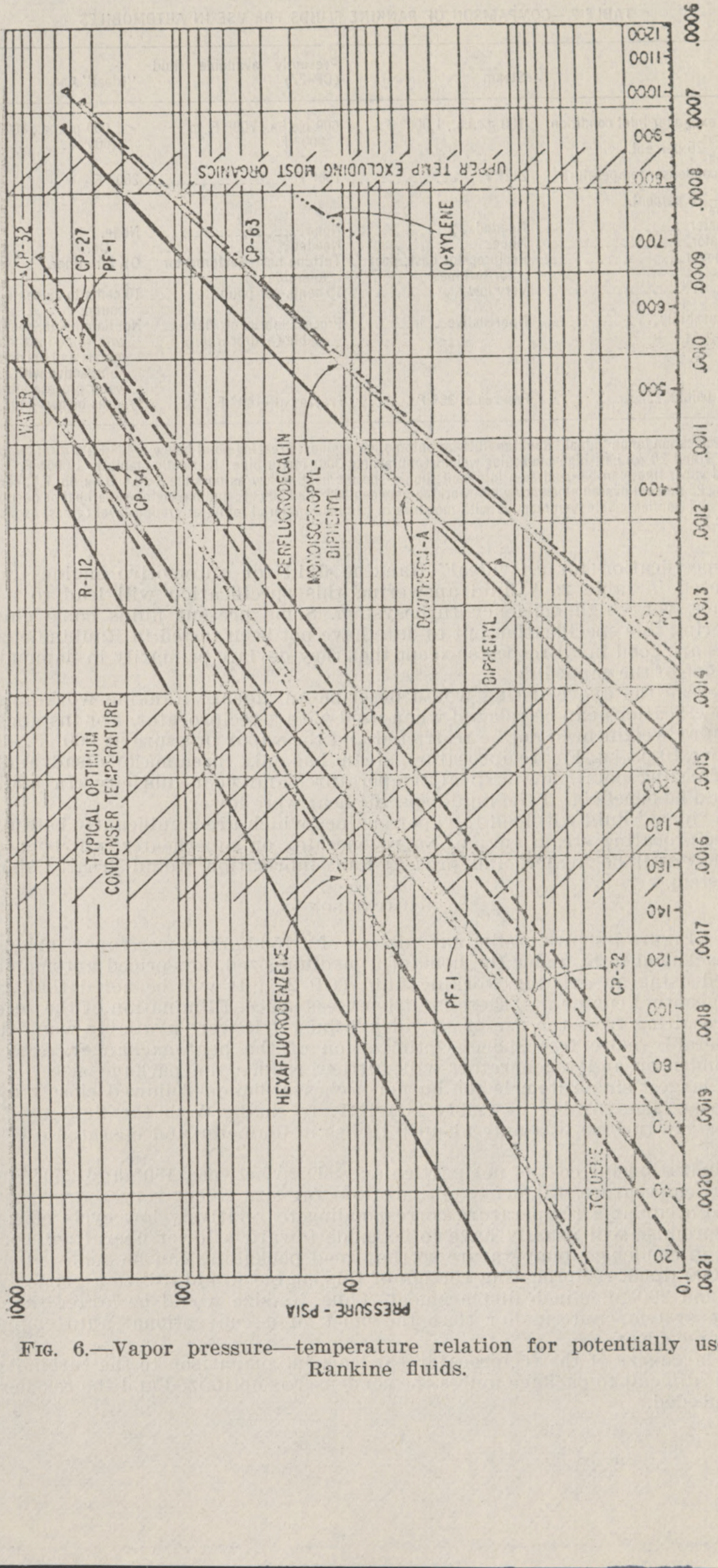


FIG. 6.—Vapor pressure—temperature relation for potentially useful Rankine fluids.

TABLE 2.—COMPARISON OF RANKINE FLUIDS FOR USE IN AUTOMOBILES

	Steam	Presently available fluid (CP–27)	"Ideal" [1]
Typical expander inlet condition for $\eta_{oa} \geq 25$ percent.	100 p.s.i.a., 1,000° F.	600 p.s.i.a., 700° F. to 800° F.	<1,000 p.s.i.a., 800° to 1,000° F.
Typical condenser temperature for $\eta_{oa} \geq 25$ percent.	212° F.	150° F.	200° F.
Superheater	Needed	None	None.
Regenerator	None	Needed	Do.
Prime mover	Reciprocator best; poor for turbines.	Turbine best; reciprocator tolerable.	OK for either.
Cost	Very low	15 cents per pound	10 cents to 25 cents per pound.
General usability	Nonreactive	Process lubricant; flammable (hydrocarbon).	Nonflammable, compatible with some inexpensive metals and elastomers, nonreactive with air or water process lubricant.
Freezing point	Freezes at 32° F.	Freezes at −40° F.	Freezes below −40° F.

[1] A specification for an "ideal" Rankine fluid for automotive engines: Freezing point below −40° F.; critical temperature between 3 and 20 p.s.i.a.; high molecular weight (appraching 300) for turbine; thermally stable to 1,000° F.; constant saturated vapor line; can be used as a lubricant; liquid-specific heat as low as possible (<0.4 B.t.u./lb. F.); capable of exceeding 25 percent overall efficiency when working between 800° and 200° F. and having no superheat or desuperheat; nontoxic and nonflammable; nonreactive with moisture or common material found at ground level (grass, asphalt, concrete, etc.).

A specification for an "ideal" Rankine fluid for automotive engines is also presented in table 2. A fluid answering this specification will lead to a very compact, very high efficiency turbosystem. Some present fluids come close to answering this specification but to date have not been tested in Rankine engines. Others are good in all respects except that they deviate primarily in flammability and slope of the vapor line

Whereas the above listing would describe an "ideal" Rankine working fluid, the specifications can be relaxed when used with a reciprocator. For instance, the molecular weight need not be restricted and the vapor pressure at 200° F. should be above 10 p.s.i.a. For reciprocators, steam has only three major disadvantages: high freezing point, low critical temperature, and poor lubricity. In addition, it would be beneficial if the liquid specific heat were lower.

The "ideal" fluid will lead to vapor engines which are significantly better than the reciprocating steam engine. No regenerator or superheater will be needed, efficiency will be higher, and process fluid lubrication would greatly simplify the system.

COMPARISON

Size: Figure 7 shows preliminary design of a 150-horsepower vapor turbine engine packaged to fit under the hood of a medium-sized, low-priced automobile. It is sized using an existing working fluid (CP–27). It will be noted that, while the conceptual engine fits, there is little excess space. Elimination of the regenerator, resulting from the use of an "ideal" fluid if it were available would leave considerably more free space. Optimization of the heat exchanger, especially the condenser and regenerator, will further reduce the package size.

The largest single item is the burner-preheater-boiler, followed closely by the condenser. The turbine assembly is relatively small. With the fluid used, the single-stage turbine was only about 9 inches in diameter and operated at 30,000 r.p.m.

Optimization for cost is not particularly sharp between 150° and 250° F. condenser temperature. Likewise, optimization for size is not very sharp, but will tend to occur at a temperature corresponding to relatively low cycle efficiency. A compromise will usually have to be made toward a lower operating economy and high condenser temperature so that good packaging can be achieved.

A 3,000 r.p.m. reciprocating version of this engine would utilize a prime mover of around 200-cubic-inch displacement. Thus, its size would be larger than the turbine system, and smaller than the block of a conventional auto engine of high horsepower.

The large size of the reciprocator (at least in comparison to the turbine) will make it difficult to package unless the condenser is optimized and the regenerator is not needed.

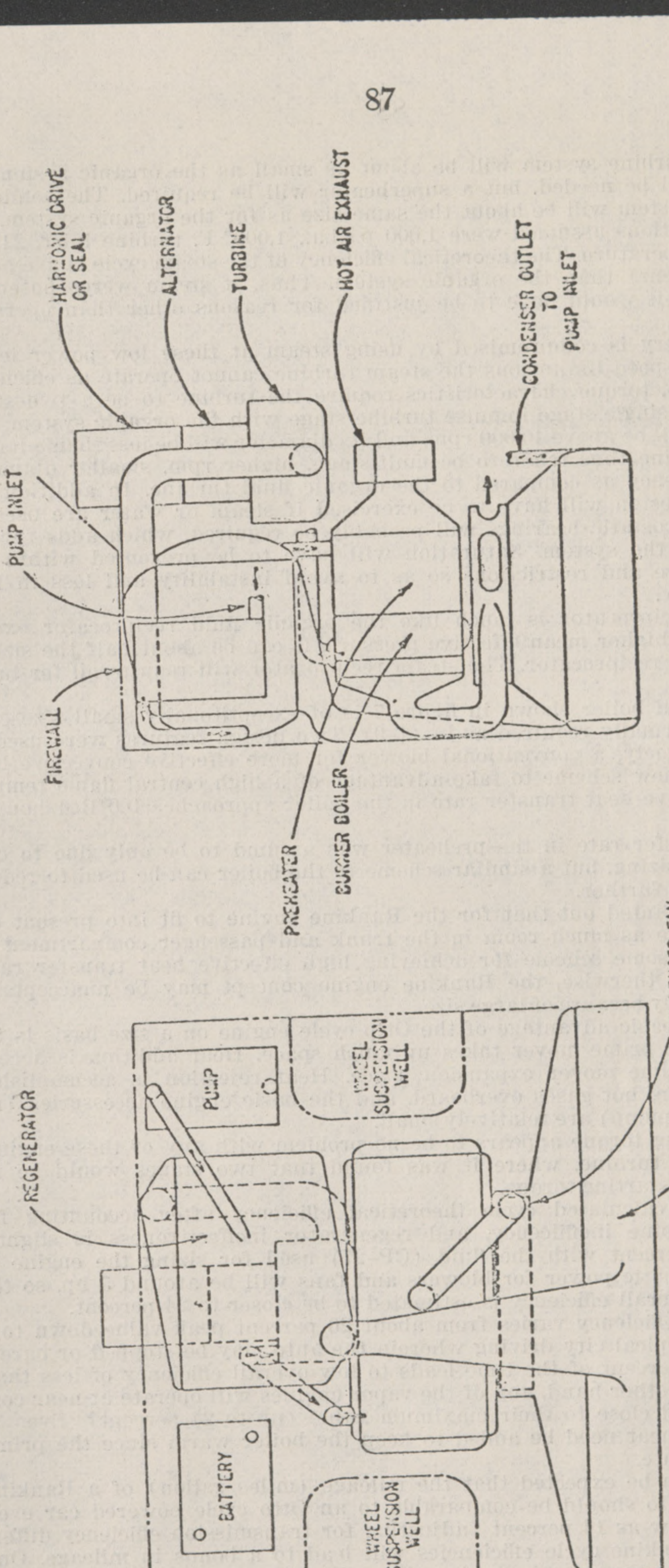


FIGURE 7.—Automotive turbo Rankine engine for present fluids, 150 horsepower, installed in medium-size passenger car.

The steam turbine system will be about as small as the organic system. No regenerator will be needed, but a superheater will be required. The condenser of the steam system will be about the same size as for the organic system. The operating conditions assumed were 1,000 p.s.i.a., 1,000° F. turbine inlet, 212° F. condensing temperature. The theoretical efficiency of the steam cycle is five points lower (19 percent) than the organic system. Thus, if steam were chosen for automotive use it would have to be justified for reasons other than operating economy.

Turbomachinery is compromised by using steam at these low power levels. Because of tip speed limitations the steam turbine cannot operate as efficiently as desired. Also, torque characteristics require the turbine to be a two stage, as opposed to a single stage impulse turbine stage with the organic system. The turbine speed will be above 40,000 rpm, and its diameter will be less than 8 inches. The steam turbine thus tends to be multistage, higher rpm, smaller diameter, and lower efficiency as compared to the organic fluid turbine. In addition, extreme care in design will have to be exercised if steam or water are used as lubricants. Hydrostatic bearings will probably be required, which adds further complication to the system. Saturation will have to be prevented within the bearing clearance and restrictions so as to avoid instability and loss in load carrying capacity.

The steam reciprocator is much like the organic fluid reciprocator except that, because of higher mean effective pressure, it can be about half the size of the organic fluid reciprocator. The steam reciprocator will require oil for lubrication.

The anticipated boiler shown in figure 7 is of exceptitonally small size compared to that normally required as in (1–9). Two design features were used to achieve this; namely, a conventional blower for more effective convective heat transfer, and a new scheme to take advantage of a high central flame temperature. The effective heat transfer rate in the boiler approaches 100 Btu/hour F. square foot.

The heat transfer rate in the preheater was assumd to be only due to convectiton for the sizing, but a similar scheme to the boiler can be used to reduce the total size even further.

It should be pointed out that for the Rankine engine to fit into present car outlines and leave as much room in the trunk and passenger compartment as presently exists, some scheme for achieving high effective heat transfer rates has to be used. Otherwise, the Rankine engine concept may be unacceptable to the public merely because of large size.

Of course, the basic advantage of the Otto cycle engine on a size basis is the fact that only the prime mover takes up much space. Heat addition is accomplished in the prime mover expansion space. Heat rejection is accomplished largely by dumping hot gases overboard, and the basic engine accessories (radiator, fan, water pump) are relatively small.

Torque: Starting torque appears to be no problem with any of these engines except the steam turbine, where it was found that two stages would be required to meet the starting torque.

Economy: The calculated cycle theoretical efficiency after accounting for pump power, turbine ineffiicency, and regenerator ineffectiveness is slightly higher than 25 percent with the fluid (CP–27) used for sizing the engine in figure 7. The parasitic power for blowers and fans will be around 5 hp, so the real theoretical overall efficiency is estimated to be closer to 24 percent.

The Otto cycle efficiency varies from about 20 percent peak value down to 0 percent at idle. Typical city driving wherein the auto may be stopped or barely moving up to 20 percent of the time leads to low overall efficiency of less than 15 percent. On the other hand, any of the vapor engines will operate at near constant efficiency and close to their maximum value (up to 24 percent). Even at idle, only enough heat need be added to keep the boiler warm since the prime mover need not rotate.

Therefore, it can be expected that the mileage (miles/gallon) of a Rankine engine powered auto should be comparable to an Otto cycle powered car even at efficiencies as low as 14 percent (adjusting for transmission efficiency differences). Higher Rankine cycle efficiencies will lead to a bonus in mileage. Our calculations indicate the organic fluid engine will give a somewhat higher bonus than the steampowered engine.

Cost: Detailed designs of each system are necessary in order to accurately compare the cost of each engine. These designs were not available for the Rankine engine therefore no final conclusion should be drawn from this section except to indicate in "ball park" fashion the potential. However, the cost of the present automotive system is available and estimates were made for the other systems based on expected ultimate cost. The cost of the present engine system was normalized at unity and compared to other systems on a relative basis. Wherever possible, experience was drawn from other systems. In preparation of the cost comparison, table 3, the area of greatest potential error is in the engine cost.

TABLE 3.—RELATIVE COST COMPARISON OF OTTO AND RANKINE SYSTEM

	Otto cycle	Steam reciprocator	Steam turbine	Organic reciprocator	Organic turbine
Engine [1]	0.42	0.40	0.20	0.40	0.16
Heat addition		.20	.18	.18	.18
Heat rejection	.04	.10	.10	.10	.10
Transmission	.35	.15	.40	.15	.38
Accessories [2]	.13	.13	.11	.10	.10
Emission control	.06				
Total	1.00	.98	.99	.93	.93

[1] Engine cost includes fuel injection system and ignition system.
[2] Accessories exclude air conditioning, power steering, power brakes, power seats, power windows.

The reciprocating engine (Otto, steam, or organic fluid) can be expected to cost comparably on a displacement basis. The organic fluid turbine prime mover should be cheaper than the steam turbine because of fewer stages. The turbo engines should be considerably cheaper than reciprocators, neglecting new investment cost for mass production equipment. The stresses are low (tip speeds only on the order of 1000 fps), and the temperatures are low so that inexpensive materials can be used. Present-day bearing technology indicates that the shaft bearing assembly can be made relatively inexpensive. The fuel injection system, ignition system, and the mixture control should be less expensive in the Rankine systems than in the Otto cycle engine. But, the preheater-boiler of the Rankine systems will be considerably more expensive than the Otto cycle heat addition system. Also, the heat rejection components of the Rankine cycles will cost more than the radiator of the Otto cycle because they are bigger.

The vapor reciprocating engines should have the least expensive transmissions. The turbine engine transmission cost, because of higher speed, are expected to be somewhat higher than the Otto engine.

The Otto cycle and steam reciprocator accessories are expected to be comparable. The steam turbine accessories should be slightly cheaper than those of the steam reciprocator because of the simpler lubrication system. It is very probable that the accuracy of table 3 is worse than 7 percent which represents the greatest difference. However, the comparison is sufficiently encouraging to warrant a detailed design from which a more accurate cost assessment can be made.

Emissions: Emissions from the Rankine systems are expected to be low and within the future emission specification. Figures 8, 9, and 10 show results of measurements made on jet engines, gas turbines, Stirling cycle engine, and unaltered Otto cycle engines (10–13), but with the results adjusted to be the equivalent of a stoichiometric mixture. This adjustment was made to account for the diluting effect of excess air. The measured ppm can always be reduced to very low levels merely by adding excess air in the exhaust, but this does not reduce the actual mass of emissions unless a chemical reaction is carried out at the same time. Since the actual mass of emissions per horsepower hour is the real issue at hand, the diluting effect has to be eliminated from the comparison. This is done by dividing all actual measurements by the overall equivalence ratio, ϵ (ϵ=actual fuel-air ratio/stoichiometric fuel-air ratio). A further adjustment has to be made for specific fuel consumption difference (the better performing engines will use less fuel, and will therefore have less emissions), and another correction would adjust for the difference between design point emissions and actual use emissions over a typical cycle of acceleration, deceleration, high speed, and low speed. However, at this point it is impractical to make these latter corrections.

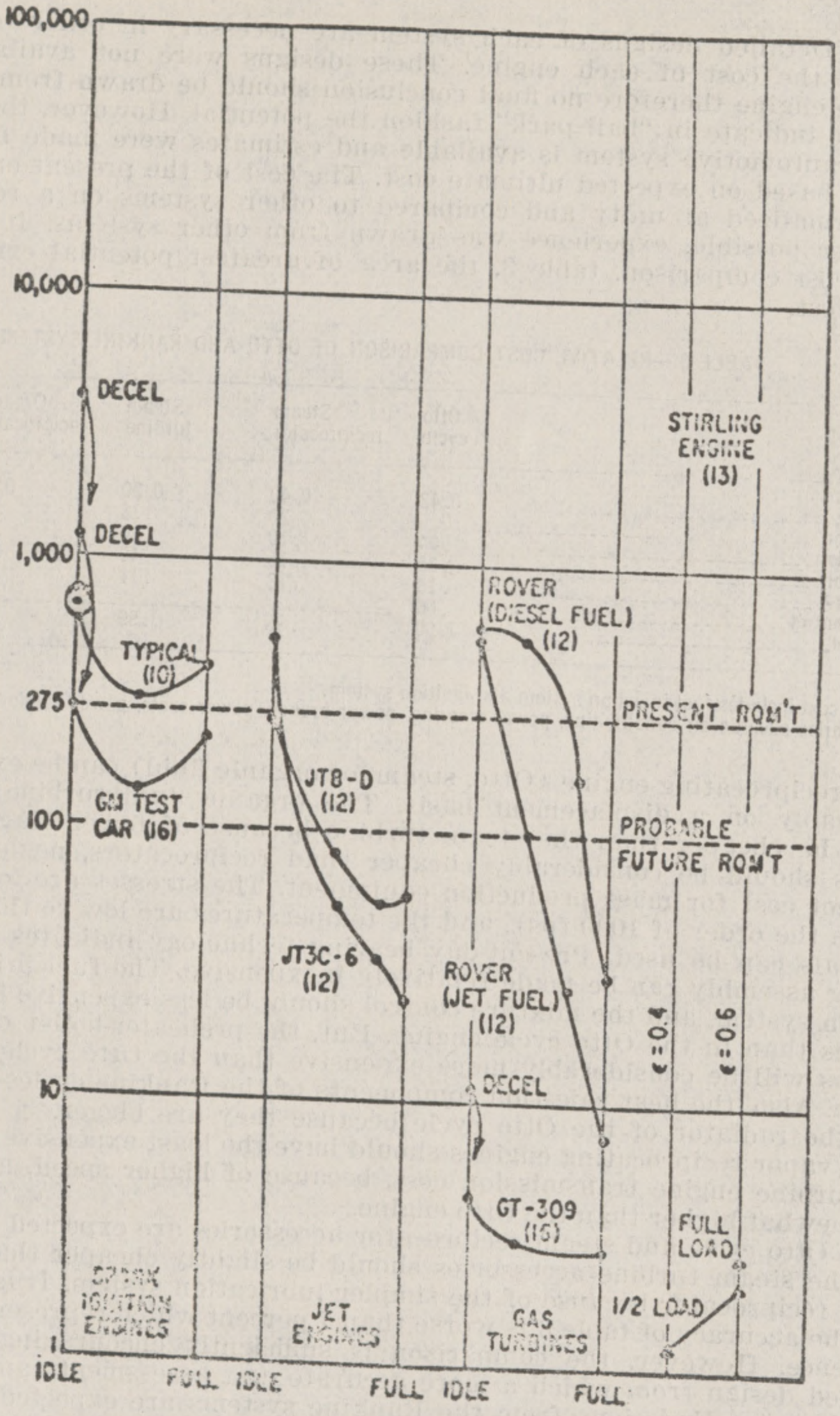


FIGURE 8.—Exhaust contaminants for Otto cycle and external combustion engines unburned hydrocarbons (as hexane).

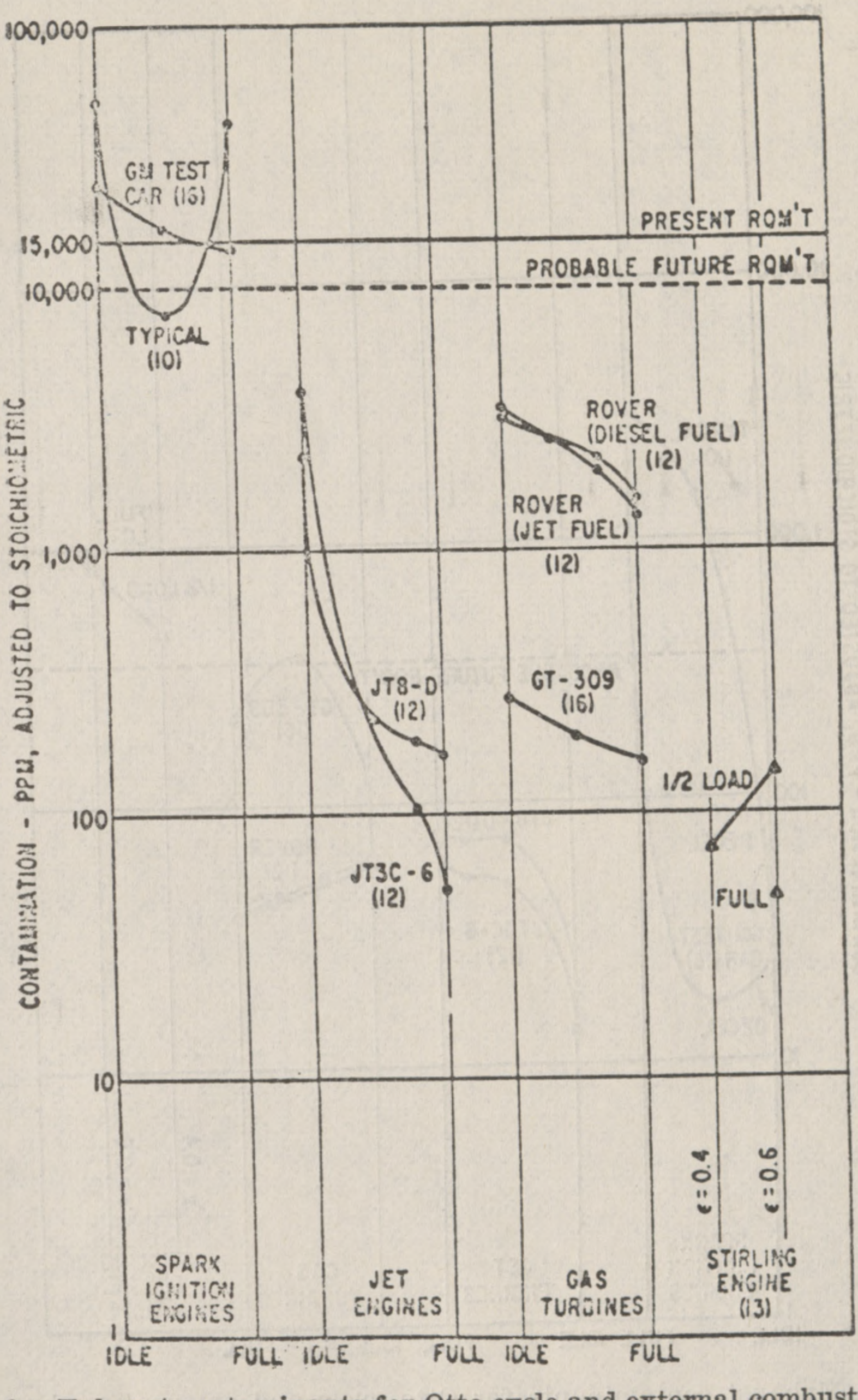


FIGURE 9.—Exhaust contaminants for Otto cycle and external combustion engines carbon monoxide.

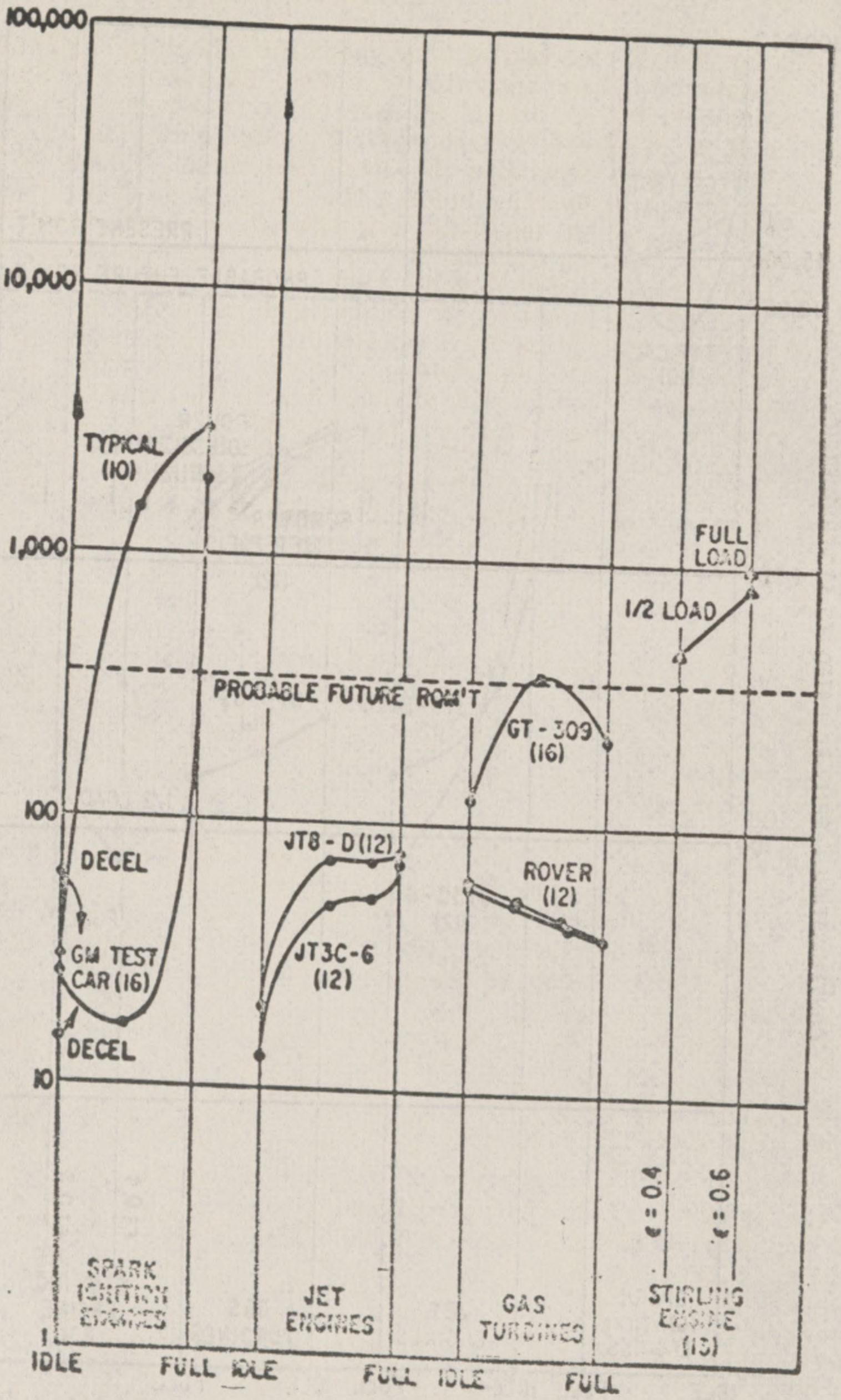


FIGURE 10.—Exhaust contaminants for Otto cycle and external combustion engines oxides of nitrogen (as NO_2).

The adujsted values of actual measurements, as shown in figures 8–10, illustrate that the fixed burner systems have the least emissions of the three pollutants normally considered (unburned hydrocarbons, carbon monoxide, and oxides of nitrogen). As pointed out (12) by Smith and associates because of the long dwell time the oxides of nitrogen generated in a gas turbine tend to be at equilibrium values at the end of the burners. Thus, they would be a maximum of about ϵ=0.8 and fall off on either side of this mixture. Based on gas turbine experience therefore, it is expected that at ϵ=0.4 the oxides of nitrogen will be lower than specified by law. On the other hand, the carbon monoxide and unburned hydrocarbons tend to fall to very low values at equivalence ratios above 0.2.

Thus, there is a band of equivalence ratios between 0.2 and 0.4 over which all three pollutants are extremely low in gas turbine burners.

The Stirling cycle burner is akin to the gas turbine burner, but generally shows even less emissions at a mixture ratio of ϵ=0.4. This burner is external to the engine as well as being fixed, and is comparable to that required by the Rankine engines. Thus, it is expected that the Stirling engine results are the measurements most closely approximating the Rankine engine emissions.

It is possible that the specific burner that is suggested for the automotive Rankine cycle will have even less oxides of nitrogen emissions than the reported Stirling engine. This is deduced from the facts that these emissions are strongly influenced by temperature as well as by free oxygen. In the conventional burner the temperature reached tends to be adiabatic flame temperatures. In the proposed burner system the flame is not adiabatic and the temperatures will be lower than normal. Thus the equivalence ratio at which oxides of nitrogen become high will be greater in the new burner than in the present ones. This would offer the possibility of extending the range of ϵ for low total emissions from 0.2 to as high as 0.6 or 0.7 as opposed to 0.4.

There are several ways in which the emissions of the Otto cycle can be made to approach tolerable levels. The afterburner and catalyst methods have been well discussed in the literature and need not be mentioned here, except to assume that they can be made technically acceptable to meet the proposed 1975 standards. However, the existence of much lower emission engines may lead ultimately to regulations more closely matching these best engines. This would outmode the 1975 standards even before they are instituted.

It is our strong belief that the Rankine engines can be made more acceptable than the Otto cycle from a total emission point of view. It can also be made as good as any other power system so far proposed. This argument holds even for battery systems if the central power station pollutants are included as part of the battery charging system.

Response: Two of the most highly desirable features of the Otto cycle are: instantaneous propulsion after turning on the ignition switch and high acceleration capability, delayed only by the movement of the driver's foot on the throttle pedal. On a time basis, and with a well-running auto on a normal day, these delays amount to 2 or 3 seconds and a tenth to a quarter second respectively. To be as desirable, the Rankine engines should be able to match, or closely approach, these short response times.

Calculation for the 150 horsepower engine shown in figure 7, and using the new boiler concept, show that the initial heat up time can be less than 10 seconds. By better optimization of the design and using stoichiometric combustion for just the initial heating period this time might be reduced to 6 seconds.

The response time of the same boiler after it is hot was also calculated. The assumptions were that the preheater-boiler was hot but fluid flow rate was zero. Then full flow was demanded. The biggest delay is the transfer of heat into the fluid rather than in maintaining the heat of the tubes. The calculated response was just over half a second.

These calculations indicate two requirements, both brought on by the boiler response after it is hot. First, a heat flow control will be required in the preheater-boiler to keep the working fluid from getting too hot when the power demand is low or nil. The other is that a small vapor accumulator will be required to assure the fastest possible response. If a 2-second full-power vapor supply is held in the accumulator, the reservoir capacity for the fluid analyzed here must have 370 cubic inches—(a 15 by 6 inch cylinder with hemispherical ends). Neither of these requirements appears to be insurmountable. They do, however, introduce a requirement for additional control and an accumulator.

Maintenance and reliability: Reliability can be compared on the basis of machine design, static and dynamic stresses, maximum temperature, and temperature gradients. Maintenance can best be compared on the basis of number of parts requiring adjustment. These are listed in tables 4 and 5.

Tables 4 and 5 illustrate the very good maintenance and reliability potential of the Rankine engines—especially the ones employing organic fluids. This is directly related to low-peak temperature and the relatively few parts that can go out of adjustment.

COMPARISON OF ADVANTAGES AND DISADVANTAGES

From this preliminary design study it is evident that there are some definite advantages of the various Rankine engines in comparison to the Otto engine. In addition to the features already mentioned, there are several other potential advantages which may be achieved with the Rankine engine.

It has been demonstrated (14) that the closed cycle powerplants are very quiet. Likewise, a turbine system may be exceptionally smooth. The reciprocating vapor engines will also tend to be smoother than an Otto cycle engine because the heat addition is a steady process, and there are no controlled explosions.

The Rankine engine burners can be adaptable to a multitude of fuels since the combustion is entirely external of the power converter. Large Rankine engines have run on such fuels as natural gas, oil, gasoline, and coal. No lead or other fuel additives are required. The fuel will be comparable in grade to that used in electrical power utilities and therefore represent a considerable saving in cost to the car user.

The fully developed Rankine cycle engine (especially of the turbine type) installed in the automobile should neither overheat, wear out, create noxious emissions, nor drop off very much in efficiency if run for a long time at low power. These features should therefore make the automobile powerplant more efficient.

Table 6 presents a comparison of all the engines considered in this study. The Rankine system holds maintenance and reliability, and fuel versatility advantages, has the fewest limitations, and has the lowest emissions and best efficiency. The ideal organic fluid turbine system should be lowest in cost and have the best fuel consumption.

TABLE 4.—RELIABILITY COMPARISON OF OTTO AND RANKINE ENGINES

	Otto cycle (V–8)	Steam reciprocator (4 cycle)	Organic reciprocator (4 cycle)	Steam turbine	Organic turbine
Main bearings	5	5	5	2	2.
Connecting rod and wristpin bearings	16	8	8	0	0.
Camshaft and rocker arm and pump bearings	22	13	13	2	2.
Set of rings or equivalent	8	4	4	0	0.
Valves	2 per cycle, cam operated	1 per cycle, mechanically operated, 1 sleeve.	Same as steam reciprocator	Variable nozzle	Variable nozzle.
Controls	Throttle control on carburetor (plus automatic control on carburetor, coolant temperature).	Valve cutoff, fuel flow pump speed (plus automatic temperature and pressure control).	do	do	Do.
Seals	2 major oil seals	1 major fluid seal	do	Same as steam reciprocator	Same as steam reciprocator.
Transmissions	Multigear, hydraulically controlled system.	Simple gears	Simple gears	Multigear, hydraulically controlled system.	Do.
Peak metal temperature	1,200° F. plus	1,000° F	700° F	1,000° F	700° F.
Minimum internal steady state temperature	180° F	212° F	150° F	212° F	150° F.

TABLE 5.—PARTS NEEDING ADJUSTMENTS OR SERVICING

	Otto cycle	Steam reciprocator	Organic reciprocator	Steam turbine	Organic turbine
Prime mover	Valve life	Cut off valve	Gate vale	Cut off valve	Gate valve.
	Valve surfaces				
	Bearings				
Heat addition	Ignition system	Fuel flow control	Same as steam	Fuel flow control	Same as steam.
	Carburetor	Valves	Reciprocator	Fluid flow valve	Turbine.
	Carbon cleanout	Igniter	do	Igniter	Do.
	Fuel pump and filter	Safety valve	do	Safety valve	Do.
Heat rejection	Fan belt	Fan motor	Fan motor	Fan motor	Fan motor.
	Clean radiator	Clean condenser	Clean condenser	Clean condenser	Clean condenser.
	Coolant				
	Water pump				
Transmission	Fluid			Fluid	Fluid.
	Bands			Bands	Bands.
Auxiliaries	Voltage	Voltage	Voltage		
	Lube system fiter oil pump	Deaerator	Deaerator	Deaerator	Deaerator.
		Lube system oil pump			
	Belt drive	Condensate and boiler feed pump.	Condensate and boiler feed pump.	Condensate and boiler feed pump.	Condensate and boiler feed pump.

TABLE 6.—OVERALL COMPARISON OF OTTO AND RANKINE AUTOMOTIVE POWER SYSTEM

	Otto cycle	Steam reciprocator	Steam turbine	"Ideal" fluid reciprocator	"Ideal" fluid turbine
Size	Smallest	Slightly larger than Otto. Probably fits presently available spaces.	Fits presently available space	Largest—expander same as Otto. Requires larger space than present engines.	Fits presently available space.
Cost, near term	Lowest	Somewhat higher than Otto	High cost	Comparable after fluid developed.	High cost.
Cost, ultimate	Present cost	Comparable	Comparable	Slightly lower than Otto	Lower than Otto.
Fuel consumption	Rated as 1	~1	~1	~0.80	~0.75.
Fuel, versatility	Limited	Broad	Broad	Broad	Broad.
Starting response, seconds	1 to 4	<10	<10	<10	<10.
Running engine response	Limited by human response.	Same as Otto with small reservoir	Same as Otto with small reservoir.	Same as Otto with small reservoir.	Same as Otto with small reservoir.
Transmission	Needs torque converter.	Gear reduction and reverse gear	Needs torque converter	Gear reduction and reverse gear	Needs torque converter.
Maintainability	Easy	Difficult	Moderate	Difficult	Easy.
Reliability	Lowest	High	Very high	Very high	Highest.
Machinery—Practicability imminence of availability.	Very high	do	Lowest	High	High.
Limitations of operation	Antifreeze required; regular servicing required; heating sometimes required; requires battery.	Heating required; requires battery; long period servicing.	Heating required; requires battery; long period servicing.	Requires battery; long period servicing.	Requires battery; long period servicing.
Emissions	With modifications can be made to meet present and near-term requirements.	Excellent	Excellent	Excellent	Excellent.

Present organic fluid Rankine systems have disadvantages in packaging as well as potential disadvantages with the working fluid. A small amount of fluid will be at high pressure, and most present fluids are combustible. In addition, most present fluids react with either air or moisture, which requires an effective seal or introduces the necessity of such components as harmonic drive (this may not be feasible from cost standpoint).

With presently available working fluids and with the most practical machinery presently developed, the steam reciprocator is best able to compete with the Otto cycle engine. Its major advantages over the Otto cycle engine are expected to be low emission, simple transmission, maintenance and reliability, fewer operating limitations.

Its disadvantages compared to the Otto cycle engine are size (all components taken together), starting response, and cost.

The Rankine turbine engine using "ideal" fluid should have even higher reliability and maintainability and not have the cost and size disadvantage of the steam system. This implies that an ultimate Turbo-Rankine engine should be ideal for automotive use on all major counts.

AREAS OF ENGINEERING DEVELOPMENT

Several technology areas have been discussed that require a significant amount of development work before truly acceptable engines (either Otto or Rankine) are available. These major areas are:

Otto cycle

1. Emission control without sacrifice in fuel economy.
2. Improved servicing and repair requirements.

These can be (and have been) attacked through studies of improved ignition sequences and new types of combustion chamber-flame propagation matching. Development studies on reaction kinetics of nitrogen oxide formation and decomposition should lead to afterburners that can treat these emissions as well as unburned hydrocarbons and carbon monoxide. A future ability to use higher wall temperatures should lead to improved performance and less emissions. Servicing and repair will always remain a major concern since so many adjustments are required for achieving fine operation.

Steam Rankine cycles

1. Improved burner-boiler technology to raise effective heat transfer coefficients and burner reliability.
2. Water lubrication of high speed pistons and bearings.
3. Steam lubrication of high speed turbine bearings.
4. Shaft seal/or hermetically sealed drive.
5. Accommodate freezing temperatures.
6. Condenser to be compatible with the wide range of environmental conditions without greatly affecting thermal efficiency.
7. Torque converter suitable for use with turbines.
8. Reduced preheat time.
9. High pressure water pump.
10. Valve gear.

Organic fluid Rankine cycles

1. Development of "ideal" working fluid.
2. Improved burner-boiler technology to raise effective heat transfer coefficients and burner reliability.
3. Controls in burner-boiler to prevent overheating of fluid under extreme conditions.
4. Shaft seal/or hermetically sealed drive.
5. Torque converter suitable for use with turbines.
6. Reduced preheat time.

Since the burner-preheater-boiler is an entirely extra component of the Rankine cycle compared to the Otto cycle, it behooves the designer and engineer to reduce its size as much as possible. The methods alluded to in this paper tend to do this, and these and other methods must be exploited for a completely acceptable Rankine engine to become a reality.

ACCEPTABILITY OF AUTOMOTIVE ENGINES

It stands without question that any engine, no matter what it is, how technically competitive, or how esthetically pleasing it is for any special reasons, must be acceptable to the public and to the auto industry if it is to be successful. There are several acceptability factors which the manufacturer, dealer, and user would generally agree on. These are:

1. Initial cost.
2. Response (starting and power on demand).
3. Safety in case of accident.
4. Convenience of operation.

The manufacturer, because of styling and present practice, is also concerned with—

5. Configuration that will fit present space.

The user has several additional concerns. A survey by the authors, consisting of relatively small sampling, put the following order of importance to the additional factors:

6. Maintenance and reliability.
7. Fuel economy.
8. Smoothness of operation.
9. Noise.

Lastly, there are three additional factors which allude to the "social" aspects of an engine. These are:

10. Fuel type.
11. Exhaust emissions.
12. Versatility.

A Rankine engine is expected to be better than an Otto cycle engine on most of these, and should be competitive on all the others (1–3, 5).

To establish a real acceptability comparison one must establish an order of importance of the various factors and compare on that basis. A combination of a survey and several additional considerations indicates that the most important factors to try to improve are: maintainability and reliability; fuel economy; safety in case of accident; exhaust emissions; and initial cost. Of these, the Rankine engine has the potential of being better than the Otto cycle engine in maintainability and reliability, fuel economy, and exhaust emissions. Also, the Rankine engine should be at least comparable in initial cost and safety in case of accident.

An acceptability factor of major concern that is not easily met by any engine is safety in case of accident. It implies that an engine that can use a less volatile or a more difficult to ignite fuel has a distinct advantage. These two implications work for the Rankine engine because of the great versatility in fuel choice.

On the other hand, the requirement for even a small reservoir of high pressure combustible vapor works against the Rankine cycle. This concern essentially dictates that a future Rankine engine will have to use a nonflammable fluid (stream or the "ideal" fluid), or that extra measures will have to be taken to locate properly and design the boiler and reservoir to prevent escape or spreading of vapor in case of an accident.

Response is one factor on which the Rankine engine is usually criticized. Again, partly from a survey and partly from logic, the authors contend that fast response from a cold start is probably not critical as long as it is less than 10 seconds. This works to the advantage of the Rankine engine. However, response with a running engine should be very fast. This requirement works to the advantage of the Otto cycle, and requires that all Rankine engines have at least a small vapor reservoir to achieve instant running response and thereby match the Otto cycle.

CONCLUSIONS AND RECOMMENDATIONS

This study should be considered as preliminary and in some areas qualitative but of sufficient encouragement in several major areas to warrant a detailed design of a Rankine system for closer comparison.

The study brings forth several conclusions:

1. The Rankine engine has the potential of having these major advantages over the Otto cycle engine for automobile use: maintenance and reliability, fuel economy, low emissions.

2. The reciprocating steam engine appears to be the best present day Rankine cycle for competing with the Otto cycle.

3. With "ideal" fluid availability (which is close to present day reality based on informationu obtained by the authors from several chemical and petrochemical companies) the Rankine engine using the fluid should be superior to the Otto cycle engine and the steam engine.

4. Almost in every way the "ideal" fluid Rankine cycle turbine engine offers major advantages over the Otto and Steam engine (see table 6).

It is, therefore, recommended that the automotive industry seriously consider the Rankine engine as the future powerplant and that the chemical and petrochemical companies concentrate on the development of the "ideal" fluid.

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CARNEGIE-MELLON UNIVERSITY,
DEPARTMENT OF MECHANICAL ENGINEERING,
Pittsburgh, Pa., February 17, 1969.

Mr. LEN SUTCLIFFE,
Senate Commerce Committee, Old Senate Office Building,
Washington, D.C.

DEAR MR. SUTCLIFFE: Mr. Varney of the office of high-speed ground transportation asked me if I would be willing to comment on the recent SAE paper by Bjerklie and Sternlicht entitled, "Critical Comparison of Low-Emission Otto and Rankine Engine for Automotive Use" and inform you of my opinion.

I'm generally aware of the activities of Mechanical Technology, Inc., and was able to hear the presentation of the paper of interest at the recent SAE meeting in Detroit. I think the paper sums up the state of the art very well. Although it's possible to argue with the authors on various points in the paper, their overall conclusions and recommendations are the same that I would arrive at.

It is very interesting to note that similar conclusions and recommendations are arrived at by almost any group of investigators that looks at the potential of Rankine cycle engines if that group is not somehow associated with the existing automotive industry. In addition, it is interesting to point out that the groups that find promise in the Rankine cycle for eliminating or reducing the adverse effects of the Otto engine emissions are active in energy conversion activities of various sorts. As such, they have a wide background and experience not only in the internal combustion engines but in other types of engines, particularly the technology that has been developed by NASA and the AEC for space power applications. Although they make conclusions and recommendations based on a nonexistent Rankine cycle engine, their conclusions and recommendations are generally not based on nonexistent knowledge.

Sincerely yours,

S. WILLIAM GOUSE, JR.,
Professor.

U.S. SENATE,
COMMITTEE ON COMMERCE,
Washington, D.C., September 10, 1968.

Hon. MARVIN WATSON,
Postmaster General, U.S. Post Office Department,
Washington, D.C.

DEAR MR. WATSON: This morning's Wall Street Journal carried an article which indicated that the Post Office Department plans to purchase 24,000 quarter-ton delivery vehicles for use by urban area letter carriers during the coming fiscal year. It occurred to me in reading this article that such a major purchasing program could provide an excellent opportunity for the Federal government to exercise its procurement function to stimulate the development of new types of low-polluting propulsion systems.

As you may realize, Senator Muskie and I, as well as many other Members of Congress, have long been concerned by the rapid increase in the pollution of our environment. An estimated 60 percent of all air pollutants originate from the internal combustion engine, and this pollution has been steadily impairing the health and shortening the lives of many of our citizens. The begriming of our buildings and the limiting of our visibility, although more obvious, are secondary outgrowths of this frightening increase in vehicle pollution of the air we breathe.

In recent years there has been a great deal of attenton devoted to both electric and steam engines as feasible, low-polluting alternatives to the internal combustion engine. Indeed certain individuals have already proceeded far enough with the development of these new propulsion systems to be able to offer them for use in limited markets. I believe that the Post Office Department could play an essential role in furthering the development and testing of these new propulsion systems by purchasing a limited number of electric or steam vehicles for use in those urban areas where air pollution today poses the most serious problem. Not only might the Department find these vehicles competitive in performance and long-term cost with the internal combustion engine, but it could dramatically illustrate the Federal government's concern with the seriousness of the pollution problem and the apparent inability of the automobile manufacturers, acting on their own, to make a meaningful impact upon it.

I hope that the Post Office Department will give serious consideration to establishing such a policy in its vehicle procurement. I can think of no better time to start, than by including a small proportion of low-polluting vehicles in its acquisition of 24,000 new delivery trucks.

Sincerely yours,

WARREN G. MAGNUSON, *Chairman.*

THE POSTMASTER GENERAL,
Washington, D.C., September 12, 1968.

Hon. WARREN G. MAGNUSON,
Chairman, Committee on Commerce,
U.S. Senate, Washington, D.C.

DEAR MR. CHAIRMAN: Just a brief note to acknowledge receipt of your letter of September 10 with regard to your deep concern over the increase in air pollution, and your request that we include some low-polluting vehicles in our new purchase of delivery trucks.

I appreciate your interest and concern in this matter and want to assure you that your letter will have the prompt attention of the appropriate officials. We will, of course, be in touch with you again in this regard in the very near future.

With kind regards.

Sincerely,

W. MARVIN WATSON.

POST OFFICE DEPARTMENT,
BUREAU OF FACILITIES,
Washington, D.C., September 18, 1968.

Hon. WARREN G. MAGNUSON,
Chairman, Committee on Commerce,
U.S. Senate, Washington, D.C.

DEAR MR. CHAIRMAN: This has further reference to your letter of September 10 to the Postmaster General and his acknowledgement of September 12 regarding our vehicle program and air pollution.

The Post Office Department has conducted a number of tests of battery-powered vehicles. We have operated a sizable experimental fleet of 3-wheel vehicles as well as a few 4-wheel powered with batteries. Two basic problems developed in these tests, reliability of controls and range. Industry is working to resolve these problems.

The Post Office Department has cooperated fully in the testing and development of electric propulsion systems and we stand ready to cooperate with industry in further refinement of these systems. Our bureau of research and engineering has a continuing interest in this work.

With respect to the current procurement of 24,000 light delivery vehicles, this constitutes a requirement to meet our normal needs. It is mandatory that these vehicles be equipped with the latest devices available which minimize air pollution. Funds for vehicle procurement are included in our plant and equipment appropriation which is not available for purchase of experimental type vehicles. When and if industry offers a propulsion system which can effectively perform in our rigorous service, the research and engineering appropriation is available for purchase of experimental units.

As operators of the biggest nonmilitary fleet in Government today, we are vitally interested in any program which promises to curb the pollution of the air in our major cities.

Sincerely,

JOHN L. O'MARRA,
Assistant Postmaster General.

[From the Automotive News, Feb. 24, 1969]

LEAR STEAMED UP ABOUT STEAM—INVOLVED IN $10 MILLION ENGINE PROJECT

RENO.—William P. Lear, Sr., inventor, designer, and industrialist, has left retirement at the age of 66 in a rather spectacular manner, embarking on a $10 million program to develop, test, race, and produce steam turbine and reciprocating steam engines for automotive, aviation, and industrial applications.

"I am extremely confident that steam or external combustion engines will replace many internal combustion engines for vehicles, stationary and portable power units," said Lear, who claims that steam will make the ICE a "collector's item" within 10 years.

Lear's current adventure was preceded by numerous endeavors that have led to the development of such products as the auto radio, Gates Lear Jet, radio and electronic devices, and eight-tract stereo tape units for autos.

The start of Lear's effort to develop steam powerplants is typical of his approach to previous adventures. Lear Motors Corp. was founded, 150 engineers and technicians have been hired and a 3,600-acre tract, the former Stead Air Force Base, has been purchased near Reno for construction of Lear Raceway, a track and proving grounds that will be an exact duplicate of the Indianapolis 500 Raceway. Lear Raceway's main track is scheduled for completion in early March to facilitate the testing of two steam-powered cars Lear says he hopes to enter this year's Memorial Day race in Indianapolis.

Three steam turbines and two reciprocating steam engines have been developed and are in limited production at Lear's industrial complex outside Reno.

"Lear power units will be substantially pollution free, quiet, smooth, powerful, and economical, operating on kerosene, furnace oil, or diesel fuel, and they should require very little service for many hours of uninterrupted service," Lear said.

Lear's steam engine is based on the theory utilized in the production of steam engines that powered a few cars developed around the turn of the century.

However, Lear says, the early pioneers in steam were unable to get more than 75 horsepower out of their engines because they had not developed heat-transfer techniques to the point where they could produce a realistically sized radiator.

Modern techniques, Lear said, have made 400 to 800 horsepower units possible with a reduction in weight and size from a comparable ICE.

Measured by British Thermal Units, the amount of heat produced, rather than revolutions per minute, a steam engine rated at 800 horsepower can power a furnace supplying heat for 200 average-size homes, Lear said.

Eliminating the need for either a transmission or radiator, the steam engines are ignited by only one spark plug and contain fewer parts than a contemporary ICE, Lear said. He said one disadvantage encountered with the steam engine is that it requires 15 to 20 seconds to heat up, at which time the engine is working to capacity.

In 1969, Lear said he hopes to produce 25 passenger cars, two trucks, two tractors, two marine installations, one aircraft installation, 10 buses, two power plants, one or two highway patrol vehicles, and the two Indianapolis race machines, which he expects will be ready for testing by March 15.

The 10 commuter buses, to be ready for testing around the end of April, are to be equipped with Lear Motor Power Units that will include heat, light, and cooling for the buses. Quiet, smokeless, smooth operation with practically no pollution is expected, Lear Motors said.

"We will be developing soft tooling for limited production in 1970 and quantity production in 1971," Lear continued, predicting a billion-dollar industry for the production of steam units in the next 5 to 10 years with Reno becoming the center of activity.

The three turbines are rated at 50 horsepower, 125 to 256 horsepower, and 450 to 850 horsepower, the company said.

The larger of the two reciprocating engines consists of six cylinders with 12 pistons arranged in triangular form. Known as the Delta, this engine displaces 132 cubic inches, delivers from 125 to 700 horsepower and weighs 150 pounds, Lear Motors said.

The smaller reciprocating powerplant contains eight cylinders and has a 70-to-450-horsepower rating with a CID of 80, according to the company. Weighing 90 pounds, the engine is 10 inches in diameter and 14 inches long. It is called the barrel engine.

Four steam generators, ranging from 200 to 800 horsepower, have also been developed by Lear Motors, the company announced. The fuel consumption of these generators, it was reported, will be slightly less than a comparable diesel engine. The largest two generators are designed for aviation use and a line of condensers, designed for both auto and aviation use, will be available for each engine.

The two cars being developed for Indianapolis will have four-wheel drive, 40 percent torque to the front wheels and 60 percent to the rear wheels, and will be powered by steam engines rated from 500 to 600 horsepower. One of the powerplants will be a Delta engine.

The Indy cars will be equipped with a new type hydraulic braking system that is attached to the inboard end of the constant velocity universal joints, a method which the company claims takes the weight of the braking system off the tires and wheels.

Some of the developments derived through the production of the race cars will be applied to a Dodge Polara Highway Patrol car for testing by the California Highway Patrol, the company reported.

Lear Raceway will include a 2½-mile oval track with a 3,300-foot straightaway and will be used for testing the Lear race cars, California Highway Patrol Steam Project vehicles and conventional vehicles proposed for future production, Lear said.

Located 10 miles north of Reno, the raceway will also feature a combination landing strip and 3,500-foot-long drag strip. To be constructed at a cost of $500,000, the raceway will have a 100-foot-wide infield, a 25-car pit area that will be 40 feet wide and 600 feet long and a shop maintenance area that will measure 300 feet by 600 feet and have a servicing capacity of 100 cars, Lear Motors announced.

Lear's entries in the Indy 500 would be to demonstrate the reliability, efficiency and economy of steam-driven vehicles, he said.

"The United States Auto Club rules for steam vehicles are nonexistent," Lear charges, "and the basis on which we are to attempt qualification is so nebulous, vague and subject to the whims of the track officials, it makes our chances to race questionable."

"Unless we can guarantee the USAC we can't win, it may be foolish to go to the '500'," he added.

Commenting on the potential speed of his steam-powered racers, Lear asked, "Who can tell? How heavy is a driver's foot?"

He asserted, "Regardless whether we race or not, our Indy 500 duplicate track will tell our story to the world. Such a track will provide facilities for other affairs of considerable value to Reno and Nevada."

Reportedly at odds with the major automakers over the development of steam-powered vehicles, Lear said his project is being undertaken without federal assistance but that he is keeping the government informed of his progress.

[From the SAE Journal, December 1968]

Alternative Nonpolluting Power Sources

(By Robert U. Ayres, vice president, International Research and Technology Corp.)

An urban transportation crisis grips the Nation—its symptoms: currently, emissions appear to be the most pressing problem.

E-c Engines Ax Emissions—Steam Prototypes Set for 1969—Current Research Into e-c Engines

"Worrying the hell out of Detroit" is how William Lear, Sr., describes his present occupation—an overstatement, perhaps, but certainly a reflection of confidence in his current project to develop and market automotive steam engines. In an exclusive interview, Lear reveals that 410-horsepower reciprocating vapor engine is set to replace the i-c unit in his first conversion, when it takes to the road probably in early 1969. Small vapor turbines suitable for use in cars are also being laboratory tested, however.

Lest anyone forget, it was with this very same type of confidence that Lear boosted his last project—the business jet. The very same type of capital, too—for Lear has over $10 million available for investment. This represents the largest infusion of funds into the steam section of the engine industry in many years.

Lear is not alone, however. Thermodynamic Systems of Newport Beach, Calif., is also testing full-size reciprocating and turbine e-c engines with promising results. Thermo Electron Corp., which recently signed a research agreement with Ford, is operating several small (up to 3-horsepower) reciprocating steam systems.

These are the first major efforts to develop an automotive steam engine since the Doble fell by the wayside in 1930. In the interim, only the Williams Engine Co. produced a significant number of automobile steam engines—all experimental (table 14). In the process, the problems associated with cold starts and variable loads have been solved. More important, however, the Williams steamcar has shown that steam powerplants are plausible and have low emissions.

TABLE 14.—MODERN RECIPROCATING STEAM OR VAPOR ENGINE RESEARCH [1]

	Williams			Thermo-electron [2]	Gibbs and Hosick XG/2000 [2]	Pritchard	Keen (thermal kinetics)	Minto (Kinetics, Inc)
Displacement, cubic inches	56	105	262	55	200	17.6	100	152
Cylinders	4	4	4	6	9	[3] 2	4	[3] 0
Inlet pressure, p.s.i.	1,000	1,000	1,000	1,200	2,000	1,000	850–1,200	500
Inlet temperature, F	980	1,000	1,000	1,250		870	750–850	390
Working fluid	([4])							([5])
Engine weight, pound	200	300	500	180	300	125	285	150
Total powerplant weight, pound	500	650	850	500		450	800	340
Rated power, b.h.p.[6]	63	150	199	100	1,000	35–40	55	350
Rated r.p.m.	2,500	3,300	3,000	1,680	2,900	1,400	1,700	700
Overload capability, percent	100	100	100	0	500	20–80	50	0
Stall torque, feet-pound	500	1,105	2,734	340	4,200	331	500	12,000
Torque at rated r.p.m., feet-pound	60	110	270	340	1,800	160		
Thermal efficiency, percent	([7])	([7])	([7])	32			17–19	30
Starting time, seconds	30–60	30–60	30–60	30–60		60–80	60	10–40
Pound vapor/b.h.p.-hour	([7])	([7])	([7])	6.9				25
Normal cutoff	([8 10])			([9])	([8])	([8 11])	([8 12])	([8 13])
Cycle	([14])	([14])	([14])	([15])	([14])	([14])	([14])	([15])

[1] Insufficient data are available to list work done by Lear, Thermodynamic Systems, Inc., and Energy Systems, Inc.

[2] Design objectives not known to be achieved in practice. Gibbs and Hosick data refer to engine alone.

[3] Double acting.

[4] Steam.

[5] Freon F–11.

[6] Assuming normal (10–12 percent) cutoff rather than maximum (60–70 percent) cutoff used for starting.

[7] Figures given by Williams Engine Co. differ from those calculated from thermodynamic data supplied. Values quoted in text are the more conservative of the two—25.8 percent efficiency corresponding to 7.8 lb./hp-hr.

[8] Variable.

[9] 10 percent (fixed).

[10] 10 percent normal.

[11] 14 percent normal.

[12] 18 percent normal.

[13] 4 percent normal.

[14] Open.

[15] Closed.

LEAR'S STEAM PROJECT

A 65-pound, 410-horsepower, uniflow reciprocating engine with an integral nonslip differential is, according to Lear, the first fruit of his research project. The engine, which fits within a 14-inch diameter, 11-inch long cylinder, replaces the vehicle's present differential. The steam generator, regenerator, and condenser occupy the forward engine compartment.

The engine's three crankshafts are arranged at the points of an equilateral triangle. They are driven by 12 pistons mounted in six 2-inch diameter cylinders. The three pinions drive a single gear. Main gear speed is 1,000 revolutions per minute which is one-third pinion speed.

There is no clutch or transmission. Forward or reverse is selected with a simple control. Dynamic braking is available. In fact, the reciprocating engine goes as fast backward as it does forward.

The monotube boiler is quite bulky and occupies most of the forward engine compartment. Since operating pressure is about 250 pounds per square inch, ordinary steel tubing is presently used. Although no contamination problems have been experienced, a noncorroding-type tubing is planned for future systems.

The system is closed and contains the equivalent of 25 pounds of water. Several fluids are being tested. Water attains a fairly low 18-percent efficiency—efficiency here is heat in per horsepower out. Freon does considerably better upping efficiency to 28 percent. Lear hopes that a proprietary fluid, showing promise in the laboratory, will achieve a 40-percent value. When this fluid proves successful, the reciprocating engine may be displaced from automobiles by a turbine unit.

The turbine unit, which has a 75-percent mechanical efficiency, is currently producing 300 horsepower. Like the reciprocating engine, the turbine is small enough (11-inch long, 10-inch diameter) to fit at the rear of the car.

Indeed, both Lear systems are not only compatible with the body shell of existing vehicles but also with their auxiliary systems. Original heating, air conditioning, and power assist systems are powered from the boiler by a small turbine which operates even when vehicle is stationary.

Though as voluminous as conventional drivetrains, Lear's steam systems weigh only about 650 pounds. Running costs should be lower than for i-c engines. I-c and e-c engines have equal fuel consumption near 60 miles per hour and considerable fuel savings are forecast for the latter in city driving. Diesel fuel less additives will probably be used.

Ken Wallis, who was responsible for Granatelli's turbine racer and is now Lear's project manager, is pushing to have the first of the prototype steam cars on the road in early 1969.

THERMODYNAMIC SYSTEMS

Another company that has expended much effort investigating reciprocating and turbine steam engines is Thermodynamic Systems, Inc. Indeed, engines, similar to those described below, are reported to have been laboratory tested at up to 300 horsepower.

A reciprocating steam engine is being touted as a possible alternate power source for automobiles, such as the Chevrolet Camaro. The powerplant and the boiler install within the existing engine compartment. Although occupying the same space as the conventional i-c engine, the boiler-steam engine combination weighs considerably less. Vehicle performance is expected to equal or better that of the standard model (table 15.) Emissions will be very low, however. Maximum limits are: hydrocarbons 100 parts per million, carbon monoxide 1 percent, and nitrogen oxides 200 parts per million. Tests indicate that these values may eventually be reduced to 50 parts per million, 0.1 percent, and 80 parts per million respectively.

TABLE 15.—SPECIFICATIONS OF PROPOSED CAMARO CONVERSION

PERFORMANCE PROJECTIONS

	Specifications
Gross vehicle weight, pounds	3,000.
Tire size, rear tires	6.75 by 15.
Rolling radius, inches	13.5.
Differential ratio (optional)	3.31–1.
Steam generator rate, pounds per hour	1,500.
Steam generator volumetric capacity, cubic feet per hour	973.8.
Steam pressure, pounds per square inch	1,000.
Steam temperature, Fahrenheit	750.
Engine water rate (estimated ideal), pounds per hour	10.
Engine bore and stroke, inches	2.5 by 2.5.
Rated engine horsepower, no overload, horsepower	150.

ENGINEERED PERFORMANCE DATA

Road speed, miles per hour	Engine speed, revolutions per minute	Engine power, horsepower	Engine torque, foot-pound	Cylinder bmep, pounds per square inch	Wheel torque foot-pound
55	1,927	100.4	272	265	900
30	1,235	96.9	412	400	1,324
15	617	90.8	772	750	2,445
5	206	40.0	1,019	990	3,373

The proposed 6-cylinder, uniflow, double-acting engine outputs 150 h.p. at 2,000 r.p.m. with 393-ft.-lb. of torque. (Thermal efficiency ranges from 14–28 percent.) The cylinders are arranged cylindrically around the shaft axis and reciprocating movement is converted to rotary motion by a cam. The resulting device is considerably smaller and lighter than a crank-type engine. Large tool-up costs are also avoided. The design also features: a ball bearing main drive, an enclosed oil bath transfer case, a rotary valve, and automatic load demand cutoff control.

A oncethrough monotube heat exchanger produces up to 1,500 lb./hr. of 1,000-p.s.i., 750-F steam. Steam temperature is automatically maintained at a near constant level.

The combustion system produces hot gases at a uniformly high temperature and at a rate controlled to meet the heat requirements of the boiler. The fuel is vaporized, mixed with incoming air, and burned in the combustion chamber. The positive displacement and fuel pumps are driven by the same motor so the volumetric air-to-fuel ratio is constant. The quantity of hot gases produced is directly proportional to pump motor speed which is regulated by the temperature control. Combustion chamber is sized for laminar flow to eliminate the noise generated by turbulent combustion. Kerosene, No. 1 and 2 fuel oil, diesel fuel, gasoline, and even paint thinner can be burned satisfactorily.

Safety controls are included to prevent damage to major system components in case of failure. The system shuts down by closing the fuel valve and venting the steam to the condenser. Shutdown occurs if the steam is over pressure (or temperature) or low water level develops. A rupture disk fitted in the generator's steam line vents the steam to the exhaust port area if the safety controls themselves fail to function.

The spray-type jet condenser is fitted with a turboelectric fan and a circulating system with a cooling radiator. Makeup water is treated by an ion exchange cartridge. The original vehicle generator is driven by a small auxiliary steam engine even when the large engine is not running.

TURBINE UNIT

The closed cycle rotating steam system is a much smaller unit than the reciprocating system. A single 18-inch diameter, 18-inch long cylindrical assembly contains the steam generator, the turbine, and the rotating jet condenser. The unit, which weighs 75-lb., is hermetically sealed so that water usage is zero. Sealing is accomplished by replacing all mechanical joints with welds. (A 10,000-hour maintenance-free life is projected but has yet to be attained.)

Initial proposed use is as a constant r.p.m. source for alternators. Constant r.p.m. is automatically controlled by torque demands and is adjustable from 4,000-6,000 r.p.m. As in the reciprocating unit, emissions are very low—maximum limits being 100 p.p.m. hydrocarbons, 0.1 percent carbon monoxide, 200 p.p.m. nitrogen oxides.

A 4-stage turbine with 180-degree buckets and land and groove seals is the drive unit. Twenty-one steam jets open into the first stage.

The steel rotor can operate at up to 20,000 r.p.m. Presently, as noted above, speeds are limited.

The steam generation rate is 1,500 lb./hr. at 1,000 p.s.i. and 750 F. Testing is being carried out with steam both at these conditions and at 500 p.s.i. and 500 F. safety controls are as described.

THERMO ELECTRON

Three small—¼-h.p., ⅔-h.p., and 3-h.p.—reciprocating steam engines have been built by Thermo Electron Corp. as part of an Army-sponsored portable generator development. The engines have been successful and scaled-up versions are planned.

Table 16 details the three basic engines. Each is a single expansion, single-acting, reciprocator with oil lubricated crankcase and a crosshead piston. The power piston is above the crosshead piston from which it is separated by a shaft seal (fig. 12). The crosshead piston and the shaft seals can be eliminated if other fluids, which serve as or are compatible with lubricants, are used instead of steam. Engine configuration is then simplified and similar to that of i-c units.

TABLE 16.—THERMO ELECTRON'S ENGINES

	¼	⅔	3
Rated shaft power, horsepower	1,800	1,800	3,600
Shaft speed, revolutions per minute	1.063	1.315	1.315
Bore, inches	0.500	0.625	0.625
Stroke, inches	1	1	3
Number of cylinders	0.445	0.84	2.52
Total displacement, cubic inches	(1)	(2)	(2)
Type of lubrication	300	700	700
Design inlet pressure, per square inch	800	800	850
Design inlet temperature, degrees Fahrenheit	4.6	6.1	17
Weight, pounds	50–60	55–65	60–70
Overall efficiency, percent			

1 Splash.
2 Forced.

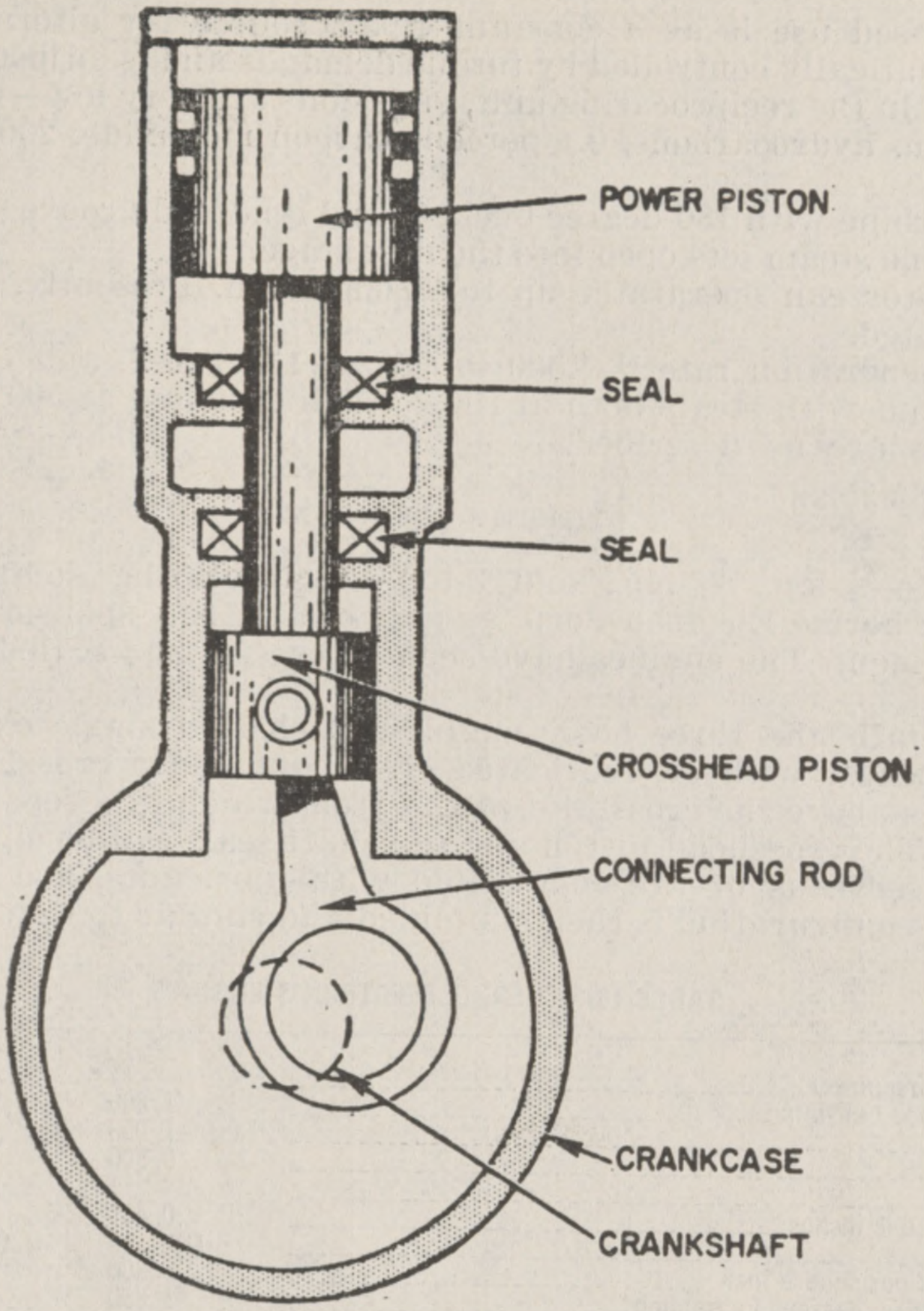


FIGURE 12.—Power piston is above the crosshead piston from which it is separated by two seals.

Valves are internal and actuated by the movement of the piston (fig. 13). This arrangement assures that the engine's friction losses are below those which would occur with a cam-driven system having valve stem seals. To exhaust the bulk of the steam, the exhaust valve remains open during the return stroke. Cylinder pressure is then constant and equal to condenser pressure.

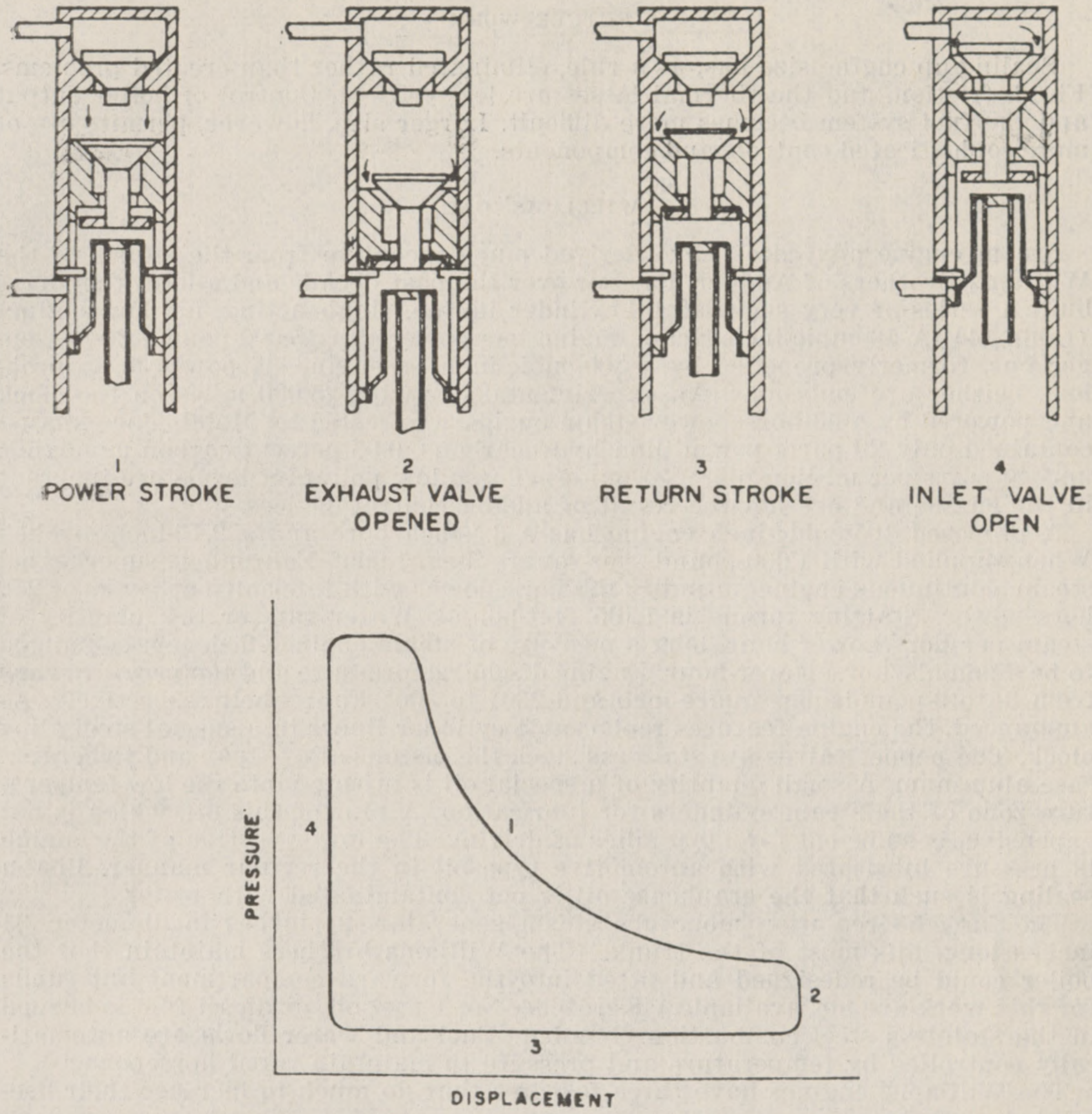


FIGURE 13.—Valves (shown schematically) are internal and actuated by movement of the piston.

Overall engine efficiencies range from 50 to 70 per cent. Typical values for a two-thirds horsepower engine are : mechanical efficiency 84.9 percent, thermal 65.6 percent, and overall 55.7 percent.[1]

Rapid response to load changes—low thermal inertia—is the primary boiler design objective. It is attained with a single-pass tube boiler in which the length of boiler tubing and quantity of contained fluid are minimized. A portion of tubing lines the combustion chamber wall, the remainder is in a bundle across which combustion gases flow. Average overall heat transfer coefficient for the tube bundle is 30 British thermal unit/hour F square foot. Only 200 cc, less than a tenth of the 3-horsepower engine's working fluid inventory, is in the boiler at a given moment.

A vaporizing-type burner is used since it combines excellent combustion characteristics, good turndown capability, and low maintenance. In the large unit, fuel is delivered by a positive displacement pump at a pressure of several hundred pounds and free of cavitation.

The condenser is a compact finned heat exchanger with top and bottom headers joined by vertical tubes.

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[1] Mechanical efficiency is defined as the ratio of actual shaft work to indicator card work. Thermal efficiency is the indicator card work to the ideal work to the release pressure. Overall efficiency is the product of the thermal and mechanical efficiencies.

FUTURE WORK

Scaling-up engine size has, as a rule, eliminated rather than created problems. Fluid, friction, and the thermal losses are less critical. Control of boiler output and the fuel system becomes more difficult. Larger size, however, permits use of more sophisticated controls and components.

WILLIAMS' CAR

Steam engine advocates have derived much incentive from the efforts of the Williams Brothers of Ambler, Pa. For over the past decade and a half, they have built a series of very successful 4-cylinder in-line, single-acting, uniflow engines (table 14). A 56-cubic-inch steam engine has powered a 15,000-pound, 30-passenger bus, formerly propelled by a 300-cubic-inch i-c engine. If power is no problem, neither are emissions. An experimental car with 25,000 miles on the clock and powered by a 43-horsepower steam engine was tested by Mobil. The exhaust contained only 20 parts per million hydrocarbons, 0.05 percent carbon monoxide, and 40 parts per million nitrogen oxides. These low pollutant levels are inherent in the engine and are not the result of add-on control devices.

A proposed 105-cubic-inch engine has a 3.5-inch bore and a 2.75-inch stroke.[2] When supplied with 1,000-pounds-per-square-inch, 1,000° Fahrenheit superheated steam, continuous engine output is 150 horsepower with intermittent peaks of 250 horsepower. Starting torque is 1,105 feet-pound. Water rate or the quantity of steam per horsepower-hour, long a measure of steam engine efficiency, is claimed to be 6 pounds/horsepower-hour. Engine discharge pressure and temperature vary from 3- to 9-pounds-per-square-inch and 230° to 300° Fahrenheit respectively. As announced, the engine features replaceable cylinder liners in a special steel alloy block. The poppet valves are stainless steel, the pistons alloy steel, and the crankcase aluminum. A small quantity of a special oil is injected into the low temperature zone of the steam cylinders for lubrication. A pint of this oil, which is not expensive, is sufficient for 1,000 miles of driving. The lower portion of the engine is pressure lubricated with automotive type oil in the regular manner. Piston sealing is such that the crankcase oil is not contaminated with water.

The forced circulation monotube steam generator, 21 inches in diameter, 31 inches long, fills most of the trunk. (The Williams brothers maintain that the boiler could be redesigned and fitted into the forward compartment but funds for this work are not available.) Kerosene, No. 1 fuel oil, or diesel fuel is burned in the stainless steel combustion chamber. Fuel and water flows are automatically controlled by temperature and pressure to maintain rated horsepower.

The Williams' engines have three features that do much to increase their usefulness; namely:

Recompression. About two-thirds of the steam remains in the cylinder after the exhaust phase and is recompressed and reheated on the return stroke. Since the compression ratio of 26.6:1 is greater than the 18.6:1 expansion ratio, the ultimate 1492–F steam temperature is higher than the 1000 F of the feed steam. Although the work done on the recompressed steam is recovered in heating the feed steam, a more efficient utilization of the heat content is obtained without resorting to a multistage cycle.

Bleed valve. This automatic valve fitted in the cylinder head drains condensed liquid from the cylinders, so the engine may run cold on water pressure alone if necessary. The long wait, mandatory in the old steamers, while cylinder walls are brought up to temperature is thus eradicated.

Regulating valve. The pressure regulating valve in the steam feedline automatically matches engine compression to feed steam pressure. Without such a mechanism, the uniflow steam engine cannot operate under rapidly varying load conditions—the engine tending to buck or stall whenever the engine compression exceeds the steam inlet pressure.

KEEN CAR

Another steamcar of comparable vintage to the Williams' car is that built by Charles Keen of Madison, Wis., in the late 1950's. It is now in the hands of Thermal Kinetics, Inc., a small firm with patents on several rotary rakine cycle engines.

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[2] Engines with displacements of up to 262 cubic inches have been built. Several 105-cubic-inch engines are in various stages of construction but work has halted due to lack of funds.

Keen's engine represents the same state of the art as the Williams' engines, as table 14 shows. Its four cylinders are arranged in a 90-degree vee, however. Bore is approximately 3⅜ inches, stroke 3½ inches. The monotube boiler, designed with the aid of Alex Doble, is a very large 30 inches in diameter, 30 inches long. The engine reportedly requires considerable tinkering to make it run.

OTHERS WORKING TOO

Australia doesn't have an emissions problem so it must be assumed that Pritchard Steampower Proprietary, Ltd., of Caulfield, Victoria, was attracted to steam engines for advantages other than their lack of pollutants. As low-speed troque is just such an advantage, the company's first engine was installed in a Chevrolet 5-ton truck. The double-acting, uniflow, 2-cylinder, 90-degree vee engine was capable of a continuous 100-horsepower output with a maximum torque of 1,500 feet-pounds.

An independent road test indicated performance was quite impressive. The 7,392-pound truck with a 448-pound load accelerated from 0–20 miles per hour in 4.2 seconds, and 0–30 miles per hour in 9 seconds. With a 40 percent cutoff, times for 10–20 and 10–30 miles per hour were 3 and 6.6 seconds respectively.

Configuration was somewhat unusual. The steam generator was located under the hood, the engine coupled to the drivetrain between the cab and the truck bed. There was decided tappet knock around 25 miles per hour, though this, it was claimed, could be cured by relatively minor design changes.

Development work is now concentrating on a steamcar, however. A new smaller 2-cylinder steam engine, installed in a 1963 Ford Falcon, is being readied for tests. Design data are listed in table 14. The engine is again a uniflow, double-acting, 90-degree vee but cylinder bore is cut to 2⅜ inches and stroke to 2 inches. The crankshaft and big end-bearings are roller type. Two distinct seals prevent leakage of water into the crankcase. Cylinder lubrication is by oil injection as in the Williams engines. The engine is installed at the rear of the hood space, up against the firewall. The once-through steam generator, which is only 15 inches in diameter and 15½ inches high, occupies the center of the compartment. The radiator-condenser is in the normal location.

Feed pumps and condenser fan are driven by a unique system using an exhaust steam positive rotary motor. An electric motor drives the burner fan, fuel pump, and the mechanical make-and-break system for burner ignition. The engine is able to idle if required.

Kinetics, Inc., has converted a Stanley engine to operate using Freon F–11 as the working fluid and a standard commercial refrigerator condenser. The system is being installed in a VW bus for testing.

The Gibbs-Hosick Trust has built three barrel-type rotory-reciprocating engines. Two are full size and should be capable of 1,000 h.p. at 2,000 r.p.m. They have not been tested at high speeds, however, due to the lack of a steam generator and condenser.

[From Sports Illustrated, Feb. 3, 1969]

LET THERE BE STEAM

This whole thing started, William Lear says, when he died. Literally died; his heart stopped on the operating table and all the systems inside him began slowly ticking to a stop while a team of doctors worked to pump his life back in. When that crisis was over and he was alive again, he began to look around with a new sense of purpose. He was 66 and retired. He had millions, and all he needed was a mission. He had been everywhere and done everything. He had developed a jet airplane that has become the darling of the business world. He had inventive talent and one more thing: he was an inspired crapshooter. All of which make up the best set of qualifications any man ever needed to go automobile racing.

Naturally, racing could only mean the Indianapolis 500—any man who has already died once is just about in the proper emotional shape for that crazy American spectacle, where racing's greatest pressures pile up. And just as naturally, not any old racing car would do. There would have to be a bigger goal than just the race. A more noble goal. Like how I won the Indy 500, shook up the establishment and purified America at the same time. With those thoughts in mind, Lear announced last fall in Reno, "I am going to build a steam-

powered passenger car. And to publicize it, I am going to build a steam race car. With it, I expect to win the 500."

Steam cars. Hoo boy. Here comes 1969, racing's fun year. Even if the thing never works, which is eminently possible, the steamcar project already has touched off an epidemic of jitters in the car manufacturing and racing worlds. Indy is still suffering from a massive jet hangover—a condition brought on by the turbine racers of 1967 and 1968, cars that sailed along with whispery whooshing sounds instead of the honest clatter of good old-fashioned pistons and things. That uprising from the ranks was put down by a series of restrictions on the size of turbine engines. But hardly has the old calm and order been reestablished when along comes Lear.

Lear was weaned on controversy and he loves it. Loves it. Suddenly, here is the old fox of big biz, the man who took on the entire aircraft industry and beat it with the first successful business jet; here he is, back again, prowling restlessly around this rickety old surplus Nevada air base, most of which he owns, shamelessly pirating top engineers and draftsmen from his competitors and spending $300,000 a month. He is building a new plant, an elaborate machine shop. Bulldozers are pushing aside tumbleweeds and sand to make his own private racetrack. He has a special team of architects and planners laying out a model city to house all his new employees, and it will be built around a model lake for them to fish in. ("I think we might call it Lake Lear," one of his draftsmen said in the first big understatement of 1969.)

Things are popping again for Lear, even at the crap tables of Reno. Mrs. Lear, a serene, lovely matron, keeps his winnings (they were up to $6,000 the other day) in a special bank account; her husband always hands it over. He doesn't want to spend it, he just wants to win it. "You have heard of mother's household account?" she says. "Well, this is mother's craps account." She is continually delighted by everything Lear does, perhaps because she is a daughter of the late Ole Olsen, co-producer with Chic Johnson of an explosive stage show called "Hellzapoppin," which was the "Laugh-In" of its day. And now the thing that pleases her most is that Lear, at 66, overweight, jowly, out of condition, is suddenly springy, dieting and living again. And building a steamer to save the world is as good a goal as any to start with.

Lear sits at his desk in a leaky wartime barracks in a ratty old red pullover sweater he fancies, his hands folded calmly, with the racket of construction going on all around him and the chill of the Nevada winter seeping in, and tells his story in the voice of a hoarse bear. In 1967 Minneapolis Publisher T. S. Denison & Co., Inc. produced a book called "William P. Lear, Creative Designer and Inventor" as part of its Men of Achievement series (other titles are "J. Edgar Hoover, Modern Knight Errant"; "J. C. Penney, Merchant Prince"; and "Lyndon B. Johnson, Man of Reason." Lear's story takes up where his stupefyingly dull biography leaves off.

"I was technically dead," he says. "This was last January. For a minute or so my heart stopped; there was no pulsebeat or blood pressure. Nothing. I had a broken artery near my brain which they were repairing. My nose wouldn't stop bleeding; that's why they were operating.

"To make matters worse, before that I had broken my damned leg getting out of my limousine and this whole thing knocked hell out of me for about 3 months. When I came out of it all, I wanted something new to sink my teeth into. Something big—maybe even to compete with my old company, Lear Jet." Lear tried a couple of projects, but they turned out to be $5 or $6 million a year things, and "still too insignificant to warrant my total effort." He put some money into Montana oil for something to do and, first thing, six high-paying wells came in—which ought to give Indy an idea of what kind of year this could be. Still, Lear claims to be unimpressed with wealth. "I've never even felt wealthy," he says. "What counts is altering a way of life for the better. For instance, I can't play any musical instrument. Hell, I can't even carry a tune in a handbag. But I showed my love for music by developing the first really fine radio set, the Majestic. It was my first successful business of 1928; stock went from $10 to $1,600 a share. Then I pioneered car radios, and you will note that Motorola has not exactly been a failure. But my love of aviation exceeded all other loves, so I left Motorola to start Lear Aviation, which became Lear Inc., which I ultimately sold for many millions of dollars."

Lear also developed radio and navigation instruments that are still the standard of the industry (he holds more than 100 patents), and he is perhaps most admired for his autopilot. In 1950 it won the Collier Award, the highest

honor the aircraft industry can bestow. And you'd better believe he's made a dollar or two from his Lear Jet stereo tape deck for cars.

But to Lear neither car radios nor autopilots nor jet planes nor tape decks were the big thing. Then he discovered air pollution. The stuff was there all along, hanging low and acrid over California, stinging lungs and reddening the eyes of millions and being thickened every day. A problem worth tackling.

A workable steam engine, one of Lear's aides suggested, could change all that—a steam engine could be made to emit only a fraction of the noxious fumes of conventional engines. Yet, so little research was being done on steam, one might suspect that the American automobile industry thought the steamer was as dead as the Stanley.

By coincidence, a couple of weeks ago the Justice Department filed anti-trust charges against the Big Four automakers, charging they have conspired for more than a decade to delay development and use of devices to control air pollution from automobiles. The Big Four said it was not so and the case is headed for the courts. But Lear can't wait. A steam-powered car, the fascinated Lear believes, could brighten up a nation which ought to have air as clean as Reno's. A steam-powered car could save lives and change the economic structure of the country. The man who made it would leave his mark on history. And that part did it.

If Lear has not made a mark on history just yet, after 4½ months of wheeling, his project has etched one on Nevada and sent shock waves out into racing and the auto industry. Reno, whose housing style is early trailer camp, is already full of engineers looking for expensive homes. More personnel arrive daily. Not long after Lear announced the steam-car project, a delegation of executives arrived from American Motors and stalked around his new plant, looking over the plans and nodding wisely. Lear offered them the exclusive sales rights to the new steam car in exchange for, as he puts it, "certain stock options." Lear was clearly pleased with their reaction. "They were flabbergasted," he says. "They admitted it would take Detroit 2, 3 years to get to the point where we are now in Nevada. To say the least, they were shook."

One of the things that shook them, obviously, was not so much that Lear has impressive plans and a brigade of impressive people at work in Reno, but the fact that he has what businessmen call a proven track record. Years ago the aircraft industry laughed when Lear sat down to build an executive jet plane—and now there are 223 Lear Jets winging around and many more on the way. "Most economic, fastest, highest flying, lowest cost business jet ever developed," says Lear, "and it is doubtful that that record will be altered for many years to come."

What Lear plans this time is a production-line, $6,000, steam-powered passenger car, plus a much more expensive steam-powered limousine—having broken a leg getting out of one, Lear has this fixation on limousines—all coming from a new $500-million industry just outside Reno. Before going to the market for more, he is willing to gamble the first $10 million.

"Here is one guy," he says, speaking of himself, "who has gathered together the greatest group of engineers in the country in what once was known as a gaming town, one guy willing to prove that by gambling $10 million on one roll of the dice he can produce a steam engine that will be the world standard of excellence. It will at the same time solve the air pollution problem—producing less than 1 percent of the pollution from internal-combustion engines. Now then. If I do it, I will have solved a national community health problem and at the same time challenged the largest single industry in America, if not the world." He pauses and wheezes just a bit. "By comparison, Nick the Greek was a piker."

Perhaps. But the world of auto racing does not care about any of that. Did Nick the Greek ever race an Indy 500 car? The world of auto racing has never bothered itself much about pollution. And as for the limousine, most Indy drivers prefer something a little quicker. What they do care about is that steam-powered race car, what it all means and what it might do to them.

Hardly had the word "steamer" come out of Reno than Speedway Superintendent Clarence Cagle and Henry Banks, who is director of competition for the U.S. Auto Club, got on a plane and flew to Nevada to look things over. Banks seemed enormously pleased to find that, in fact, there was no steam race car. He looked all around the old surplus barracks to make sure. "All I saw was drawings on the drawing board and no hardware," he said, "no bits and pieces of a racing car. But I do think they have a sincere desire and will attempt to build a car."

What Banks wanted to make clear to Lear was that Indy does not have a set of rules for steamcars. There are no specifications on what sort of steamcar would be properly competitive with the current piston cars.

"Use my specifications," said Lear, and handed them over.

Well, then. Did Lear understand that with no specifications on a steam race car, the USAC could not sanction it?

Did he ever. Lear was way ahead of them. He had already run the whole play around the auto club and gone directly to Tony Hulman, the gentleman who owns the speedway. Not many people realize the 500 is Hulman's race and the USAC only sanctions and runs it for him. And if owner Hulman decides a steamcar will brighten up the proceedings, it seems safe to bet a steamcar will be allowed to try for the lineup on Memorial Day. In fact, the speedway's official entry blank says propulsion systems not covered by USAC are encouraged. Thus, if it met the basic requirements on size and shape, a steam race car could be accepted under a special waiver for 1 year. "We would welcome a steamcar entry under these terms," Hulman said. And a year is all that Lear wants. He came away from his chat with Hulman elated.

Lear also dropped in to see Ralph Nader, the "Unsafe at Any Speed" man. The prospect of a nonpollutant car intrigued Nader right away. Having its marvelous potential paraded at the Indy 500 intrigued him also—more even than the recent electric car revival talk.

"He told me," says Lear, "to keep him posted on the project—and if it looked like the speedway might turn down the steam race car, to let him know before they did it." The implication is clear that Nader might bring unusual national opinion pressures to bear if he thought someone were holding back American motoring progress and safety while continuing to dirty up the air with those old piston engines.

Another point in Lear's favor: USAC and the speedway are still smarting from criticism over the restrictions imposed on the turbines. The speedway likes to boast that it is in the forefront of motoring progress. Throwing out the new race cars in favor of the old ones did not do much for that image. A steam race car could help restore that forward-thrust air about the place.

Chief designer of Lear's steamcars is a wandering British carbuilder named Ken Wallis, who is either a mastermind or the "Peck's Bad Boy" of racing. Wallis meandered into Indy a few years ago, helped STP impresario Andy Granatelli produce the sensational turbine car in 1967, and the next year built a pair of turbo-cars for Carroll Shelby. The Shelby-Wallis race cars were mysteriously with-drawn just before final inspection, and Indy promptly exploded with charge and countercharge as to whether the cars were cheaters; that is, illegal under the specifications. Wallis left Indy under a sort of mechanical cloud, and even now Banks is not sure that USAC would let Wallis come back to the speedway until certain allegations have been cleared up.

No matter. Wallis does not plan to go back to Indy anyway. "I'll be too busy working on the passenger cars at the time," he says. What he does plan to do is to build two steam race cars and send them to Indy with a team of drivers and mechanics.

The fact that he has Wallis to rub into the racing establishment touches a well of ironic humor in Lear. "I know all about Wallis' background," he says. "I have heard all about the cars that did not make the race and I have heard that all of it is still under a cloud. But I also know he is a great engineer and race car designer. He has a following second to none among machinists and engineers, and he already has attracted a group to Reno that I feel can meet this challenge."

It had not started that way. Wallis walked in one day last August and asked Lear to lend him $39,000 to buy a 12-meter yacht. "He said he had put $2,000 down on the yacht," Lear says, "and figured if he could borrow the rest, he could get a Government contract to do some research. Well, I liked him so much I bought him the yacht and made him my chief engineer as well."

With the yacht tied up at San Francisco and Wallis aboard at Reno, the steam race car project began to take shape. And Reno began to brace itself for what can only be a wild adventure.

But—as everybody keeps asking—what is a steam racing car supposed to look like? People keep getting a mental picture of something pretty big and bulky, filled with dials and tubes and whistling like a calliope—and with a big boiler and a guy wearing a red bandana and shoveling coal into a furnace.

Maybe that sort of image was O.K. for 1875 and the Grenville Steamer, which did look a whole lot like a locomotive, with one man driving and one man stoking. But by 1906—at an early speed week in Daytona Beach, Fla.—a Stanley Steamer

driven by Fred Marriott took on Henry Ford's six-cylinder Model K and beat it in a 30-mile touring race, going so well that it set a 127.66-m.p.h. world speed record. Several critics insisted it was a freak record because Ford driver Frank Kulick spun out and got stuck in a sandbank.

A little more than a year later Ford got into production with his new T model and by 1927 had built 15 million of those critters. Steamcars, as everyone knows, have been museum items ever since.

Lear insists the only reason steamcars have not been resurrected before now is that the science of space-age controls has not been applied to them. Wallis is not only approaching steam scientifically, but figures it might be a good idea to get away from the word steam entirely. "It has a bad history," he says. "People get a picture of a big boiler and explosions and that sort of thing. The name sounds dangerous. Our engine is not, of course. Since everything happens outside the engine, it is called an external combustion engine."

But how does it work? Does it take a plumber to run it rather than a mechanic? If a turbocar goes whoosh, does a steamcar bubble, like a high-speed Lawrence Welk?

Without getting technical, it may be said that the Lear-Wallis steam engine will be a rather dainty thing. Its boiler will not be much bigger around than, say, Raquel Welch, and the engine, Wallis assures one, will be a small, efficient-looking affair to be called a Delta. The old steamcars had large boilers full of water that took forever to get hot enough. The Reno Steamer will use yards of coiled tubing instead of a simple boiler and a special chemical preparation rather than water. This fluid will be superheated to vapor by burners fed by kerosene or heating oil. It is on the clean burning of the fuel that Lear rests his pollution salvation case. The boiler will be hooked up to the six-cylinder reciprocating Delta—or, possibly, a turbine engine—and the power will be delivered to all four wheels. In either case some steam will be diverted to a small turbine to run the auxiliary electrical and hydraulic systems. Ultimately the steam is condensed back into fluid and reused indefinitely—the music goes round and round.

The physical race car, Wallis said, doesn't matter much, anyone can build a chassis once the power problem is solved. The drawings for the Reno Steamer look an awful lot like the new wedge-shaped turbine racers built for Granatelli last year—and the next howl you hear will be from England's Colin Chapman, who designed them. Plans are to plunk the boiler up there beside the driver, put the engine just over the rear wheels and go racing.

Since the racing world is not exactly crawling with steam engine experts, an output figure of 450 h.p. that Lear has released is being bandied about. This would be dandy with the piston engine people, since they are producing far more horsepower than that with conventional engines. What they will be hearing more about is the steamer's inlet valve effect.

"The principal difference between our engines and conventional piston engines," says a Lear engineer, "is that a steam engine can operate in two basic modes, a power mode and an economy mode. In the economy mode one puts a little bit of steam into the engine and expands it. In the power mode we can keep the steam inlet valve open a little bit longer and furnish tremendous sudden power. It means we could design a steam engine for, say, 250 h.p., and if it needed instant acceleration we could supply up to a thousand horsepower for 20 seconds or so—thus giving the car any dragging speed it needed. It would be limited only by the wheelspin on the track. Another advantage is that a steam engine generates total power at 0 r.p.m. just sitting there. We can store the power in the boiler and dump it out all at once if we need to."

But what of that wonderful moment when the race is about to start and all those gentlemen are called upon to start up? Surely they can't be expected to wait for a boiler to get up to pressure. "No," says the engineer. "This happens in 15 seconds. And not only that, to refill it one just adds fluid—tap water will do—perhaps twice a year."

Lear, of course, is looking forward to the screams of anguish certain to come from the Indy old guard. Since the steam race car is meant to be a publicity device to swing attention to the new steam passenger car that will purify America, the more howls the better. And if the race car actually works—that is, if Lear gets it built on time, if it is accepted by the speedway and if it qualifies—it should run quietly and without any noxious exhaust. Thus anyone who complains about it figures to be lined up against progress and national health.

"We'll have the weight of public opinion behind us," says Wallis. "The racing establishment cannot cry 'airplane engine' as they did in the case of the turbines. These are simply efficient, safe motors that do not produce any smog or air

pollutants. This race car is for the good of mankind—and how can anyone complain against a thing like that?" How, indeed? It has all the makings of a huge, motorized mousetrap for the Indy 500. Even if everything goes wrong and Lear can't go to Indy, perhaps Indy can come to him. Keeping pace with his blockbuster-a-day series of developments, a few days ago Lear's crews began pushing sand around just off the old airport runways. It began to look strangely like a racetrack in the desert.

"It is," Lear said. "I am building an exact duplicate of the Indianapolis Speedway right here. I mean exact: It will be 2½ miles, all blacktopped, all banked the same, same curves and straights, same pits—everything. We will start practicing here March 1 with the steam race cars. And lest this sound too fancy, remember that it will be cheaper for us to practice here than to keep running back and forth to Indy with the cars and crews. Then, we will go to Indy with our shakedown completed."

Not long ago Lear and Wallis introduced their Nevada crew to a rugged-looking man who studied their drawings a long time. It was the inimitable Parnelli Jones, once a 500 winner, driver of the 1967 turbocar and one of the most talented Indy drivers of all time. "Interesting," Jones said, and he allowed as how he would have to take a serious look at the car with an eye to driving if they ever got it built. The other steam car, Reno rumor has it, would be driven by Jackie Stewart of Formula I fame.

Lear has a couple of other steam irons in the fire as well. There is the great highway patrol car for one. At its last session the California legislature—on one of those days when the smog in Sacramento was unbearable—moved to have the state patrol study the feasibility of steam cars by trying out some samples. After 15 years of fighting air pollution and losing, the State was at the "peril point," warned Assemblyman John Francis Foran, a San Francisco Democrat, "We have 12 million registered vehicles in California now," he said. "And there will be 20 million by 1980." Which is a lot of smog. Next thing, General Motors had offered to provide up to six new car bodies and $20,000 each for anyone who wanted to put steam engines into them.

"Actually, General Motors figured that nobody could do it and that this offer would finally put a stop to all this steam-engine nonsense," says Wallis. "So we responded right away."

But Lear's tack was a bit different, which is typical. No free cars, thanks, he said, because anyone who accepted the GM plan would have to make his steam secrets public. Instead, when Lear discovered that the patrol had ordered a covey of 440-cu.-in. Dodge Polaras for 1969 patrolling, he promptly bought a new Polara; the crew mocked it up for steam power and then called the patrol back to see it. "They went away walking on air," Lear says. "And they indicated that we're their great white hope now as far as steam cars are concerned. Naturally we'll give them this one without cost."

If California will now be patient, Lear says, he will hand over a steam-driven patrol car by early spring that will dazzle the world. Then will come the two sleek race cars, the production-line passenger car and that luxurious limousine. But it is clear that the prospect of the Indy race car intrigues Lear the most. There is so much publicity attendant on the 500 and he so plainly like the image he is gaining as Nevada's highest roller. Anyone who will plung with money like that has Reno's respect.

Saving the world does not keep Lear pinned to Reno. A couple of weeks ago he flew his personal Lear Jet east to New York to attend a dinner for Richard Nixon. The next morning he tossed his coat on a seat of the jet, warmed up the engines lightly and kicked it more or less straight upstairs to 43,000 feet before giving the controls to his copilot. Lear likes to fly up or down; just piddling along in a straight line does not interest him. He dropped in at Chicago for a business lunch and at Wichita, Kans. for a fast tour of the Lear Jet factory before flying on to Reno. The next day, just to give some visitors a little feel of his as-yet-unpaved Indy track, he led a madcap automotive procession in his limousine over the ruts and gouges of the course at A. J. Foyt speeds.

The romance of the adventure has caught up both Lear and Wallis. Lear has become a well-known figure about town, a nightly celebrity at the round table at the casino in the Holiday Inn, which is where everyone important gathers for a few drinks after work. The table is not really round, it is a couple of square tables pushed together off to one side right next to the ladies room. But the men who run Reno are always seen there. Wallis, meanwhile, has been so busy that he has not had a haircut in months. He appears all over town in a long curling

pageboy vaguely reminiscent of June Allyson when she was playing those ingénue roles.

If he gets them to Indy, Lear would like to qualify the Reno steamers just slightly ahead of the fastest piston-engine car, the better not to overscare the establishment. Then, in the race, he would like to suddenly pump out all that hidden power and beat everyone so badly all the world would take notice and make a rush for his steam passenger cars. "And if someone cried that it was an unfair race," Wallis says, "it would be very much like Mr. Lear to say, 'You're right fellows,' and give back all the prize money to the next-place car. It would be the sort of gesture he might make. He would have made his point anyway, you see?"

"I know Ford would pay me $25 million for this operation right now," Lear says. "And then they would tell me to go off and take a long, long vacation."

The biggest gambler of them all gets up heavily from the round table and strolls over to the crap tables to try his luck. "Talk about odds," he says. "Listen. The other night I was standing at the crap tables over at Harrah's Club when it came my turn to shoot. The croupier pushed some dice over to me and—just for fun—I scooped up three of them and rolled them out on the table. The guy didn't blink an eye. He simply picked them up. Then he palmed one of them and handed me back two, And he said, 'All right, mister, your point is 15.'"

[From the Washington Post, Feb. 22, 1969]

Leaded Gasoline Presents Hazards to Health

(By Joshua Lederberg)

Lead tetraethyl ("ethyl") was introduced about 45 years ago as an antiknock additive to gasoline. Shortly thereafter, it was recognized as an industrial health hazard following the deaths of some workmen handling it. Public health officials and the oil refining industry reacted promptly to the occupational problem but left unanswered the question of how lead particles from auto exhausts affect the population.

With the increasing demands made by high-performance auto engines, the use of lead in gasoline has increased tremendously. Today, about two pounds of lead per capita are blown into the air of the United States each year. The levels are highest of course, in such urban centers as Los Angeles.

Lead is well known as a poison. Until lead-based paints were restricted, there were many cases of brain damage to young children who had nibbled the paint from peeling walls and toys. We are, however, in a serious quandary about the hazard from the present levels of lead in the environment.

The most persuasive argument of the oil industry is that no case of lead poisoning can be proven to have resulted from airborne lead originating from auto exhausts. It is generally accepted that lead exhaust could be practically eliminated but only at a probable cost of at least one cent a gallon of gasoline. The prohibition of lead antiknock would furthermore discriminate against smaller, less efficient refineries, which would be less able to reconstruct their fuel mix to meet antiknock requirements in other ways.

On the other hand, the feeding of lead to mice and rats in amounts comparable to the present human intake has been found to result in significant shortening of the life span by a general reduction in vigor. Other experiments point to the red blood cells as the principal suffers from low lead intake; the brain, the kidneys and other organs become involved only with larger doses.

The situation might be summarized by the finding that the blood of apparently healthy individuals contains from 100 to 300 p.p.b. (parts per billion) of lead. This is a two- to five-fold increase over the levels that would be expected if the environment were not artificially contaminated.

On the other hand, clearcut symptoms of lead poisoning have not been reported at less than 800 p.p.b. and 1000 to 1500 p.p.b. are usually required to be acutely dangerous. Yet if blood levels were a direct indicator, they would suggest a safety margin of only two- or three-fold above the present readings.

Unfortunately, we are quite ignorant of important details about the way that lead is handled by the body. Some individuals may dispose of lead less efficiently than the average or be more sensitive to present levels. In fact, this can be theoretically predicted for certain rather common genetic diseases of the red cells.

For normal individuals, we could speculate that 500 p.p.b. in the blood would be safe. Over this level, the kidneys operate to eliminate excess lead in the urine. Thus much more lead would have to be absorbed to drive the content from 500 p.p.b. to toxic levels over 800 p.p.b.

In any event, however, the proven safety margin is so small that if the procedures routinely applied to new drugs by the Food and Drug Administration were applied to lead tetraethyl, it could hardly be approved unless it carried enormous lifesaving benefits in compensation. Recognizing that environmental contamination by many industrial, agricultural and food chemicals needs to be scrutinized at least as carefully as new drugs, Sen. Gaylord Nelson (Democrat of Wisconsin) has introduced legislation for the establishment of a Public Health Hazards Commission with broad responsibilities for the oversight of these problems.

We cannot afford to banish every hazard from life by destroying other values. But we can afford even less to permit entrenched habits and economic positions to dominate our policy without the most thoughtful review of the real costs of these innovations, and who is paying for them.

[From the Automotive News, Jan. 13, 1969]

Problems Ahead on Nitrogen Oxide

three approaches outlined in gm report to sae

(By Joseph M. Callahan)

A progress report on General Motors' efforts to reduce nitrogen oxide (NOx) emissions in auto exhaust indicates that both the engineers and the Nation's motorists have real problems ahead with these devices.

Jack D. Benson, an engineer at GM's research laboratories, will spell out these problems this week at the SAE International Automotive Engineering Congress and Exposition in his detailed report on three different approaches GM has tested in its efforts to reduce nitrogen oxides.

California's Assembly recently passed a law requiring NOx devices on all California cars by 1971, with nationwide installation expected a year or two later. California requires that the NOx be reduced to 4 grams per mile for 1971, to 3 grams per mile for 1972, and to 1.3 grams per mile for 1974.

The 1.3-gram objective, equivalent to 340 parts per million (p.p.m.), represents about an 80 percent reduction from the total of 2,000-plus p.p.m. of NOx in an uncontrolled car's exhaust.

Nitrogen oxide is of concern these days because it is one of the reactants in photochemical smog. However, there is disagreement over the value of partly eliminating the NOx. GM researchers said in 1964 that a partial NOx reduction would not reduce the smog in Los Angeles and might even increase it.

Prof. A. J. Haagen-Smit, head of the California Air Resources Board and sometimes called the father of photochemical smog, insists that any NOx reduction will mean a smog reduction.

NOx reduction is difficult for the engineers because it's formed by the chemical reaction of nitrogen and oxygen at high-temperature combustion in the engine. Most measures that reduce the nitrogen oxides either increase the emission of unburned hydrocarbons (HC) and carbon monoxide (CO), or reduce engine performance and economy or do both.

The procedures for evaluating the three NOx-control approaches consisted of making three types of changes on two 1967 cars. One car was equipped with the air injection system for controlling hydrocarbons and CO and the other was equipped with the engine-modification system for limiting emissions.

The emissions of each car were measured in the standard way with the car running on a Clayton Chassis dynamometer. Driveability tests were run at the GM Proving Ground in Milford, Mich.

Benson's first efforts to reduce the NOx emissions from these cars consisted of making carburetor changes that enriched the fuel-air mixture 5 to 10 percent and by retarding the spark three different amounts.

He said that, in general, NOx decreases rapidly when the spark is retarded and when the carburetor is enriched. A spark retard of 12 degrees in one case reduced the NOx by 85 percent on the air-injection car and by 90 percent on

the engine-modification car. The 10-percent carburetor enrichment produced a smaller NOx reduction.

Benson added that the retarded spark timing usually slows down the combustion process and lowers the peak combustion temperature, reducing the NOx.

"However," he continued, "enriching the carburetor caused the car to fail the 1.5-percent CO limit. Lowering peak temperatures by retarding the spark and enriching the mixture would also be expected to lower the thermal efficiency and hence decrease fuel economy.

"In general, it appears that complete emission control with NOx, at the 340 p.p.m. level on a large car population by modification of spark timing and carburetion would not be technically feasible. Even partial NOx control by this approach might incur a penalty in fuel economy."

The next approach tried by Benson's team consisted of recirculating 15 percent of the exhaust gas back through the induction system of an air-injection car. The exhaust is drawn from the exhaust crossover leg of the intake manifold, passes through a recycle valve which controls the flow rate and then enters the intake manifold through a 1-inch steel spacer below the carburetor.

In this test, the NOx, HC, and CO all were reduced to their required levels, but the penalties that had to be accepted were unacceptable vehicle driveability, up to a 24-percent loss in fuel economy and a 1.4 second loss in full-throttle acceleration from 0 to 60 miles per hour.

"It appears," Benson concluded, "that acceptable NOx control to the assumed target level by exhaust recirculation would not be technically feasible. Although the penalties in driveability and fuel economy could be reduced if the quantity of exhaust recirculated was reduced, this would apparently result in only partial NOx control."

A third approach at NOx reduction consisted of combining these techniques by recirculating 3 to 4 percent of the exhaust and modifying the carburetor, distributor, intake manifold and rear axle. The result was labeled the NOC (Nitric Oxide Control) system.

Benson said this one car met the HC and CO requirements, while reducing the NOx emissions 74 percent. It also passed the driveability test at 40° F., but had a weak part-throttle response. Although the NOC system reduced the full-throttle octane requirement, it also incurred a 13-percent fuel-economy penalty. In addition, driveability problems might arise in subzero weather.

Benson concluded, "Extensive development experience is necessary before the NOC system could ever be applied to all cars. Some important factors which have not yet been evaluated with the NOC system are: Compatibility with other engines and other exhaust control systems (particularly at anticipated future hydrocarbon and CO levels), carburetor deposit accumulation, engine durability, cold weather driveability, hot weather driveability (near 100° F.) and engine oil contamination."

[From the Automotive News, Feb. 24, 1969]

GM Builds No-Smog Car—But It Has Drawbacks

After several years of resourceful engineering and the spending of considerable funds, General Motors has finally done what the industry critics have urged all along—developed a car with an efficient powerplant that emits practically no smog-causing fumes.

Called the GM Stir-Lec I, it's basically a neat little Opel Kadett with a hybrid power system consisting of a Stirling engine in the trunk and a lead-battery electric drive unit under the front hood.

Stir-Lec I is a fully operational vehicle but, lest someone be misled, it's not really practical because of a number of drawbacks that will be mentioned subsequently.

The Stirling engine is an external combustion powerplant. Fuel and air are burned in one burner or cylinder, without any combustion products entering the power cylinder which employs a completely sealed working gas—hydrogen. The engine also can use helium, but it has not been perfected for helium operation.

Essentially complete combustion of the fuel is achieved in this engine because it continuously burns the diesel fuel, with enough fuel "residence" time in the burner and enough air.

Therefore, the engine gives off virtually no odor and very low emissions. Hydrocarbons normally amount to about 0.1 gram per mile (compared with the Federal

1970 standard of 2.2 grams per mile). Carbon monoxide usually is about 1 gram per mile (compared with the Federal 1970 standard of 23 grams per mile).

Oxides of nitrogen emissions are cut in half by this engine, but this still doesn't satisfy the demands California is planning for this pollutant.

In addition to having no odor or "bad breath," the Stirling engine is also very acceptable in our current social environment because it's much quieter than other engines.

The U.S. Army purchased a number of these engines for portable electric powerplants that could be used near the front lines without alerting the enemy.

In this experimental vehicle, the Stirling engine drives an alternator whose output is converted from AC to DC current to charge the 14 lead-acid batteries stacked in the front engine compartment.

Power from these batteries goes to a large inverter behind the grille that modulates the electricity and converts it back from DC to AC current, as was done in the GM Electrovair I and the Electrovan.

This current then goes to a three-phase induction motor capable of producing about 20 horsepower for driving the rear wheels through reduction gears and the differential. With two passengers Stir-Lec I weighs some 3,100 pounds, about a half-ton more than the conventional Kadett.

Nevertheless, the car can still accelerate from zero to 30 miles an hour in 10 seconds and has top speed of 55 miles an hour.

Since this electric car has its own battery-charging system, it seems intelligent to ask "Does this car have the range of a conventional automoblie?"

The answer is "Yes" and "No." First of all, none of the components—the motor, batteries, or engine—have been designed for this installation and therefore top efficiency has not been reached.

However, GM engineers say that in an "optimized installation," the Stirling engine would be able to propel the vehicle on a level road at about 30 miles an hour until the fuel was exhausted. At this speed, Stir-Lec I could travel between 30 and 40 miles an hour and have a range of 150 to 200 miles since it has a 5-gallon fuel tank.

At top speed, the range would be limited to 30 to 40 miles because the energy at the batteries would be consumed faster that it could be produced. Without the engine operating, the car has an emission-free range of 15 to 30 miles, depending on the speed and acceleration.

Stir-Lec I is another effort by GM Research to learn about alternative methods of driving a car and to demonstrate the compromises that must be made.

While this vehicle has very low emissions and is very quiet, it's quite deficient in range and power, has no trunk space and would be expensive to buy and maintain because of the double system of powerplants.

A Scottish minister, Robert Stirling, invented the first Stirling engine in 1816. Then, in 1938 Philips Research Laboratories of Eindhoven, Holland, revived the engine and began researching the Stirling idea.

For the past decade, Philips and GM have cooperatively researched the engine. In 1967, GM decided to couple the Stirling engine with an electric power train and Stir-Lec I was the result.

[From the Automotive News, Feb. 10, 1969]

TRUCK INDUSTRY NEWS

TURBINE ERA DAWNS—DETROIT DIESEL ABOUT TO DELIVER

(By Ken Kelley)

DETROIT.—The truck industry will start playing for keeps in the turbine power area in mid-1971 and that is about 2 to 5 years before the turbine era was expected to dawn.

The idea of using turbines in heavy trucks has had appeal for some time and many companies are developing truck turbines. The fact that the industry will move out of the test stage and begin selling turbines in mid-1971 became apparent when Detroit Diesel Engine Division of General Motors announced that it will begin producing turbines at that time.

Most earlier predictions on the beginning of commercial sales of turbines fell in the 1973 to 1975 area.

Detroit Diesel will sell its turbines to all comers. The division has been selling diesel engines to truck makers other than GM divisions for some time. The only availability problem will be the usual limited nature of any initial production program.

The new turbine was designed from the ground up as an industrial turbine—Detroit Diesel considers the truck as an industrial application of power. The division makes a point of the fact that it set out to design an industrial product and has not modified an aircraft turbine (jet engine).

The division sees many applications for the product outside the truck field, much as it sells its diesels in such applications as generation of electricity and as boat motors.

Detroit Diesel sees the turbine supplementing the diesel engine in the power field, not replacing it, said C. W. Truxell, general manager.

The turbine has looked like a sure winner in the heavy truck field for years. There are a number of reasons but the key is one the thought that diesel engines which develop more power than those offered today will be too big to fit in trucks—and truck operators are calling for more and more power.

Besides relatively high power and small size, turbine appeals include a low level of emissions and noise, both of which have become increasingly important as regulation of vehicles has grown and operators have become interested in buying trucks which please hard-to-get drivers.

On the two main problem areas on turbines, Detroit Diesel had these points to make about its product:

Fuel consumption: The new turbine will use less fuel than a gasoline engine but more than a diesel. (In short, the turbine will be sold on features other than its fuel economy).

Cost: On a system-versus-system basis, a turbine will cost about 20 percent more than a diesel. The system comparison is used because installation of a turbine as a truck's engine calls for certain other changes in the truck. For instance, there are no radiator and related cooling system parts in a turbine-powered truck.

Detroit Diesel indicated that the turbine will be sold on the total cost of ownership idea with the comment that—over 200,000 miles of use—the division expects that the costs of a turbine and a diesel will be a standoff.

The division has a number of major tasks to complete before turbine production and sales start about 2½ years hence. An extensive program of fleet testing is planned.

In addition, a new turbine factory will be needed. The division has run out of space on its land on the western edge of Detroit. Site of the new facility was not announced.

Long range plans call for a series of four basic turbine models from Detroit Diesel. Horsepower ratings range up to 2,000.

The initial turbine for truck application will have a horsepower range of 280–400. (An increase in the air flow in a given turbine model ups the horsepower, within limits.)

The bulk of the division's diesel engine sales have been coming in the 200–350-horsepower range and the demand for more power has been mounting.

The Detroit Diesel turbine is the fruit of a turbine development program started by GM's corporate research organization and was assigned to Detroit Diesel in 1964.

Kenneth L. Hulsing, divisional director of engineering, said that the product makes only limited use of exotic metals, is made with conventional tools and that the aim was to produce a rugged engine. It has a cast iron block.

The turbine, when set up to produce 280 horsepower, develops 575 pounds-feet of torque with the output shaft turning at 3,000 revolutions per minute. The gasifier turbine turns at 36,000 revolutions per minute at full load.

This version of the turbine weighs about 1,425 pounds which is about half the installed weight of a comparable diesel.

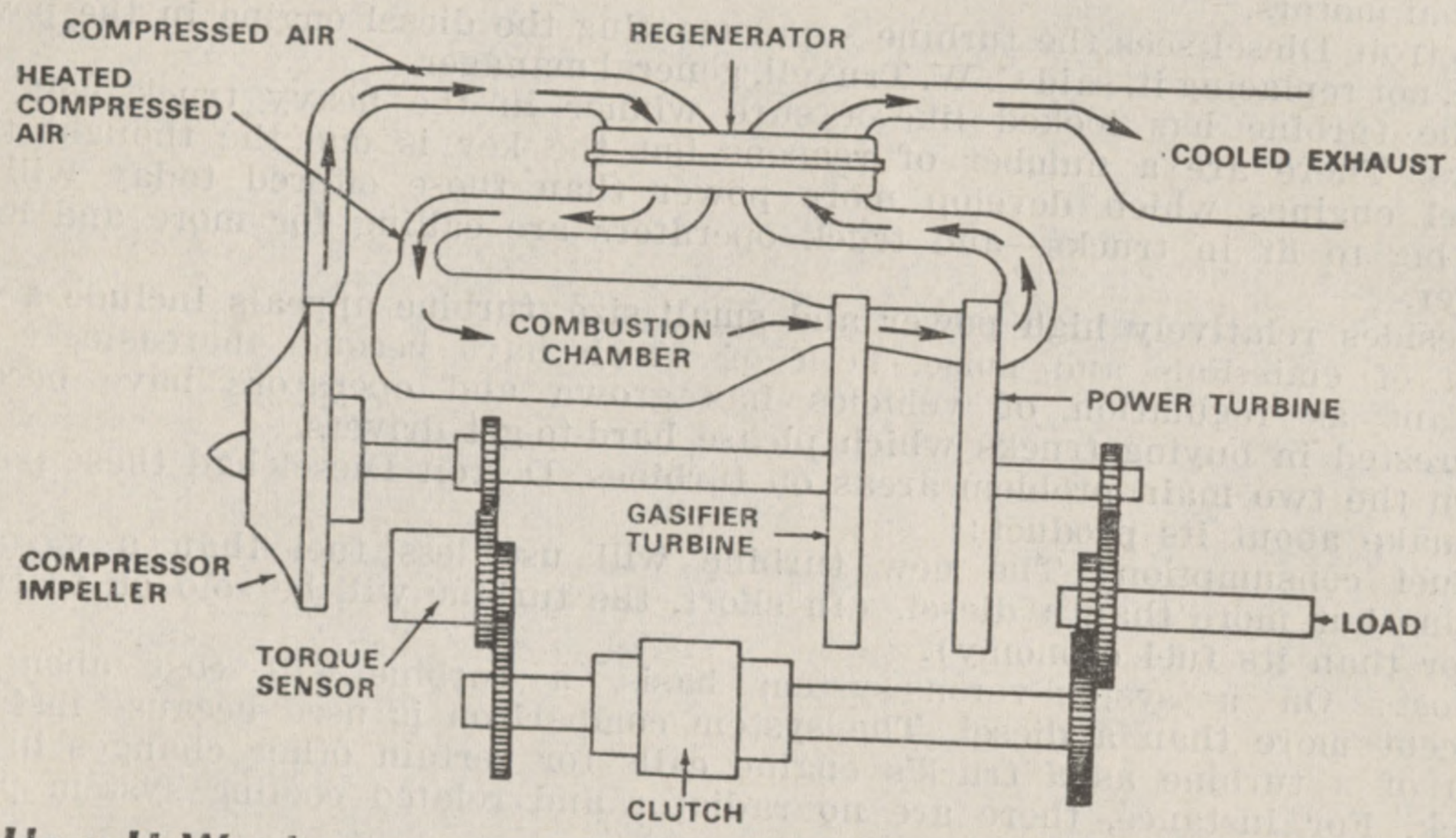
The turbine can be equipped with a regenerator—ceramic or stainless shell steel—which cuts fuel consumption. A regenerator is a disk which, in its rotation, picks up heat from exhaust gas and discharges heat into incoming air.

Two alternate systems are available. One is direct discharge of exhaust gas and the second is the use of a recuperator which is a form of heat exchanger with no moving parts. Direct discharge is employed when there is a use for the turbine's heat outside of the turbine. It is not a typical truck setup and does penalize economy.

Detroit Diesel people pointed to one feature of their turbine which they think is unique. It has the GM patented Power Transfer System which links the shafts of the two-shaft turbine. (An oil-cooled clutch is inserted in a link from the gasifier shaft to the power turbine shaft.)

The division said the device permits as much as the full horsepower of the turbine to be used in braking the truck. The system is also said to protect against overspeeding of the power turbine and to reduce fuel consumption.

The turbine also has just about the same accessory drive setup as existing diesels from the division to ease installation in existing vehicles.



How It Works—

This is a drawing of the new turbine from Detroit Diesel. A variation from other turbines is the use of the link across the bottom of the sketch which ties the gasifier shaft and the power turbine shaft together. The link, the GM-patented Power Transfer System, has an oil cooled clutch and can be automatically actuated by the torque sensor near the impeller.

[From the Wall Street Journal, Jan. 30, 1969]

Smog-Control Feud

(Automakers attempt to shift pollution onus to gasoline producers but oil companies respond that test data are faulty, warn of price increases)

A knock for tetraethyl lead

(By Charles B. Camp)

Detroit.—The automobile industry, in an apparent effort to simplify its own efforts to reduce auto-caused air pollution, is now trying to shift part of the blame for dirty air to gasoline.

Carmakers contend that most gasoline formulas run too heavy to tetraethyl lead and butane. And they claim these ingredients make it much harder and more expensive to develop antismog devices than would be the case if the gas formulas were changed.

The oil industry, needless to say, is not pleased by the indictment of its products. Oil companies assert that the changes automakers demand would not only raise the price of gasoline by 10 percent or more but would also make it less efficient. Besides disputing the technical validity of the automakers, charges, some oilmen bitterly question their motives. "They're just looking for someone to join them on the hot seat," complains a research executive for one major oil company.

Tougher plans afoot

Carmakers are indeed on the hot seat. For the past several years, they have borne the brunt of demands that something be done to reduce the amount of pollutants emitted into the air by auto exhaust. State and Federal laws now require that automakers equip their cars with two smog-control devices, and plans are afoot to force installation of even more sophisticated gear in the next few years. Earlier this month the Justice Department filed an antitrust suit charging automakers with conspiracy to delay the introduction of antismog devices.

The indusry claims that the devices now in use have reduced emission of pollutants by as much as 65 percent compared with 1960 models. But it says the devices have boosted the cost of making each car by about $35, and it figures future standards may raise costs another $100.

Such increases are, of course, passed on to auto buyers in the form of higher car prices. But auto companies nonetheless complain about the effort of developing and installing the devices.

Ostensibly, the oil industry has been in sympathy with the automakers' problems. The two industries have been close allies for years. As Henry Ford II, chairman of Ford Motor Co., puts it: "Like flowers and bees, where you find one the other is sure to be near." In fact, automakers and oil companies are teamed up in several expensive studies aimed at finding ways to curb air pollution.

A quiet gathering of data

But the joint studies have yielded few results so far, and automakers are getting impatient. They have been quietly gathering research data on their own that strongly indicts gasoline formulas, and there are indications they plan to use it to campaign for new antipollution laws and regulations covering fuels. At present, there are no such controls.

Part of the data was made public at the annual meeting of the Society of Automotive Engineers here this month. One result was an immediate uproar on the part of oil companies. Several issued their own research findings—inevitably running counter to those of the auto companies—and in one case a subsidiary of Standard Oil Co. (New Jersey) cranked out press releases rebutting a General Motors Corp. study hours before it was even presented.

The chief targets of the auto researchers' attacks, tetraethyl lead and butane, are ingredients of practically all gasoline sold in the United States. Lead is added to gas in the refining process to make it burn more evenly and to prevent engine misfiring, or "knock." Butane, a highly volatile substance, helps gasoline to evaporate as it passes through the carburetor; this is necessary because engines actually burn gasoline in vapor form, not as a liquid.

Researchers for Ford, who have concentrated on tetraethyl lead, contend that leaded gas leaves deposits inside auto engines that cause greater emissions of unburned fuel, a major source of auto-caused smog. The result, Ford researchers say, is that engines using leaded gas operate up to 35 percent "dirtier" than ones burning nonleaded gas.

A catalytic complaint

Ford also complains that leaded gas prevents development of an efficient antifume system that would use a catalyst, or chemical reaction agent, to destroy noxious fumes on their way through the muffler or exhaust pipe. Ford's engineers say leaded gas is "stronger" than the catalyst and would cause it to wear out fast, necessitating annual replacement at a cost of $20 or so to the car owner.

It is possible, through changes in the refining of gasoline, to make a nonleaded gas that has the same antiknock qualities as leaded gas. American Oil Co., a subsidiary of Standard Oil Co. of Indiana, already markets a nonleaded premium gasoline in several Eastern States.

Most oil producers contend, however, that to convert all domestic refineries to production of nonleaded gasoline would be prohibitively expensive. The American Petroleum Institute estimates the conversion cost at $4.25 billion and says refining costs would rise at least 2 cents a gallon. (American Oil currently charges 1 cent to 2 cents a gallon more for its unleaded gas than for comparable leaded premiums in its market area.)

Moreover, oil producers claim Ford is wrong in some of its critical research findings. A study by Du Pont Co., a maker of tetraethyl lead, shows pollutant emissions of engines using leaded gas are only 7 percent higher than those using nonleaded gas—instead of the 35-percent difference reported by Ford. C. A. Hall, research adviser for Ethyl Corp., another tetraethyl lead maker, insists there's

no difference at all. "I found engine deposit buildup practically identical regardless of which type gas was used," he says.

Demands for changes in the butane content of gasoline have come mainly from General Motors, whose engineers say high butane content makes gas so volatile that large quantities evaporate into the air without ever being burned. The evaporation problem is great enough that the California Air Resources Board, a pollution-control body, has ruled that all new 1970 model cars brought into California must have devices that will reduce evaporation by at least 80 percent. One such device was developed by Jersey Standard. The oil company says the device, costing $5 to $7, will absorb fumes that escape from the engine and fuel tank. A Federal standard, similar to the California regulation, will require such devices on all 1971 model cars.

But GM maintains that the evaporation fumes from all cars—new and used—could be reduced sharply by simply reducing the butane content of gasoline. GM engineers calculated that fumes entering the smog-prone Los Angeles atmosphere could be cut by 12 percent immediately by lowering the volatility of gasoline. By contrast, it will be an estimated 10 years before all cars now on the road are replaced by cars that have the antifume devices.

Moreover, GM says a study of 1,800 drivers showed that most couldn't tell the difference between the way their cars operated on high-volatility gas and the way they worked with low-volatility gas.

Although Chrysler Corp. hasn't issued any public statements about the pollution effects of fuel, its engineers also are conducting volatility studies. Some of their research so far indicates the volatility of some gasolines may have to be lowered to avoid operating problems for cars equipped with evaporative control devices, sources say.

Oilmen contend that a switch to low-volatility gas could increase refinery costs by more than a cent a gallon "and perhaps considerably more." One factor: Butane is in oversupply, and putting less of it in gasoline would mean replacing it with more expensive ingredients. "At the refinery gate, gasoline sells for about 15 cents a gallon and butane for about 2 cents," says one oil researcher. "Needless to say, it pays to get as much butane as feasible into gasoline."

A Jersey Standard researcher, David T. Wade, also claims that GM didn't properly analyze all the results of its study of drivers' reactions to low-volatility fuel. Mr. Wade claims that his analysis of the results showed that "a significant number" of drivers—10 percent to 20 percent—had starting, idling, and running problems with their cars when they used low-volatility gas.

Actually, practically all gasoline companies already vary the volatility of their gasolines on a seasonal basis. They add more butane in the winter so cars will operate better in cold weather and reduce the content somewhat in summer. But the butane content is usually higher than that suggested by General Motors.

There's already evidence that the auto companies' suggestions for changing gasoline are catching the ear of the agencies responsible for smog control. The California Air Resources Board says it's studying the possibility of requiring changes in the composition of gasoline, and an official of the U.S. Department of Health, Education, and Welfare says the agency also plans to look into the situation.

DEPARTMENT OF CALIFORNIA HIGHWAY PATROL,
Sacramento, Calif., January 20, 1969.

Mr. LYNN SUTCLIFFE,
Counsel, Senate Commerce Committee,
Old Senate Office Building, Washington, D.C.

DEAR MR. SUTCLIFFE: In response to your recent telephone conversation, I am pleased to enclose a copy of our original request for proposal which was directed to all known and/or interested prospective steam/vapor engine vendors. We received five responses to our original request for proposal. These were from the Kenetics Corp., Sarasota, Fla.; Thermodynamic Systems, Inc., of Newport Beach, Calif.; Richard J. Smith and Carl A. Peterson of Midway City, Calif.: Dynalear, Inc., of Reno, Nev.; and Mr. Berry W. Foster, of Redondo Beach, Calif.

A review of their proposals indicated that there was a lack of communications between this department and the proposers. In view of this, Commissioner H. W. Sullivan exercised his prerogative and rejected all five proposals. The request for proposal was subsequently restructured and again mailed to those persons on our original mailing list. A copy is attached for your information. We received

four responses to the restructured request for proposal. They were from the following persons: Lear Motors Corp., Reno, Nev.; Thermodynamic Systems, Inc., Newport Beach, Calif.; Paxve, Inc., Newport Beach, Calif.; and Mr. Berry W. Foster, Redondo Beach, Calif.

We are, at the present time, evaluating the proposals and expect a determination to be made in the next several weeks. We will be pleased to keep you informed of our progress in this regard, should you be interested.

Should you desire further information, please advise.

Very truly yours,

D. S. LUETHJE,
Supervising Inspector-Special Projects Planning Coordinator.

ORIGINAL REQUEST FOR PROPOSAL

DEAR SIR: The Department of California Highway Patrol, in accordance with California Assembly Concurrent Resolution No. 111 (copy attached), is embarking on a program to equip up to six vehicles with steam powered engines. The scope of the program is attached.

The General Motors Corp., has offered to participate in this program to the extent of furnishing the test vehicles and certain financial support, provided the Department of California Highway Patrol enters into a firm commitment with a vendor for the installation of the steam power plant in such automobiles.

It has been learned you and/or your organization may have an interest in participating in such a program.

If you desire to participate in this program, your interest should be evidenced by the submission of a proposal. Such a proposal shall be based upon and responsive to the attached documents.

Your particular attention is invited to the meeting of September 11 and the deadline for submission of proposals.

Very truly yours,

H. W. SULLIVAN, *Commissioner.*

ASSEMBLY CONCURRENT RESOLUTION NO. 111—RELATIVE TO THE TESTING OF STEAM-POWERED VEHICLES

Whereas, the California Legislature has long recognized the serious and growing threat to health, agriculture, and the economy created by motor vehicle air pollution and has systematically and progressively acted to combat this threat through legislation and the encouragement of research; and

Whereas recent legislative studies and hearings have indicated that modern steam engines are characterized by very low emissions, economical operation and high power output; and

Whereas the Department of the California Highway Patrol has expressed an interest and willingness to test operational steam-powered vehicles, provided this may be done at little or no cost or inconvenience to the patrol; and

Whereas at least one manufacturer of a steam-powered engine has indicated a willingness to submit steam-powered vehicles to the Department of the California Highway Patrol for testing, and for such time as the Department of the California Highway Patrol may need to make a full appraisal of modern steam cars; and

Whereas various public and private organizations have expressed an interest in underwriting the cost of a program involving the testing and appraisal of steam-powered vehicles: Now, therefore, be it

Resolved by the Assembly of the State of California, the Senate thereof concurring, That the Members request and encourage the Department of the California Highway Patrol, provided that it may do so at little or no cost or inconvenience, to (1) explore all likely possibilities for carrying out testing of steam-powered engines in standard fleet vehicles of the Department of the California Highway Patrol and under the usual operating conditions and requirements for such vehicles; (2) commence consideration of the design of an appropriate test program; and (3) consult with such public and private agencies, firms and individuals as will assist the Department of the California Highway Patrol in carrying out the intent of this resolution; and be it further

Resolved, That the Chief Clerk of the Assembly transmit copies of this resolution to the Commissioner of the California Highway Patrol, the Chairman of the State Air Resources Board, the Administrator of the Health and Welfare Agency, the Secretary of Health, Education and Welfare, and the Secretary of Transportation.

STEAM-POWERED VEHICLE STUDY—CALIFORNIA ASSEMBLY CONCURRENT RESOLUTION 111

PROGRAM ELEMENTS

1. One 1969 Oldsmobile chassis and body will be delivered to the vendor selected to provide a steam-powered engine. The vehicle will be less engine, transmission, and radiator.

2. The vehicle furnished will meet the specifications as described in annex A.

3. The selected vendor will be required to install one steam-powered engine [1] of sufficient size to meet the performance standards as indicated in annex B.

4. The steam engine installed shall constitute a complete replacement for the internal combustion engine, and shall perform all those functions expected of the conventional power source.

5. The completed vehicle shall be delivered to the Motor Transport Section, Department of California Highway Patrol, 2812 Meadowview Road, Sacramento, Calif., not later than 6 months from the date the chassis and body are delivered to the vendor selected.

6. The vehicle will be subjected to a series of tests which will include safety, performance, fuel economy, maintenance, general operations, and such tests concerning exhaust emission as may be required by the California Air Resources Board. Representatives of both the vehicle and engine manufacturers may be in attendance during these scheduled tests.

7. Should the initial testing indicate the vehicle is satisfactory for field use, it will be assigned to various locations in the State for continuous evaluation. Such evaluation will be documented and will be available to both the vehicle and engine manufacturers.

8. Based upon the results of the tests indicated above, the California Highway Patrol may test an additional five vehicles powered by steam engines. In this event, five 1969 or 1970 Oldsmobile vehicles (depending on time schedules) will be delivered to the original vendor of the steampowered engine. Said vehicles will be like the original vehicle described above and shall be equipped with a steam engine and delivered as provided above. The time schedule for delivery of these additional vehicles shall be indicated by the vendor in response to this proposal.

9. The additional five vehicles will be subjected to the tests indicated in items 6 and 7 above.

GENERAL

1. Based upon the acceptance of the first vehicle, the California Highway Patrol will pay the vendor selected an amount not to exceed $20,000. This amount will include the steampowered engine, the necessary labor and parts required to deliver the completed vehicle and post delivery assistance as required by items 3 and 5 of the "Specific Requirements". Schedule of payment is subject to negotiation with the Department of the California Highway Patrol.

2. Should the additional five vehicles be furnished for equipping of steam-powered engines, the Department of California Highway Patrol will pay up to $20,000 for each completed vehicle accepted by the department.

3. The department recognizes that, in view of this innovative undertaking, the required specifications might not be totally fulfilled; however, total compliance shall be attempted. Specific items which the vendor believes are impossible of attainment should be indicated in the response. These items then may be subject to negotiation with the department. If, in the opinion of the department, the safety and operational capability of the vehicle will not be adversely affected, the department may waive compliance with such requirement.

4. The response to this request for proposal should be framed in such a manner as to constitute an agreement if accepted by the Department of the California Highway Patrol.

SPECIFIC REQUIREMENTS

1. The completed vehicle must meet all specifications and requirements as indicated in annexes A and B insofar as applicable and practicable. (Proposed deviation, if any, shall be indicated as provided in item 3, "General," above.)

2. The completed vehicles shall meet all of the applicable motor vehicle safety standards as established by the U.S. Department of Transportation.

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[1] For the purpose of this proposal, "steam powered engine" means a steam (vapor) powered external combustion engine.

3. The vendor selected shall provide on-the-spot assistance upon and after delivery of the first car, if necessary, in order to work out any problems that may develop during the first period of operation.

4. A manual of maintenance and operating instructions shall be provided by the vendor.

5. The vendor shall provide training for the officers and others who may be working with or evaluating the vehicle, as determined by the department.

6. The safety of the power generation unit shall be demonstrated so the department can be reasonably assured that damage or injury will not occur as a result of failure of the boiler, or of the burner or pressure regulating controls. Such gages and instruments should be installed in the vehicle to provide the operator with advance information as to any impending danger in this regard.

7. It will be the responsibility of the vendor to handle all engine and related component breakdowns and to pay the cost of all parts and labor to maintain the engine in an operative condition for the period of testing and evaluation.

8. The Department of the California Highway Patrol is a public agency and is required to furnish the California Legislature reports of the progress and results of the undertaking. It should be clearly understood that such reports would constitute public documents and thus will be available to the general public upon request.

9. Proposals will be rejected if the prospective vendor is unable to provide a working steam-powered engine for examination by the department on the date established for submission of such proposals. Such engine may be installed in a vehicle or may be bench operable.

10. A meeting to discuss all aspects of the program will be held for those interested vendors on September 11 at 9 a.m. Pacific daylight time in the conference room of the California Highway Patrol headquarters at 2611 26th Street, Sacramento, Calif. It is the intent of the department that all bidders be provided the same information. Any questions subsequent to the meeting must be submitted in writing and will be answered in writing. The questions and answers will be made available to all interested bidders. The proceedings of the meeting on September 11 will be tape recorded. Attendance or nonattendance at the meeting will have no effect upon the evaluation or selection of the vendor's proposal.

11. Proposals must be received no later than 5 p.m. Pacific daylight time on October 9, 1968, to be considered. Proposals may be delivered in person at 2611 26th Street, Sacramento, Calif., or via mail, with postage prepaid, addressed to the California Highway Patrol, Attention: Inspector D. S. Luethje, Post Office Box 898, Sacramento, Calif. 95804.

ANNEX A.--GENERAL DESCRIPTION OF VEHICLE CHASSIS AND BODY TO BE EQUIPPED WITH STEAM ENGINE, AUGUST 1968

This specification generally describes a California Highway Patrol type chassis and body into which an experimental steam engine is to be mounted.

Generally the unit shall have the same and/or similar components as were used on the 1967 Oldsmobile (Delmont) California Highway Patrol vehicles delivered to the department with the exception that the engine, transmission, and radiator are to be omitted.

It is the intent of these specifications to describe an automobile chassis and body to be used in high speed highway traffic and law enforcement work. The vehicle with steam engine installed, will at times be operated at speeds considerably in excess of 100 miles per hour for both short and long durations. It will be driven on all types of roads and road surfaces and at altitudes ranging from approximately 200 feet below sea level to 10,000 feet above sea level. Temperatures to which the vehicle will be exposed will range from approximately minus 20 deg. F. to plus 120 deg. F.

It is intended that the manufacturer of the chassis and body in the selection of components will use materials and design practices that are the best available in the industry for the type of operating conditions to which the completed vehicle will be subjected. Drive line, differential, brake, suspension, wheel, tire, and other component parts of the vehicle shall be selected to give maximum performance, service life, and safety.

The vehicle chassis and body shall in all respects meet all requirements of the Federal safety standards and shall meet all requirements of the California Vehicle Code.

The term "heavy duty" as used in these specifications shall mean that the item to which the term is applied shall exceed the usual quantity, quality, or capacity supplied with standard production vehicles; and it shall be able to withstand unusual strain, exposure, temperature, wear, and use.

BODY

Style: Four-door sedan with center post.

Color: Body and wheels, black, Ditzler No. DQE 9000 or comparable. Roof panel and lower portion of both front doors below the belt moulding, white, Ditzler No. DQE 8000 or comparable.

Front door trim: It must be possible to mount California Highway Patrol insignia 15 inches in diameter on front door below the belt moulding without metal trim intersecting or interfering with insignia. If metal trim interferes, it shall be removed and the holes plugged before painting door.

Front seat and upholstery: Front seat to have heavy-duty springs and a minimum of 1 inch of foam padding in seat. Upholstery shall be a light gray or other similar color of nylon or nylon and vinyl plastic material. All vinyl seat covering material is not desired. Front seat to be manually adjustable fore and aft and provision for shop adjustment up and down.

Head room: Shall not be less than 38 inches measured by AMA standards.

Leg room: Shall not be less than 41.8 inches measured by AMA standards.

Steering wheel: White, light gray, or other heat-reflecting color.

Tools: Bumper jack, jack handle, and wheel wrench to permit changing a wheel.

Front and rear wheel to body clearance: Must be adequate to allow the vehicle to operate at not less than 30 miles per hour with mud and snow tires and skid chains installed while the vehicle is carrying a load of approximately 700 pounds. Steering or operation of the vehicle shall not be hampered by this requirement.

Speedometer: The vehicle described in these specifications will be used in law enforcement, and extreme speedometer accuracy is essential. The speedometer shall be driven off the left front wheel and calibrated to be accurate within 2 miles per hour at all speeds up to 100 miles per hour. Dial face to be marked up to 120 miles per hour. The permanent magnet (Lodex or comparable) and design of the speedometer shall insure accuracy throughout the life of the vehicle and over an ambient temperature range of 50° to 150° F. Face markings shall not be in increments greater than 2 miles per hour. The face shall contain the wording "certified speedometer."

Rear package shelf: California Highway Patrol will install two lights, 6 inches in diameter, 4½ inches deep, and 7¼ inches high on the rear package shelf and space for the installation is desirable.

Spotlights: California Highway Patrol will install two spotlights, one on each windshield post.

Sound and vibration deadener: Required under hood.

Floor mats: Heavy duty rubber or vinyl floor mats front and rear.

Hood release: The hood release device shall be located inside the passenger compartment adjacent to the driver so as to prevent the hood from being opened when the vehicle is locked.

ELECTRICAL SYSTEM

Electrical equipment shall consist of all wiring normally supplied in vehicles plus multiple beam headlights, instrument panel lights, dual stop and tail lights, rear license light, dome light, heavy duty 70-ampere hour capacity at 20-hour rate battery, 12-volt electrical system, and heavy-duty alternator-regulator system with not less than 60 amperes output. All electrical equipment shall, if necessary, be shielded to minimize radio interference in the 42.18 to 42.72 megahertz range.

CHASSIS

Wheel base: Not less than 122 inches.

Vehicle weight: The chassis and body will weigh approximately 3,650 pounds.

Suspension: Front and rear suspension including shock absorbers to be heavy-duty design for police work.

NOTE.—A push bumper weighing approximately 60 pounds will be mounted on front of the car by the California Highway Patrol.

Stabilizer bars: To be provided front and rear and to be of a heavy-duty type.

Differential: Conventional heavy-duty type. Gear ratio to be selected by engine manufacturer just prior to chassis being built.

Transmission: To be left out of chassis. Transmission shift lever to be provided in steering column.

Drive shaft: Heavy-duty type to be supplied.

WHEELS AND TIRES

Wheels: Shall be 15-inch diameter with *6-inch minimum* rim width and shall have a safety ridge rolled into rim or otherwise designed to prevent the tire from separating from the wheel in the event of a flat. A total of five wheels shall be supplied.

Spider shall be heavy duty.

Tires: Tubeless, black—8: 45 by 15, six full ply, nylon cord, low cord angle for high speed operation, $11/32$ inch tread depth minimum.

A total of five tires shall be supplied.

BRAKES

Disc brakes (ventilated rotor type) on two front wheels, standard heavy-duty drum type on rear with vacuum booster. Heavy-duty lining for police work.

Parking brake with warning light.

Brake system shall meet brake performance tests of this specification as detailed under "Performance."

Axles, spindles, wheel bearings, and hubs: Heavy-duty.

RADIATOR

To be left out of chassis. Radiator support shroud to be installed.

FUEL TANK

Standard for vehicle shall be supplied installed.

GENERAL

All equipment cataloged as standard except engine, transmission, and radiator, are to be furnished with vehicle whether or not it is listed in this specification.

The "report of sale" for the vehicle chassis and body shall be delivered to the California Highway Patrol, 2611 26th Street, Sacramento, Calif. 95818 (attention motor transport section), at the time of delivery of the vehicle to the engine manufacturer.

With the engine and transmission out of the chasis the front coil suspension will be almost fully extended and the vehicle will assume a "nose up" attitude. The necessary action shall therefore be taken to clamp or chain down the front suspension prior to shipping the car so that the vehicle chassis and body are sitting with the bottom of both lower rocker panels parallel with the ground.

TECHNICAL INFORMATION

The following manuals shall accompany the vehicle at the time of its delivery:

1. Service manual covering all the components normally in the year model chassis and body supplied.
2. Parts manual covering all the components normally in the year model chassis and body supplied.

DELIVERY OF CAR

Chassis and body shall be delivered to a designated steam engine manufacturer or his designated representative.

1. The specific name and address of vendor to be supplied at a later date.

GUARANTEE

The manufacturer delivering the chassis and body shall guarantee that it meets the minimum requirements set forth herein and that the vehicle meets all the requirements of the Federal safety standards and the California Vehicle Code.

ANNEX B.—SPECIFICATIONS FOR EXPERIMENTAL STEAM CAR (WITH ENGINE INSTALLED), AUGUST 1968

I. ENGINE

The mounting location of the engine (under the hood or connected directly to the rear axle) is at the option of the engine manufacturer. It however, is preferred that the engine and the generator be "under the hood" if at all possible.

All components must be within the vehicle body or chassis and no externally mounted accessories will be permitted.

STEAM GENERATOR

Shall be compact and of such a design that it takes up the minimum amount of space necessary for its efficient operation. The steam generator shall be so designed and manufactured that it has an adequate safety factor with the necessary safety devices to prevent damage to the car or injury to an occupant of the vehicle in case of a malfunction.

Steam generating tube(s) shall not clog from the deposits of the liquid used for generating vapor.

CONDENSER

The condenser unit shall be of such a design, adequate size, and so mounted in the air stream that it will properly and efficiently condense the vapors back to a liquid under all operating conditions to which the vehicle may be subjected.

FUEL

Engine to operate on kerosene or other fuel available or that can be easily stored and dispensed from a service station.

STARTING TIME

It must be possible to start the engine and get underway within 30 seconds (20 seconds preferred) and have full power available in no longer than 60 seconds.

LIQUID CONTAMINATION

The engine and its related parts shall be so designed and manufactured that they do not permit contamination of the operating liquid by the lubricants used.

The emissions of hydrocarbons, carbon monoxide, and oxides of nitrogen as well as other air contaminants shall be at a minimum and in any event within State of California standards.

FORWARD AND REVERSE MOTION

A means shall be provided so that the vehicle may be driven either forward or in reverse.

The means of shifting from forward to reverse motion shall be relatively simple and not require an undue amount of motion or time delay to change the direction of travel of the vehicle.

A safety device shall be provided so that the vehicle cannot be accidentally placed in reverse while the vehicle is moving forward.

If possible, the standard steering column shift lever shall be used for this purpose.

RETARDER

It is desired that the engine, if possible, be so designed that it will act as a retarder to slow down the speed of the vehicle or act as a form of a brake when descending steep grades.

The means of engaging the retarder function shall be positive and simple.

COLD WEATHER OPERATION

The engine and related parts shall be designed so that the vehicle may be operated in sub-zero freezing weather and that it may be parked outside inoperative for a period of 1 week with no damage resulting to the various component parts. It shall also be possible to park the car overnight in freezing weather with no damage; and the engine shall start and be ready to get underway within the normal time period specified.

FILTERS

Adequate filters shall be installed in the fuel, lubricant, and other liquid systems to prevent foreign matter that could be detrimental to the system from passing through.

NOISE LEVEL

The noise level of the engine, its accessories, and the completed vehicle shall not exceed 86 dbA at 50 feet when tested as prescribed by section 1045, title 13, California Administrative Code.

II. Chassis

WEIGHT AND BALANCE

The completed vehicle with all components installed and the liquid tanks full shall have proper weight and balance distribution to provide exceptional handling characteristics when driven at a wide range of speeds and through various maneuvers.

SUSPENSION COMPONENTS

The springs, shock absorbers, and other suspension components shall be matched front and rear for the loads they are to carry, and dampen out so as to provide superior handling characteristics.

ROAD CLEARANCE

Shall be comparable to that of an internal combustion engine car and such that vehicle can be operated both on and off the normal road surfaces.

DIFFERENTIAL RATIO

The engine manufacturer, if he wishes, may select the differential gear ratio he desires.

III. Body

PASSENGER COMPARTMENT

Both front and back seat passenger areas shall remain relatively unchanged from their initial configuration and shall permit the carrying of the normal number of passengers in both the front and back seats.

Unusual or high operating temperatures in the passenger compartment will not be acceptable.

TRUNK

Adequate room shall be available for the mounting or carrying, at a minimum, the following items in the trunk of the vehicle:

1. Spare tire.
2. Mobile radio transceiver (approximately 21 by 14 by 4 inches).
3. Fire extinguisher (approximately 17 by 10 by 6½ inches).
4. First aid kit (approximately 11 by 10 by 10 inches).
5. Box of flares (approximately 11 by 11 by 11 inches).

Minor accessories will be permitted in the trunk providing they permit the mounting and carrying of the items listed above.

CONTROLS

The speed of the engine shall be controlled by a lever or device similar to an accelerator pedal in an internal combustion engine car. Its mounting location shall also be in a similar position.

Adequate controls shall be provided in reach of the driver to control all normal operating functions of the engine and car.

INSTRUMENTATION

At a minimum the following gages and/or warning lights shall be provided; others as necessary for the correct and safe operation of the vehicle shall also be provided:

1. Speedometer.
2. Fuel quantity.
3. Ammeter.
4. Temperature(s).
5. Pressure(s).
6. Water quantity.
7. Oil pressure(s).

PASSENGER COMPARTMENT HEATER

A technique shall be provided so that the passenger compartment heater and windshield defroster will operate normally and supply adequate heat for cold weather at all times when the engine is operating.

FILLER OPENINGS, FUEL AND WATER

The filler openings to the fuel and water tanks shall be easily accessible and shall be clearly marked as to the liquid that it is permissible to pour or pump into the opening.

It is believed that it would be preferable to have the fuel supply opening at the rear outside of the vehicle.

RADIO INTERFERENCE SUPPRESSION

Radio interference suppression or shielding, as necessary, shall be provided to minimize radio interference in the 42.18 to 42.72 megahertz range.

IV. Accessories

ACCESSORY ITEMS WHICH WILL BE INSTALLED BY THE CALIFORNIA HIGHWAY PATROL

When the vehicle is received, it is planned to install the following law enforcement accessories, at a minimum, on the body, inside the car, or under the hood:

1. Push bumper on front of vehicle.
2. Spotlights (two) through A-posts.
3. Mechanical siren under hood.
4. Outside radio speaker under hood.
5. Shotgun in front-seat compartment.
6. Mobile radio transceiver in trunk.
7. Radio head and microphone in driver's compartment.
8. Fire extinguisher in trunk.
9. First aid kit in trunk.
10. Two rear emergency lights will be mounted on the rear package shelf.

Note.—The total weight of this equipment will approximate 180 pounds.

ELECTRICAL ENERGY

A 12-volt alternator having a minimum curb idle output of 35 amperes and not less than 60 amperes maximum output shall be driven in some manner so that a continuous supply of electrical energy flows from it even when the vehicle is stopped or standing.

VACUUM

A continuous source of vacuum shall be supplied adequate to operate the disk brake vacuum booster anytime the vehicle is placed in operation.

GENERAL

Those other items, if any, normally attached to or propelled by the engine, will be included with the vehicle and should be installed.

V. Performance

The completed vehicle shall possess outstanding roadability, maneuverability, cornering, and other road-handling characteristics necessary for a vehicle engaged in high-speed law enforcement work which includes long runs over various types of roads and operation during all kinds of weather.

PERFORMANCE MINIMUMS

Accleration: 82 miles per hour in one-quarter mile from standing start; 87 miles per hour in one-quarter mile from flying start of 50 miles per hour; 115 miles per hour in 1 mile from standing start with top speed of 125 miles per hour at end of 2-mile run.

Top speed: 130 miles per hour shall be attained in not less than a 3-mile run. The top speed of the vehicle shall be such that the driving power cannot exceed the reasonable safe handling and design characteristics of the chassis.

Sustained speed: It shall be possible to drive the vehicle at 100 miles per hour for a distance of 25 miles without slacking the speed or making any unusual adjustments.

GRADE-CLIMBING ABILITY

Design and installation of engine shall be such that vehicle will climb, at a reasonable speed, any of the grades normally found in the roadway system of the States of California.

On any of the grades it shall be possible to stop the vehicle and get underway again without spinning the drive wheels.

WATER, FUEL, AND OIL SUPPLY

The amount of water-fuel-oil supply carried on the vehicle shall be adequate to permit the vehicle to travel approximately 250 miles without stopping.

Vehicle shall not require periodic maintenance checks any more frequently than an internal combustion engine.

SAFETY FEATURES

There shall be no high temperatures or hot accessories in such a location that a person normally servicing the engine, vehicle, or its component parts could burn or otherwise hurt himself while making routine service checks.

Check "safety" valves shall be provided as necessary to insure that system design pressures are not exceeded. Safety valves shall be vented in such a manner so that if they should open they will not injure a person riding, performing normal service checks on, or standing adjacent to the vehicle.

Adequate visual and/or audible warning devices shall be provided, where necessary, to indicate any malfunctions in the pressure or other critical systems. Examples are—

1. Burner fails to cut off.
2. Burner fails to ignite.
3. Excessive pressure.
4. Low water.

DEPENDABILITY

It is desired that the vehicle shall be able to operate a minimum of 75,000 miles in 18 months without any major breakdowns or need for major service work.

VI. Evaluation

While the vehicle is being operated it is planned to evaluate the following factors which are not necessarily listed in order of importance:

1. Performance.
2. Power-to-weight ratio.
3. Torque.
4. Acceleration.
5. Smoothness.
6. Quietness (noise level).
7. Fuel consumption (fuel economy).
8. Operating range.
9. Safety.
10. Emissions.
11. Maintenance.

12. Economy (costs).
13. Overhaul frequency.
14. Dependability.
15. Driveability.
16. Retarder operation.
17. Winter operation (freezing up of generator, engine, and condenser).
18. General operation.
19. Startup time.
20. Pollution of liquid and/or vapor.
21. Reliability.
22. Serviceability.
23. Sensors and controls.
24. Exhaust system.
25. Use of multifuels.
26. Fire danger.
27. "Bulk" of engine and related parts.
28. Design and installation ingenuity.

VII. Technical

QUALITY

Quality of workmanship and material going into the engine, vehicle, and other component parts shall be of the highest level and shall compare favorably with aircraft standards.

REPAIR PARTS

Repair parts shall be reasonably available.

Restructured Request for Proposal

Dear Sir: As indicated in my letter of October 28, 1968, the department was, at that time, in the process of developing a new request for proposal for the installation of a steam vapor-powered engine in a patrol vehicle for the reasons indicated. The request for proposal has been completed and is transmitted to you herewith in duplicate.

The department, at the present time, is in a position of only being able to expend those funds as provided by the General Motors Corp. in certain amounts for each unit produced and is generaally committed with reference to time.

It, however, recognized that money and time may be of vital concern to prospective vendors. It also recognized. because of a particular system, each vendor may not be able to meet certain of the specifications. Therefore, the request for proposal has been restructured to solicit more information and to provide for better communication between the prospective vendor and the department.

The general agreement may be completed, should you be interested, by merely indicating in the first portion thereof the acceptance of each element by filling the wording "No exception" in each of the blanks (———), or should there be an exception, please indicate the exception in the blank space provided, crossing out that portion which is being amended.

There is also attached an alternate agreement that solicits your reaction to the equipping of a regular patrol vehicle with a steam vapor engine system. This agreement begs your proposition. Should you not be interested, do not return the alternate agreement.

With regards to the second portion of the request for proposal, please indicate your ability to: (1) comply, (2) partially comply, or (3) not comply, in the appropriate space provided after each item. If you are unable to comply or to partially comply with the specific item, please attach a statement referencing the item number, indicating if this, in your opinion, will affect the system you propose or whether this item can be met through an alternative. If an alternative is provided, please describe. The more information you can provide will give us a better picture of your offer and the possibility of a successful joint venture.

For your response to be considered, please submit one copy of the attachment, completed as above indicated. Proposals must be received no later than 5 p.m. Pacific standard time (P.s.t.), January 3, 1969. Proposals may be delivered in person at 2611 26th Street, Sacramento, Calif., or via mail with postage prepaid addressed to the California Highway Patrol, Attention Inspector D. S. Luethje, Post Office Box 898, Sacramento, Calif. 95804.

Very truly yours,

H. W. Sullivan, *Commissioner.*

[From the Automotive News, Feb. 10, 1969]

Two Steam Buses To Be Tested in San Francisco

San Francisco.—Steam buses will be tested here and in the East Bay in a new year-long experiment designed to combat smog and to reduce transportation costs.

Assemblyman John Foran, chairman of the Assembly Transportation Committee, announced application by the State for a Federal grant of $450,000 to pay for the steam engines, installation and costs of development.

Foran said two buses will be provided by the San Francisco Municipal Railway and two by AC Transit of Oakland. The steam engines will be installed in these four buses. The two firms will contribute the cost of the buses and the installation labor.

The grant, if approved, would come from the U.S. Department of Transportation.

"California's experiment with six steamcars for the State Highway Patrol," Foran said, "should put us first in line for funds from this department."

[From the Department of Transportation News]

Urban Mass Transportation Administration, Washington, D.C., February 17, 1969

For the first time in the United States, bus riders in the San Francisco Bay Area, in 1970, will be riding buses powered by steam engines.

Under a demonstration project announced jointly today by Secretary of Transportation John A. Volpe and John Francis Foran, chairman of the Assembly Transportation Committee of the California Legislature, four steam engines—more properly known as external combustion engines—will be installed in buses operated by the San Francisco Municipal Railroad (MUNI) and the AC Transit Co. in Oakland.

Although the Stanley steamer is now a museum piece, new technology and new methods of production are now at a point where it appears that the steam engine may, in fact, live up to the potential identified for it years ago. This, coupled with the dangers of pollution from the internal combustion engine, has rekindled interest in the steam engine and in other vapor cycle engines for cars, buses, and trucks. Congress focused attention on external combustion technology in hearings held last May before the Subcommittee on Air and Water Pollution of the U.S. Senate. These hearings pointed up the attractive features of the external combustion engine—its low pollution output, its operating efficiency and trouble-free maintenance. Federal concern about the problems of air pollution was underscored last week when Robert H. Finch, Secretary of Health, Education, and Welfare announced new Federal guidelines for controlling air pollution.

In making today's announcement, Secretary Volpe said: "This project emphasizes the Department of Transportation's desire to coordinate Federal efforts with those of leaders in other public sectors and with private business in the search for solutions to the problems created by transportation's impact on the environment. It represents a significant first step toward reducing air pollution from public transportation."

Under the grant, an engine will be selected from among the many which are currently being developed. These engines will be fully tested for safety, operating efficiency, and ease of maintenance, after which they will be put into service on a demonstration basis. This 2-year project will be the first in which Federal support is provided on a demonstration basis for the development of external combustion technology. A consulting firm hired by the State of California will monitor the demonstration project, collecting information on cost of operation, pollution output, maintenance problems, power, noise, performance, and public reaction.

The demonstration project is supported under DOT's program of research, development, and demonstrations of the Urban Mass Transportation Administration which is aimed at improving mass transportation in all cities across the Nation through the application of new technology. The total cost of the program for 3 years is estimated at $610,000 of which the Federal share will be $450,000. The initial Federal grant is for $244,250 to aid in the purchase, installation and

testing of the engine. The State of California, AC Transit and San Francisco MUNI will contribute $160,000 in services.

For further information contact Assembly Rules Committee, California Legislature, Room 3173, State Capitol, Sacramento, Calif., 95814. Project No.: CAL–MTD–13.

[From the Department of Transportation News]

URBAN MASS TRANSPORTATION ADMINISTRATION, WASHINGTON, D.C.,
FEBRUARY, 20, 1969

John A. Volpe, Secretary of Transportation, today announced a second award in a Department of Transportation program to develop non-polluting buses for city mass transit service.

Secretary Volpe said, "The Department of Transportation has assigned a high priority to the search for solutions to the problems of air pollution."

The City of Dallas will soon see buses powered by an external combustion engine using Freon, a completely safe, non-toxic fluid extensively used in refrigerators, air conditioners, and spray cans. The engine was developed by Kinetics Corp. of Sarasota, Fla. Engineering work is being done by the Vought Aeronautics Division of LTV Aerospace Corp.

On Monday, February 17, Secretary Volpe announced an award to the California State Committee on Transportation for a research and demonstration project using steam buses in San Francisco and Oakland, the first departmental grant to study the use of external combustion engines in the effort to reduce air pollution and improve the quality of urban transportation systems.

The Dallas project will cost $464,684 of which the Federal grant from the Urban Mass Transportation Administration will be $309,789. The City of Dallas will pay $114,895 of the project's cost with the balance to be provided by LTV Aeronautics Division in services.

Secretary Volpe praised Dallas for its initiative in undertaking the project. Prior to applying for a demonstration grant, Dallas retained LTV to study a number of external combustion engines.

LTV selected the freon engine because it reduced difficulties with freezing, lubricating, starting, and operating at high temperatures and pressures inherent in many older versions of steam engines.

For further information contact Mr. William Driggs, Dallas Public Transit Board, Dallas, Tex. 76602. Project No. TEX–MTD–2.

Washington, D.C., February 28, 1969.

FEDERAL GRANT WILL AID DALLAS TRANSIT TO DEVELOP NON-AIR-POLLUTION STUDY

DALLAS, TEX.—The Department of Transportation February 20, awarded the Dallas Transit System (DTS) a Federal grant of $309,789 from the Urban Mass Transit Administration to develop non-air-polluting buses for city mass transit service.

The announcement was made in Washington by John A. Volpe, Secretary of Transportation.

E. O. Cartwright, Dallas Transit board chairman, said the board will award a subcontract to LTV Aerospace Corp., Dallas, to conduct the experimental project using a newly developed external combustion propulsion system.

"This evaluation program may well solve the problems of urban air pollution and noise from mass transportation sources," Cartwright said. "The system to be installed and demonstrated in test buses is lighter than the internal combustion engine, virtually does not emit air pollutants and is more economical to operate."

DTS WILL HEAD PROJECT

The Dallas Transit System will be primarily responsible for carrying out the activities of this project. Wilson C. Driggs, general manager of the Dallas Transit System will be the program manager. The subcontractor, LTV Aerospace, will be responsible to him for the successful completion of their contractual tasks.

Driggs will assign several of his top maintenance personnel to the project to work directly with the research engineers of LTV Aerospace.

"During the test, the actual air pollution of the test bus will be measured and compared to the conventional transit bus," Driggs said.

PROJECT THREEFOLD

The project will be divided into three phases and this initial grant will cover only the estimated cost of conducting phase 1 which involves the modification, installation and operational check out of the external combustion engine in two of the test buses.

Phase 2 of the program will consist of operating an endurance test, correct operating deficiencies, improvement studies related to the utilization of the external combustion engine as a propulsion system and transfer of these systems to two modern city buses upon completion of this testing. This transfer of the external combustion engine propulsion system to two modern city buses will prepare these vehicles for phase 3.

During phase 3 of the program, the two modern city buses will operate on the routes of the Dallas Transit System and they will be displayed and demonstrated to large audiences at special events, such as: the State Fair of Texas, Cotton Bowl games, and other special events attended by special transportation, regional and city groups.

PROGRESSIVE EVALUATION

The project is so designed that at the conclusion of phase 1 and again at the conclusion of phase 2, an evaluation will be made by the program manager to determine whether it is feasible to proceed beyond each of these phases, or scavenge the program at the conclusion of any phase.

It is anticipated that if all three phases are carried to a successful conclusion, the total project cost will be in the neighborhood of $2 million with the Dallas Transit System supplying one-third of the cost and the Department of Transportation supplying two-thirds.

Dr. Walter J. Hesse, LTV Aerospace Corp.'s vice president for developmental programs at Vought Aeronautics Division, said the basic engine has been undergoing tests in Grand Prairie for several weeks.

USES FREON

"This system uses freon, a safe, nontoxic fluid, instead of water, to generate steam," Dr. Hesse said. Freon is used extensively in our homes today in spray cans, refrigerators and air conditioning; so we know it is a safe agent. By heating the freon, we generate vapor which enters a modern steam-driven engine developing about 125 horsepower. Because this power is applied almost directly to the axle, it is equivalent in power to a 200-horsepower internal combustion engine.

According to Cartwright, the ultimate objective is to provide an evaluation base which hopefully will lead to substantial improvements in urban mass transportation.

CALIFORNIA LEGISLATURE,
ASSEMBLY COMMITTEE ON TRANSPORTATION AND COMMERCE,
Sacramento, Calif., December 17, 1968.

MR. PAUL L. SITTON,
Administrator, Urban Mass Transportation Administration,
Department of Transportation, Washington, D.C.

DEAR MR. SITTON: A complete application for a steam bus demonstration project is enclosed. Everyone concerned with the proposal has worked hard on it and all are enthusiastic of its success.

A final transportation study proposal will follow shortly.

Sincerely,

JOHN FRANCIS FORAN.

MEMORANDUM

To: Paul Sitton, Director, Urban Mass Transportation Administration.
From: Arthur Bolton, director, assembly office of research.
Re: External combustion engine demonstration project.

EXHIBIT A. DESCRIPTION OF PROJECT

1. PROJECT OBJECTIVE

The objective is to demonstrate the complete operational feasibility and superiority and public understanding and acceptance of an external-combustion-

engine-based propulsion system for urban mass transit bus use. The project will demonstrate the ECE system's principal performance, operational (fleet economics) and environmental advantages over the internal-combustion-engine-based system. Among others, these advantages include better acceleration, higher speed, absence of noise, fumes and hazardous exhaust emissions, and reduced operating costs. (The justification for the foregoing assertions is presented at length in the U.S. Senate hearings conducted by Senators Magnuson and Muskie during the latter part of May 1968).

2. SUMMARY OF PROJECT ACTIVITIES

This project will be conducted in collaboration with the Municipal Railway of San Francisco and the Alameda-Contra Costa Transit District. The former is an agency within the government of the city and county of San Francisco; the latter is a political subdivision of the State of California. Four ECE power systems will be acquired from a vendor pursuant to an RFP-type process, and will be installed in buses supplied (two each) by the respective fleet operators. These four ECE-equipped vehicles will then be subjected to "test track" operation for a period of up to 3 months; thereafter, they will be placed in regular transit service for 9 months.

From installation of the systems through the entire 12 months of service, the systems will be subjected to intensive and exhaustive engineering scrutiny, testing, and evaluation. The test and evaluation program will also comprehensively treat all pertinent performance, operational, safety and public and patron satisfaction characteristics. In addition to detailed engineering documentation, the project will supply a motion picture covering the entire project history, a public and patron attitude survey, and cost-effectiveness comparisons between ECE and ICE bus performance over identical routes during the 9-month transit service test period. Test routes will be selected to provide the sternest possible test of ECE performance, in terms of terrain, stop-and-go traffic congestion, and similar factors.

Project participants, in addition to the applicant, will include (*a*) the two municipal fleet operators; (*b*) the nonprofit consulting firm, Scientific Analysis Corp., of San Francisco; (*c*) a private consulting firm, International Research & Technology, Inc., of Arlington, Va.; and (*d*) the ECE system vendor, to be selected.

Data collection, analysis, and reporting having to do with total system performance will be carried out by I.R. & T.; similar work in the area of public and patron acceptance and having to do with administrative reporting (progress, fiscal, and so forth) will be done by SAC and/or the Office of Research, as required by pertinent state of Federal regulations.

The project is designed to take 24 months, assuming commencement on or about February 1, 1969. The initial 6 months will be devoted to system selection, design of test and evaluation procedures, and coordination of planning for installation and proving ground operations between the fleet operators, the systems vendor and I.R. & T. The latter part of the first year will be devoted to conduct of the proving ground phase (including validation of system safety), detailed planning for the regular transit service phase and development of the public and patron acceptance study plan. The first 9 months of 1970 will be used for the main "test," that is, operation of the ECE-equipped buses in regular service. The final portion of 1970 will be used for reportage.

In connection with this proposed schedule, both I.R. & T. and SAC will, to the extent feasible, coordinate all findings with those provided by the California Highway Patrol as a result of its six-cruiser test of ECE-equipped patrol vehicles in standard patrol operations.

On a preliminary basis, the project is estimated to cost approximately $610,000, of which over 25 percent will be supplied in the form of noncash contributions by the applicant and the fleet operators. About $150,000 will be required to procure four systems, together with 15 months of development and maintenance assistance from the vendor. About $150,000 will be required for project management and attitude surveys; $125,000 will be required for test and evaluation and other systems engineering services; and $25,000 for producing a motion picture covering the project history.

3. GENERAL APPLICABILITY

The strategy common both to this proposal and to the ECE demonstration being conducted by the California Highway Patrol is straightforward: it assumes that these two demonstrations, if successful, under the most rigorous operating conditions and engineering scrutiny, will have a powerful impact upon the opinion of the American motoring public and upon the investment decisions of the massive segment of industry that serves that public. In short, it believes success will provide a powerful stimulus to the commercial introduction and widespread use of ECE power systems for car, truck, and bus use in this country, with attendant benefits to users and metropolitan communities at large.

4. APPLICANT

The California Legislature is unique both in its philosophy of independent policy origination, vis-a-vis the executive branch, and in its practical implementation of that philosophy, as represented by the most heavily staffed legislative body in the Nation.

In particular, the assembly office of research (AOR) was established to give the lower house a long-range, policy planning, and analysis capability, and to make superior research methods accessible to committee chairmen and individual members. Over the past few years, the AOR has provided the staff input to major legislative innovation and reform, in such areas as mental health, air pollution control, manpower development, and compensatory education.

The office is staffed by a variety of talents and is supported by an extensive clerical/library apparatus; the office also has recourse to outside consulting assistance as necessary. Senior staff meet routinely with their counterparts in the private sector, the university system, and State and local agencies. In the recent past, several staff members have been retained as short-term consultants to the legislatures and executive agencies of other States.

With respect to the pending proposal, the AOR, through its principal investigator, will work closely with the assembly rule committee and the assembly transportation and commerce committee. Formal authorization for this participation by the principal investigator will be made by the assembly rules committee. The principal investigator will meet regularly with those persons with whom rules committee has contracted for the administration and fiscal management of the project and will inform appropriate assembly officials of the progress of the project and other related information which may be useful to their legislative business.

EXHIBIT B. PROJECT AREA

This project will be conducted within the corporate boundaries, respectively, of the city and county of San Francisco and of the Alameda-Contra Costa Transit District. The demonstration vehicles will be operated over specific transit routes, selected jointly by the fleet operators and the systems engineering consultant to provide a maximum test of the ECE system capabiliy.

As a technology demonstration, the project is believed to have little or no immediate relevance to comprehensive planning or transoprtation planning within the communities or areas involved. The extreme importance of transportation as a metropolitan development issue within California is well known, and it is possible that a successful demonstration would ultimately influence both the provision of transit service and equipment procurement decisions. The degree to which a successful demonstration might lead to widespread use of low-emission vehicle power systems is also imponderable at this time. As a legislatively sponsored test, a successful demontration is likely to have a substantial impact on legislative decisionmaking affecting the future development of urban mass transportation programs.

EXHIBIT C. WORK PROGRAM

1. WORK TO BE DONE

Specifically, four ECE power systems will be procured and installed in transit buses supplied by the two fleet operators. Installation will be performed jointly by the fleet operators and the vendor.

As indicated previously, the ECE systems will then be subjected to a prolonged test and evaluation program, involving the systems engineering consultant, the operators, and the vendor. This test and evaluation program will take place in two phases. Phase I is the proving ground effort, an obvious necessity, prior to

placing the systems in routine service. In this phase, fleet personnel will become familiar with required operating and maintenance requirements, and the systems themselves will be tested for basic safety and operational capability: "debugging" and general system modification needs will be dealt with during this phase. In phase II, the buses will be run in the conventional manner, to the accompaniment of detailed observation, by instrumentation and otherwise; similar scrutiny will take place during maintenance periods.

During the regular transit service phase, a public attitude and patron acceptance study will be conducted, and other public information activities will be carried out to familiarize a wide audience with ECE's potential. A documentary motion picture will be made and made available to DOT for later use. A final report will also be prepared.

2. PROJECT ORGANIZATION

(*a*) The assembly will furnish a principal investigator to provide coordination between DOT officials, the assembly rules committee, the assembly transportation and commerce committee, and assembly contractors under the terms of the project proposal. Subject to the terms of relevant assembly contracts, the principal investigator will provide quarterly reports on the project to the assembly and to DOT.

(*b*) Actual project administration and fiscal management will be provided by Scientific Analysis Corp. (SAC), a nonprofit firm, which will be contracted with by the assembly to provide these services. As noted in (*c*) and (*d*) below, SAC will subcontract for necessary additional services. SAC will also provide the public and patron attitude studies.

(*c*) International Research & Technology (I.R. & T.), will serve, under subcontract to SAC, as the systems engineering consultant for the project, with responsibility for system selection, safety validation, technical liaison with the vendor, design and conduct of test and evaluation and related engineering services.

(*d*) An engine vendor, selected under request for proposal (RFP) procedures designed and submitted by I.R. & T., will be subcontracted with by SAC to provide and maintain the engines.

(*e*) A documentary motion picturemaker will be subcontracted with by SAC to prepare a motion picture of the entire history of the project.

(*f*) The fleet operators will provide all transit equipment, personnel, maintenance facilities, and services required to carry out the project. Each operator will also appoint a project manager.

Exhibit D. Data Collection, Analysis, and Reporting

1. TECHNICAL REPORTING

I.R. & T. will be responsible for all technical reporting pertaining to total system performance. The results of the test and evaluation program will be presented so as to qualify for presentation in the SAE proceedings and other professional journals; special attention will be given to the presentation of findings for use in the popular press.

2. PROGRESS AND ADMINISTRATIVE REPORTING

SAC will be responsible for overall progress reporting and for administrative and fiscal reporting. SAC will also conduct and present the results of the public and patron acceptance study.

3. REPORT TIMING

It is believed that report timing is clearly implied by the schedule previously described.

4. CONSULTANT QUALIFICATIONS

SAC has been selected on the basis of the quality of its previous contributions to policy planning/analysis investigations carried out by the AOR and the administration of such studies, its experience and facility in dealing with local government officials in California, its low, indirect-cost rate, and because of its special competence in the field of public attitude surveys.

I.R. & T. has been selected because Dr. Robert Ayres, an officer in that firm, has recently completed the most comprehensive technical investigation of modern ECE technology yet done, has the broadest personal and professional knowledge of persons and firms active in this area of technology, and because his firm has an excellent systems engineering capability.

UMTA FORM 1 (7-68)

Form approved
Budget Bureau No. 63-R1070

DEPARTMENT OF TRANSPORTATION
URBAN MASS TRANSPORTATION ADMINISTRATION

APPLICATION FOR MASS TRANSPORTATION DEMONSTRATION GRANT

FOR DOT USE

PROJECT NO.

RECEIVED

1. APPLICANT *(Exact legal name given in charter, authorizing legislation, etc.)*

ASSEMBLY RULES COMMITTEE, CALIFORNIA STATE ASSEMBLY
State Capitol, Room 3173
Sacramento, California 95814

2. PROJECT LOCATION *(City or urban area which is center of proposed demonstration)*

SAN FRANCISCO, ALAMEDA and CONTRA COSTA COUNTIES

3. PROJECT DESCRIPTION *(Brief description of proposed project)*

This project will demonstrate the feasibility of using an external combustion engine (ECE) propulsion system for powering urban mass transit buses and the superiority of such external combustion engined systems over the conventional internal combustion engined system. Basically, this demonstration will be accomplished by installing ECE systems in four vehicles to be furnished by the Municipal Railway of San Francisco and by the Alameda Contra Costa Transit District, pre-testing the systems in non-passenger use and then running these buses for nine months in routine transit operation, during which time public and patron attitude studies will be accomplished, and exhaustive engineering tests and evaluation will be conducted on pertinent operating characteristics and total system performance. In addition, cost-effectiveness comparisons will be made between the ECE-equipped vehicles and conventional vehicles operating over the same routes during the same time period.

4. FEDERAL GRANT AND ESTIMATED PROJECT COST *(From UMTA FORM 4)*

Federal Grant requested . . . . . $ 450,000

Non-Federal contribution. 160,000

Total estimated project cost. . . $ 610,000

5. ESTIMATED DURATION OF PROJECT *(including preparation of final project report)*

24 MONTHS

6. THE APPLICANT REPRESENTS THAT THE DATA IN SUPPORT OF AND CONSTITUTING A PART OF THIS APPLICATION ARE TRUE AND CORRECT.

(Signature of Applicant's Representative)
JOE A. GONSALVES

CHAIRMAN, ASSEMBLY RULES COMMITTEE *(Title)*

12/17/68 *(Date)*

Form approved
Budget Bureau No. 63-R1070

UMTA FORM 2 (7/68)

DEPARTMENT OF TRANSPORTATION
URBAN MASS TRANSPORTATION ADMINISTRATION
DEMONSTRATION PROJECT BUDGET

PROJECT NO.

ESTIMATED DURATION OF PROJECT 24 MONTHS

APPLICANT

CALIFORNIA STATE ASSEMBLY RULES COMMITTEE

LINE	DESCRIPTION	PRESENT BUDGET Use only if this is a request for revision (1)	REQUESTED BUDGET (2)	APPROVED BY HUD (3)
1	Staff salaries (from schedule A) } Assembly non-cash Contribution (1)		3,400	
2	Employee benefits (from schedule A)		340	
3	Travel (from schedule A)		2,160	
4	Other administrative costs (from schedule A)		2,100	
5	~~xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx~~ Other Non-cash Contributions:			
	San Francisco Municipal Railway (2)		75,000	
	Alameda-Contra Costa Transit District (3)		75,000	
	California Air Resources Board (4)		2,000	
6	Construction or rental contracts (identify)			
	Steam Engine Supplier (5)		150,000	
7	Consultant contracts (identify consultant or purpose)			
	Scientific Analysis Corp. (administration, surveys and fiscal) (6)		150,000	
	International Research & Technology (engineering) (7)		125,000	
8	Other project costs (identify)			
	Documentary Motion Picture (8)		25,000	
	Printing project report (100 copies) - to be produced within above costs.			
9	SUB-TOTAL		610,000	
10	Contingencies (1) through (8). See attached sheets.			
11	TOTAL PROJECT BUDGET		610,000	

REQUEST: Approval is requested in the amounts shown in Column 2

DATE OF REQUEST

SIGNATURE JOE A. GONSALVES

TITLE CHAIRMAN, ASSEMBLY RULES COMMITTEE

APPROVAL: Budget approved in the amounts shown in Column 3

DATE OF APPROVAL

Department of Transportation, Urban Mass Transportation Administration, by

TITLE

Authorized DOT Official

EXPLANATION OF ITEMS IN UMTA FORM 2

Assembly Non-cash Contribution:
(1) Explained in budget Schedule A.

San Francisco Municipal Railway:
(2) See attached letter from Mayor Joseph Alioto

Alameda Contra-Costa Transit District:
(3) See attached letter from Alan Bingham

California Air Resources Board:
(4) Tentative commitment. Formal resolution will follow

Steam Engine Supplier:
(5) This is a tentative figure based on informal discussion with steam engine manufacturer and with the California Highway Patrol staff currently conducting a six car test of steam powered cruisers. The amount covers installation, maintenance and personnel as well as the actual cost of the engines.

(6) Scientific Analysis Corporation:
This figure is based upon discussions between Assembly staff and SAC executives. It breaks down as follows:

Staff Salaries - 24 months

Administrative				
Project Director	@	$22,000/yr.	100%	$44,000
Administrative Secretary	@	8,000/yr.	100%	16,000
Fiscal Manager	@	15,000/yr.	100%	30,000
Research				
Research Associate	@	15,000/yr.	50%	15,000
Research Ass't.	@	10,000/yr.	50%	10,000
Secretary	@	8,000/yr.	50%	8,000
				$123,000
Fringe benefits @ 12%				14,760
				$137,760
Travel		$1500/yr.		3,000
Communications		400/yr.		800
Office Supplies		220/yr.		440
Overhead (rent, lights, insurance, etc.)		4,000/yr		8,000
				$150,000

(7) International Research & Technology:
This figure is based upon tentative discussions between Assembly staff and an IR&T executive. As the proposal makes clear, SAC would sub-contract with IR&T for systems engineering services.

(8) Documentary Motion Picture:
This figure is based upon tentative discussions with a San Francisco Bay Area documentary motion picture maker who has done previous work of a technical nature.

Form approved
Budget Bureau No. 63-R10.

UMTA FORM 3 (7/68)

DEPARTMENT OF TRANSPORTATION
URBAN MASS TRANSPORTATION ADMINISTRATION
BUDGET SCHEDULE A - ADMINISTRATIVE EXPENSES

PROJECT NO.

DATE OF BUDGET REQUEST

BUDGET LINE 1. STAFF SALARIES POSITION TITLE	% TIME ON PROJECT	ANNUAL SALARY RATE	AMOUNT REQUESTED IN BUDGET	DISTRIBUTION BY PROJECT YEAR 1ST YEAR	2ND YEAR	3RD YEAR
Director, Assembly Office of Research	8.5/ yr.	20,400	3,400	1,700	1,700	
NOTE: SEE ATTACHED PAGE FOR DETAILED BREAKDOWN OF S.A.C. COSTS: SALARIES, TRAVEL AND ADMINISTRATION.						
TOTAL STAFF SALARIES			$ 3,400	$ 1,700	$ 1,700	$

If salary rates are fixed by law or civil service regulation, so indicate. Otherwise, indicate basis for salary determinations. If the time of any employee is to be prorated, indicate basis for proration.

Mr. Bolton's salary is determined annually by the Assembly Rules Committee for whom he has worked five years. Because he will perform none of the detailed administrative tasks, which are contracted to SAC, and because his responsibilities will be primarily to insure coordination of the various elements of the project at crucial junctures, it is estimated that no more than one month each year of his time will be needed.

BUDGET LINE 2. EMPLOYEE BENEFITS (*percent of Budget Line 1)*

If employee benefits paid by applicant are fixed by law, civil service regulation, or contract, so indicate. Otherwise, identify benefits covered by this item.

Assembly employee benefits run at approximately 10% as established by the Assembly Rules Committee. They include 1.5 days/month vacation, health plan contribution and an insurance contribution.

TOTAL EMPLOYEE BENEFITS	$ 340	$ 170	$ 170	$

BUDGET LINE 3. TRAVEL DESCRIPTION AND PURPOSE OF TRAVEL *(By Categories)*	AMOUNT REQUESTED IN BUDGET	DISTRIBUTION BY PROJECT YEAR		
		1ST YEAR	2ND YEAR	3RD YEAR
As principal coordinator of the project, Mr. Bolton will need to make periodic (6-8 times annually) trips to the San Francisco Bay Area project site, 2-3 trips to the vendor's factory, and 2-3 trips to IR&T (in Arlington, Virginia) and to DOT in Washington, D.C.	2,160	1,080	1,080	
TOTAL TRAVEL	$ 2,160	$ 1,080	$ 1,080	$

BUDGET LINE 4. OTHER ADMINISTRATIVE COSTS. All other administrative costs to be incurred by the applicant and charged to the project must be specifically identified below.

Other administrative costs include Mr. Bolton's secretary ($600/mo. for 2 months and fringe benefits at 10% or $120), telephone ($150/yr. for 2 years), and office supplies and overhead ($240/yr. for 2 years).	2,100	1,050	1,050	
TOTAL OTHER ADMINISTRATIVE COSTS	$ 2,100	$1,050	$ 1,050	$

Form approved
Budget Bureau No. 63-R1070

UMTA FORM 4 (7/68)

DEPARTMENT OF TRANSPORTATION
URBAN MASS TRANSPORTATION ADMINISTRATION
BUDGET SCHEDULE B - SOURCE OF FUNDS

PROJECT NO.

DATE OF BUDGET REQUEST

LINE	SOURCE	AMOUNT
1	Federal Grant	$ 450,000
2	Non-Federal Contribution	$ 160,000
	SOURCE OF NON-FEDERAL CONTRIBUTION	AMOUNT
3	Applicant's Cash Contribution to Project	$ -----
4	Applicant's Non-Cash Contribution (identify)	$ 8,000
	Director, Assembly Office of Research, salary and fringe benefits for two months, travel and administrative and overhead expenses.	
5	Sources Other Than Applicant (identify)	$ 152,000
	Air Resources Board staff advice to transit operators and State Assembly	2,000
	Transit equipment (4 buses @ $25,000), project managers (2 @ $10,000 /yr. for two years), and driver training and loss of bus service time ($10,000).	150,000
6	TOTAL FUNDS AVAILABLE (Must equal Budget Line 11, Total Project Budget)	$ 610,000

7 Cite evidence that the Non-Federal contribution is now available for commitment; or that it will be available when required to match payments of the Federal Grant.

Letters from the Chairman of the Assembly Rules Committee, the Mayor of San Francisco, and the General Manager of the A-C Transit Company are attached. Air Resources Board staff participation was tentatively pledged by a senior staff member but remains subject to official Board resolution which will be forwarded as soon as it is available.

CALIFORNIA LEGISLATURE,
ASSEMBLY RULES COMMITTEE,
December 17, 1968.

MR. PAUL L. SITTON,
Administrator, Urban Mass Transportation Administration, Department of Transportation, Washington, D.C.

DEAR MR. SITTON: This is to inform you that the California State Assembly Rules Committee today agreed by unanimous vote to participate in the proposed urban transportation study ($80,000 noncash assembly contribution) and the steam bus demonstration project ($8,000 noncash assembly contribution).

We have asked Arthur Bolton, the director of the assembly office of research, to appoint appropriate assembly staff to work on the transportation study and to act as principal investigator on the demonstration grant.

Both of these projects are fine examples of responsible Federal-State cooperation to meet the challenge of pressing urban problems. I congratulate both you and Mr. Foran on arranging this timely opportunity for all of us.

Sincerely,

JOE A. GONSALVES,

OFFICE OF THE MAYOR,
San Francisco, December 12, 1968.

Hon. JOHN FRANCIS FORAN,
Member of the Assembly, State Building,
San Francisco, Calif.

DEAR MR. FORAN: This is to acknowledge your letter of December 6, 1968, regarding the tentative commitment of the urban mass transportation administration of the Federal Department of Transportation to provide $400,000 to help fund a steam-propelled bus demonstration project through the California State Assembly.

The Public Utilities Commission of San Francisco has indicated that they will participate in the demonstration project by providing two municipal transit buses to be run on normal routing in the city for a 9-month period.

In addition, the public utilities commission will provide a noncash contribution, which includes the two vehicles, maintenance, and personnel, of approxmately $75,000 as required by DOT's proposal.

As you know, air pollution is one of the constant growing threats to our urban environment. San Francisco has been fairly fortunate in escaping this threat to date. However, from time to time, there are days in which San Francisco is plagued with smog conditions. How long we will be able to pollute the air is a matter of conjecture among the experts. Any research and development that could possibly result in a lessening of air pollution in the urban area should be thoroughly investigated. Steam-propelled buses should help.

Based on the outline of the project in your letter of December 6, whereby a scientific analysis corporation would contract to provide the bulk of the day-to-day administration of the project, and do necessary public attitude surveys and oversee the technical testing of the demonstration project, the results obtained from such a demonstration could prove beneficial to all of our cities.

The public utilities commission decision to participate is encouragng. I assure you the performance of the steam-propelled buses willl be observed with great interest.

Sincerely,

JOSEPH L. ALIOTO, *Mayor.*

ALAMEDA-CONTRA COSTA TRANSIT DISTRICT,
OFFICE OF THE GENERAL MANAGER,
Oakland, Calif., December 12, 1968.

(Attention of Mr. Karsten J. Vieg, research specialist).

ASSEMBLY OFFICE OF RESEARCH,
State of California, State Capitol Building,
Sacramento, Calif.

GENTLEMEN: This is to confirm results of a meeting held in my office on Wednesday, December 11, 1968, concerning a proposed application by the Assembly Transportation and Commerce Committee, State of California, for a Federal grant in the amount of $400,000 from the Department of Transportation to demonstrate the feasibility of using a steam engine propulsion system for powering urban mass transit buses.

Our executives who were present at the meeting received your suggestion that AC transit participate in the testing program with a great deal of enthusiasm.

We are aware of the urgent nature of your proposal and, accordingly, have taken steps for entire matter to be brought to our board of directors at a meeting tentatively scheduled for 4 p.m., Monday, December 23, 1968. Needless to say, it will carry my strong recommendation that we participate in the project with noncash contributions in an approximate amount of $75,000, in the manner

presented to us. You then will be furnished an appropriate document certifying to the district's official participation.

Thank you for affording us the opportunity to consider this matter.

Very truly yours,

ALAN L. BINGHAM.

[Assembly bill No. 356]

CHAPTER 765

An act to add Chapter 5 (commencing with Section 39200) to Part 1 of Division 26 of the Health and Safety Code, and to add Section 14808.5 to the Government Code, relating to low-emission motor vehicles.

[Approved by Governor July 25, 1968. Filed with Secretary of State July 25, 1968]

The people of the State of California do enact as follows:

SECTION 1. Chapter 5 (commencing with Section 39200) is added to Part 1 of Division 26 of the Health and Safety Code, to read:

CHAPTER 5. LOW-EMISSION MOTOR VEHICLES

39200. The Legislature finds and declares that emission of pollutants from motor vehicles is a major contributor to air pollution within the State of California and, therefore, declares its policy to encourage the development and testing of various types of low-emission motor vehicles, which would contribute substantially to achieving a pure and healthy atmosphere for the people of this state.

39201. As used in this chapter "low-emission motor vehicle" shall mean a self-propelling vehicle which does not have exhaust emissions of more than .5 grams per mile of hydrocarbons, 11 grams per mile of carbon monoxide, and .75 grams per mile of oxides of nitrogen.

39202. Low-emission motor vehicles shall be submitted to the board for testing to determine if such vehicle meets the standards set forth in Section 39201.

39203. After determining that the low-emission motor vehicle meets the standards prescribed by Section 39201, the Department of General Services in consultation with the board shall determine if the low-emission motor vehicle meets all of the following requirements:

(a) Such vehicle can be manufactured in sufficient numbers for the purpose of proper evaluation.

(b) Such vehicle meets the performance needs for state vehicles.

(c) The cost of such vehicle does not exceed by more than 100 percent the average of state passenger vehicles purchased in the preceding fiscal year.

(d) If such vehicle is purchased by the state there would be a sufficient number of servicing and maintenance outlets.

(e) The average servicing and maintenance costs for a low-emission vehicle are comparable to the average servicing and maintenance costs for all other state passenger vehicles, but in no event shall the average servicing and maintenance costs for the low-emission vehicle exceed the average costs of servicing and maintaining all other state passenger vehicles by more than 50 percent.

39204. If a low-emission motor vehicles meets the requirements of this chapter, the state shall, if funds are appropriated for the purpose of purchasing such low-emission motor vehicles, purchase, beginning with the next fiscal year, as many of such low-emission motor vehicles as the Department of General Services determines are reasonable to meet state needs and which are in accordance with manufacturing capability, performance, cost, servicing, and maintenance of such vehicles. If a sufficient number of low-emission vehicles are available, the percentage of all such vehicles to be purchased in that year shall not be less than 25 percent of all motor vehicles purchased by the state in the preceding fiscal year.

39205. The provisions of this chapter shall not apply to the following vehicles:

(a) Patrol cars of the Department of the California Highway Patrol.

(b) Any motor vehicle classified as a special-purpose vehicle by the Department of General Services.

SEC. 2. Section 14808.5 is added to the Government Code, to read:

14808.5. All purchases of motor vehicles by the state shall be in accordance with Chapter 5 (commencing with Section 39200) of Part 1 of Division 26 of the Health and Safety Code.

SEC. 3. Section 14808.5 is added to the Government Code, to read:

14808.5. Except for motor vehicles described in Section 39205 of the Health and Safety Code, the provisions of Chapter 5 (commencing with Section 39200) of Part 1 of Division 26 of the Health and Safety Code shall govern the purchase of all motor vehicles by the state to the extent that the Department of General Services determines that such low-emission vehicles are reasonable to meet state needs pursuant to Section 39204 of the Health and Safety Code.

In the purchasing of the motor vehicles described in Section 39205 of the Health and Safety Code and in purchasing motor vehicles for the state when the Department of General Services has determined there are no low-emission motor vehicles which meet the requirements of Section 39203, Section 14808.1 shall govern the purchase of motor vehicles by the state.

SEC. 4. Section 3 of this act shall become operative only if Assembly Bill No. 357 is enacted by the Legislature at its 1968 Regular Session and in such case at the same time as Assembly Bill No. 357 takes effect; at which time Section 14808.5 of the Government Code as added by Section 2 of this act is repealed.

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