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AUTOMOBILE STEAM ENGINE AND OTHER EXTERNAL COMBUSTION ENGINES

GOVERNMENT
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JOINT HEARINGS

BEFORE THE

COMMITTEE ON COMMERCE

AND THE

SUBCOMMITTEE ON AIR AND WATER POLLUTION

OF THE

COMMITTEE ON PUBLIC WORKS UNITED STATES SENATE

NINETIETH CONGRESS

SECOND SESSION

ON

THE AUTOMOBILE STEAM ENGINE AND OTHER EXTERNAL COMBUSTION ENGINE ALTERNATIVES TO THE INTERNAL COMBUSTION ENGINE

MAY 27 AND 28, 1968

Serial No. 90–82

for the use of the Committees on Commerce and Public Works

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AUTOMOBILE STEAM ENGINE AND OTHER EXTERNAL COMBUSTION ENGINES

MONDAY, MAY 27, 1968

SENATE COMMITTEE ON COMMERCE AND THE
SUBCOMMITTEE ON AIR AND WATER POLLUTION
OF THE SENATE COMMITTEE ON PUBLIC WORKS,
Washington, D.C.

The committee met at 9:45 a.m., in room 5110, New Senate Office Building, Washington, D.C., Senator Edmund S. Muskie, presiding.

Present: Senators Magnuson, Muskie, Moss, Pearson, and Baker.

Senator MUSKIE. The committee will be in order.

As a guest in this room, I feel a little presumptuous in opening the hearings, but it is a pleasure to do so at the invitation of Senator Magnuson, chairman of the Commerce Committee. And I would ask him to open this hearing.

Senator MAGNUSON. You are a welcome guest here in this committee room.

The matter before us today not only touches the deep interests of your Subcommittee on Air and Water Pollution, but it also raises subjects affecting transportation and the Commerce Committee. That is why we are holding these joint hearings.

Last year in 5 days of hearings our committees explored the technical and economic feasibility of electric vehicles. This year we will be concerned with the potential and possibilities for steam vehicles.

Although the last steam car to receive any general public acceptance was the fabled old Stanley, with its cumbersome boiler and long warmup time, last year's report of the Department of Commerce's Panel on Electrically Powered Vehicles, entitled "The Automobile and Air Pollution," suggested that steam car technology has taken giant strides since the days of the Stanley Steamer. For that report stated that the steam engine might be the most "reasonable alternative to the internal combustion engine in terms of meeting both performance and emission requirements."

We hope, therefore, through these hearings, Mr. Chairman, to learn whether some of the earlier problems with steam propulsion systems have been overcome and whether there are specific advantages which steam engines might offer—both in the emission of fewer pollutants and in improved performance and maintenance.

Naturally, we shall also be interested in these hearings to receive estimates of the cost of such vehicles and to hear discussion of those economic barriers which a producer of steam cars might encounter.

With public discussion of alternatives to the internal combustion

engine, we hope to stimulate increased inventiveness in this area and to indicate the sincere interest of the Federal Government—and I underline that—in reducing, through developments such as these, the frightening pollution of our environment.

So we look forward to the testimony at these hearings.

In addition, I am pleased to note, Mr. Chairman, that we shall have an actual demonstration of two modern steam cars outside the north entrance of the New Senate Office Building, at First and C Streets NE., immediately after the hearings are recessed. We were going have them earlier this morning, but because of the weather conditions we postponed them until after the hearings today.

And now I am sure the distinguished chairman, who has done so much to make the public aware of both air and water pollution, the distinguished Senator from Maine, may have a short statement before he proceeds with the hearings.

Senator MUSKIE. Thank you very much, Senator Magnuson.

I am pleased once again to join with the chairman of the Senate Commerce Committee in holding hearings on alternatives to the internal combustion engine.

The Subcommittee on Air and Water Pollution has a deep and continuing interest in any proposal which will assist in the Nation's effort to preserve its vital air resources. It was for this purpose that the Clean Air Act Amendments of 1965 were enacted. The automotive emission standards promulgated since enactment of that legislation are the beginnings of the essential effort to cut down on our major source of air pollution.

New standards will soon be promulgated for 1970 model cars, trucks, and buses. If the industry meets those standards and the control systems designed for 1968 model cars are effective, a reduction in air pollution will result. But there may be a limit on the ability of the industry to control emissions from the internal combustion engine. The need for reduction of emissions may exceed the technology of control.

It is this possibility with which we are concerned today and with which we were concerned last year when hearings were held on electrically powered vehicles. The Congress and specifically the Commerce Committee which has jurisdiction over transportation matters and the Subcommittee on Air and Water Pollution have a public responsibility to pursue and develop these alternatives.

I look forward to these hearings and hope the testimony which will be received today and tomorrow will add to public, industrial, and governmental understanding of better means to control the quality of our environment.

So, Mr. Chairman, it is a pleasure to join with you once again for this most constructive purpose and at this point to invite our colleagues to make any comments they would like to make.

Senator Pearson?

Senator PEARSON. I have none.

Senator MUSKIE. Senator Moss?

Senator Moss. I have none.

Senator MUSKIE. Senator Baker?

Senator BAKER. I have none.

Senator MUSKIE. Our first witness, is identified with an organization whose name is a challenge in itself, Dr. Robert Ayres, of Resources for the Future, Inc.

STATEMENT OF ROBERT U. AYRES, RESOURCES FOR THE FUTURE, INC.

Senator MUSKIE. Mr. Ayres, it is a pleasure to welcome you this morning. You may proceed in your own way.

Dr. AYRES. Thank you.

As you just said, my name is Robert Ayres, my education was in mathematics and physics, with degrees from the University of Chicago, University of Maryland, and a Ph. D. from the University of London.

In 1962 I joined the Hudson Institute, a policy research organization specializing in national security problems, mostly for the Department of Defense.

Two years ago I embarked on a broad study of urban transportation technology under the sponsorship of the environment quality program of Resources for the Future, Inc., which is a nonprofit organization here in Washington.

Last year I joined RFF on a full-time basis to continue the study and others of a related nature, and I might mention that a first draft of the study in urban transportation technology was finished earlier this year. We are currently working to complete the final version.

It is a great privilege to have the opportunity to be here today.

I take it the purpose of these hearings is not to discuss the effects of economic concentration on the acceptance of new technology in the automotive industry, or to rehash the reasons why the Stanley brothers, Abner Doble and others, were not able to compete effectively against Ford and General Motors. If this is relevant at all today, it would presumbly be in the province of another subcommittee. The explicit purpose of these hearings is to explore the present technological capabilities and future potentialities of steampower, or more generally, external combustion engines for automobiles, buses, and trucks. Before going into specific details on this question, however, I think a few remarks on the broader context would be in order.

In a perfectly operating free competitive market system there would be no "pollution" problem. The markets' "invisible hand" would—subject to some qualifications I need not discuss here—operate to produce maximum social welfare. This is one of the basic postulates we make about the operation of our economy.

This term "welfare" is used in a technical sense quite remote from the usual connotations of assistance to the indigent; welfare, here, refers to the extent to which the whole range of needs and wants of the entire population are satisfied. If, as I say, a competitive market existed for all goods and services as well as disservices, then economists believe the optimum social result would occur if the market were allowed to operate without any interference.

Unfortunately things do not work out that way in practice, due to failures in the market mechanism. One such failure is the existence of monopolies or quasi-monopolies which eliminate or reduce competition. Another more subtle failure is the fact that certain goods, services, and disservices—and if for example, you unwillingly breathe

smog, you are getting a disservice—are excluded from the market because of the pattern of existing laws and common property institutions. Most notably, this applies to public goods, which everyone theoretically has a right to use and, by implication, abuse.

In other words, since everybody "owns" the environment, everybody can use it, without payment, as much as he pleases. Unfortunately, some uses exclude others, as we all know: thus if a papermill or chemical factory exercises its right to unlimited free use of the environment as a place to dispose of residuals or wastes from its production processes, the rest of us are unable to exercise our rights to enjoy the natural environment clean and unsullied, and this is an inherent contradiction in the ration of "public" goods.

The point here is that the exclusion of certain goods and services, notably those provided "free" by our natural surroundings, from the marketplace makes it possible—indeed inevitable—that two parties engaged in an economic transaction within the operation of the competitive market will often impose uncompensated disservices on third parties not involved in the transaction. The paper mill or chemical plant I spoke of are examples in point. So is the private automobile. Whenever we use our cars we impose uncompensated disservices on others. I refer not only to noxious exhaust gases and noise, but also to congestion—each additional automobile on a crowded highway slows down all the others a little bit—and even to social disharmony, since automobile usage requires highways, which must be built through somebody's backyard and some of those who are unwillingly displaced are not the major beneficiaries of the roads.

To summarize my introduction, then, automotive transportation is a producer of a wide variety of significant external costs to parties not involved in the buying or selling of vehicles. These would, in a perfectly competitive market, be internalized and therefore taken into account. As our economy presently works they are not internalized and can only be taken into account through the political process. These hearings are one step in that process.

The topic for today is steampower—or external combustion engines—but the underlying question is how to reduce or eliminate the external costs of the internal combustion engine.

I will not dwell on a point which will doubtless be made by others and which I think is established beyond any reasonable doubt; namely that even ordinary reciprocating steam engines are at least the equal of conventional reciprocating ICE's with respect to response, acceleration, peak power and thermal efficiency, or specific fuel consumption. As applied to various types of automotive vehicles, however, there are a number of other important points of comparison.

Perhaps the outstanding advantage of steam engines and potentially, all types of external combustion engines, is the fact that high torque at zero speed makes it possible to eliminate the clutch and transmission which adds substantially to the complexity, weight, cost and maintenance problems of today's ICE-powered vehicles. The last point is especially significant for large vehicles, such as trucks and buses, with relatively much less power per unit weight than automobiles. Because they are underpowered they require a great deal more gear changing than automobiles. As a consequence bus and truck transmissions re-

ceive very heavy wear and require a great deal of maintenance. This could be totally eliminated by using steam or vapor engines.

Brake lining wear and replacement—another constant problem for heavy vehicles—apart from the possibility that serious health hazards may arise from the asbestos particles injected into the atmosphere, could be substantially eliminated since a steam engine can provide instantaneous reverse acceleration, not merely an added drag as in the case of an internal combustion engine, thus making mechanical brakes virtually unnecessary except for keeping the wheels locked when the engine is off. I am assuming here that the engine is properly designed for this purpose.

In addition, steam engines and external combustion engines in general, require no starter motor, no carburetor, or fuel injection, no engine-block cooling system, no distributor, only one spark plug, no muffler and no elaborate air-pollution control equipment. The engine itself is likely to be smaller, since a 2 cylinder double acting (or 4 cylinder single acting) has the same number of power strokes as an 8 cylinder ICE. These savings more than compensate for the extra weight of the steam or vapor generator and condenser. Moreover, most of the above-mentioned ancillaries absorb parasitic power and detract from the power available at the rear wheels.

In toto, it is estimated that 40 percent of the engine power of an ordinary internal combustion engine is dissipated within the power train, whereas only about 10 percent of the power of a steam engine is wasted in this manner. A comparison between several types of internal combustion engines, including turbines and several types of external combustion engines is shown in the following table.

COMPARISON OF ALTERNATIVE PRIME MOVERS PROVIDING A MAXIMUM OF 200 HORSEPOWER AT WHEELS

Engine	Transmission needed? [1]	f Overload capacity (percent)	g Parasitic losses [2] (percent)	R Rated horsepower to supply 200 horsepower maximum at wheels [3]	Maximum thermal efficiency at normal full load (percent)	Energy conversion efficiency including parasitic losses [4] (percent)	Specific engine weight (pounds per horsepower)	Total weight power train (pounds) [1]
Otto cycle reciprocating (4-stroke)	Yes	30	40	256	[5] 27.0	16.0	3.0	900 (±25)
Wankel, rotary	Yes	15	40	290	[5] 24.0	14.5	1.5	575 (±25)
Diesel, reciprocating	Yes	30	30	220	32.0	23.0	5.0	1,250 (±50)
Gas turbine, simple (nonregenerating)	Yes	15	15	204	[5] 25.0	21.0	1.5	450 (±50)
Differential turbine (nonregenerating)	No [6]	15	15	204	[5] 22.5	21.0	2.0	400 (±50)
Mallory, rotary (differential)	No [6]	15	15	204	[5 7] 25.0	21.0	.6	120 (± ?)
Steam, reciprocating (open-cycle) [8]	No [6]	100	10	111	26.0	20.0	6.0	600 (± 25)
Steam, reciprocating (closed-cycle)	No [6]	0	10	222	30.0	23.0	4.0	800 (± 50)
Vapor, reciprocating (closed-cycle)	No [6]	0	20	222	30.0	20.5	.5	250 (± 25)
Stirling (closed-cycle)	No [6]	50	10	148	40.0	36.0	10.0	1,400 (±100)

[1] Transmission weight assumed to be 150 lbs. in all cases.
[2] Including muffler, air cleaner, engine block cooling system, transmission losses, fan, water pump, etc.
[3] $R=200/(1+f)(1-g)$ where f and g values are expressed in decimals not percent.
[4] Allowing 85 percent boiler efficiency for steam or vapor engines.
[5] Efficiency under partial load tends to drop sharply for engines using carburetors and for turbines.
[6] Transmission not strictly necessary, but a clutch would be required to permit idling; and reduction gears are needed for turbines. In computing weight, an allowance of 50 lbs. is made for the clutch and 50 for reduction gears.
[7] Estimated.
[8] This engine is assumed to recycle most of its water but retains a "vent" capability. 1,000 p.s.i. and 1,000° F. steam conditions assumed.

It will be noted that, contrary to folklore, a reciprocating steam engine of a conventional design, together with its associated steam generator, condenser, and water tank, will probably require a significantly smaller rated horsepower and weigh less than an internal combustion engine power train capable of delivering the same amount of peak power at the rear wheels. This is the only appropriate basis for comparing horsepower outputs. When engines using working fluids other than steam, such as freon gas, are considered, the comparisons are even more favorable to the external combustion engine.

Since fuel is burned continuously at atmospheric pressure—rather than explosively in a confined space—there are no stringent requirements on "octane" ratings and no need for tetraethlyl lead in the fuel. From tetraethyl lead we get about 200,000 tons of finely divided lead particles in the atmosphere environment each year. This is, I think, generally admitted to be a growing health hazard.

Since any distillate hydrocarbon fraction, will serve quite well—and I say distillate only because we don't want sulphur in the fuel—there is no need for catalytic "cracking" and secondary reforming in the petroleum refining process. The extreme scarcity of platinum, now used as a catalyst (notably in the platinum reforming process called platformate in Shell Oil Co. commercial advertising) might be somewhat relieved. More to the point, the petroleum companies would recover more salable fuel per barrel of crude oil, and I think this is a rather important advantage. Continuous combustion at low pressures also results in far more complete burning. Even without controls, external combustion engines produce far fewer unwanted emissions than internal combustion engines, as shown in the next table.

MAJOR EMISSIONS (LBS.) PER POUND OF FUEL CONSUMED (1965)

		CO	HC	NO NO_2	Part.	SO_2 H_2S
Spark Ignition ICE [1] (Otto cycle)	L.A. data	0.500	0.093	0.024	0.00022	0.00014
	N.Y. data	0.472	0.104	0.018	0.00018	0.00014
	PHS est	0.560	0.072	0.031		
		(35,000=3.5%)	(900)	(1500)		
Diesel Engine	L.A. data	0.0045	0.018	0.018	0.0045	0.0045
	N.Y. data	0.0067	0.020	0.025	0.0125	0.0045
Gas Turbine [2]		~0.02		~0.0003		0.002
(Rover 2S-140)		(340)	(neg)	(5.5)	(neg)	(60)
External Combustion [3]	Steam	~0.0075	~0.0016	~0.001		0.0045
	(Williams)	(500)	(20)	(70)	(neg)	
	Steam Thermo-Electron. [4]	$\lesssim$0.0002	(neg)	$\lesssim$0.003	(neg)	0.00042
	Stirling	~0.0015	(neg)	~0.002		0.0045
	(Philips)	(100)	(1.5)	(150)	(neg)	

[1] Calculated by assuming volumetric emissions shown in parentheses (in ppm), 15 lb of air/lb of fuel and molecular weights as follows: CO=28 (=air), HC=140 (≅5×air); NOX=36 (=1.3×air); also

[2] Calculated assuming 63 lb of air/lb of fuel, volumetric emissions in ppm as shown in parenthesis and molecular weights as above, plus SOX=64 (=2×air).

[3] Calculated by assuming volumetric emissions shown in parenthesis (in ppm) 15 lb of air/lb of fuel and molecular weights as above. Sulfur emissions assumed to be the same as Diesel, with similar fuel. If external combustion engines use more than 15 lbs air/lb of fuel coefficients should be increased by the corresponding ratio.

[4] Coefficients supplied by letter from Robert J. Harvey, Manager, Advanced Programs and Planning, Thermo-Electron Engineering Co., Waltham, Mass.

Comparing the Williams engine with the uncontrolled internal combustion engine you would expect a reduction of about a factor of 70 for carbon monoxide and 45 for unburned hydrocarbons. However, the Thermo-Electron burner is probably a better indicator of what a modern external combustion engine can do. The improvement factor is of the order of 1,000 except with regard to NOX. Even so, the im-

provement would be a factor of 10 to 30, whereas NOX is not reduced at all by current air pollution control devices.

Also, because of the continuous, rather than intermittent, nature of the combustion process in an external combustion engine, and the reduced dependence on parasitic auxiliaries, there is no loss of intrinsic engine efficiency under part-load conditions. If a steam car and an internal-combustion-engine-powered car had equal fuel consumption at a steady 40 miles per hour, the steam car would do at least 20 percent better than its ICE counterpart in urban stop-start conditions, according to tests undertaken in Australia. (Light Steam Power (London), January 1968.)

A steam-powered vehicle, would, finally, be considered less noisy than its internal-combustion-engine-powered counterpart. The difference between peak noise levels would be roughly 20 decibels, which implies cutting "apparent" loudness by a factor of 4. It is also approximately equivalent to multiplying the distance between an individual sound source and the listener by a factor of 10. Thus, the loud roaring of bus and truck engines during acceleration and gear changing—one of the greatest annoyances of urban living—would be eliminated, or greatly reduced. The noise level produced by a frequency would also drop very considerably, although at high speeds tires also make a significant contribution. However, new synthetic rubbers are available which can cut tire noise substantially. If engine noise were eliminated, a stronger incentive might exist for undertaking measures to reduce noise from tires.

It may be worth noting of noise and pollution were substantially reduced there might be less objection to utilizing air rights over urban highways, for residences and parks and commercial buildings, thus some of the unfortunate external costs associated with urban freeway construction and some of the resulting opposition to the program might be reduced.

The disadvantages of steamcars in the early years of the 20th century were: high cost; slow starting, 30 minutes or so; risk of boiler explosion; high water consumption; inefficient, bulky design; and danger of winter freezeup.

The high cost was strictly due to low volume production. Stanley Bros., the best known steamcar manufacturer, never produced more than 650 cars in a year, at the same time—1910—Ford was producing 600 cars per day. Stanley never attempted to go into mass production. ("Steam—The Answer to Smog?" Road Test, October 1967.)

Due to its simpler construction, a steam-powered automobile today would cost less to produce on the same scale, and could be produced on a much smaller scale at equal cost, than a comparable internal combustion engine-powered vehicle.

The problems of slow starting and the risk of boiler explosion were both eliminated as early as 1917 when Abner Doble replaced the old "teakettle" type of boiler by a monotube steam generator in which only a small amount of water is contained at any given time. Hence, no explosion is possible. In fact, if you puncture one of the tubes, you get a hiss and some fog and that is about all. It is now realistic to talk about cold starts in 30 seconds or less, and virtually instantaneous starts within 2 hours of the last use of the car.

Water consumption can, in principle, be eliminated completely by means of hermetically sealed closed-cycle design. An alternative approach might permit steam venting perhaps 5 percent of the time during periods of maximum power demand. Nevertheless, it is quite feasible to hold water consumption down to 1 gallon per thousand miles or so.

In the case of a vapor engine, you would have to have a completely hermetically sealed closed cycle. Older steam engines were quite inefficient, resulting in high fuel consumption, due to poor thermodynamic design and limitation to temperatures below 600° F. to 700° F. Today it is perfectly feasible to operate at 1,250° F., as the thermo electron engine does. And 1,000° F. is more or less standard. Using new low-cost, high-temperature, iron-based alloys developed for the gas turbines, it may shortly be possible to exceed even these operating temperatures, and with vapor engines even higher efficiencies seem to be possible with lower temperatures.

The maximum thermal efficiency is related to the difference between the maximum and minimum temperatures during the cycle; to avoid condensation in the cylinder—which would greatly reduce efficiency—the lower temperature is generally held to about 230° F. Thus the older engines achieved about 400° to 450° of superheat, whereas today 800° to 1,000° are normal. This factor alone more than doubles the conversion efficiency of the cycle.

The supposed bulkiness of steam engines has traditionally been due to the boiler, or steam generator. Today, this can be reduced a good deal by using smaller diameter tubing and less of it, as has been demonstrated by the Pritchards, among others. One of the functions of the steam in the steam generator is to store heat so as to "smooth out" the peaks and valleys of the demand for power. However, there exist other inexpensive materials, which have a much greater heat capacity than water vapor. For example, by making use of a molten salt just above its melting point, for instance, as a thermal reservoir, the quantity of steam required and the bulk of the steam generator can be considerably reduced. However, even without such measures the steam generator bulk can be reduced evenly by product engineering. We are not talking about fundamental research here; good design is all that is really needed.

The only remaining difficulty is the last and the most trivial. Winter freezeups can be prevented in numerous ways. The most obvious approach is to add a suitable antifreeze to the water—if one can be found which does not decompose at high temperatures. Alternatively, a "pilot light" or a small electric immersion heater—activated by a thermostat—would be perfectly satisfactory for the water tank if it were reasonably well insulated. Freezing in the condenser—that is, the radiator—if it ever occurs, could be prevented, or cured, by means of thermostatically controlled bypass valves to control the effective heat exchanger surface and even to admit a small quantity of live steam if necessary.

Of course, if a vapor other than water is used, it is easy to specify one that will not freeze at temperatures normally encountered in the Temperate Zone. I mentioned Freon, which has a freezing temperature of −68° F.

Indeed, the very impressive performance of the Freon vapor engine recently developed by Kinetics, Inc., of Sarasota, Fla., suggests that external combustion engine technology may be on the verge of a power-to-weight breakthrough which could open up an entirely new area of applications, for example, to aircraft, high-speed trains, and air-cushion vehicles.

It seems appropriate to conclude this section with a slightly doctored quotation from George Huebner, director of research product planning and development at Chrysler Corp.:

> Many experts believe that the piston engine, internal combustion engine, can only be improved further by greater complication and higher costs. There may well be a trend in this direction. The fact that the engine can compete with the piston engine today in many things and even exceed its desirable characteristics in many others is an indication of its inherent potential. (George Huebner, Testimony at the Hearing of the Subcommittee on Anti-trust and Monopoly, "Economic Concentration" (Part 6), held September–October, 1967, U.S. Government Printing Office, Washington, D.C. (1968).)

Huebner does not apparently believe the internal combustion engine is such a paragon as the industry has been saying. As it happens, the missing word is "turbine," which is natural, since Chrysler has been trying since 1939 to adapt the aircraft gas turbine to automotive use. Without commenting here on the potential values of turbines per se, the evidence suggests that Huebner's optimistic words are even more applicable to steam and/or vapor engines than to automotive turbines. The table which follows lists a number of existing modern steam-cars or engines intended for or thought to be suitable for automotive applications.

The fact that reciprocating steam or vapor engines can be built today which equal or improve upon the performance of conventional internal combustion engines in virtually every important respect—despite a relatively negligible investment in research and development over the past half century—is remarkable testimony to the inherent appropriateness of the external combustion engine to automotive applications.

So much for the facts as I see them. What is to be done about them? Conceivably their publication alone will have an impact by bringing to the attention of some entrepreneur with adequate capital the potential profits to be made here. Indeed, this truly seems to be a case where the external costs of an automobile—I mean the external costs to the public—could be reduced very significantly without any sacrifice in terms of higher direct costs. Even the big auto manufacturers, if they began today with a well-planned gradual phasing out of internal combustion engine production facilities, would probably lose little or nothing by the change. They might also, through real innovation, reverse the growing tide of foreign car imports, which I believe are up 40 percent or more this year, over last.

Unfortunately, the automobile industry may not be willing to act, due to inherent conservatism, and outsiders may be unwilling to enter the field, due to the quasi-monopoly situation which now exists in the industry and the enormous "price of admission" which has been estimated at $300 to $400 million—but may well be more—to set up manufacturing facilities, dealer networks and the like. This situation favors the existing companies and discourages possible competition.

If this is the case that the automobile industry will not do anything, there are two choices. First, it is at least hypothetically possible to

Steam Car Prototypes

	Max. Hp. (overload)	Starting Torque (lb.-feet)	Thermal eff.%	Power train wt. (lb.)	Temp. °F	Pressure psi	Displacement (in^3)	Remarks
Controlled Steam Thermodynamics Mesa, Arizona								7 cyl. Barrel-type engine No. information
Empirical Engineering Co. Los Angeles, Calif.	250	400	?	~100	~800	1000	42	Converted 4 cyl. Mercury Outboard Installed in VW
Energy Systems, Inc.(a) Cambridge, Mass.	200	2100	~26%	?	1000	1000		GM GV-71 Proposal to convert/ Diesel engine
Gibbs & Hosick (a) "Elliptocline" Greensboro, N.C.	1000	4200	?	300 (engine only)	1000	2000	200	9 cyl. Barrel-type open cycle Complete system not operating
Kinetics, Inc. Sarasota, Fla.	350	12,000	30%	340	390 (90 at condenser)	500	150	2 cylinder double-acting vapor engine using freon F-11 Installed in VW
Pritchard Steam Power Pty , Ltd. Melbourne, Australia	~50-75	331	?	~450	870	1000	17.6	2 cylinder double-acting engine Installed in 1962 Ford Falcon
Thermal-Kinetics, Inc. Rochester, N.Y.	~80	500	?	800	to 850	to 1200	100	4 cyl. "V" chain drive Special Chassis Operating since 1958
Thermo-Electron Engineering Corp. Waltham, Mass.(a)	100	340	~30%	500	1250	1200	55	4 cyl. in-line (100 hp version) closed cycle Largest engine is 10 H.P. to date
Williams Engine Co. Ambler, Pa.	125 300 400	500 1105 2734	~26%	500 650 850	1000 1000 1000	1000 1000 1000	56 105 262	4 cyl. in-line open cycle 43 in^3 engine installed in car Special Chassis Operating since 1960

(a) projected

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"legislate" the internal combustion engine off the roads. Statements made by officials of the State of California in the past few years suggest that this may not be so inconceivable as it sounds at present. However, I think it would be a bad precedent and at best a very clumsy use of the power of government.

On the other hand, it is not inconceivable that the Government—Federal or State—could create, by direct or indirect means, a new industry in this field. The precedents exist: the nuclear power industry was essentially created by acts of Government. This has hurt the interests of coal miners and coal mine owners, but on the whole it has probably been in the national interest—not least, because it provides cities with some means of reducing their air pollution problems. Comsat Corp. is another civilian activity created by the Government, this time directly contrary to the interests of the largest company of all—A.T. & T. I think A.T. & T. will survive quite well in its slightly restricted sphere.

To be blunt, I think the time has come for the Federal Government to create another new industry in competition with entrenched and intransigent existing interests. This need require very little, if any, actual investment of Government funds. The determination of Congress to see it done would probably be sufficient to attract ample captial from the private sector. Possible alternative ways of proceeding are, of course, numerous and encompass research, developments, demonstration and procurement, but need not be discussed here in greater detail by me.

Thank you.

Senator MUSKIE. Mr. Ayres, you have taken us into the future at a much faster rate than I expected when I arrived here this morning. You are talking about what is possible today if we were to use it; is that correct?

Dr. AYRES. That is correct.

Senator MUSKIE. The steam engine as a replacement for the internal combustion engine is here in your opinion?

Dr. AYRES. The steam engine per se is here and I think in many respects quite competitive. I do not by any means believe that the steam engine as it exists today is the last word. The fact that the progress has been so considerable with such minimal resources suggests that a great deal of further progress will be possible if real resources are put into this.

Senator MUSKIE. I think at this point it might be useful to include a glossary of terms which the staff put together. This may be helpful before this testimony is over for the lay reader to understand some of the technical discussion that we may get involved in.

Without objection, it will be included.

(The glossary follows:)

GLOSSARY OF TERMS WHICH MAY BE EMPLOYED BY WITNESSES

This glossary is *not* a rigorous, technical set of definitions of the terms listed. It is intended for use as a quick reference to orient Committee Members during witnesses' testimony. Terms are alphabetically arranged.

Brayton cycle engines.—A general class of engines of which gas turbines are the most common example.

Closed cycle engines.—Engines in which the working medium or fluid is not

exhausted to the atmosphere but is re-used over and over again. Modern steam engines proposed for automotive use would be closed cycle.

Combustor.—Burner.

Condenser.—Device in which steam is cooled sufficiently to cause it to change back to the liquid, or water, phase. In a steam car the condenser would be cooled by the ambient air.

Cut-off.—The point during the power stroke when the working fluid inlet valve closes. Witnesses will normally speak of "long cut-off", "percentage cut-off", etc. Cut-off is generally variable in automobile steam engines, and changing it has the same effect in driving the car as shifting gear does in a conventional gasoline car. Long cut-off is equivalent to low gear and short cut-off to high gear.

Diesel cycle engines.—The general class of compression-ignition engines. They are internal combustion engines not requiring spark ignition—used widely on trucks, tractors, small power stations and ships.

Efficiency.—A ratio of output to input energy. There are many different kinds of efficiencies spoken of by engineers When a witness uses this term he should be asked which *specific* efficiency ratio he is referring to.

Expander.—The machinery which converts the expansive energy of the working fluid into mechanical energy. In the context of these hearings, most expanders will be piston-cylinder assemblies However, turbines also are expanders.

External combustion engine.—Engines where the working fluid (such as steam) is separated from the products of combustion by a wall or barrier through which heat must pass. Steam boilers are external combustion devices. So is a hot air furnace in a house heating system. Gas turbines are technically *not* external combustion engines but are often classed with them because of similarities in burner characteristics.

Generator (Also, vapor generator or steam generator).—Equivalent to boiler. The device that utilizes heat energy from a burner to convert a liquid into a gas.

Internal combustion engine.—The products of combustion are the working fluid in the engine. Conventional automobile engines and diesel engines are internal combustion engines. Witnesses will often refer to them as "IC" engines.

Open cycle engines.—Engines in which the working medium or fluid is exhausted to the atmosphere such as in Internal Combustion engines and non-condensing or partially condensing steam engines. Railroad steam engines and "Stanley Steamers" were open cycle engines.

Otto cycle engines.—The general class of engines that operate like the conventional automobile gasoline engine. Most such engines are spark-ignited.

Rankine cycle engines.—A general class of engines of which steam engines are the most common example.

Stirling cycle engines.—The general class of external combustion gas engines.

Torque.—Effort to rotate a shaft as produced by an engine. Characteristically measured in foot-pounds.

Working Fluid.—The fluid or medium which is heated either directly or indirectly and which produces work in the engine expander. In a steam engine, water is the working fluid.

Senator MUSKIE. Is it your judgment that the internal combustion engine, considering the alternative which you discussed this morning, should have no future on the American highway as an automotive vehicle for the average American citizen?

Dr. AYRES. So far as I can judge, it has been developed about as far as it can be. It looks as though it is inherently an inappropriate engine for the purposes that it is being used for. And from the standpoint of the user, the public, it is my belief that an external combustion engine would satisfy our needs better.

Senator MUSKIE. We have been told in the Subcommittee on Air and Water Pollution that the internal combustion engine can be cleaned up to any degree that the public welfare, in the sense that you use the word "welfare," requires. Do you share that view?

Obviously not, but I would like you to expand on it.

Dr. AYRES. I think it can be cleaned up to a significant extent. We might not be having these hearings if the industry had been prompter

to do what it could. But I think when you get beyond about 90 percent, or perhaps 95 percent of the existing level of emissions—which is extremely high—the costs of going further will make it infeasible. Not impossible, but economically infeasible.

Senator MUSKIE. What would be the effect of this kind of cleanup of the internal combustion engine? You are talking about 90 percent now. What would be the impact on the size of the engine, its weight, its cost, its complexity?

Dr. AYRES. Well, the 1970 standards are roughly 70-percent cleanup for hydrocarbons and carbon monoxide. They do not touch oxides or nitrogen, which are toxic. They do not touch lead at all. I mentioned during by earlier testimony that asbestos is also possibly something of a serious health hazard. And by eliminating or reducing the need for mechanical brakes, which would be possible using the dynamic breaking that you get from an external combustion engine, you also reduce the asbestos problem. So the external combustion engine inherently has the capability of reducing a whole spectrum of pollutants, of which we are at the moment tackling only the two most obvious ones, the unburned hydrocarbons, which constitute about 10 percent of the fuel in an uncontrolled car, and the carbon monoxide, which is produced at the rate of about 1 pound for every 2 pounds of fuel consumed in the uncontrolled car.

I think even a 70-percent cleanup is by no means far enough. A 90-percent cleanup is by no means far enough. I think we really should be thinking in terms of bringing the existing level of emissions down to well below 1 percent of the uncontrolled level. This is perfectly possible. It happens without any effort with an external combustion engine. For that reason I see no reason to be lenient with industry going the way they want to go. If they want to go the ICE route, let them equal these results, or at least come close to them.

Senator MUSKIE. In other words the external combustion engine eliminates all of the pollutants which you mentioned?

Dr. AYRES. Essentially all of them. It eliminates lead completely. It would reduce the asbestos problem greatly. It would reduce the oxides and nitrogen problem by about a factor of 25 from the uncontrolled ICE engine, whereas the existing control procedures used on the internal combustion engine may in fact increase that. And it would reduce the carbon monoxide and unburned hydrocarbons down well below 1 percent of the uncontrolled.

Senator MUSKIE. What time frame would be required in your judgment to move from the internal combustion engine to the complete substitution of the external engine?

Dr. AYRES. Complete substitution would certainly take a number of years. I know of no reason, at least one or two production lines might not be put up within 2 or 3 years. I realize you cannot do this overnight, but I do not see any reason for delay in getting started.

Senator MUSKIE. I am going to ask my colleagues to come in for questions at this point. You have opened up areas of questioning which could go on for quite some time and I think we have to get at you from a number of different angles.

Senator Magnuson?

Senator MAGNUSON. What is the Stirling engine concept?

Dr. AYRES. The Stirling engine is an external combustion engine using hydrogen or helium, as the working fluid under very high pressure, and at very high temperatures. Because of its extremely high pressure and temperatures it does require rather exotic alloys, and it also involves a rather complicated mechanical crankshaft arrangement. It is certainly extremely good in terms of emissions. It would also be extremely quiet. It is a very efficient engine. But I think it would not be competitive with a vapor engine or a steam engine in terms of cost. However, for a bus or truck, a Stirling engine might be appropriate.

Senator MAGNUSON. Is Stirling a trade name or a company or what?

Dr. AYRES. Robert Stirling was a Scottish minister, and inventor in the early 19th century.

Senator MAGNUSON. A Scotsman. That was his name?

Dr. AYRES. Yes.

Senator MAGNUSON. The reason I asked, Mr. Chairman, is that an old friend of mine and a very distinguished American scientist, Vannevar Bush, who is in semiretirement—for like all people in that profession he never retires—is very excited about the possibilities of the Stirling engine. I have a letter from him which he sent to me personally, and I would like permission to put it in the record at this point.

Senator MUSKIE. Without objection.

(The letter follows:)

BELMONT, MASS., *May 20, 1968.*

HON. WARREN G. MAGNUSON,
U.S. Senate,
Washington, D.C.

DEAR WARREN: I would be happy to join you at the Hearings this month except for one thing. I put a kink in my back recently, the physicians cannot find out what it is, and in the meantime I cannot travel. I hope they clear it up soon, but I doubt if they will.

I would be glad to write on anything where it might be of some service. You are quite right, I have been much interested in this subject for many years. Let me give you a summary of my point of view.

I feel sure a steam engine can be built which will make a better automobile engine than we now have, and that will not pollute the atmosphere significantly. If someone will show how to make such an engine which is hermetically sealed it will be far better. I am sure Dick Morse can give you the whole picture on this.

My own interest is in the Stirling engine. This, too, will not pollute. I think it will be even better than the steam engine.

I worked on this in the Thirties, but quit when the war came on. Later Phillips and General Electric made models. These were interesting but had serious faults. The primary one was that their output per pound of weight was so low that it ruled them out.

In the last few years I have been at it again, and now I see how to correct the faults. I have made many calculations, filed some patent applications, but have not yet made a model.

I believe I can now build a Stirling engine which has an efficiency in the Diesel range, a weight per horsepower of output less than that of present automobile engines, low maintenance, no pollution. I would be happy to tell you anything about it you might care to know.

But I do not think the automobile industry is going to introduce any new type of engine whatever until it has thoroughly proved itself in some other application. My guess is that steam or Stirling engines will first appear in the marine field on pleasure craft. So it will be many years before we get rid of automobile pollution.

It would be different if we could put through a crash program, as we did for example on the DUKW, and the WEASEL in time of war. But that sort of thing does not happen in time of peace, if we call this peace.

Cordially yours,

V. BUSH.

Senator MAGNUSON. He suggests, as you do, in looking down the road a little bit, that this would not be the alternative for automobile propulsion, but he feels that it has a great future in powerboats and marine propulsion. Do you share that opinion?

Dr. AYRES. Anything in large sizes, yes. I think it is probably best to compare a Stirling engine with a Diesel. In comparison with a diesel it would be much quieter, at least as efficient, perhaps more efficient, and in many ways superior.

Senator MAGNUSON. Dr. Bush, of course, is not one to get too excited. He is what I would call a conservative scientist. But he really feels that this engine has great potential in that field.

So it isn't a company. It is a Stirling theory, is that right?

Dr. AYRES. Yes. The modern Stirling engine has been developed mainly by the Phillips Co. in the Netherlands and General Motors has a license.

Senator MAGNUSON. I will put his comments in the record. That is all.

Senator MUSKIE. Senator Pearson?

Senator PEARSON. Doctor, what is the engine principle, the mechanism of the steam automobile?

Dr. AYRES. Well——

Senator PEARSON. Can you describe it very generally?

Dr. AYRES. Very briefly you have a burner, similar to an oil burner in your home, which heats water and vaporizes it and creates steam. The steam, or other vapor is stored in a coil of small diameter tubing. That is the steam generator. When you want to move a valve lets high pressure steam or vapor into the cylinder, where it expands and pushes the piston forward. And when the piston reaches the extremity of its stroke another valve opens and lets the expanded steam out. So you have a piston action very similar to the internal combustion engine except that instead of an explosion occurring inside of the cylinder you allow high-pressure steam in from an external reservoir, and when it has expanded against the piston you let it out. Then you conduct this exhausted steam back through a condenser, where it is returned to the feedwater tank and thus recycled, so you don't have to lose it out the tailpipe.

Senator PEARSON. What would be the comparison as far as noise is concerned? I know you dealt with that problem in your statement.

Dr. AYRES. Essentially it is as though if you were 10 feet from an internal combustion engine, you moved to 100 feet away.

Senator PEARSON. I was interested in your recommendation that the Government enter this field, because private industry would not. I see a rather clear distinction between the nuclear power industry and COMSAT and that which you propose the Government promote or enter into the field of construction of automobiles. Do you actually feel that the public interests and the nature of this enterprise is such that the Federal Government should in your words "create a new industry" in competition?

Dr. AYRES. I do not feel the Federal Government should become involved in manufacturing automobiles by any means. When I said create a new industry I meant indirectly.

Senator PEARSON. You meant research and development?

Mr. AYRES. Through research and development, and possibly pro-

curement. For example, you might direct an agency of Government to procure a certain number of vehicles of a certain type, from whatever source they become available.

Senator PEARSON. Thank you very much.

Senator MUSKIE. Senator Moss?

Senator Moss. Thank you, Mr. Chairman.

What would be the difference in the bulk or the weight of an external combustion engine which is comparable to an internal combustion engine in the power that it delivers?

Dr. AYRES. I have some data on one of these charts here. As I said, in the testimony, there is some folklore to the effect that steam engines are bulkier and heavier than internal combustion engines, and they might be, if you are comparing shaft horsepower. But if you are comparing horsepower available at the rear wheels, which is the appropriate figure of merit, the steam engine need not be larger. In fact, the evidence seems to suggest that it will be lighter and certainly no more bulky.

Senator Moss. In your statement you said that the transmission was eliminated in the external combustion engine. Would you inform me as to the means used to transfer the power to the wheels, and could you comment on the complexity of that system as compared to the transmission in the internal combustion engine with which we are acquainted?

Dr. AYRES. The steam engine would operate in a fashion very similar to an electric motor. If you had the electric motor attached directly to the axle, or directly to the wheel, when you want to go you turn it on and when you want to stop you turn it off. And you control the amount of power you want by appropriate means. It is just the same with the steam engine. The steam engine produces a maximum torque at zero speed, which means it is self-starting. The engine would be off when the car is stopped, with nothing happening at all, except maybe the burner and/or an auxiliary power takeoff might be operating. When you wish to move the car you open the valve and allow steam into the cylinder and you go.

Senator Moss. In other words there is a direct connection all of the time to the rear wheels? It doesn't have to go through any gears or anything of that sort?

Dr. AYRES. Correct; yes.

Senator Moss. Are you aware of the prior work on the freon Rankine cycle engines, and the conclusions as to feasibility, including safety considerations, which were reached?

Dr. AYRES. I am aware of some prior work on freon Rankine cycle engines. The steam cycle is the Rankine cycle. What you may be referring to is work on turbines. There has been a lot of theoretical and experimental work done in the aerospace industry, for the space program mainly, in connection with very small turbines. But I am not aware of any work, other than the company I mentioned in Florida, that has worked on freon Rankine cycle engines in a reciprocating configuration, that is, of the piston engine type.

Senator Moss. I think the Army Corps of Engineers has been doing some work on this.

Dr. AYRES. Not that I know of. They have certainly looked at tur-

bines. I don't know of any freon reciprocating engine work they have done.

Senator Moss. Getting back to this transmission, would these external combustion vehicles be as easy to operate as the internal ones that we know now?

Dr. AYRES. At least as easy. There is on gear changing. You have the pushbutton ease of operation.

Senator Moss. Just push it on or off?

Dr. AYRES. Yes; push it on or push it off.

Senator Moss. Would the sensation then be somewhat similar to that a person now has in driving his car? It would start more slowly, maybe?

Dr. AYRES. No. In fact, it is quite easy to design a steam engine to spin the wheels. In fact in some cases you have to gear them down—actually reduce the effective torque. You get a completely smooth acceleration up to the speed of the car, which can be set at whatever you want to provide the horsepower for.

Senator Moss. What about fuel consumption? Would that vary with the speed at which you were driving the vehicle?

Dr. AYRES. Fuel consumption would always vary with the speed, because it varies with the power that you use. However, I did comment that the efficiency of the use of fuel would not vary with the speed very much. Much less than the efficiency of the internal combustion engine.

Senator MAGNUSON. What kind of fuel are you talking about?

Dr. AYRES. Any kind of distillate petroleum based fuel. That could be kerosene, diesel oil, or gasoline.

Senator MAGNUSON. You could use any variation of petroleum products?

Dr. AYRES. Presumably it would be some middle type low-octane gasoline.

Senator MAGNUSON. Kerosene?

Dr. AYRES. Kerosene or gasoline.

Senator MAGNUSON. Could you use gasoline?

Dr. AYRES. Oh, yes.

Senator MAGNUSON. So you would still be using the technology of our great petroleum industry?

Dr. AYRES. Yes. As a matter of fact, as I commented, the industry would be able to obtain more salable fuel per barrel of crude oil without the extremely difficult requirements for high-octane antiknock qualities.

Senator MAGNUSON. Excuse me. I didn't mean to interrupt you.

Senator Moss. I am going to be very curious to see the demonstration vehicles. I have grown up in an age, as I guess we all have, when all automobiles had internal combustion engines. It is hard for me to visualize another type.

Thank you very much.

Senator MUSKIE. Senator Baker?

Senator BAKER. Thank you, Mr. Chairman.

The chairman made reference to the use of petroleum products. I might point out respectfully that during the recent gold crisis one of my constitutents suggested we substitute burley tobacco and Tennessee whisky for gold, so maybe we can do that for fuel.

Dr. Ayres, you talked, as I understand it, almost entirely about reciprocating cycle?

Dr. AYRES. That is right.

Senator BAKER. Is there a comparable advance or inquiry into the field of closed-cycle turbine applications for steam?

Dr. AYRES. I didn't discuss that. There is, I think, a very distinct possibility for small closed-cycle turbine, using a fluid other than steam, which would be feasible for automotive application. In all probability steam would not be appropriate for a small turbine.

Senator BAKER. But a vapor engine of some type using a turbine, external combustion, or some other type of energy excitement might still be in the realm of possibility for automotive use?

Dr. AYRES. Yes; it might indeed.

Senator BAKER. Is there active inquiry into that field to your knowledge?

Dr. AYRES. There are several projects that I have heard of. I haven't heard that any of them have gotten very far. I don't know that any have attempted to install an engine in a vehicle. I don't believe so.

Senator BAKER. It is your present view that for the immediate future a reciprocating cycle would be more practical and feasible for automotive applications than a closed-cycle turbine system?

Dr. AYRES. I would say so, simply because the technology is very familiar, and because of the torque characteristics. However, it is more complicated in a way; having to use a crankshaft certainly adds to the complexity.

Senator BAKER. Adds to the what?

Dr. AYRES. We are already talking about quiet, smooth power, but closed-cycle vapor turbine to work without a transmission, then it might indeed be a good future alternative.

Senator BAKER. As a matter of fact, inherently, and from a theoretical standpoint, a continuous operation closed-cycle turbine would deliver smoother power and more efficient power?

Dr. AYRES. We are already talking about quiet, smooth power, but possibly so. As for efficiency, that remains to be seen.

Senator BAKER. Speaking of efficiency, whether we are talking about an internal or external combustion engine or Stirling engine or freon cycle engine, we are still essentially talking about some version of a thermodynamic machine which has an upper theoretical limit of efficiency, which would be in the range of what, for a reciprocal steam system?

Dr. AYRES. It depends on the temperature.

Senator BAKER. Say in the range of 1,100°, which is, I think, the practical upper working limit at the moment as I understand it?

Dr. AYRES. Well, perhaps 1,200; yes. At those temperatures I think there is every possibility of obtaining efficiencies above 30 percent.

Senator BAKER. It is almost theoretically impossible to go above 40, 45, or 50?

Dr. AYRES. With a Stirling engine you can do better than 40 percent. They have done so. But at much higher temperatures.

I agree with you, that going beyond that, with existing materials, would be very difficult. And if you are thinking of fuel cells, for example, as a comparison, yes, this is quite true, that you may theoreti-

cally eventually get better efficiencies with fuel cell. But I think that is some way down the pike.

Senator BAKER. I am not really trying to elicit a criticism of any steam application on the basis of comparative efficiencies. I am just trying to fix it in my mind that with all of the systems we are speaking of—internal, external, Stirling, recip—with all of them the upper limits of efficiency are fairly low, because they are all thermodynamic machines.

Dr. AYRES. That is correct.

Senator BAKER. By way of comparison, I take it your evaluation of the upper practical limits of efficiency of the internal combustion engine would be below 30 percent?

Dr. AYRES. No; its upper theoretical efficiency may be even higher. The problem is it never achieves its theoretical efficiency.

Senator BAKER. That may be higher because of higher combustion temperatures and better fuel utilization?

Dr. AYRES. Partly that, and partly because it is not strictly speaking a heat engine, so it is not limited by quite the same parameters that a heat engine is limited by. But the problem really is in practice it never achieves those efficiencies.

Senator BAKER. That is quite so. And the internal combustion engine is something of a hybrid of a pure thermodynamic machine and a kinetic machine, something between the two?

Dr. AYRES. Something of a hybrid; yes.

Senator BAKER. And the theoretical efficiencies of an internal combustion engine would probably be higher than a heat engine, but the practical efficiencies are probably lower. Is that a fair statement?

Dr. AYRES. No; I wouldn't quite put it that way. In the case of an internal combustion engine, the efficiencies are limited by temperature and pressure, usually. And it is again a question of materials. For any given set of alloys available at a given time, I don't really know which type of engine would give you the higher theoretical efficiency. But I don't know it matters terribly. They would be within shooting distance of each other.

Senator BAKER. Now, as Senator Muskie pointed out, you have, and quite effectively, catapulted us into the future, so to speak.

I would like to leapfrog a little bit and go from the near-term future to the far-term future, and that is why I brought up the matter of thermodynamic machines.

What do you visualize as the next possible step for small-unit automotive-type power applications that would be freed of this 40 percent or 50 percent upper efficiency limitation?

Dr. AYRES. Well, that actually opens a wide field for speculation. One way of getting away from such limitations is to run vehicles on tracks or to feed power in from the outside, somehow. This could conceivably be done by electromagnetic means. In other words, if all of the highways were fitted with suitable electromagnetic devices at some point in the far future, you might operate at rather higher overall system efficiencies. Or alternatively, you might use fuel cells, assuming they can be developed to somewhere near their theoretical potential, which will give 50, 60, or 70 percent efficiency.

Senator BAKER. But the hangup on an electromagnetic machine is so far as the power is derived from a thermodynamic device.

Dr. AYRES. Ultimately, yes.

Senator BAKER. So you still are limited by thermo-dynamic——

Dr. AYRES. That is even true of nuclear power. Even nuclear power is dependent on a thermodynamic——

Senator BAKER. Until we get controls of thermonuclear fission or hydrodynamics.

Dr. AYRES. Even that might be thermodynamic in origin.

Senator BAKER. The CTR would not be of thermodynamic energy.

Dr. AYRES. It need not be, but it depends on the design.

Senator BAKER. What do you see as the next step? As I see it, when we are speaking of steam engines, freon engines, whether recips, or turbines, we are still talking about the same relatively low range of ultimate efficiencies.

I am wondering what the next step beyond this middle ground of steam et cetera might be, whether fuel cells or electric engines or the like. I think you have already answered. I think it must be in the electromagnetic range, and that gets you back to the electric car.

Dr. AYRES. I think in the long run, yes; but I do think it is somewhere in the long run.

Senator BAKER. Thank you.

Senator MUSKIE. Just two or three more questions, only because we need to provide enough time for the other witnesses.

How would you compare the potential of the electric car with the external combustion engine?

Dr. AYRES. As of now?

Senator MUSKIE. Yes.

Dr. AYRES. As of now, probably with an all-out effort you could build an electric car which would perform in a satisfactory way. It would be extremely difficult, because you would have to use very sophisticated electronics. You would probably have to use a high temperature battery, either sodium sulfur or chlorine, because other batteries which might ultimately be usable at lower temperatures simply haven't yet been developed to the point where they can supply the necessary power, as well as energy. Fuel cells are still far from their theoretical potential. They do still involve very costly catalysts, platinum, notably, and so you could build something if you want to spend quite a lot of money, and it would still take you some years to fit everything into place; but you could. And it would perform adequately: it would give you ranges of two to three hundred miles, and very good efficiency. However, I don't think it is something that we can count on in the very near future to satisfy the bulk of our transportation demands.

I don't know whether there exists a large market for a small electric runabout, city car, such as a number of companies are thinking of producing. I wish them luck; I hope it does turn out to be a commercial success. But that is speculation.

Senator MUSKIE. So that of all of the options now available to us, you would say the external combustion engine is the best answer to our automotive needs for the grassroots driver.

Dr. AYRES. For the near future; yes.

Senator BAKER. May I ask one more question that I meant to ask and didn't.

Dr. Ayres, you piqued my curiosity when you spoke of using molten salts as the vapor drive.

Dr. AYRES. As a thermal storage technique.

Senator BAKER. Right. Did you intend to use it as a thermal source or what?

Dr. AYRES. Simply thermal storage device so you can store heat in less volume than would be required, for your only source of stored heat is the steam or vapor.

Senator BAKER. So you would use it in the generator?

Dr. AYRES. Yes; in conjunction with the steam generator.

Senator BAKER. You would still have water vapor drive.

Dr. AYRES. Yes; or some other vapor.

Senator BAKER. That brings up one other brief line of inquiry.

Molten salts, of course, are in some ways uniquely limited themselves to the sustaining of fission reactions. You can have molten salts of radioactive material, for instance, which are heat forming themselves. Do you see that as a possibility for a power source? There is a good bit of work in that field by the AEC, in preparation for building thermal reactors.

Dr. AYRES. I did some thinking about using a beta emitter such as strontium-90 as a source of power. Certainly in terms of compactness, and length of time you could go without refueling——

Senator BAKER. Which would be several thousand years probably.

Dr. AYRES. Actually 10 or 20 years. But it would be terribly costly. So costly that despite a fairly serious effort, we couldn't see any conceivable way of bringing the cost down to the right ballpark. Maybe somebody has, I don't know.

Senator BAKER. What would be the heavy elements of cost? The piping, tubing, pumping and valving, would that be the cost burden?

Dr. AYRES. No, just the cost of the isotopes themselves.

Senator BAKER. And the shielding effects.

Dr. AYRES. You do have to have some shielding. The use of gamma emitters really falls down due to the shielding problem in small vehicle sizes. You spend so much weight on shielding that you don't have anything left. A beta emitter can be shielded within a fairly compact size. If you could find a way of translating the energy release on these beta particles emitted into heat or directly into electricity you are on the way. But the isotopes are quite costly. I don't know of any way to bring the cost down.

Senator BAKER. The volume required for a closed cycle system would be very, very small.

Dr. AYRES. It would be physically small, yes. But in terms of the amount required for a vehicle, it would still be very costly.

As I recall the number is something like $25,000 for strontium-90 to power a small car.

Senator BAKER. For strontium-90.

Dr. AYRES. For example.

Senator BAKER. As the salt of strontium-90.

Dr. AYRES. I don't know what form it is usually available in.

Senator BAKER. Thank you.

Senator MUSKIE. In the internal combustion engine, the average driver uses engine drag as a means of controlling the car. Would you

have anything comparable in the external combustion engine? Would the absence create any special problem?

Dr. AYRES. No, in fact with the external combustion engine you can do better. Instead of just allowing the engine to drag and thus slow down the car, you can in fact reverse it—that is to say, you can get reverse torque—simply by pushing a button, or positioning a lever, and thus get so-called dynamic braking. This is how you can potentially save a great deal on brake wear.

Senator MUSKIE. From the point of view of the consumer, how would the external combustion engine compare with the internal combustion engine in cost, maintenance, and in complexity of operation?

Dr. AYRES. Well, the evidence that I see suggests that the external combustion engine would be basically much simpler. It would eliminate all of the auxiliaries I mentioned, notably the transmission and clutch, also the starter and so on. It would be, therefore, basically cheaper to produce and because of its simplicity, its maintenance problems would be reduced.

Now a number of people believe that steam engines can be built to run 500,000 miles. That I leave for time to tell. But I don't think there is any doubt but that a steam engine can run at least as long and quite possibly longer—quite possibly much longer—than an internal combustion engine for a similar amount of maintenance.

Senator MUSKIE. Thank you very much for very stimulating testimony. You have been an ideal opening witness for these hearings.

May I announce that due to the weather we have moved the demonstration to the upper level garage of the ground floor of this building.

The next witness is Mr. Herbert L. Misch, vice president of engineering, Ford Motor Co.

Would you identify the gentlemen with you and proceed, Mr. Misch?

STATEMENT OF HERBERT L. MISCH, VICE PRESIDENT, ENGINEERING STAFF, FORD MOTOR CO.; ACCOMPANIED BY JAMES E. HEYWOOD, CHIEF RESEARCH ENGINEER, FORD MOTOR CO.; AND DONALD JENSEN

Mr. MISCH. Thank you, Mr. Chairman. I have a relatively brief formal statement. If it serves your purpose, I would prefer to read it.

I refer to some exhibits that are attached to the statement and I would like that they be made a part of the record. After we have completed this statement, we are prepared then to cover the exhibits in more detail and have charts here that we can point to, so that it may be a little easier to go through the exhibits that way.

Senator MUSKIE. Fine. You may proceed. And the exhibits will be included in the record.

Mr. MISCH. I am Herbert L. Misch, vice president, engineering staff, of the Ford Motor Co., and I am accompanied by James E. Heywood, our chief research engineer, and Mr. Donald Jensen, executive engineer—vehicle emissions and regulations.

We at Ford are pleased to have an opportunity to share in the continuing effort of these committees and their leadership to serve the

public's interest in improved environmental conditions. In response to the invitation of Senators Magnuson and Muskie, I am here today to present the views of Ford Motor Co. research engineers and scientists with respect to the feasibility and possible use of steam-powered automotive vehicles.

As we have stated on a number of occasions, our company is concerned with automotive transportation in the broadest and most varied sense of that term. It is our policy to seek out and examine any and all propulsion techniques and technologies that might have application in our business, including those that offer promise of serving a broader public interest than might be involved in normal customer demands. For example, low-emission characteristics are an essential parameter for any power source we might investigate.

We have teams of research engineers and scientists continually investigating the development and design of new or improved powerplants. These teams are, in fact, competing with each other to see which can be first to demonstrate a successful advance.

At present, in addition to our continuing work on the internal combustion engine, there are teams working on such power sources as the electric battery, gas turbine, steam, and the stratified charge engine. A full progress report on the electric car, you will remember, was made before these committees by Dr. Michael Ference, Ford vice president of scientific research, at a previous hearing.

Our people have been working for many years on the stratified charge principle, a variation of the internal combustion engine involving the separate metering of fuel and air to permit the burning of very lean mixtures. We are now developing a military application of this power source for the Department of Defense.

We have been doing gas turbine research for some 15 years. In October 1966, we announced the 707 gas turbine engine, the lastest generation in a series of such experimental powerplants. This engine is designed for our present heavy-duty Ford trucks. The turbine, as you know, has the same low-emmission characteristics attributed to the steam engine, but in addition has many other performance features that make it a likely power source for heavy-duty trucks with the next several years.

As to steampower, it may be of interest to the committees that we have from time to time over the years conducted research on the steam engine. Our earlier conclusions indicated a number of disadvantages and problems that discouraged further pursuit of the project. In addition to the relative complexity of this powerplant—and here I now talk about the total system, rather than just the engine itself—and in most instances when we talk about powerplants we are talking about the total system; in addition to the relative complexity of this powerplant, we found a need for extensive controls to permit operation of the steamcar with the same ease and convenience that could be enjoyed with a conventional internal combustion engine.

In the fall of 1966, the Williams Co. of Ambler, Pa., was kind enough to permit us to consult with its people and make a preliminary evaluation of its steamcar, built on a 1953 Ford chassis. We arranged to have the car tested for emissions and found the results to be favorable. We later ordered from the Williams Co. a steam engine installed in a Ford

Fairlane for further test and evaluation. Delivery of this unit has not yet been made and we are informed that delivery may not be possible.

This is only one of many efforts we have made, on a continuing basis over many years, to seek out companies or inventors who might have knowledge or new techniques of potential value in the area of steam propulsion. The most promising of the activities we have noted in this field have been those of Thermo Electron Corp. of Waltham, Mass. As you may remember, Ford Motor Co. announced on March 18 of this year that it has entered into an agreement for joint development with that company of a small steam engine.

Under a contract with the Department of Defense, Thermo Electron has had substantial experience with small generator sets using low horsepower units with ultraquiet operation. This experience, coupled with our own experience in commercial product development, could lead to research results having more general market application. Any advances in technology resulting from this program will, of course, be considered for application to automotive powerplants.

In addition to our arrangement with Thermo Electron, we have had underway in our own Ford laboratories a study aimed primarily at determining whether or not available new technology, when applied to the steam engine, can sufficiently improve its earlier characteristics to make it competitive with the internal combustion engine.

A research program of this kind consists of several stages. Each stage must provide sufficient encouragement to warrant proceeding to a later stage of development.

At present, the Ford steampower program is in the analysis or study stage. Whether or not we proceed to a design and development program will depend upon how encouraging our findings are. The next logical stage would be component development, just as with our gas turbine program, before we move ahead to a prototype vehicle.

A steampower plant in an automobile would require materials capable of withstanding high temperatures. But this same problem has been present in our development of the gas turbine engine. We have made considerable progress in this area, as I pointed out earlier, and this experience should be valuable to us in our steam engine research work. The knowledge gained in one pursuit, therefore, can be applied to another.

We cannot overlook the fact that any power alternative, such as steam, must have sufficient merit to replace the internal combustion engine, which has benefited from the contributions of tens of thousands of engineers, scientists, and manufacturing experts over many years. Components of the steam system will require development to the same high level of sophistication if they are to meet the formidable competition of the internal combustion engine.

In any event, it must be recognized that a change from the present power source to any alternative source would have to be evolutionary. It is not an overnight or 1 year to the next proposition.

It has often been 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. We therefore want to

make certain that our products represent the best in technology for the period of time these facilities will be in use.

In response to the committees' request for specific assessment of the steam engine as we know it today, we have included three exhibits in this statement:

Exhibit I represents our assessment of the basic advantages and disadvantages of a steamplant for automobile use. Also shown are some representative and difficult engineering problems that, at this time, we believe it is reasonable to assume can be resolved. The nature of this resolution, however, may importantly add to the basic complexity disadvantage of steamcars; the balance of factors leading to this disadvantage are indicated in exhibit II. This complexity is important not just as an indicator of cost, but more importantly as a fundamental limitation on reliability and serviceability in customer hands.

Exhibit III is an artist's rendering of one of the steampower concepts we are studying and is shown in comparison with the internal combustion system in a common vehicle environment. It represents that, from a bulk arrangement standpoint, the steampower plant will fit in cars.

I hope that the foregoing information will prove useful to the members of the committees. It is brief, but it represents our present technical assessment of steampower for automobiles.

Let me add that the future of steam or any other alternative to the internal combustion engine depends upon a number of criteria not entirely subject to our control. For example, if experience dictates the desirability of future emission requirements that could be met only by making the internal combustion engine significantly more complex than it is today, then, of course, the comparison of complexity we have shown you would be altered.

It should also be recognized that in addition to our research on alternatives we necessarily must direct a large measure of our talent and resources toward immediate and near-term research, development, design, and testing of the internal combustion engine and its fuel system. This is essential if we are to meet Government standards and other immediate requirements that production and marketing interests dictate.

We feel that our work with the internal combustion engine is indeed a good investment in the future. We are firmly convinced that dramatic progress has been made by our industry in the control of emissions.

With the adoption of exhaust emission controls on 1968 models throughout the country, we already have achieved a reduction of about two-thirds of the hydrocarbon and carbon monoxide emissions on equipped cars. We will be programed to control well over 80 percent of the hydrocarbon emissions of our new motor vehicles by the fall of 1971.

This is a significant achievement but we must look beyond this to possible future needs in emission controls. Some 6 months ago, the Automobile Manufacturers Association, the American Petroleum Institute, and the National Center for Air Pollution Control, an agency of the Department of Health, Education, and Welfare, launched a joint 3-year basic research program aimed at determining the need for further reductions in emission levels as well as defining air quality standards more accurately.

This program is administered by the Coordinating Research Council. Upon completion of this and other corollary programs launched by the Department of Health, Education, and Welfare under terms of the Clean Air Act, the Federal Government will be able to advise us more accurately on what levels of emission control will be required. With a designated target, the automobile industry in turn can better direct its engineering efforts in this field.

In the meantime we continue our extensive activities to reduce vehicle emissions from the internal combustion engine. One phase of this is the $7 million joint research program announced a year ago by Ford and the Mobil Oil Co. Five other petroleum companies have since joined the project. This also is a 3-year program and is concerned primarily with the development of hardware and improved fuel composition which will aid in reducing emissions.

Some very ambitious goals have been established. Program targets for gasoline-powered automobiles are 65 parts per million hydrocarbons, 0.3 mol percent of carbon monoxide and 175 parts per million oxides of nitrogen from the exhaust, with zero levels from the crankcase, fuel tank, and carburetor.

It is, of course, too early to say that we will reach these targets. I mention them only to indicate that our goals for the internal combustion engine are comparable to the emission characteristics of both the steam engine and the turbine. If we are successful, it will, of course, take considerable leadtime to move these concepts to production vehicles, but such an improved internal combustion engine probably could be phased into production in less time than would be required to develop, test, and produce a completely new type of powerplant for a motor vehicle.

With all of these forces aggressively attacking the emissions problems, we have great confidence in the future of the internal combustion engine. Much progress is being made and, as we noted in testimony before your subcommittee last year, Senator Muskie, our projections for 1980 with presently programed controls reveal that hydrocarbon levels in Los Angeles will be no greater than they were in 1940—despite a quintupling of the car population over this period. We believe that this kind of progress nationwide will bring us to the point where vehicle emissions will no longer be a public problem.

In summary, then, I want to assure the members of these committees that Ford Motor Co. is aggressively pursuing all avenues leading to the ultimate goal of clean air. We have no hypothetical blocks to our pursuits, and we remain flexible and open to any technically and economically feasible alternatives to the internal combustion engine. We want to provide the best possible powerplant to meet not only our customers' demands but broad social goals as well. We shall continue our active research projects in pursuit of these goals.

Thank you, gentlemen.

We can, if you would like, go on to an explanation of the charts that are attached to the statement at this time.

(Exhibits I, II, and III follow:)

95-905 O—68——3

ADVANTAGES - DISADVANTAGES OF A STEAM POWER PLANT

	ADVANTAGES	DISADVANTAGES
MAJOR & FUNDAMENTAL	• ULTRA-LOW EMISSIONS • ULTRA-QUIET OPERATION	* COMPLEXITY • HIGH TEMPERATURE MATERIALS
SECONDARY	• MULTIFUEL CAPABILITY • QUICK PASSENGER COMPARTMENT HEAT	• START-UP TIME • POOR HIGH SPEED FUEL ECONOMY

ENGINEERING PROBLEMS - ASSUMED SOLVABLE

- LUBRICATION AT HIGH TEMPERATURES
- MAINTAINING PURITY OF WORKING FLUID
- BOILER DESIGN FOR SAFE OPERATION
- ISOLATION OF POWER IMPULSES
- FREEZING OF THE WORKING FLUID
- ACHIEVE ADEQUATE RELIABILITY & SERVICEABILITY

Exhibit I

POWER PLANT COMPLEXITY COMPARISON

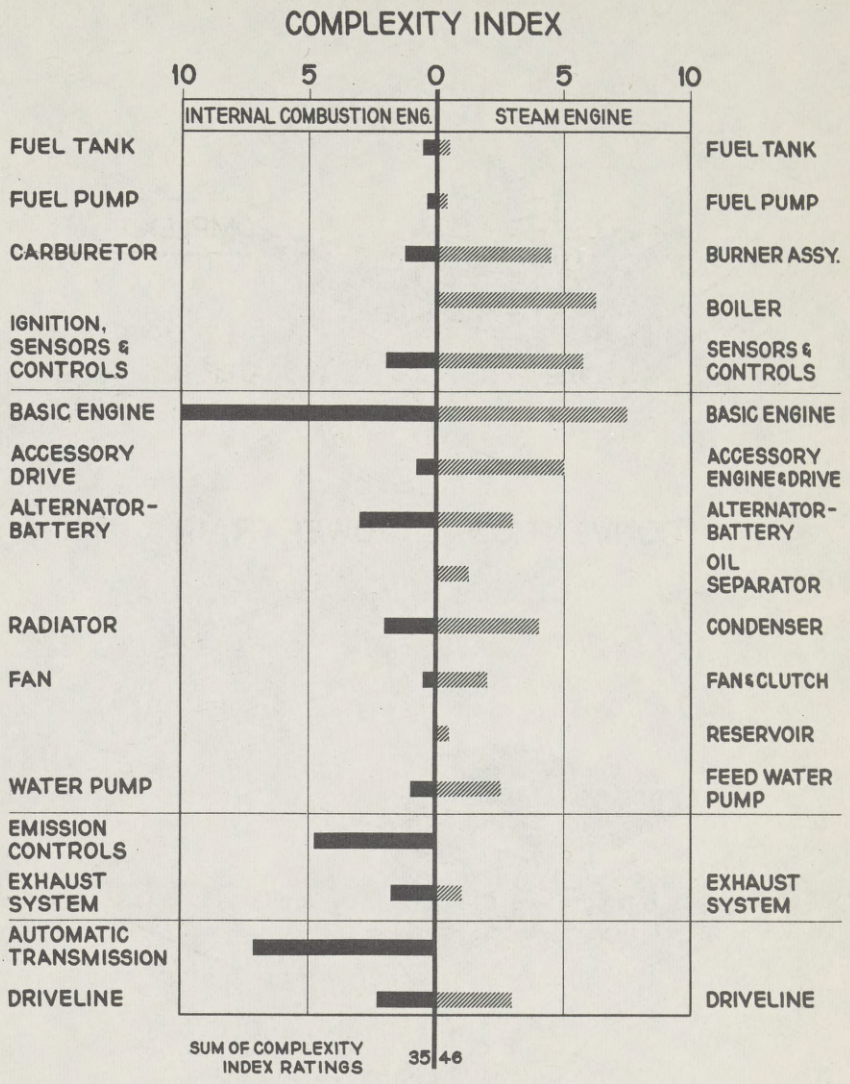
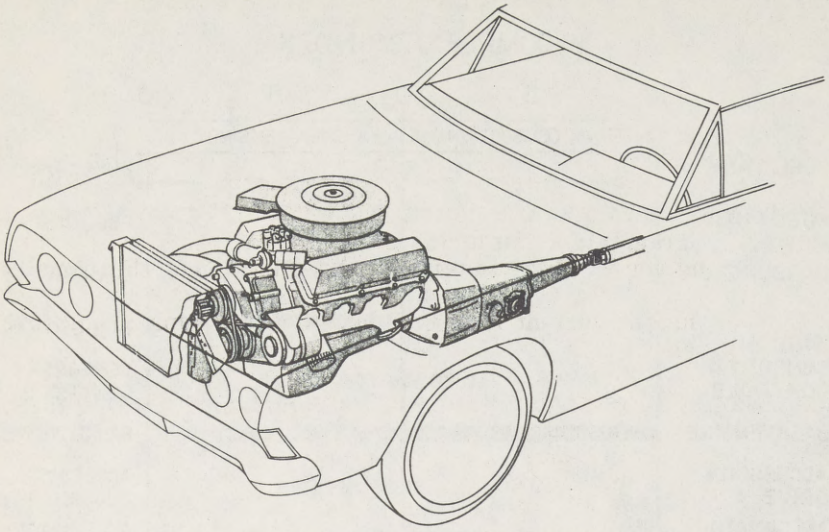
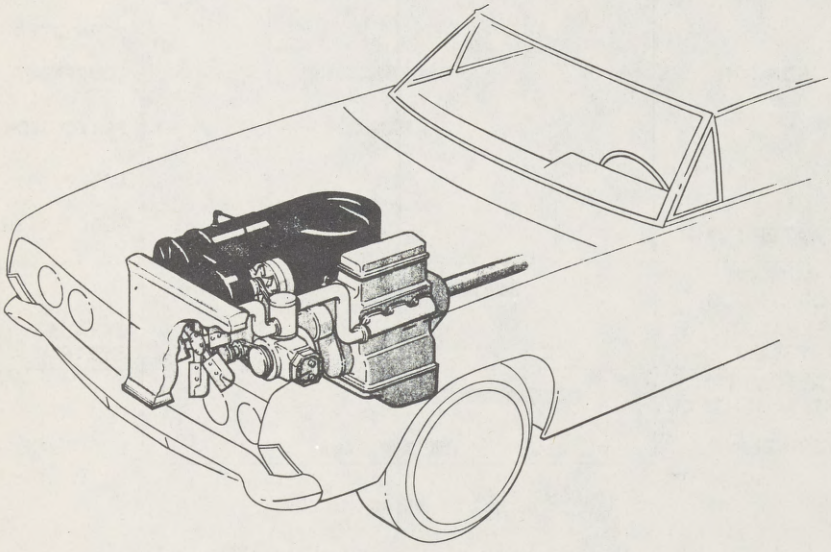


Exhibit II

VEHICLE INSTALLATION COMPARISON



CONVENTIONAL POWERTRAIN



STEAM ENGINE POWERTRAIN

Exhibit III

Senator MUSKIE. I will leave that to your judgment. If you think it would add to the testimony, we would of course be delighted to hear it.

Mr. MISCH. I know your time is pressed today. We would be happy to answer any questions that you have.

Senator MUSKIE. All right. Why don't we do it that way, and then, to the extent you may need to answer our questions, why don't you refer to your charts?

Mr. MISCH. Thank you.

Senator MUSKIE. I was interested in your testimony where you state the program targets for hydrocarbons. As I recall your testimony last year, and you will have to refresh my recollection on this, you did not consider it possible to get as low as 65 parts per million hydrocarbons pursuing the current lines that you were pursuing to improve the performance.

I forget what you said was the floor. It seemed to me it was something above 100, less than 200 parts per million, that was the ultimate. Could you refresh my recollection on that?

Mr. MISCH. I am sorry, I don't remember exactly the context in which we mentioned numbers.

Senator MUSKIE. Well, the 1968 standards are 275 parts per million?

Mr. MISCH. That is right.

Senator MUSKIE. As I recall, you felt that pursuing the technological line you were following at that time, that you still have, you thought you could get down to 200 or maybe below. I then asked at some point whether you could achieve 50 parts per million, because that seemed to be the performance potential of the turbine. As I recall the pretty uniform testimony of the industry at the time, you said you could not get down to 50 using the present technological line you were following.

Mr. MISCH. Well, I think I agree—I remember the testimony, and we did say that at that time we saw no way of getting as low as 50 parts per million. I want to emphasize that these are targets for this inter-industry research program. There are, I believe, 15 different projects ivolved in the program, several of which are research directed toward minimizing the hydrocarbons by various approaches, and it is too early for us to say in fact, in a positive way, that we will reach these targets.

But, they are appropriate goals for such a research program. There is general agreement that they may well be attainable.

Senator MUSKIE. Now, to oversimplify, perhaps, my concept of the development line that you have been pursuing, what you have been trying to do is essentially clean up the internal combustion engine as we now know it to achieve its maximum potential for reduction of hydrocarbons primarily, and also the other pollutants.

How revolutionary must the change from our present concept of the internal combustion engine become in order to achieve something like 50 to 60 parts per million of hydrocarbons?

Mr. MISCH. Well, we are looking at a series of different approaches. We still are looking at catalytic devices, and at various ways of possibly trapping lead to extend the life of catalytic devices. We are optimizing the catalytic reactors for unleaded fuels to make a positive determination as to how far we can go that way.

We have a series of programs—and this is the reason why it is so important that we have a combined program of both members of the petroleum industry and our industry involved—a series of programs that deals with fuel additives, fuel compositions, and any changes in fuel structture that could contribute to lowering of emissions.

So that, putting these things all together and assuming a reasonable percentage of success, we do think that these are appropriate goals.

Senator MUSKIE. To a layman, what you are describing as being underway suggest that the automobile is going to cost more, and that it is going to become more complex and sophisticated. Is this an accurate description of what is likely to be an accompanying phenomenon from the point of view of the consumer?

Mr. MISCH. This is the reason that I qualified my remarks with regard to the complexity comparison of the steam engine system and the internal combustion engine. It is at this point in time somewhat unknown as to the degree to which the internal combustion engine might become more complex in order to arrive at these goals.

I can only say this: a few years ago we would have been very hesitant to predict that we would be in the position that we are in now with 1968 products until in fact we had accomplished it. We think that we can see greater accomplishments with the internal combustion engine than were predictable a very few years ago.

If we can extrapolate this accomplishment, we have a good chance that the complexity will not be as great as one might imagine But we still leave it open. If it is necessary to go to thermal reactors, that sort of thing, in order to get down to these values, we will, as a result of these programs, be in a position to quantify the tradeoffs, the economic tradeoffs and the improvement in emission levels, so that then a judgment can be made.

Senator MUSKIE. It seems to me, and I say this in all objectivity, that you have a greater sense of urgency about further developments in cleaning up the internal combustion engine than you do about exploring these other alternatives, such as the external combustion engine.

It is understandable from a certain point of view, but isn't it true?

Mr. MISCH. Yes; it is true. It is true because we have to meet the current needs, we have to meet the near-term projected needs as best we know them. This has to be done on a wide variety of vehicles and powerplants and represents a tremendous technical effort to keep up with the need as it is established.

Senator MUSKIE. What is the cost of your research effort in connection with the internal combustion engine?

Mr. MISCH. As it relates to——

Senator MUSKIE. As it relates to this problem?

Mr. MISCH. Perhaps I could answer the question this way, if I may: in 1967 we had an expenditure of over $50 million in internal combustion and external combustion engine activities.

The vast majority of this was for the internal combustion engine. But obviously for proprietary reasons we would prefer not to break down our expenditures between the approaches.

Senator MUSKIE. You have mentioned a $7 million program.

Mr. MISCH. This is just highlighting one specific cooperative program with members of the petroleum industry.

Senator MUSKIE. How do you account for the wide difference in the point of view between you and Mr. Ayres on the potential of the steam engine?

Mr. MISCH. Well, I certainly don't want to impugn the testimony of anyone else. But I do believe that the degree of optimism at times, certainly in my case, is constrained by knowing that the statements I make are expected to be carried out and results produced.

And we are looking, on a continuing basis, at all factors. In all candor, the differences between Mr Ayers' testimony on this point and mine can be based upon the experience I have had over 26 years in recognizing the pitfalls that can occur between the early analysis stage and complete development of a product for mass production.

Senator MUSKIE. You make the point, which is very legitimate, that the internal combustion engine has benefited from the contributions of tens of thousands of engineers, scientists, and manufacturing experts over many years. In addition, there is this commitment to the internal combustion engine in terms of investment, and consumer acceptance, 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.

It is our considered judgment that we will arrive at a satisfactory point at an earlier date by the pursuit of the internal combustion engine than we would if we were to say, "All of this is lost, and we must turn around to an alternative approach."

I am certain that everyone agrees that any rapid turnover would be catastrophic in nature. It would have to be one of evolution, in factoring this in. We believe that the approach we are taking, without forgetting about the alternative sources, and doing what we believe is an appropriate amount of research work on alternative sources, is the best approach to protect the public interest.

Senator MUSKIE. If we were able to start from scratch today, knowing all of the problems and potentials of the internal combustion engine, the external combustion engine, and the electric automobile, which of the three do you think would be the most useful from the public point of view and the wisest to pursue?

Mr. MISCH. May I qualify my answer this way: I would like to have one other constraint upon the question, namely that it would be continually important that the direction our industry took would be one to lead both technologically and product-wise in a manner that would continue to make us highly competitive on a worldwide basis. We are in serious competition in this country with overseas products.

And with that additional constraint, I think I would today still choose the pursuit of the internal combustion engine.

Senator MUSKIE. Senator Pearson?

Senator PEARSON. Mr. Misch, is the research and development effort within the industry, being carried out on an individual basis, company by company, or is it a cooperative effort, at least within this country?

Mr. MISCH. The research and development on alternate power sources?

Senator PEARSON. Yes.

Mr. MISCH. So far as I know, in the main it is a company-by-company basis. The degree to which it might be considered to be cooperative would be only that which is involved in the Department of Defense contract work, Atomic Energy Commission work, that sort of thing, of which there is a considerable amount of research and development on other than internal combustion engines.

Senator PEARSON. I am interested in your statement that after defining the goals and the targets you hope to meet, and without putting a time limitation on it, such an improved internal combustion engine probably could be phased into production in less time than would be required to develop, test and produce a completely new type of power plant for a motor vehicle.

That is an expression of opinion. Is that also the policy of the Ford Motor Co.? Is that a decision that you have made?

Mr. MISCH. To the extent that the policies of the Ford Motor Co. are influenced by any technical input and other technical people, yes, it is.

Senator PEARSON. I am assuming it is enormous.

Mr. MISCH. Yes——

Senator PEARSON. Could you say that that statement of opinion represents a policy statement of Ford Motor Co.?

Mr. MISCH. Yes, I think it is a policy statement of Ford Motor Co., that we believe it would take considerably more leadtime to design, develop and test a completely new powerplant and get it into production in quantities that would be meaningful than to pursue the improvements in the internal combustion engine.

Senator PEARSON. In spite of the fact that you didn't give any time estimates in your statement, can you make an educated guess now as to what time frame we are talking about?

Mr. MISCH. Well, I think we are talking about a time frame of roughly 1980.

Senator PEARSON. Let me ask you this question, which was prepared by the staff: How would an internal combustion engine that would equal a steam engine in low emission of pollutants compare in complexity?

Mr. MISCH. Well, I think this is the point that I made earlier. It is difficult to be able to assign a complexity increase for the internal combustion engine. But maybe if I can, I would like to show the exhibit, exhibit 2.

Mr. Heywood will point out our present evaluation of the complexity comparison of an internal combustion engine with the steam engine. And I would like to make the point clear that one must remember we are looking at a total system one that would be capable of providing the same functions, convenience and operation as our present-day automobiles. Mr. Heywood, take them through the chart, if you will, please.

Mr. HEYWOOD. As Mr. Misch indicated, this is a summary of what we believe would be contained in both a modern internal combustion engine on the one hand, and a modernized steam engine, embodying our assessment of what the best in modern technology could provide it.

Each of these bars represents for each of the components of the respective powerplants an indicator of complexity that we have assigned to the powerplants. The long bar on this side, of course, rep-

resents an indicator of complexity for the internal combustion engine, the long bar over here indicating the disadvantage in terms of that component's complexity.

Many of us speak about the steam engine, and this refers only to the basic engine block, which is represented by these two lines. You will see, indeed, it is also our assessment in terms of basic engine block, that the steam engine is in fact simpler. It is in the many auxiliaries required to make the total cycle work that the steam engine accrues its disadvantage.

Specifically, it has a separate burner assembly, separate boiler assembly and quite a complex set of sensors and controls in order to both operate the cycle, monitor and control it. Also, the steam engine must have an accessory engine drive, since the engine does not operate when the car is still. In addition it must have a large condenser and fan because of the great amount of heat that must be rejected.

The internal combustion engine has disadvantages in terms of the emission control devise, as well as the automatic transmission, as compared with the steam engine which does not have any significant transmission requirements. The sum of these respective columns in our assessment gives an index rating of 35 for the internal combustion engine and 46 for the steam engine, representing a significant disadvantage for the steam engine.

Again, the emission control complexities shown here are above and beyond that which we are immediately planing for near-term requirements, and represents our assessment of some laboratory devices we are working with that might meet the needs some 8 to 10 years in the future.

Senator PEARSON. Is that on the present development of the engines, or the theoretical date when they will have equal efficiency and performance?

Mr. HEYWOOD. Both of these columns represent a picture roughly 10 years from now—advanced emission controls here and advanced modern technology of the steam engine here.

Senator PEARSON. Thank you, Mr. Chairman.

Senator MUSKIE. The chart seems to indicate that the internal combustion engine 10 years from now, with the relative inputs of research and effort that you can expect in the next 10 years as a result of current momentum, will be 75 percent as complex as the steam engine?

Mr. HEYWOOD. Approximately; yes, sir.

Senator MUSKIE. Some of the long bars on the steam engine side seem to fall in areas that Mr. Ayres suggested have great potential for improvement as a result of development if somebody worked at it.

The burner assembly, the boiler, sensors, and controls are three of the long bars. As I recall his testimony, Mr. Ayres indicated that these are three areas in which great potential development is possible if we applied ourselves to it. Is that your assessment?

Mr. HEYWOOD. Not at all, sir. These are not bars representing a Stanley Steamer or steam engines of the past, but rather an advanced steam engine, wherin there are complicated requirements on these several components.

May I call your attention to the boiler, where safety valves and containment devices would be required in any event to assure that

anyone in the broad public would not be hurt or injured in the event of accident or any other event that might cause a safety hazard.

Senator MUSKIE. I am curious as to how you arrived at the length of these bars on each side?

Mr. HEYWOOD. Well, this is done by a group of engineers, looking at the designs they have, for an improved internal combustion engine and a steam engine, assessing the number, intricacy and precision of the parts, and the temperatures at which they must operate. On the basis of those factors they judge the complexity of that basic component.

Senator MUSKIE. The values that went into these bars are not susceptible to mathematical measurement.

Mr. HEYWOOD. They are based on the expected results of some future research, so they must be somewhat judgmental; yes, sir.

Senator PEARSON. That is an index of the complexity of the production. How about the maintenance and operation of the cars?

Mr. HEYWOOD. I think this relative complexity holds for either factor and would accrue a substantial disadvantage in terms of reliability and serviceability of the steamplant.

Senator Moss. You don't have any bar on there for the braking system and this is one thing Mr. Ayres talked about as a difference. Isn't that considered a matter for complexity?

Mr. HEYWOOD. In our assessment, the braking system would not be affected at all by the steamplant from two standpoints. First of all the peak power required in brakes, particularly for panic conditions, is such that the steamplant could not provide that peak power, and second, the larger share of braking power in vehicles is applied to the front brakes, when the steam engine would not be connected.

Senator Moss. I noticed that there is a bar for fan and clutch that appears on the steam engine side. I understand that there wouldn't be a clutch, in the sense as we think of one with an internal combustion engine, in the steam car. What does that represent?

Mr. HEYWOOD. The steam engine rejects essentially all of its waste heat through the condenser and thereby must have a substantially larger fan, as you see from the bars, than is required for the internal combustion engine. Because fan power consumption is so large, we prepared the design so one wouldn't waste so much power and therefore added a clutch to the fan to conserve power. This is not the clutch that connects the engine to the rear wheels.

Senator Moss. That is just on the fan. I see.

On the exhibit that was attached to the statement you have complexity listed among the disadvantages of the steam powerplant, and and then it is circled and has an asterisk by it. What does that mean?

Mr. HEYWOOD. I believe you are referring to this chart, sir. (Exhibit I, p. 28.)

Senator Moss. Yes.

Mr. HEYWOOD. It indicates that on this chart, in comparing all of the principal advantages and disadvantages that we see for the internal combustion versus the steamplant, complexity is the strongest and overriding factor. The others are less significant.

Senator Moss. I see. This would be directly contrary, then, to Mr. Ayres' evaluation, when he said that simplicity was one of the advantages of the external combustion engine.

Mr. HEYWOOD. Yes, sir.

Senator Moss. Does the steam propulsion system have fewer moving parts than the internal combustion engine?

Mr. HEYWOOD. I believe they have approximately a comparable number of moving parts. There are many more parts in the steamplant to contain, operate, pressurize, and the like, the additional working fluid one has in a steamplant.

Senator Moss. How would this be in the maintenance factor? Would there be more or less maintenance on a steam engine?

Mr. HEYWOOD. I believe there would be more maintenance because of the additional complexity.

Senator Moss. Doesn't the high torque and zero speed characteristics of the steam engine give it a greater performance advantage over the internal combustion engine in urban driving?

Mr. HEYWOOD. You are quite right; it does have a good low-speed torque characteristic and it is that characteristic that allows the elimination of the transmission and helps offset the otherwise much greater disadvantage in complexity of the steam engine. This factor comes out in the complexity comparison; torque in an internal combustion engine is essentially provided for by the transmission.

Senator Moss. How many years has Ford been in the analysis or study stage on steam engines?

Mr. HEYWOOD. The first extensive effort I am aware of took place about 14 years ago, sir.

Senator Moss. And do you anticipate now moving into the component development stage, having been in the study stage for this period of time?

Mr. HEYWOOD. First, we have developed certain components from time to time to better assess the problems in those components. We expect to continue that work.

Senator Moss. I understand that in January of 1966 one of your new Fords equipped with a smog suppressor was extensively tested against the Williams steam car in New Jersey to compare the output or pollutants. Could you tell us about the results of those tests?

Mr. HEYWOOD. Well, it was approximately January 1967 that I believe such tests were run. The emission tests on the Williams car were quite favorable.

Senator Moss. More favorable than on the Ford internal combustion engine on which you had the suppressor, is that correct?

Mr. HEYWOOD. Yes, sir.

Senator Moss. In Mr. Knudsen's letter to the committee, accepting the invitation to testify, he stated that "there will be no insurmountable problem in accomplishing the necessary changeover in production facilities if the steam car is feasible." And yet in the latest issue of Look, Mr. Ford is quoted as saying, "We have tremendous investment in facilities for engines, transmissions and axles, and I can't see throwing these away just because the electric car doesn't emit fumes."

Which of these quotes represents the company's position?

Mr. MISCH. May I answer that, please?

I think the two answers are not incongruous. They both say roughly the same thing in my opinion. Mr. Ford had been influenced on a continuing basis by the encouragement that we have given him with regard to our accomplishments on the internal combustion engine, No. 1. And No. 2, I am certain that he, like all of us, look at the real

world situation and recognize that any changeover would need to be an evolutionary one. Therefore, his reference to throwing away facilities is exactly right. We wouldn't imagine that it would be required to throw away facilities.

I might draw an analogy here to our company position with regard to the concern for studying the conversion to the metric system in this country. We have gone on record in saying that we do support such a study. We don't see it as being a catastrophic problem for our industry or industries, as long as there is a plan for conversion, and as long as facilities are replaced for whatever reason such a program could be instituted.

I see a strong analogy between that and that to which Mr. Ford and Mr. Knudsen are referring.

Senator Moss. Since you are going ahead in this development of the steam engine and other low pollution systems, would you be willing to report periodically to this committee as to your progress or your findings as you develop them?

Mr. MISCH. Yes, sir; we certainly would to the committee, that is, if we could report it in a confidential way. We would prefer not to submit for the record those items of progress that we consider to be proprietary.

Senator Moss. After we complete these hearings today and tomorrow, there may be some questions that remain. Would you be willing to answer written inquiries from the committee to any further questions which we may have?

Mr. MISCH. We would be happy to do so; yes, sir.

Senator Moss. Thank you very much.

Thank you, Mr. Chairman.

Senator MUSKIE. Senator Baker.

Senator BAKER. Thank you, Mr. Chairman.

Mr. Misch, let me ask one or two questions about terms, if I may, first. You spoke of a thermal reactor when you spoke of further steps toward control of emissions. Is that an afterburner in the exhaust system, or a reheating and reburning system for hydrocarbons?

Mr. MISCH. It is either reheating, reburning or maintaining that temperature, whichever way it might be applied, yes.

Senator BAKER. Secondary combustion of unburned hydrocarbon?

Mr. MISCH. That is correct.

Senator BAKER. You also speak of having great confidence in the internal combustion engine and the progress being made to the point where the hydrocarbon levels in Los Angeles will be no greater than they were in 1940. I take it that relates to your previous statement that your ambitious goal has been and is to reduce unburned hydrocarbons to 65 parts per million?

Mr. MISCH. No. That relates to the accomplishment of what we at the moment believe will be the requirement in 1970 and beyond in California.

Senator BAKER. Let me ask it this way to make sure we are both on the same frequency: Your ultimate objective for the internal combustion engine is to reduce the level of unburned hydrocarbons to 65 parts per million?

Mr. MISCH. Our ultimate objective is to reduce the unburned hydrocarbon emissions to just as low a value as is economically and practically feasible.

Senator MUSKIE. May I ask, what level of hydrocarbon emissions were the 1940 target geared to?

I don't think it was 65.

Mr. MISCH. No, it was higher than that. In parts per million, I believe it was 180 parts per million. Yes the average car would be at 180 parts per million from the exhaust. But then there would be a significant reduction also in the contribution of unburned hydrocarbons from the vehicle by virtue of the control of evaporative losses.

Senator BAKER. What I am trying to get at, Mr. Misch, is what is your long term objective's as far as unburned hydrocarbons are concerned in the ultimate development of the internal combustion engine? Is it 65 parts per million or less than that?

Mr. MISCH. I think in the foreseeable future, our target is 65 parts per million. We make the target for the Ford program as practical as we knew how to make it.

Senator BAKER. The reason I ask is that in February of 1967 when the subcommittee on air and water pollution held hearings in Los Angeles we heard some testimony to the effect that to reduce the level of pollution in the Los Angeles Valley as distinguished from that in 1940, but rather to reduce the level of pollution from unburned hydrocarbons, the emission level would have to be in the range of 35 parts per million, or according to another witness, less than 100 parts per million between 100 and 50 parts, if my memory serves me correctly. And Mr. Chairman, in that respect if I may, I would like to ask at this point for the staff to insert a citation of the relevant testimony in this respect from the Los Angeles hearings so we will have a point of comparison.

Senator MUSKIE. Without objection.

(Material to which Senator Baker refers appears in hearings before the Subcommittee on Air and Water of the Committee on Public Works, U.S. Senate, entitled, "Air Pollution 1967—Automotive Air Pollution", pp. 221–227, see also colloquy pp. 242–244.)

Senator BAKER. If that is the case, do you have any basis for judging whether or not a reduction in the range of 35 parts per million would be necessary to positively improve the situation, for instance, in the Los Angeles Basin?

Mr. MISCH. I have no reason to have a position on that.

Senator BAKER. Do you have any reason to believe that it is possible from a practical standpoint in the foreseeable future to build internal combustion engines with any devices or combination of devices that would reduce the level of unburned hydrocarbons to 35 parts per million or less?

Mr. MISCH. I don't have any reason to believe that it would be possible to get that low. I would rather say that we would like to meet the targets we presently established and then go on to the lower targets after that.

Senator BAKER. Is it your present judgment that you can or cannot build an engine that will emit 35 parts per million or less of unburned hydrocarbons?

Mr. MISCH. It is my present judgment that we cannot.

Senator BAKER. I believe that is all.

Senator MUSKIE. What are the other emissions? You use 175 parts per million or oxides of nitrogen as the target. Now, the California

standard that is likely to be established, or that has been established, is 350. Is that right?

Mr. MISCH. There is a sliding scale. Mr. Jensen might answer that.

Mr. JENSEN. Mr. Chairman and members of the committee, there is no California standard at the present time for oxides of nitrogen. There was when you were out there last year. That was 350 parts per million for visibility, not for photochemical smog. At the present time there is legislation pending in the State legislature which has passed the assembly and as of this week, is before the Senate. It provides for 1,200 parts per million in 1971, on a sliding scale down to 500 parts per million in 1974.

So although there is no standard, there is an indication at least in one house of the State legislature of a start in 1971 of 1,200 parts per million, going down to 500 in 1974.

Senator MUSKIE. How does this compare with typical emissions from uncontrolled cars?

Mr. JENSEN. The emissions of oxides of nitrogen are measured in many different ways. I think the way they are talking about in California, and it isn't clear when you write a law how they are measuring it, we are probably talking about 1,500 parts per million now with a first-step reduction to 1,200 and then on down to 500 parts per million.

Senator MUSKIE. So you have established rather low standards for oxides of nitrogen, I take it, in your terms?

Mr. JENSEN. Yes, sir.

Senator MUSKIE. I notice you made no reference to lead. Is this something with which you don't feel you need to be concerned at the present time?

Mr. MISCH. Well, from a health standpoint, we would be guided, of course, by the criteria as they are developed. As I said in my statement, the more completely these criteria are developed, the more direction we will have with regard to our research, and we will be concerned when there is an identified need for being concerned.

There are many opinions, and I am sure there are many qualified people on either side of this particular question. We would consider that it would be direction to our company and to our industry when the Federal Government decides to establish given levels.

Senator MUSKIE. How far in advance of a national problem should you be given a reading as an industry, in light of the fact that you build up momentum, you do have built-in investment, you do create problems in the evolution of your industry in changing technological direction? How far in advance should you apply preventive medicine as compared with surgery when you deal with these problems?

I realize that the testimony before this subcommittee is that we don't know enough about lead in the atmosphere to conclude that lead emissions from automobiles are a positive health hazard, and yet we know enough about it to be concerned, and to watch it. As I understand in one newspaper over the weekend there is a story that there is evidence that concentrations of lead in the bones is rising.

The steam engine would avoid this problem altogether. You say that you will avoid it at such time as the Government says it is a serious enough problem so it ought to be avoided. Suppose we make that decision too late?

Mr. MISCH. Well, we certainly don't want to make that deci-

sion too late. And if the Congress in its wisdom determines that it is appropriate to take preventive action, this, of course, would help us in the direction of our activities.

Senator MUSKIE. You see, the thing that troubles us is that it is so hard for you to change direction when the public interest indicates it. One of the reasons we passed legislation in 1965 was that it takes 8 years for the car population to turn over.

And that is one of the things that troubles us. At such point that we conclude that lead ought to be positively controlled, it would take us 8 years, then, to replace the automobiles which are creating the problem. How far in advance of that kind of a development ought the industry itself be anticipating the difficulty and building automobiles that can avoid the lead problem, for example?

Mr. MISH. Well, obviously it is more than just a problem for the automobile manufacturer, because this involves the structure of the fuel itself, and there are many implications beyond that that I can speak to. But as far as our automobiles are concerned, we could operate them with unleaded fuels, but there are many other considerations, other than just the automobile.

Now, I am not prepared to say how much leadtime would be necessary or if it is practical from a total resources standpoint to predict when such a changeover might be appropriate.

Senator MUSKIE. Thank you, Mr. Misch. There are many, many areas of inquiry in this complex field we could get involved in, but we have three more witnesses and I think we ought to get on. Thank you.

Mr. MISCH. Thank you.

Senator MUSKIE. Mr. Lawrence R. Hafstad, vice president, General Motors research laboratories, General Motors Corp.

STATEMENT OF LAWRENCE R. HAFSTAD, VICE PRESIDENT, GENERAL MOTORS RESEARCH LABORATORIES, GENERAL MOTORS CORP.; ACCOMPANIED BY WORTH H. PERCIVAL, HEAD, GENERAL MOTORS RESEARCH LABORATORIES' MECHANICAL DEVELOPMENT DEPARTMENT; AND WILLIAM A. TURUNEN, HEAD, ENGINEERING DEVELOPMENT DEPARTMENT

Mr. HAFSTAD. Good morning, Senator and members of the committee. My name is Lawrence R. Hafstad. I am vice president of General Motors in charge of the research laboratories.

I am accompanied by several associates. With me today are Mr. Percival, next to me, head of the General Motors research and mechanical development department, and William A. Turunen, head of our engineering development department. Each of these men is an expert in special phases of heat engine work.

We welcome this opportunity to present our views here today. We believe it is vital to your continuing study of automotive powerplants to examine steam power in the context of the alternatives presented by all existing and experimental power sources. A comparative approach is the only method by which one may realistically evaluate performance characteristics of the many competitive vehicle powerplants which are available. The regulatory approach that has prevailed in air pollution control and traffic safety suggests that we should be con-

cerned with performance rather than specifying a particular concept or engine. In achieving cleaner air, the ends are more important than the means.

We will try to give you a report based on our studies and also on our experience.

First, in an attempt to be responsive to the specific questions in your letter to General Motors, let me give you a short set of answers. Then, after our prepared statement, which we hope will clarify some of the problem areas, we can discuss any further questions you may have.

In paragraph 3 of your letter, you present two questions, and I quote:

> We would like to learn whether your company has been actively engaged in research on the steam engine; and, if so, whether you believe it is feasible for the automotive industry to convert gradually from an internal combustion engine to a steam engine in automobiles.

The answer to the first question is definitely "Yes." General Motors has been actively engaged in research on the steam engine.

The short answer to the second question is that, while we could build a laboratory steam car that would run, serious problems would have to be overcome before we would have a vehicle that would be practicable, completely aside from questions of economics and customer acceptance. For example, a significant safety hazard must be overcome, and devising suitable heat rejection components—that is, condensers—promises to be a major undertaking.

As to your question of time scale, this can be answered only after all such design problems are solved. Assuming this were done, we would start by pointing out that the leadtime on our present cars is, as you know, about 3 years. For a completely new powerplant and suitably modified chassis configuration, 5 or more years might be required for significant initial production after the final dimensions of the engine are fixed.

Without more detailed analysis of the vehicle and powerplant, it would be impossible to estimate the costs or the leadtime for such a program. However, tooling capacity available within our own company and the industry would limit us to phasing in the steam engine on a gradual basis. Complete conversion could require a decade or more. Let me emphasize once again, this time sequence would begin only after solution of all design problems.

Finally, your letter requested an approximation of costs of conversion. Such costs would range from detailed paper studies costing tens of thousands of dollars to research prototypes, production prototypes, and finally, initial production which would require investments in equipment and tools of tens to hundreds of millions of dollars, depending on the volume involved.

The latter steps could not even be started until after successful completion of the research—especially the life and environmental testing of the production prototype.

This I want to emphasize. This testing is extremely expensive, running to many millions of dollars. It must be understood that a research prototype is one which will work during a demonstration; but a production prototype requires a design which will not fail after long use and under adverse operating conditions. The difference between research and production prototypes is very substantial.

GM POWERPLANT RESEARCH

For more than 40 years, General Motors has studied and examined every type and configuration of powerplant that offered any possibility of application to motor vehicles.

Each engine type or configuration has its own advantages and disadvantages which make it either attractive or unattractive for certain motor vehicle applications. Only by evaluating, reevaluating, and comparing the many types of engines and the various "tradeoffs" involved, can a reasonable choice be made.

The various types of internal-combustion, external-combustion, and electric-propulsion systems, which we have examined in detail and continue to examine and reevaluate for possible application to motor vehicles, include the following:

Spark ignition engine, ammonia engine, diesel engine, gas turbine engine, free piston engine, fuel cell, various batteries, nuclear energy, Stirling engine, steam engine, vapor engine, hybrid Stirling-electric engine and gasoline-electric engine. We also used thermal storage, which you discussed a few minutes ago. We had an operating car running on thermal energy storage about 4 years ago. I would like to talk about the differences between internal and external combustion engines.

The major and most important difference between internal and external combustion engines, as they might apply to motor vehicles, is the way heat reaches what we call the working gas inside the engine.

Internal combustion engines, which include both the present gasoline and diesel engine as well as the gas turbine, use air as the working gas and receive heat directly by combustion of the fuel inside the engine.

External combustion engines, which include steam and Stirling engines, require two separate circuits to transfer heat, while the internal combustion engine needs only one circuit. Generally speaking, this means that external combustion engines are inherently more complex than internal combustion engines, and, therefore, more expensive to manufacture. The external combustion engines require more plumbing, high temperature stainless steel in the combustor and perfectly fitted seals. These are some of the factors that add to the cost of external combustion engines.

The second important difference between the internal and external combustion engine is in the way unused heat is rejected. External combustion engines require much larger radiators and fans than internal combustion engines. Providing space for these large heat rejection components in modern passenger cars is a serious problem.

CURRENT STATUS OF VARIOUS INTERNAL COMBUSTION ENGINES

As you know, all of the 1968 model passenger cars and light trucks built by General Motors are equipped with emissions control systems which reduce total hydrocarbon and carbon monoxide emissions by about 60 percent compared to vehicles not so equipped. This represents substantial progress toward cleaner air. All 1970 model GM passenger cars will have modified emissions control systems that will reduce exhaust hydrocarbon and carbon monoxide emissions by an additional 10 percent. In California, hydrocarbon emissions are a special problem. In that State, we expect to add a system to control

evaporative losses which will reduce total hydrocarbon emissions by nearly 80 percent compared to an uncontrolled car.

Beyond 1970, there is good reason to believe that hardware will be developed to achieve reduction of internal combustion engine pollutants by as much as 90 percent below emission levels of uncontrolled vehicles.

Experimental automotive gas turbines have been under intensive study in our research laboratories since the early 1950s. General Motors, in fact, built and tested the first American gas turbine-powered passenger car in 1953—now so long ago it has generally been forgotten by many persons. The automotive gas turbine engine, particularly types developed for heavy duty or commercial application, now has moved out of the research stage into the preproduction stage at one of our divisions. Nonetheless, research on components is continuing, and this engine, which has attractive low emission characteristics, is being reevaluated constantly for its potential in other than heavy duty applications.

CURRENT STATUS OF VARIOUS EXTERNAL COMBUSTION ENGINES

The steam (vapor) and the Stirling engines have attracted increased interest in recent years because each has low emission characteristics. Each is an external combustion engine.

Current interest in the steam engine has developed because of its low emissions characteristics, its ability to accept a wide variety of heat sources and because of its low noise level.

The Stirling engine has all these characteristics plus high efficiency, and in addition it avoids the hazards of high pressure steam. Because the Stirling engine has these unique advantages, we have concentrated more research and development work on the Stirling. Current developmental efforts are aimed at reducing its weight and bulk, as well as the cost of components and manufacturing complexity.

The Stirling engine was used extensively in the last century in various applications in place of the still older but more dangerous steam engine. In turn, it was displaced by the internal combustion engine. The Stirling was revived before World War II by Philips of the Netherlands and in recent years has had a renewed lease on life.

Stirling engine research and development has been in progress at General Motors since 1959 in a cooperative program with Philips. At General Motors, some 15,000 hours of operating time have been accumulated on experimental Stirling powerplants ranging from 8-horsepower single-cylinder engines to 400-horsepower four-cylinder engines.

As one element in this program, we have studied the so-called "hybrid" powerplant in a variety of configurations. We have constructed the world's first hybrid Stirling-electric automobile, which is now operating at our research laboratories in Warren, Mich. The car is powered by a bank of conventional lead-acid batteries. They are recharged by the Stirling engine, which has low emission characteristics and can be operated continuously within fuel tank limitations. This combination gives us all of the advantages of the electric car and the Stirling engine and avoids many of the disadvantages of the steam engine. This powerplant, which has been installed in an Opel Kadett, is being studied to ascertain its commercial potential.

A serious evaluation of the steam cycle was made by General Motors as early as 1927. A steam-powered motor coach was actually built and tested in 1930 and I have here the reports of that experiment. Studies using modern technology have continued in the field of steam and vapor cycle powerplants. Beginning in 1951, we undertook studies of suitable fluids other than water, to avoid the freezing problem, for use in small, silent vapor cycle generating sets applicable to the Armed Forces. Vapor-powered operating systems were designed and tests completed successfully in 1953. Society of Automotive Engineers Paper No. 931B entitled "Fluorochemical Vapor Engine" published in 1964 described General Motors' work in this field.

Findings of an extensive evaluation, a very professional job, of the steam cycle, conducted by the McCullough Co., were published by the SAE in 1962. This evaluation reaffirmed our own contemporary assessment as to the state-of-the-art at that time.

Extensive technical information and operating experience are available on the steam engine, and its parameters are quite well defined. Nevertheless, component development in combustors, compressors, blowers, and heat exchangers continues. Much of this research is common to gas turbines, Stirling and steam engines. The steam engine also continues to be reevaluated periodically in light of new technology which might be applied to solve some of the problems which steam powerplants pose, one of which is its relatively low thermal efficiency.

The matter of thermal efficiencies for steam powerplants has been reported from various sources during the past year. One such report (A Hudson Institute study entitled "Technology and Urban Transportation: Environmental Quality Considerations," Volume 1, provides an efficiency curve (fig. 2–4, p. 45)) which extrapolates the thermal efficiency trend of automotive size steam powerplants over the next decade by using as a model the trend for large steam turbine generating plants for electric power. We are not convinced that an examination of the trend for large steam generating plants, where weight and space play a minor role, provides a realistic basis for projecting the efficiency trend for steam-powered passenger cars.

Our people believe that the level of engineering sophistication achieved by some of the early steam cars was perhaps higher than has been generally recognized. A source (American Society of Mechnical Engineers, ASME transactions, vol. 28, 1907, p. 579), reporting on the White car of 1907, indicates a full load brake thermal efficiency of approximately 13 percent, based on a ratio of power output to fuel input. We believe that present-day automotive steam powerplants may achieve full load efficiencies of between 14 and 19 percent at best.

The report previously cited, which presents a concise summary of calculated efficiencies, seems to confirm the conclusion that modern-day steam power plants cannot hope to achieve any thermal efficiency miracles. The maximum overall thermal efficiency given in this report is 14.8 percent for realistic non-reheat conditions, which is hardly superior to the efficiency of the Doble steam car of the 1920's, shown as approximately 14 percent. In contrast, today's internal combustion engine achieves an efficiency of approximately 30 percent and the Stirling engine up to about 35 percent.

At the present time, General Motors views some of the potential

problems and potential advantages of the steam engine for passenger cars as follows:

Potential advantages

1. Exhaust emissions should be low.
2. Engine noise level is low.
3. Favorable torque characteristics minimize transmission requirements.
4. It provides simple passenger compartment heating.
5. Engine breaking is possible.
6. It has multifuel capabilities.

There is no question about these advantages, and I would like to say here that demonstration steam cars have been made every few years for the last 150 years, to demonstrate these advantages.

The problems are that they have not been able to demonstrate overcoming the disadvantages of the steam car. And this is where your emphasis should lie from here on out.

The potential problems

1. Size, weight, and cost of major components appear to be large.
2. A 1,000 pounds per square inch boiler at 1,000° F. presents a real safety hazard. All of the experiences with steam engines historically have had trouble with high-pressure steam. I might digress here for a moment to help you understand the reason why we have trouble with steam.

You have heard many statements of the acceleration of the steam car. There is no question but that this is good. The reason it is good is that you will have available a reservoir of high-pressure steam to provide energy. In the conventional auto cycle engine you generate the pressure only when you need it, where you need it, and as you need it, in the cylinder of the car. In the steam engine or any of the other engines where you have a reservoir of steam pressure, it is always there available to be used; if you open a valve, the piston moves. This is what gives you the acceleration.

But having all of this energy stored in a reservoir is a potential hazard. I don't want to belabor that point here, but this is the reason why this question always comes up, and so far we have never gotten around it.

There are statements that this hazard has been greatly reduced. It was greatly reduced from the early steam engines, wherein lots of water was contained in a single vessel, when the switch was made to the monotube construction where relatively little water is carried in the tube and is being heated at any one time. But the amount of this water is still significant, and if you want to get into questions on this, we can do that after my presentation.

3. Freezing of feedwater can be a serious consideration. That is obvious.

4. Water purity, and contamination by lubricants, is serious. This is another problem we have been underestimating. Any of the steam-plant operators will tell you that maintaining pure water is one of the biggest problems with the steam boilers. It just happens that you can't use all available water. You can use distilled water, but distilled water attacks the metal and if you go to an alkaline solution, which you have to have in steam boilers, the alkalinity has to be carefully controlled

between about 9 to 11 on the scale of alkalinity. And this requires careful control.

In other words, with the steam boiler, you can't just fill it with a convenient source of water. You have to have water which has been treated. This is another problem which we can go into on our discussion.

5. Another major problem is that of providing power for accessories at idle speed if the transmission is eliminated. It is true you can eliminate the transmission as far as moving the car is concerned, but if at idle when your car stops, then your steam engine slows down and you still have to provide what we call the accessory load, or the hotel load, or if you have air conditioning, you still have to provide some means of getting the power for that.

This is not an insignificant amount of power in a modern passenger car. This amount of power is something like, let's say, 15 horsepower in a passenger car. In a bus the need might go up to about 85 horsepower. So you do have to provide for this additional load somehow, and if you don't have a transmission, you have to provide an additional engine of some kind.

6. Slow startup time requires improvement.

These are facts of life as far as operating the car over a long period of time is concerned. Our future research programs include further evaluations and comparison of the various powerplants noted previously. Beyond these substantial internal investigations, we are working actively with outside organizations to develop further technology, including projects particularly oriented to steampower.

For example, beginning last March as a result of a telephone call from Dr. Morse, discussions have been underway with Energy Systems, Inc., headed by Dr. Richard Morse, to cooperate in the development work which he has undertaken.

Also, we have agreed to negotiate with California authorities a proposal to provide the California Highway Patrol with passenger cars and funds to install steampower of their own choosing, not ours, but their own choosing, for roadtesting. The tests—to be conducted independently by the Air Resources Board and the highway patrol—would evaluate the emissions and performance characteristics, including safety, of steampowered vehicles. Test results would be made public. The California authorities would be responsible for all engineering and related aspects of the conversions.

These California tests would provide a part of the "feedback" needed to serve as a yardstick for laboratory analyses of the current state of the art pertaining to steam engines. In addition, these tests should be of great assistance in arriving at an objective evaluation of steam engines with respect to both technological and economical feasibility.

GM was approached by California authorities during the first week of March with the proposal that we enter into this cooperative effort. The matter has been under discussion since then. Legislation authorizing the program passed the California Assembly May 20, but still must be approved by the California Senate.

Summary

At this time, 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. However, new ideas are needed to reduce costs in competitive powerplants, and it is for this reason that we welcome independent approaches.

The most critical requirement at this point in time is the establishment of accurate and reasonable ambient air quality needs in our metropolitan areas. This is a highly scientific undertaking and requires the full resources of government rather than industry to furnish this valid base, upon which all future pollution control standards logically could be applied.

In closing, to summarize quickly the relative advantages and disadvantages of the various internal and external combustion engines, we have prepared a chart which we would like to show you now.

This chart compares some of the engines General Motors has considered. Notice that no single powerplant combines the best characteristics of all, and further that there are some "trade-offs" which one must accept when any given powerplant is selected.

CHART I

COMPARISON OF VARIOUS VEHICULAR POWER PLANTS

		EMISSIONS Grams/Mile California Driving Cycle			EMISSION INDEX	NOISE INDEX	FUEL CONSUMPTION Lbs/HP-Hr	RELATIVE WEIGHT	RELATIVE COST Morse Estimate	RELATIVE COST GM Estimate
		HC	CO	NO						
GASOLINE ENGINE 1960		11.0	80	4	HIGH	MEDIUM	.45	1	1	1
GASOLINE ENGINE	1970	2.2	23	4?	LOW	MEDIUM	.50	1—1.5	---	1—1.5
	197X	STILL LOWER								
DIESEL		3.5	5	4	MEDIUM	HIGH	.40	2.5	1.85	2—2.5
REGENERATIVE GAS TURBINE		0.22	2.4	1.0	LOW	MEDIUM	.45	2	3.75	3
STIRLING		0.1	1.0	2.6	LOW	LOW	.40	2.5	2.5	3
STEAM		0.62	2.8	1.0	LOW	LOW	.70+	3.0	1.5	3
ELECTRIC BATTERY AND MOTOR		---	---	---	LOW	LOW	?	4?	---	6?

PROPOSED 1970 FEDERAL STANDARDS: Hydrocarbons: 2.2 Grams per Mile
Carbon Monoxide: 23 Grams per Mile

(The complete prepared statement of Mr. Hafstad follows:)

STATEMENT OF THE GENERAL MOTORS CORP.

Good morning Senator Magnuson and Senator Muskie and members of the Senate Committee on Commerce and Subcommittee on Air and Water Pollution. My name is Lawrence R. Hafstad. I am a vice president of General Motors in charge of the Research Laboratories. Before joining General Motors in 1955, I was the first director of the U.S. Atomic Energy Commission's Reactor Development Division and remained in this post for five years. Prior to that I was executive secretary of the Research Development Board in the Pentagon under Secretary Forrestal and Vannevar Bush. Before that I was a professor of physics at Johns Hopkins University and director of the Institute for Cooperative Research, a staff member and then director of the Johns Hopkins Applied Physics Laboratory working during the war on new weapons development and before that a research physicist for the Carnegie Institution here in Washington. I received my doctorate in physics from Johns Hopkins in 1933.

Currently, I am chairman of the General Advisory Committee to the U.S. Atomic Energy Commission, a member of the Defense Department's Science Board, a consultant to the President's Office of Science and Technology and am associated with a number of other government committees and university and scientific organizations. I have recited these affiliations only as background to my statement on the scientific and engineering matters in which your distinguished Committees are interested.

I am accompanied today by several associates. With me at the table are Worth H. Percival, head of GM Research Laboratories' Mechanical Development Department, and William A. Turunen, head of our Engineering Development Department. Each of these men is an expert in special phases of heat engine work.

We welcome this opportunity to present our views here today. The joint hearing held a year ago by your Committee and Subcommittee was very successful in getting into the public record a balanced view of the overall situation regarding some automotive power plants, especially with respect to electric cars. The present hearing should serve a similar purpose for other low emission power plants.

We believe it is vital to your study to examine steam power in the context of the alternatives presented by all existing and experimental power sources. A comparative approach is the only method by which one may realistically evaluate performance characteristics of the many competitive vehicle power plants which are available. The regulatory approach that has prevailed in air pollution control and traffic safety suggests that we should be concerned with performance rather than specifying a particular concept or engine. In achieving cleaner air, the ends are more important than the means.

While there are many specialized studies of the various power plants available in the technical journals, only a series of more general reports can establish the significance of these studies. We will try to give you one such report based on our studies and also on our experience.

First, in an attempt to be responsive to the specific questions in your letter to General Motors, let me give you a short set of answers. Then after our prepared statement, which we hope will clarify some of the problem areas, we can discuss any further questions you may have.

In paragraph three of your letter, you present two questions, and I quote: "We would like to learn whether your company has been actively engaged in research on the steam engine, and if so, whether you believe it is feasible for the automotive industry to convert gradually from an internal combustion engine to a steam engine in automobiles." Unquote.

The answer to the first question is definitely yes. General Motors has been actively engaged in research on the steam engine.

The short answer to the second question is that while we could build a laboratory steam car that would run, serious problems would have to be overcome before we would have a vehicle that would be practicable, completely aside from questions of economics and customer acceptance. For example, a significant safety hazard must be overcome, and devising suitable heat rejection components (i.e., condensers) promises to be a major undertaking.

As to your question of time scale, this can be answered only after all such design problems are solved. Assuming this were done, we would start by pointing out that the lead time on our present cars is, as you know, about three years. For a completely new power plant and suitably modified chassis configuration, five or more years might be required for significant initial production after the final dimensions of the engine are fixed.

A substantial number of our manufacturing and assembly facilities would be involved in converting our existing manufacturing plant capabilities from internal combustion to steam. Without more detailed analysis of the vehicle and power plant, it would be impossible to estimate the costs or the lead time for such a program. However, tooling capacity available within our own company and the industry would limit us to phasing in the steam engine on a gradual basis. Complete conversion could require a decade or more. Let me emphasize once again this time sequence would begin only after solution of all design problems.

Finally, your letter requested an approximation of costs of conversion. Such costs would range from detailed paper studies costing tens of thousands of dollars to research prototypes, production prototypes, and, finally, initial production, which would require investments in equipment and tools of tens to hundreds of millions of dollars, depending on the volume involved.

The latter steps could not even be started until successfully completing the research especially the life and environmental testing of the production prototype. This testing is extremely expensive, running to many millions of dollars. It must be understood that a research prototype is one which will work during a demonstration, but a production prototype requires a design which will not fail after long use and under adverse operating conditions. The difference between research and production prototypes is very substantial.

GM POWER PLANT RESEARCH

For more than forty years, General Motors has studied and examined every type and configuration of power plant that offered any possibility of application to motor vehicles.

This evaluation process has been a continuing one as new technology and processes have developed and new requirements have come into the picture. The latest of these requirements involved in the evaluation process, of course, is added emphasis on engine emissions as a contributor to air pollution.

Each engine type or configuration has its own advantages and disadvantages which make it either attractive or unattractive for certain motor vehicle applications. Only by evaluating, re-evaluating and comparing the many types of engines and the various "trade-offs" involved can a reasonable choice be made.

The various types of internal combustion, external combustion and electric propulsion systems which we have examined in detail and continue to examine and re-evaluate for possible application to motor vehicles include the following:

Spark ignition engine, ammonia engine, diesel engine, gas turbine engine, free piston engine, fuel cell, various batteries, nuclear energy, Stirling engine, steam engine, vapor engine, hybrid Stirling-electric engine and gasoline-electric engine.

DIFFERENCES BETWEEN INTERNAL AND EXTERNAL COMBUSTION ENGINES

The major and most important difference between internal and external combustion engines, as they might apply to motor vehicles, is the way *heat* reaches what we call the working gas inside the engine.

Internal combustion engines, which include both the present gasoline and diesel engine as well as the gas turbine, use air as the working gas and receive heat directly by combustion of the fuel inside the engine

Heat for external combustion engines, which include steam and Stirling engines, must pass through the metal walls of some sort of heat exchanger. This transfers the heat from the combustion of fuel and air outside the engine to the working gas contained within the engine.

In effect then, external combustion engines require two separate circuits to transfer heat, while the internal combustion engine needs only one circuit. Generally speaking, this means that external combustion engines are inherently more complex than internal combustion engines, and, therefore, more expensive to manufacture. The external combustion engines require more plumbing, high temperature stainless steel in the combustor and perfectly fitted seals. These are some of the factors that add to the cost of external combustion engines.

The second important difference between the internal and external combustion engine is in the way unused heat is rejected—this is the unavailable heat energy which results as a consequence of the laws of thermodynamics governing all heat engines.

While the internal combustion engine rejects part of the unused heat into a radiator, *most* of the unused heat is rejected to the atmosphere through the exhaust system. On the other hand, in an external combustion engine, heat is rejected mostly into a radiator or condenser. The result of this basic difference, naturally enough, is that external combustion engines require much larger radiators and fans than internal combustion engines. Finding adequate room for these components was difficult for the early steam car of 20 to 40 horsepower. Providing space for the larger heat rejection components in modern passenger cars is an even more serious problem. Condensers can be reduced in size by exhausting steam to the atmosphere, for example, when using high power in climbing a hill. However, as a "trade-off" the feed water tanks must then be refilled frequently with distilled or specially treated water.

CURRENT STATUS OF VARIOUS INTERNAL COMBUSTION ENGINES

The atmosphere is a vital natural resource, and we agree that whatever impurities are allowed to accumulate should be kept below reasonable limits with

regard to both public health and damage to plant life. These are factors that make essential the prompt specification by government of attainable ambient air standards which studies show necessary.

As you know, all of the 1968 model passenger cars and light trucks built by General Motors are equipped with emissions control systems which reduce total hydrocarbon and carbon monoxide emissions by about 60 per cent compared to vehicles not so equipped. This represents substantial progress toward cleaner air. All 1970 model GM passenger cars will have modified emissions control systems that will reduce exhaust hydrocarbon and carbon monoxide emissions by an additional 10 per cent. In California hydrocarbon emissions are a special problem. In that state we expect to add a system to control evaporative losses which will reduce total hydrocarbon emissions by nearly 80 per cent compared to an uncontrolled car.

Beyond 1970, there is good reason to believe that hardware will be developed to achieve reduction of internal combustion engine pollutants by as much as 90 per cent below emission levels of uncontrolled vehicles.

Experimental automotive gas turbines have been under intensive study in our Research Laboratories since the early 1950's. General Motors, in fact, built and tested the first American gas turbine-powered passenger car in 1953—now so long ago it has generally been forgotten by many persons. The automotive gas turbine engine, particularly types developed for heavy duty or commercial application, now has moved out of the research stage into the pre-production stage at one of our divisions. Nonetheless, research on components is continuing, and this engine, which has attractive low emission characteristics, is being re-evaluated constantly for its potential in other than heavy duty applications.

CURRENT STATUS OF VARIOUS EXTERNAL COMBUSTION ENGINES

The steam (vapor) and the Stirling engines have attracted increased interest in recent years because each has low emission characteristics. Each is an external combustion engine.

Current interest in the steam engine has developed because of its low emissions characteristics, its ability to accept a wide variety of heat sources and because of its low noise level.

The Stirling engine has all these characteristics plus high efficiency, but in addition it avoids escaping steam hazards. Because the Stirling engine has these unique advantages, we have concentrated more research and development work on the Stirling. Current developmental efforts are aimed at reducing its weight and bulk, as well as the cost of components and manufacturing complexity.

The Stirling engine was used extensively in the last century in various applications in place of the still older but more dangerous steam engine. In turn, it was displaced by the internal combustion engine. The Stirling was revived before World War II by Philips of the Netherlands and in recent years has had a renewed lease on life. Philips has commercialized the Stirling extensively in its widely used Cryogenerators for producing liquid air and liquid oxygen (LOX) and has sold thousands of these units.

As Philips is not in the heat engine business, the company is licensing several engine manufacturers to exploit the heat engine version of this engine's reversible cycle. This development work in Europe has been directed primarily toward marine and military applications.

Stirling engine research and development have been in progress at General Motors since 1959 in a cooperative program with Philips. At General Motors, some 15,000 hours of operating time have been accumulated on experimental Stirling power plants ranging from 8-hp single-cylinder engines to 400-hp four-cylinder engines.

As one element in this program, we have studied the so-called "hybrid" power plant in a variety of configurations. We have constructed the world's first hybrid Stirling-electric automobile, which is now at our Research Laboratories in Warren, Michigan. The car is powered by a bank of conventional lead-acid batteries. They are recharged by the Stirling engine, which has low emission characteristics and can be operated continuously within fuel tank limitations. This power plant, which has been installed in an Opel Kadett, is being studied to ascertain its commercial potential.

A serious evaluation of the steam cycle was made by General Motors as early as 1927. A steam powered motor coach was actually built and tested in 1930. Studies using modern technology have continued in the field of steam and

vapor cycle power plants. Beginning in 1951, we undertook studies of suitable fluids other than water, thus avoiding the freezing problem, for use in small, silent vapor cycle generating sets applicable to the armed forces. Vapor-powered operating systems were designed and tests completed successfully in 1953, using a special power fluid known commercially as FC–75. Society of Automotive Engineers paper No. 931B entitled "Fluorochemical Vapor Engine" published in 1964 described General Motors' work in this field.

Findings of an extensive evaluation of the steam cycle conducted by the McCullough Company were published by the SAE in 1962. This evaluation reaffirmed our own contemporary assessment as to the state-of-the-art.

Extensive technical information and operating experience are available on the steam engine, and its parameters are quite well defined. Nevertheless, component development in combustors, compressors, blowers and heat exchangers continues. Much of this research is common to gas turbines, Stirling and steam engines. For example, the gas turbine heat exchanger or regenerator can be used as combinstion pre-heater for either the Stirling or steam engines. Since all continuous combustion engines require nozzles, igniters, pumps and blowers, this research and development can be used interchangeably. Cycle analyses to determine the most favorable arrangement which might minimize size and weight, as well as complexity, are being pursued. The steam engine also continues to be re-evaluated periodically in light of new technology which might be applied to solve some of the problems which steam power plants pose, one of which is its relatively low thermal efficiency.

The matter of thermal efficiencies for steam power plants has been reported from various sources during the past year. One such report [1] extrapolates the thermal efficiency trend of automotive size steam power plants over the next decade by using as a model the trend for large steam turbine generating plants for electric power. We are not convinced that an examination of the trend for large steam generating plants, where weight and space play a minor role, provides a realistic basis for projecting the efficiency trend for steam power passenger cars.

Our people believe that the level of engineering sophistication achieved by some of the early steam cars was perhaps higher than has been generally recognized. Dependable data from careful experimental work was rare in those early days, but one such source [2] reporting on the White car of 1907 indicates a full load brake thermal efficiency of approximately 13 per cent, based on a ratio of power output to fuel input. We believe that present day automotive steam power plants may achieve efficiencies of between 14 and 19 per cent at best.

The report [1] previously cited, which presents a concise summary of calculated efficiencies, seems to confirm the conclusion that modern day steam power plants cannot hope to achieve any thermal efficiency miracles. The maximum overall thermal efficiency given in this report is 14.8 per cent for realistic non-reheat conditions, which is hardly superior to the efficiency of the Doble steam car of the 1920's, shown as approximately 14 per cent. In contrast, today's internal combustion engine achieves an efficiency of approximately 30 per cent and the Stirling engine up to about 35 per cent.

At the present time, General Motors views some of the potential problems and potential advantages of the steam engine for passenger cars as follows:

Potential advantages

1. Exhaust emissions should be low.
2. Engine noise level is low.
3. Favorable torque characteristics, minimizing transmission requirements.
4. Provides simple passenger compartment heating.
5. Engine braking is possible.
6. Multi-fuel capabilities.

Potential problems

1. Size, weight and cost of major components appear to be large.
2. A 1000 psi boiler at 1000°F presents a real safety hazard.
3. Freezing of feedwater can be a serious consideration.
4. Water purity, and contamination by lubricants, is serious.

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[1] A Hudson Institute study entitled "Technology and Urban Transportation: Environmental Quality Considerations," Volume 1, provides a efficiency curve (Fig. 2–5, p. 45). Volume 2 gives efficiency summary (Table 4–1, p. 71).

[2] American Society of Mechanical Engineers (ASME Transactions, Vol. 28, 1907, p. 579).

5. There is a problem of providing power for accessories at idle speed if the transmission is eliminated.

6. Slow start up time requires improvement.

It is important to keep in mind that all thermal power plants ultimately require a trade-off among such various characteristics as power, response, weight, volume, efficiency, safety, emissions, manufacturing costs, reliability, maintainability and operating cost. For this reason, in contrast to a research prototype adequate for a demonstration, very complex calculation and extensive testing must be undertaken with regard to a production prototype in order to optimize a design for commercial production.

For example, a power plant such as the Stirling engine is capable of brake thermal efficiencies much higher than steam engines. If the Stirling is considered for a vehicle application some trade-offs can be made if the efficiency is lowered somewhat. This would permit lowering the peak metal temperature, perhaps, to a point where a less expensive material could be used and a less expensive manufacturing process employed.

However, this reduction in thermal efficiency must be balanced against the somewhat increased size and weight which would probably result if power and transient response characteristics are not compromised. Safety and emissions are usually not affected by a reduction in thermal efficiency and even may be improved slightly.

It is possible, also, to tailor the torque curve of a Stirling engine to give it a rising characteristics as speed decreases, which would simplify the transmission requirements and reduce overall power plant costs. This is the kind of analysis that must be made for every power plant in order to determine its feasiblity, specific application and market acceptability.

This is the type of study now being done on GM's hybrid Stirling-electric car, which I mentioned earlier, as a current "state-of-the-art" project. At last year's hearings conducted by this joint Committee, we discussed fuel cell-electric and battery-electric vehicles in some detail and showed you our Electrovair and Electrovan. These vehicles were constructed to demonstrate the state-of-the-art at that time. This is the way steady progress is made.

Our future research programs include further evaluations and comparison of the various power plants noted previously. Beyond these substantial internal investigations, we are working actively with outside organizations to develop further technology, including projects particularly oriented to steam power.

For example, discussions are underway with Energy Systems Inc., headed by Dr. Richard Morse, to cooperate in the development work which he has undertaken.

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SUMMARY

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The most critical requirement at this point in time is the establishment of accurate and reasonable ambient air quality needs in our metropolitan areas. This is a highly scientific undertaking and requires the full resources of govern-

ment rather than industry to furnish this valid base, upon which all future pollution control standards logically could be applied.

These ambient air quality needs should have the fullest scientific resources applied. Also, proper Congressional review in a committee such as this would give all industry some guidance as to its future control requirements regarding both automotive and stationary air pollution sources.

With such basic guidelines and a reasonable and sensible schedule of air pollution control over the next two decades, the automotive industry can orient its long-range developments toward tangible objectives.

In closing, to summarize quickly the relative advantages and disadvantages of the various internal and external combustion engines, we have prepared a chart which we would like to show you now. This chart compares some of the engines General Motors has considered. Notice that no single power plant combines the best characteristics of all, and further that there are some "trade-offs" which one must accept when any given power plant is selected.

Mr. HAFSTAD. I believe this chart might be the basis of some questions and I think I can try to answer them.

If it is of any help to you, I will show you the highlights of this.

On the left-hand end of the chart you will see emissions in grams per mile using the California driving cycle. We are switching from parts per million to grams per mile in our standards.

The proposed 1970 Federal standards as you see at the bottom of the chart are hydrocarbons 2.2 grams per mile and carbon monoxide 23 grams per mile.

The gasoline engine of 1960 was about 11 grams per mile hydrocarbons, 80 CO and four of the nitrous oxides.

For 1970 these should be reduced to 2.2 for hydrocarbons, 23 for CO and somewhere in the neighborhood of four for the nitrous oxides, because we don't know how to handle those yet.

Looking into the future, for the next decade, we expect these to be still lower. How long we don't know, because that is a question of the technology involved and the costs that will be involved.

Note that the diesel is fairly good as far as emissions are concerned. And then we get into the group of external combustion engines or rather continuous combustion engines, the gas turbine, the Stirling, and the steam.

These are all engines with a separate combustion system and I think I can take some of the mystery out of this if I call your attention to the fact that in these last three the metal parts in the combustor are all at a red heat. And for this reason all of the fuel mixture which is in contact with the metal parts burns completely, whereas in the first three, the gasoline engines, you have a cold metal surface surrounding the combustion chamber and you have the unburned hydrocarbons then in a layer in contact with this cold surface. And this is the reason why the external combustion engines are so much better as far as pollution is concerned.

With an optimized combustor, I think there is no reason why the regenerative gas turbine, the Stirling, and the steam engines shouldn't have essentially the same or equivalent low pollution.

Senator MUSKIE. This chart is based upon what year; 1970?

Mr. HAFSTAD. The gasoline engine prediction there is what we are now talking about for 1970 production. The rest of the figures are our guesses as best we can make them at the present time.

Senator MUSKIE. On relative cost, this is the cost to the consumer?

Mr. HAFSTAD. This would be the cost of production and ultimately to the consumer. You will note I have shown both the Morse report

estimates and our own estimates and I would say they are in pretty good agreement with the single exception of the steam engine down at the bottom. The reason there is our estimates were based on what has been done and what we have done ourselves and what we know about; in the Morse report they are taking credit for what various inventors hope to do. We hope they are right, but this hasn't been demonstrated yet.

Senator MUSKIE. I am interested in the figures on emissions. How did you obtain these figures for the various types of vehicles?

Mr. HAFSTAD. All of these are our own measurements. Those for the regenerative gas turbine, Mr. Turunen made, those for the Stirling engine, Mr. Percival. Those for the steam are the best we have been able to find in the open literature. I think they are for the Williams engine, if I remember correctly.

Senator MUSKIE. They are the results of your own experiments?

Mr. HAFSTAD. Except for the steam. You will note I have included the noise index as well, because we think looking ten years down the road this is going to be as important as the air pollution.

Senator MUSKIE. With respect to oxides of nitrogen, I assume those figures are all on uncontrolled, for all types of engines?

Mr. HAFSTAD. Yes, so far they are, and there is a good reason for this. In order to get your hydrocarbons low, you use excess oxygen and excess air, and if you use excess air in your combustion and high temperatures, you increase the nitrous oxides. So this is a typical engineering trade-off that those of us who live with these problems have to face.

Senator MUSKIE. I notice oxides of nitrogen is high in the Stirling engine. What is the explanation for that?

Mr. PERCIVAL. The Stirling engine has a higher air preheat than the steam and the regenerative gas turbine, but we have made some recent experiments in which we have sort of optimized this and brought this down to about half that figure. So we feel quite encouraged about the future. But at present it is in this region.

Senator MUSKIE. On the figures for fuel consumption, pounds per horsepower-hour, Dr. Ayres suggested this ought to be measured in terms of the power delivered to the wheels. Is that the test that was used here?

Mr. HAFSTAD. This is a question of efficiency and where you measure it.

Mr. TURUNEN. These are specific power numbers and they are at the shaft. The losses in between the output shaft and the wheels I don't think—they are not quite as significant as may have been thought.

Senator MUSKIE. Is it true a higher percentage of the engine power in steam propulsion is actually used to move the vehicle?

Mr. TURUNEN. If one had—this would exclude the transmission losses. If one had no transmission, yes, that is true.

Senator MUSKIE. Do the figures on this chart reflect that fact?

Mr. TURUNEN. No, they did not reflect the transmission losses; no, sir.

Senator MUSKIE. If they did, then would the Stirling and the steam engines be more favorably indicated on the chart than they are?

Mr. TURUNEN. To some degree.

Senator MUSKIE. About how much?

Mr. TURUNEN. Mr. Percival?

Mr. PERCIVAL. I think one would actually have to build a complete powerplant in the vehicle and test it as such in order to really determine this figure. This has not been done yet.

On the other hand, in the case of steam, if it is required to have a separate small engine or small turbine to drive the accessories, then this gets you back into a similar problem again. Usually, the little engine will not be as efficient as the main engine, so you may come back to the higher fuel consumption in spite of the fact that you are eliminating the transmission.

Senator MUSKIE. You characterize the emission index of the gasoline engine in 1970 as being low. This is the same adjective you use for the steam engine. Actually, the performance of the steam engine would be several times better than the gasoline engine in 1970; will it not?

Mr. HAFSTAD. That is true.

Senator MUSKIE. You use the same adjective to describe widely differing performances in this respect.

Mr. HAFSTAD. This came about in trying to simplify the chart. I think we could say medium for the 1970, and we hope that the 1970—*X* would be low.

I think that would be a more accurate presentation.

Senator MUSKIE. You ought to have a low and lower, then.

Mr. HAFSTAD. That is right.

Senator MUSKIE. Senator Pearson.

Senator PEARSON. I want to go into this safety thing again that you indicated you would be willing to talk about.

We have a note here that modern steam generators contain only about a pint of steam under pressure. Is that right or wrong? And would you elaborate on your quote that a significant safety factor must be overcome?

Mr. HAFSTAD. I will go back in history then and say that historically steam boilers and steam generators have always caused trouble and the ASME has a special safety code for operating steam engines of any kind. It happens that the operators of steam powerplants must be licensed if they operate at anything over 15 pounds per square inch as far as pressure is concerned. And according to the present rules, the operator of a steam powerplant should be a mechanical engineer or have equivalent special training.

Senator PEARSON. We are told also that the existing pollution condevices on the internal combustion engines lose their effectiveness over a period of time. Do the steam engines have a comparable problem?

Mr. HAFSTAD. No, because built into the combustion system of any one of these three low emission engines you have continuous combustion, they run continuously, no variation up and down the way an automobile does, and for that reason they can be essentially adjusted for optimum combustion conditions.

Senator PEARSON. On page 10, when you relate and itemize the potential problems, I should like to ask you to what degree General Motors is doing research and development on steam engines and what you consider to be the most serious problem of the six problems that you have outlined here?

Mr. HAFSTAD. I put these essentially in the order in which I would rank them. It might interest the group that I managed to reach George

Besler on the long-distance telephone last night and the Besler Bro. manufactured for sale steam cars up through the 1930's. They are a generation after the Stanleys and Whites. So I think they are the people who have had the most recent commercial experience in this area.

He cited as his opinion of the major problems cost, because he was selling the cars at $75,000 each in the early 1930's, and he cited the steam boiler problem, and particularly the problem of the pump which has to pump feed water back into the boiler at up to 3,000 pounds per square inch. The maintenance of the steam powerplant is important. I stress again the importance of pure water because if you have deposits forming, two things happen: your valves don't operate and close properly, and you get scale deposits on the inside of your boiler and you reduce the heat transfer properties of the water.

Some numbers there might be of interest to you. With distilled water you have up to 2,000 b.t.u. per square foot per degree in an area, and as I remember the table I looked at, if you use treated water, you are down to 1,000, and if you use Chicago sanitary sewer water you are down to 130. So much scale forms on the inside of the boiler that your heat transfer goes "kaput."

Senator PEARSON. I think that is all I have. I might say I asked for a copy of this testimony and I didn't receive it, but I did receive a biography of the witness today and I read that and I should like to publicly indicate the great contributions you have made to the Nation, particularly in regard to your work with the Defense Department and the many awards you have received.

If no one has any objection, I will ask that it be inserted in the record here.

Senator MUSKIE. Without objection.

(The document referred to follows:)

DR. LAWRENCE R. HAFSTAD

Dr. Lawrence R. Hafstad, General Motors vice president in charge of the Corporation's Research Laboratories, was born June 18, 1904, at Minneapolis, Minn. He received his early education in the Minneapolis public schools and was graduated from the University of Minnesota in 1926 with a bachelor's degree in electrical engineering.

He continued at the University of Minnesota until 1928 as a graduate student in physics and in 1933, was awarded a doctor of philosophy degree in physics by Johns Hopkins University.

From 1920 to 1928, while a university student, Dr. Hafstad worked as an engineer for Northwest Bell Telephone Company. From 1928 to 1942, he was a physicist for the Carnegie Institution of Washington, D. C.

He was on the staff of the Applied Physics Laboratory of Johns Hopkins at Silver Spring, Md., from 1942 to 1945 and served as the laboratory's Director from 1945 to 1947.

In 1947, he was named executive secretary of the Research and Development Board, Office of the Secretary of Defense, serving until February, 1949. From 1947 to 1949, he also served as Director of the Johns Hopkins University Institute for Cooperative Research at Baltimore, Md.

In February of 1949 he became first Director of the U.S. Atomic Energy Commission's Reactor Development Division, Washington, D. C., and continued in that capacity through 1954.

From 1949 to 1951, he was also chairman of the Government's Interdepartmental Committee on Scientific Research and Development at Washington.

In January, 1955, Dr. Hafstad was named director of the Chase Manhattan Bank's Atomic Energy Division at New York City, and in September of the same year he succeeded Charles L. McCuen as General Motors vice president in charge

of the Research Laboratories. In January, 1962, the Defense Research Laboratories of General Motors were organized and added to his responsibilities.

Well known professionally for his studies in peacetime uses of nuclear energy, Dr. Hafstad has received several major scientific awards.

For development of a million-volt vacuum tube he shared the American Association for the Advancement of Science Award with M. A. Tuve in 1931. The Secretary of Navy in 1946 presented him the Medal for Merit for his "major contribution in development of significant improvements in ordnance for the Army and Navy," and the same year the British government conferred upon him the "King's Medal in Defense of Freedom."

In 1954, the Atomic Energy Commission named him for its distinguished Service Award. In 1956, the Scientific Research Society of America (RESA) presented him its annual William Proctor Prize as one of the nation's leading scientists. In 1967, he received the Charles F. Kettering Award from George Washington University, and the Sesquicentennial Award from the University of Michigan.

Under his own name and in collaboration with others, Dr. Hafstad has a long list of scientific and technical papers, chiefly in the field of physics.

He is chairman of the General Advisory Committee to the U.S. Atomic Energy Commission, and a member of the Defense Science Board of the Department of Defense. He also serves as a consultant to the Office of Science and Technology, in the Executive Office of the President, and on Ad Hoc Panels of the Department of Defense and the Navy. He is a Trustee of the Carnegie Endowment for International Peace.

Dr. Hafstad is a Member of the National Academy of Engineering, as well as a Member-at-Large of the National Research Council. He serves on several of the NRC committees, such as that on Undersea Warfare, Long Range Planning for the Highway Research Board, and Urban Technology.

Dr. Hafstad is a Trustee of The Johns Hopkins University, and a member og the Visiting Committee for the Physical Sciences. He is also a member of the Board of Visitors of Tulane University. He is a member and past Chairman of the Directors of Industrial Research; a fellow of the American Nuclear Society, and the Institute of Electric and Electronic Engineers; a member of the American Physical Society, the American Nuclear Society, the American Geo-physical Union, the Society of Automotive Engineers and other professional societies.

Senator MUSKIE. Senator Baker?

Senator BAKER. Mr. Chairman, I won't take but a moment. I know we are anxious to recess.

Doctor, I am a little bit out of kilter here on page 9 where you speak of efficiencies.

In speaking of the White car of 1907 you speak of full-load brake thermal efficiency of approximately 13 percent and present day automotive steam powerplants in the range of 14 to 19 percent.

What is full-load brake thermal efficiency?

Mr. PERCIVAL. Well, it is merely the power output divided by the fuel input times a factor which turns that into efficiency.

Senator BAKER. Well, it is not a thermal efficiency then as such?

Mr. PERCIVAL. It is a true thermal efficiency.

Senator BAKER. Is it the same efficiency you compare in the next paragraph down when you speak of the Doble car of 1920, with a 14 percent?

Mr. PERCIVAL. Yes, sir; it is the same efficiency.

Senator BAKER. In contrast to today's internal combustion engine which achieves an efficiency of 30 percent?

Mr. PERCIVAL. Yes, sir; it is the same efficiency.

Senator BAKER. So all of these efficiencies are as you put it full-load brake thermal efficiencies?

Mr. PERCIVAL. Yes; they are.

Senator BAKER. Which is a ratio of fuel input to power output?

Mr. PERCIVAL. Work output to fuel input times a factor which converts fuel to energy units.

Senator BAKER. Measured at the drive wheels?

Mr. PERCIVAL. No; at the shaft, because we don't have enough good data on complete cars to make this kind of a measurement.

Senator BAKER. Then it is a shaft measurement without the incumbrance of the transmission or drive train?

Mr. PERCIVAL. That is right, sir; but it has all of the accessories like the muffler, air cleaner, generator, and the fan.

Senator BAKER. All right. These are measured at—is the torque measured for efficiency purposes at a standing stop?

Mr. PERCIVAL. No; this is on a dynameter system.

Senator BAKER. So it is a brake horsepower?

Mr. PERCIVAL. Yes, sir.

Senator BAKER. Do you have a useful horsepower or dead stop horsepower rating?

Mr. PERCIVAL. Well, this is the—I don't quite understand what you mean by that.

Senator BAKER. What I mean is at 2,300 or 2,700, I believe, revolutions per minute, you will get a brake horsepower that you could compare on the shaft?

Mr. PERCIVAL. It takes it all of the way from 800 to 4,000 revolutions per minute.

Senator BAKER. What are these taken at; do you know?

Mr. PERCIVAL. For example, on a particular car the best efficiency, say at 30 percent efficiency, might be—it depends on the engine. One might be at 1,600 or another at 2,000.

Senator BAKER. For the sake of brevity, the point I am getting at is, do you have a ratio of full-load brake thermal efficiency at zero revolutions per minute or at 100 revolutions per minute comparing the internal combustion engine with the steam engine?

Mr. PERCIVAL. No; because they won't run that slow. The internal combustion won't run that slow.

Senator BAKER. They will certainly come to a stop. Do you have an initial horsepower rating on startup?

Mr. HAFSTAD. What is the torque under those conditions? With the internal combustion it is low; with the steam engine it is high; no question.

Senator BAKER. Do you have those figures?

Mr. PERCIVAL. No, sir.

Senator BAKER. I am trying to get at the comparative output of the two on startup, as distinguished from 2,700 revolutions per minute.

Mr. PERCIVAL. On a torque basis, with a transmission, the internal combustion engine has a startup torque ratio of 5 to 1 with slipping clutch, or equivalent, and the steam engine can do the same possibly without a transmission.

Senator BAKER. But you don't have an efficiency rating at the startup?

Mr. PERCIVAL. No; it is such a short time, you don't usually worry too much about it.

Senator BAKER. But it is significant in terms of judging the relative efficiency through a full range of operating conditions.

Mr. PERCIVAL. Yes, sir. It would have to be done on a complete steam vehicle versus a gasoline vehicle.

Senator BAKER. You also speak of the difficulty one might have with accessory power. Of course I take it you are speaking now of the generator or alternator, or air-conditioning compressor?

Mr. PERCIVAL. And power steering; yes.

Senator BAKER. Power steering and the like. Just offhand, in a nontechnical way, I can think of two or three ways to approach that problem. One would be with a steam-electric hybrid, which you use very effectively in locomotives.

Mr. PERCIVAL. Yes; it is possible.

Senator BAKER. And another one would be to use an evaporative air-conditioning system instead of a compressor.

Mr. PERCIVAL. Yes; that is possible.

Senator BAKER. This really isn't a significant problem; is it?

Mr. PERCIVAL. We think it is. For instance, the evaporative type of air conditioning is very inefficient compared to the other type.

Senator BAKER. That is a function of cost and if you have the bleed heat there and available and it will be fed through the radiator and dissipated, it won't cost a thing.

Mr. PERCIVAL. It is bulky. You are using the steam; you have to put heat in to make the steam.

Senator BAKER. But it won't require any additional heat, assuming you had bleed heat going through the radiator, condenser, into the atmosphere any way.

Mr. PERCIVAL. I don't know.

Senator BAKER. One further thing, if I may. On the question of potential problems with water purity, contamination by lubricants, of course water is not the only solution that might be used to provide vapor or heat storage or the like. There are many, many elements that might be used that would either be neutral or of appropriate chemical characteristics so they would not attack or corrode the internal fittings and valves.

Mr. PERCIVAL. We did this in 1951. We built an engine running on fluorocarbon as you mentioned, as an experiment.

Senator BAKER. And that really is not an insuperable problem?

Mr. PERCIVAL. It will eliminate freezing problems. The efficiency is worse, however. And the cost of these chemicals is quite high, in the $5 to $10 per pound class.

Senator BAKER. Last question. In the judgment of either of you or all of you, is it reasonably probable that in the foreseeable future the internal combustion engine in its present format and configuration can ever be designed to perform realistically with hydrocarbon emissions of 35 parts per million or less?

Mr. HAFSTAD. I would answer that by saying yes as far as laboratory devices are concerned.

The question is whether we can make those sufficiently reliable and durable in order that they would meet the requirements of the customer.

Senator BAKER. Of course my question is whether it is reasonable and practical to assume that this can be done for the mass production of automobiles, that is produce an internal combustion engine in production runs for general operation, general maintenance, for the general public that will emit unburned hydrocarbons of 35 parts per million or less.

Mr. HAFSTAD. I think it is probably going to be possible, but it will take a lot of development work to make it reliable enough and I would say this is the reason we are in the horserace here between the gasoline engine and some of these other three to see which comes out the best.

Senator BAKER. Would you judge it will be any more difficult to perfect and produce a steam engine for automobiles than it would be difficult to produce a reliable production run of internal combustion engines that would produce 35 parts per million or less?

Mr. HAFSTAD. We think the operating problems and problems of cost and the bulk of the steam engine will be so high that probably the gasoline will come out ahead. This remains to be seen.

Senator BAKER. At this rate, 35 parts per million?

Mr. HAFSTAD. That is correct.

Senator BAKER. So you feel it can be done?

Mr. HAFSTAD. Yes, I think it can be done at a price. And the question is whether that price will be as high as that of the steam or other external combustion engines.

Senator BAKER. Is that question in doubt at this point?

Mr. HAFSTAD. This is what we are trying to decide by our experiments.

Senator BAKER. At this point we don't know and you don't know. Do you have any speculation on whether it will be cheaper and easier to develop an internal combustion engine that emits 35 parts per million unburned hydrocarbons consistently and reliably or cheaper and easier to tool up and build a steam engine?

Mr. HAFSTAD. We can't answer that question authoritatively until we have done both in the laboratory and we are approaching that stage.

Senator BAKER. Do you intend to do both?

Mr. HAFSTAD. This is one reason we are working with the Williams people, to see how good their engine is, on the other things besides this. Yes. We accept the facts about the pollution.

Senator BAKER. And you are proceeding in good faith to explore both of these areas?

Mr. HAFSTAD. Of course.

Senator BAKER. Thank you.

Senator MUSKIE. I think I should say at this point from now on Senator Baker is not only a member of this committee, he is a technical consultant.

Mr. HAFSTAD. Yes, he qualifies.

Senator MUSKIE. Just a routine question in closing. Would you be willing to answer written questions that we might put to you in addition to those we have put to you here?

Mr. HAFSTAD. Of course, within proprietary information limits. And we would like to invite the committee to come to the laboratory and ride in our hybrid car.

Senator MUSKIE. We have done that before and we will probably do it again. Hybrid committee, hybrid cars. And you would also be willing to report to this committee periodically within the same limitations?

Mr. HAFSTAD. It would be a pleasure.

Senator MUSKIE. Thank you very much. We will recess now until 2 p.m. We have two more witnesses. I had hoped we might finish them

this morning, but I don't think we ought to rush them, so we will recess until 2 o'clock.

(Thereupon, at 12:45 p.m. the hearing was recessed, to reconvene at 2 p.m. the same day.)

AFTERNOON SESSION

Senator BAKER. The committee will come to order.

Mr. Lloyd D. Orr is our next witness. Mr. Orr is professor of economics at Indiana University.

We welcome you to the hearing, Professor. You may proceed in your own manner.

STATEMENT OF LLOYD D. ORR, ASSOCIATE PROFESSOR OF ECONOMICS, INDIANA UNIVERSITY

Mr. ORR. Thank you very much.

The contention of many enthusiasts that steampower represents a viable alternative to the internal combustion engine in automotive use has received recent impetus from a study entitled "The Automobile and Air Pollution" recently completed by an advisory panel of the Department of Commerce. This morning I propose to comment on the prospects for such an innovation and the economic impact it would have on the automobile industry. Perhaps the best way to illustrate these economic characteristics is to compare them with the probable impact of an alternative innovation—the electric propulsion system.

At the outset I would like to state my general agreement with the conclusions reached by the Department of Commerce panel. Three of these conclusions are directly relevant to the subject matter being considered today.

1. During the next decade no significant reduction in air pollution will be achieved through the introduction of unconventional propulsion systems.

2. Steam propulsion systems have potential as a low-polluting alternative to the internal combustion engine.

3. The present state of technology does not permit the development of an economically feasible electric car except for limited-range use.

My acceptance of the third conclusion must be heavily qualified. By "limited-range use" the panel appears to have in mind a maximum of 50 miles at a steady speed of 25 miles per hour. However, the best available battery system and the best vehicle concepts clearly indicate the feasibility of an economical vehicle within an urban, suburban, or highway range of at least 100 miles and with a 20-minute, 80-percent recharge capability. Given that 99 percent of all automobile trips are of less than 100 miles and 80 percent of total mileage is on trips of less than 100 miles, the term "limited-range" clearly should have a much less restrictive interpretation than that given by the Department of Commerce panel. With your permission I would like to submit a separate statement for the written record on this point.

Senator BAKER. When it is received, it will be placed in the record at the end of your statement which you are presenting today.

Mr. ORR. Thank you, Senator, I will now continue with my statement.

I. THE ECONOMIC IMPACT OF UNCONVENTIONAL PROPULSION SYSTEMS

A. *Market Structure.*—Any attempt to assess the innovative character of the automobile industry must take account of some basic characteristics of the industry. Since the 1930's three companies have dominated the production of automobiles. Since perpetuation of concentrated economic power may be described in terms of barriers that must be surmounted by those who might wish to enter the industry. The most formidable barriers to entry in the automobile industry are:

1. Economies of scale and heavy capital investment. In order to produce at minimum unit cost a company must produce 300,000 to 600,000 units per year and invest hundreds of millions of dollars in capital equipment.

2. The dealer system. A strong retailing system is required to market and service the product. A satisfactory dealer system is very expensive and difficult to build from scratch.

3. Dynamic obsolescence. Frequent model changes are a vital part of market strategy in the American automobile industry. Small firms are at a decided cost disadvantage in this area since the substantial fixed costs of changes must be spread over the number of units produced in the model run.

I have argued elsewhere that an electric automobile innovation would substantially reduce these barriers to entry and that the automobile industry would therefore be reluctant to foster such an innovation. Small economies of scale and the ability to subcontract major components would markedly reduce the capital requirement for the production of electric cars. Simplicity, low maintenance requirements, and the limited range of the electric cars all suggest the adequacy of a simpler and markedly less expensive retailing organization. High durability of the vehicle and the likelihood of a substantially different product image suggests a strongly reduced importance of dynamic obsolescence as marketing concept.

Steam propulsion systems do not appear to have this same potential for reducing the barriers to entry into the automobile industry. Steam vehicles would be somewhat simpler, more durable and maintenance free than present day automobiles. But, in all the relevant aspects of production and marketing, the steam propulsion system would be closer to the current internal combustion system than to a system of electric propulsion. From this point of view the innovation therefore should encounter less resistance from the industry as currently structured.

B. *Industrial Structure.*—Substantial innovation in an industry of the size and complexity of the American automobile industry would be strongly disruptive, and would require a serious reorientation in production, materials usage, and coordination with supporting industries. However, for any given percentage penetration of the market, a steam innovation would be less disruptive than an electric innovation. But, since the steamcar would be a general purpose vehicle, a successful design would probably lead to a much more rapid market penetration than would an electric car innovation. The speed of market penetration would, in itself, affect the degree of disruption.

Basically a steam vehicle would have the same structure and use the same production, fuel, and service facilities as present day vehicles.

Capital equipment used in the production of transmissions, ignition, and cooling systems, and other supportive components for the internal combustion engine would be obsolesced by a successful steam innovation. Adaptations of existing capital equipment to the requirements of a substantially redesigned vehicle would have to be made throughout the production process. Oil refining processes would have to be alerted to meet the fuel requirements of steam engines.

II. PROSPECTS FOR AN INNOVATION

At this point I would like to read some statements pertaining to innovation by spokesmen from the automobile industry. The first two statements were made in testimony during the joint hearings on electric automobiles during March and April, 1967.

Harry F. Barr, vice president, engineering, General Motors Corp.:

> The development of efficient and constantly improved systems of energy conversion is vital to the continued progress in transportation. For this reason we will continue to pursue aggressively any method of energy conversion which offers potential for more efficiently satisfying the power requirements for automotive vehicles and other applications in our business.

Michael J. Ference, Jr., vice president, scientific research, Ford Motor Co.:

> In order to realize the business potential and the public advantages of electric vehicles, Ford Motor Company is making the maximum possible effort to overcome their present limitations as quickly as possible.

Although these statements are necessarily vague in some respects, they appear to be very much in the innovative spirit. But, the following statement by Henry Ford II as quoted in a recent Look magazine and as noted here this morning, places these statements in the perspective of some concrete reality.

> We have tremendous investment in facilities for engines, transmissions and axles, and I can't see throwing these away just because the electric car doesn't emit fumes.

The same statement would apply with similar force to the steam propulsion innovation. In fact, since the steam vehicle poses a rather limited threat to the market structure of the automobile industry, the case against it places heavier emphasis on the resulting disruption of the industrial structure and obsolescence of existing capital goods.

It is not my purpose to condemn Henry Ford or the automobile industry. Business leaders function in the interests of stockholders. If an automobile producer can meet his social responsibilities while producing internal combustion engines, then that should be his privilege.

There are, nevertheless, some disturbing implications that are clearly indicated by Mr. Ford's statement. In contrast to the usual claims that the customer determines the type of automobile produced, Henry Ford has implied that the industry has power to determine what the customer is offered in a very fundamental way. The customer undoubtedly exerts strong influence, but the discussion here is not focused on the difference between Falcons, Fairlanes, and Mustangs where his preferences are meaningful. The problem is that where economic power is concentrated in a few hands, the discipline of the classical competitive market is absent. Thus we see the forces underlying the

conclusion of scholars who have investigated the innovative process. The large corporations with vast resources and research facilities do not usually initiate fundamental innovations which compete with their existing capacity. Why should they? In the absence of sufficient competitive pressure, the large successful business protects what it has achieved. The risks and uncertainties of innovation are for the hungry man who has much to gain and relatively little to lose.

I have attempted to establish the case that steam-propelled vehicles constitute less of a threat to the market structure and established industrial complex than electric vehicles. The easy conclusion is that a steam innovation would therefore be the most likely of the two. Under present circumstances my own conclusion is the opposite and is rooted in several propositions on technology, consumer appeal, and market dynamics. The key proposition is the first one.

1. It is very doubtful that the automobile industry, as presently structured, will pursue either of these innovations in the absence of a stiff competitive threat, actual or potential.

2. People purchase automobiles on the basis of private benefits expected. The level of harmful emissions produced by his own car does not affect the welfare of the customer significantly and will not usually be considered as a relevant factor in the purchase decision.

3. The electric car now has the potential to perform a somewhat limited transportation function better than any available alternative. This function covers 80 percent of the current automobile mileage in the United States. I should add that this figure does not imply the present feasibility of anything approaching 80 percent of our vehicle fleet using electric power, but the potential market is nevertheless substantial. The steamcar would have to compete as a general purpose vehicle, and while it has some interesting private advantages over current vehicles, it is not clear that these advantages are compelling.

4. Since electric vehicle technology sharply reduces the barriers to entry in the automotive industry, the small innovator has an opportunity to survive all but the most predatory behavior on the part of current producers. If his vehicle is well designed and efficiently produced, he should be able to prosper and grow. The ready availability of major components, such as motors, control systems, and batteries, on a subcontract basis minimizes his initial capital investment. Since his customers will not be concerned with long-range travel, initial sales and service facilities can be limited to a few major urban centers. Initial success will stimulate development of a more general purpose type of vehicle, but the time required should give the innovator sufficient opportunity to develop his production and marketing structure to meet the challenge.

5. 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 the 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 shortlived. The automobile industry could readily adapt its production and service complex to steampower if forced by serious com-

petitive 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?

III. PUBLIC POLICY

The most satisfactory solution to automobile air pollution problems ultimately lies in the design of vehicles which are attractive to the consumer and inherently free of toxic emissions. A public policy which encourages the development of such vehicles is in the long run much more compatible with the private enterprise system than an entire phalanx of Federal and State regulations designed to reduce the level of emissions from the internal combustion engine to acceptable levels.

I would, therefore, encourage the Federal Government to support financially the development of propulsion systems which hold the double promise of economic feasibility and inherently low pollution potential. Efforts should not be concentrated on a single system since it is very difficult to predict which systems will ultimately prove successful. Producers could also be encouraged by governmental purchase of vehicles with unconventional propulsion systems that meet specific performance standards. The Federal Government would accomplish by these programs a partial compensation for market incentives which are insufficient to force a desirable rate of product innovation.

Senator BAKER. Professor, thank you very much. I have one or two questions I would like to put, if I may. On page 5 of your statement, you point out that large corporations have a built-in inertia that operates against change, and thus presumably against progressive improvement. I think of one exception, and I am sure there are others, but I am thinking of the aircraft industry and the transition from reciprocating engines to turbine and jetpower engines which was done more or less, it seems to me, from the framework of the existing industrial structure that produced aircraft engines.

I wonder what distinction you see between that situation and the postulation that the automotive industry might not respond to the impetus of obviously superior product line or innovation?

Mr. ORR. This would have to be somewhat speculative, since I am not intimately familiar with the specific case. But there are factors that are present. I think one would be the obvious private advantage to the purchaser of the jet propulsion over the piston. That purchaser would be the airlines.

Another important factor would be the expertise of the purchaser. He knows clearly what the advantages of the alternatives are, whereas the people who buy automobiles in general do not have this level of sophistication.

Senator BAKER. I wonder if the real crux of the question isn't whether or not the advantage of the new technique or new innovation is great enough from the competitive standpoint, or the performance standpoint, which is also competitive, to bring about this change. I wonder if it isn't a question of the degree of attractiveness rather than the proposition itself, as you put it.

Mr. ORR. Certainly, it is very important.

Senator BAKER. The thesis on the unacceptability of steam cars as generally put in this statement, from the standpoint of the manufac-

turer, is based on the premise that none of the major manufacturers would produce them.

Mr. ORR. Under current circumstances.

Senator BAKER. Under current circumstances, even if these vehicles demonstrated superior performance and emission characteristics. Do I understand that to be the proposition you put here?

Mr. ORR. Yes.

Senator BAKER. If one of the four manufacturers were to respond, and to enter the production of steam turbine automobiles, do you believe it would be more likely that the remaining car manufacturers would follow suit?

Mr. ORR. I think it is almost unquestionable that the remaining ones would follow suit, assuming that a design is attractive to consumers.

Senator BAKER. Don't we finally get back to the same proposition I tried to put, that is, that the determining factor is the degree of the attractiveness of the innovation, whether it is the steam propulsion system or the electric propulsion system or some other fairly new or different system?

Mr. ORR. Of course, the other factors are the costs of producing it, and the pressure from the customer side for the innovation. The automoblie purchaser knows very little about what the attractiveness of the alternatives are, and in fact has some rather strong built-in prejudices against them that are by no means discouraged by the automobile industry.

Senator BAKER. By the same token, there is a spirit of adventure in the purchasing public, especially when it comes to automobiles, that might militate in favor of it.

Mr. ORR. I would hope so, at least among a sufficient number so that when someone builds these alternatives at an economical cost their attractiveness would be clearly demonstrated.

Senator BAKER. I assume you have been speaking of the automobile industry as such when you speak of this resistance to change.

Mr. ORR. Yes.

Senator BAKER. I wonder if you would evaluate the prospects of innovative devices, either steam or electric, for competition in specialized applications such as buses, trucks and the like in the same manner?

Mr. ORR. Your purchasers represent a more expert clientele and they pay more attention to such things as costs. They nevertheless are not in a good position to pressure manufacturers into doing this sort of thing.

Senator BAKER. Conversely, the effectiveness of their pressure ought to be proportionately greater, because there are fewer of them as potential customers. And presumably they aren't as concerned with design and obsolescence.

Mr. ORR. Quite correct.

Senator BAKER. Then we come to the question of foreign imports, and especially of the Volkswagen, when we speak of design obsolescence. Pretty clearly the Volkswagen has done well in the American market and in other markets as well. And they are the antithesis of the necessity for design change. Do you say this casts any doubt on one of the propositions you put in your statement?

Mr. ORR. I don't believe it casts doubt on the proposition. It is just that the automobile industry is currently structured in this way. The Volkswagen offers a somewhat different package that is attractive

enough in other respects that a significant number of people are willing to forego the latest style.

Either the electric or the steam vehicle would be much more unconventional in terms of offering an entirely different set of advantages when compared to the ordinary automobile. And if these advantages are attractive, then to that extent styling is less of a factor in the purchase decision.

Senator BAKER. I wonder if you don't see the "buglike" structure of the Volkswagen as a sort of reverse field that might carry over in comparison to the field of steam and electric vehicles.

Mr. ORR. They make an excellent form of protest.

Senator BAKER. The first item that you put on the list of difficulties involved in market structure, of course, is the requirement for heavy capability and high-volume production. Do you have any estimates of how high the volume of production would have to be in the case of steamcars in order to compete with the existing established automobiles?

Mr. ORR. I expect at this point this figure could not be established. My statement was based on the fact that in many respects the steamcars are very similar to the internal combusion car. Differences are relatively minor, as compared to the electric automobile. The techniques of production will therefore change less dramatically.

Engines and bodies, which constitute the highest economy of scale production, would be pretty much the same as they are today.

Senator BAKER. In this same respect, since you have spoken of the electric and steam automobile as they relate to potential competition with existing internal combustion machines, do you have any judgment or estimate on which one, that is the electric automobile or the steam automobile, might have the best chance of competing in the market generally with the established order?

Mr. ORR. I have a rather strong feeling that we will see both. Or at least that we will see the electric and something other than the internal combustion. The electric may take over, but that won't be in the immediate future. It is somewhat discouraging to confront official statements on the serious limitations of the electric.

I would suggest that the committee might check back with Mr. Aronson, of Electric Fuel Propulsion, who testified last year. In a call to him on Wednesday, he informed me that they now have developed a lead-cobalt battery that measures 70 inches by 70 inches by 7 inches, which means it fits in the fore pan of the automobile. It is 38 kilowatts and 1,200 pounds. This should put to rest forever the notion of the glorified golf cart image that the electric car has been given. The battery is economical, it performs very well for either highway or suburban use. It is still nevertheless not quite in the category of the general-purpose vehicle.

I think we will see electric automobiles and I think we will also see other alternatives to the internal combustion engine. But it will be very difficult, under present circumstances, to encourage somebody to take the risk of producing a steamcar.

Senator BAKER. One last question. You pointed out, I think correctly, that is the marketplace traditionally, and accurately, the producing unit seldom assigns a great deal of weight to social concerns such as air pollution, and that is entirely understandable.

I wonder if you have an elaboration of that thesis along the lines of how we might broaden this recognition of social concern within the framework of a free competitive system as we enjoy it.

Mr. ORR. I happen to be in favor of the free competitive system, and believe that the Government should provide this kind of a social framework and should do it without hesitancy, with full knowledge that is really working in the longrun interests of the free system.

If we want the best of the enterprise system, then managers must be free to pursue the interests of owners. The framework of social concerns which restrains their activities must be provided by the Government. They should not be expected to provide an adequate framework themselves.

Senator BAKER. How would you propose to do this? Would you do it through a system of more rigid and strigent exhaust emission standards, or through purchasing policies of the Government, or how?

Mr. ORR. Those two, and I also mentioned the funding of development by Government.

Senator BAKER. Senator Pearson?

Senator PEARSON. Professor Orr, I really don't know where this leads us. You state under current circumstances the automobile industry will not undertake the development that is necessary and suggest that the Government might do it.

Mr. ORR. They should support it.

Senator PEARSON. In the list of priorities we have today, I don't know where that would be on the list. I suspect it would be on the downside: $30 billion in Vietnam, the budget deficit of last year, $40 billion, and anticipated this year, $20 billion. The SST, I understand, is under quite hard scrutiny on the House side.

There is another point, and I think really so much of the trend today in the Government—understanding what its limitations are in the field of financial support is to provide incentives, maybe by tax credits or otherwise, rather than seek to make any sort of appropriations.

That is part of the current circumstance we are operating in here today. I thank you for your statement. I don't have any questions.

Senator BAKER. Professor Orr, thank you very much. I appreciate it. The committee will stand in recess. The last signal we got was for a vote. We will return, hopefully in 30 minutes.

(Whereupon a brief recess was taken.)

(Subsequent to the close of the hearings, Mr. Orr submitted the following supplemental statement:)

SUPPLEMENTAL STATEMENT OF LLOYD D. ORR, ASSOCIATE PROFESSOR OF ECONOMICS, INDIANA UNIVERSITY

ENERGY STORAGE AND ENERGY REQUIREMENTS OF ELECTRIC VEHICLES

The primary conclusion of the Department of Commerce Panel on the feasibility of electric vehicles is stated in Part I, page 2 of their Reports.[1]

> "The state of technology does not permit the current development of an economically feasible electric car except for special purpose limited range use."

No one has seriously claimed that present technology would permit the development of a versatile full-range vehicle. However, if we look at the supporting evidence in the Report we find that the Panel's conclusion is heavily dependent

[1] "The Automobile and Air Pollution," U.S. Department of Commerce, October 1967.

on a paper study that purports to demonstrate that current technology in lead-acid batteries will not propel a vehicle more than 50 miles at a steady 30 m.p.h.

My purpose in this brief comment is to show that such conclusions do not adequately represent the performance that can be achieved with current technology in lead-acid batteries. In particular:

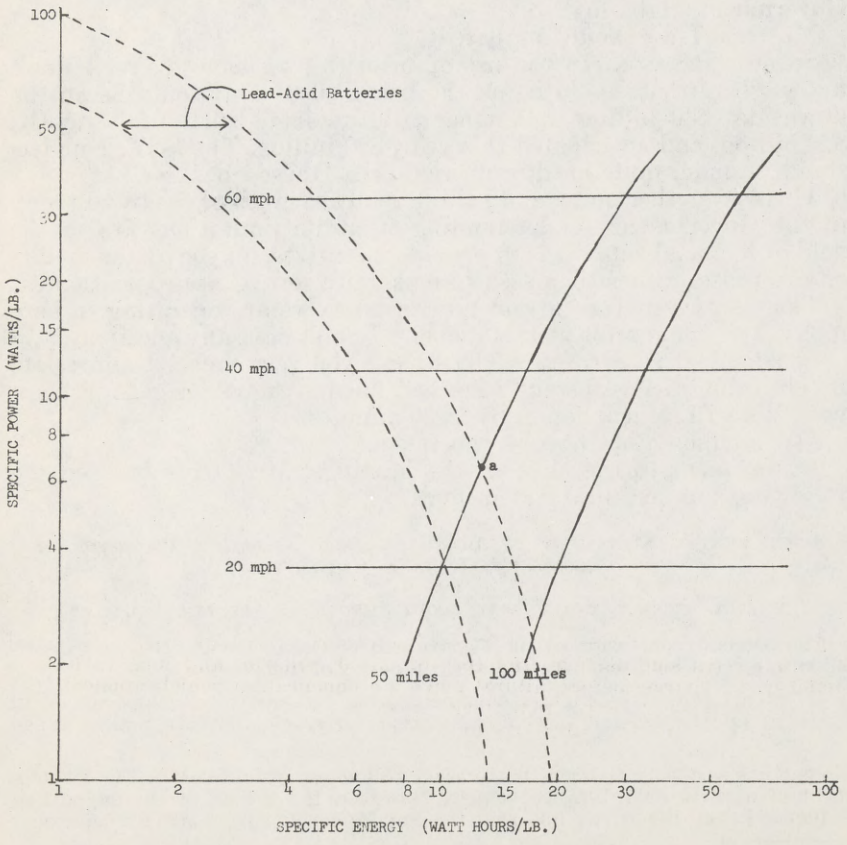
1. Recent improvements in the lead-acid battery give it performance characteristics which are superior to those shown in the Department of Commerce Report. Data on the performance of this battery was not available at the time the Report was written.
2. Assumptions on the design characteristics of the hypothetical automobile used in the study were very conservative and resulted in a serious underestimate of electric vehicle performance.

I. PERFORMANCE CHARACTERISTICS OF LEAD-ACID BATTERIES

The energy capacity of storage batteries generally depends upon the rate at which they are discharged—*i.e.* the rate at which power is drawn from them. Figure 1 shows the range of specific energy versus specific power characteristics for lead-acid batteries as given in the Department of Commerce Report.[2] In

FIGURE 1

Department of Commerce Panel Projection of
Electric Car Performance Using
Lead-Acid Batteries



[2] Ibid., pt. II, p. 63.

FIGURE II

Actual and Projected Performance of
Electric Fuel Propulsion Car

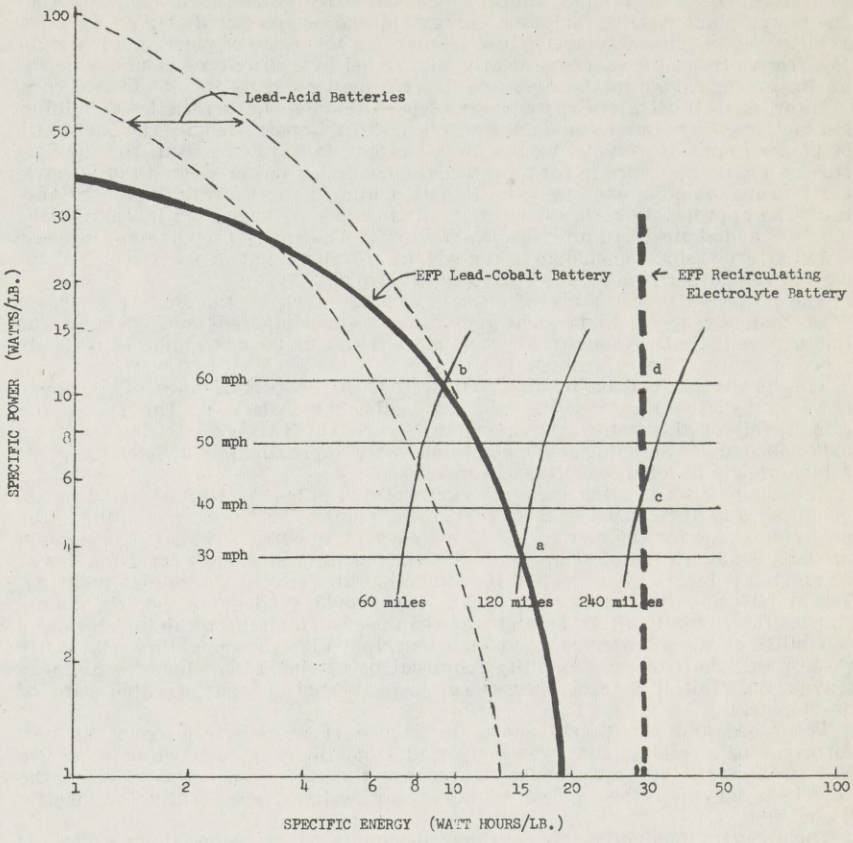


Figure II these characteristics are compared with those of two lead-acid batteries designed specifically for automotive use by Electric Fuel Propulsion of Ferndale, Michigan.

The heavy solid line in Figure II is the tri-polar lead-cobalt battery developing 18 watt hours/lb. at the 20 hour rate of discharge. This battery was mentioned in the Report. Its characteristics place it along the outer fringe of the performance area given in the Report.

The heavy dashed line represents the newly developed recirculating electrolyte tri-polar lead-cobalt battery. This battery develops 31 watt hours/lb. and shows virtually no decline in energy density up to a specific power of 30 watts/lb. This is a very desirable characteristic in automotive applications where power requirements are relatively high. The battery can be given an 80% recharge in 20 minutes without damage. It's cost of 25–30 cents/lb. and long cycle life (number of recharges before failure) make it economical for vehicle applications.

The recirculating electrolyte battery is not yet in a fully engineered prototype form: however, no difficulties are anticipated. No further technological breakthroughs are required, and the performance of the prototype and production versions is expected to equal or exceed that of the test batteries. Confidence in these predictions stems from long experience in the economics and technology of lead-acid batteries.

II. PERFORMANCE CAPABILITY OF ELECTRIC VEHICLES

The Department of Commerce Report projected performance for electric vehicles on the basis of a paper study for a hypothetical automobile. The serious underestimate of attainable range stems primarily from the assumption that the power plant weight, including energy storage, is restricted to 25% of gross vehicle weight. This assumption also results in a low ratio of power plant weight to effective frontal area (frontal area multiplied by a drag coefficient) which is an important factor in the high speed performance capability of electric cars.

In order to illustrate a comparison of performance characteristics for different motive power sources on a "uniform basis" the Report assumes the 25% ratio of power source to vehicle weight for all propulsion systems. But, the application of a ratio appropriate for an internal combustion powered car to an electric car is a meaningless exercise—the Panel's claim to the contrary notwithstanding.[3] The appropriate ratio for electric automobiles, as suggested in engineering studies [4] and achieved in practice, is about 50%. The entire proportional increase is in batteries, since no change in the weight of other components is required for a given vehicle performance and gross vehicle weight.

The projected performance of electric cars as given by the Report is shown with a steady speed, and range grid that is superimposed on Figure I. The implication is that we should expect no more than a range of 50 miles at a steady speed of approximately 30 m.p.h. (point a).

This projection can be readily compared with the performance of a vehicle powered by Electric Fuel Propulsion's lead-cobalt batteries. The speed and range grid for this vehicle is shown in Figure II.[5] This grid is derived from experience under actual cruising conditions with approximately 55% of the gross vehicle weight devoted to motive power source.

The comparison is remarkable. A range of 120 miles is attained at 30 m.p.h. (point a) and at 60 m.p.h. it is still 60 miles (point b). Even more striking is the projected range for the new recirculating electrolyte battery. This battery would propel a configuration of components like that of the test vehicle for 240 miles at 40 m.p.h. (point c). At 60 m.p.h. the range is still close to 200 miles (point d). The implication is that current technology provides adequate electric energy storage for virtually all urban and suburban needs. In addition the fast recharge capability of these batteries provides a marginal highway capability. Obviously we are still short of the flexibility required for extended long-distance highway travel. But, initial market success can be expected to spur a rapid rate of development.

The speed and range grid shown in Figure II was derived from the performance of a vehicle that was converted from internal combustion power to electric power. The performance figures are therefore conservative, since the vehicle is inevitably less efficient than a car designed specifically for electric propulsion.

The primary goal of electric vehicle design is to overcome the problem of limited energy storage. Efforts are concentrated on reducing rolling resistance and effective frontal area, and increasing the proportion of vehicle weight devoted to energy storage. Heavy use of electric power for non propulsion purposes is minimized by the use of such accessories as air-conditioner-heater combinations powered by distillate fuels. It is difficult to say exactly what the performance characteristics of mass produced electric cars would be. However, it is clear that Figure II gives a much more accurate representation of what can be achieved with current technology than Figure I. By ignoring design goals and design achievements in the area of electric vehicle technology, the Department of Commerce Panel has damaged an otherwise excellent report.

Senator BAKER. The committee will resume its hearings.

The next witness is Mr. S. William Gouse, Department of Mechanical Engineering, Carnegie-Mellon University, Pittsburgh, Pa. Professor Gouse, we welcome you to the committee. We are going to have another vote on the Senate floor shortly. If you would proceed, we would appreciate it.

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[3] Ibid., pt. I, pp. 27–30.
[4] G. A. Hoffman, "The Electric Automobile," Scientific American, CCXV (October 1966), pp. 34–40.
[5] Derived from data supplied by Robert Aronson, "The Mars II Electric Car," Society of Automotive Engineers Mid-Year Meeting, Detroit, Mich., May 20–24, 1968. No. 680429.

STATEMENT OF S. WILLIAM GOUSE, JR., DEPARTMENT OF MECHANICAL ENGINEERING, CARNEGIE-MELLON UNIVERSITY, PITTSBURGH, PA.

Mr. GOUSE. I am with the mechanical Engineering Department of Carnegie-Mellon University. I was educated in mechanical engineering at MIT. I have been working with energy conversion of all types for the past 12 years or so.

I was a member of the Morse committee and responsible for the steam engine conclusions in that committee report which is, I guess, why I am here today.

The recent past has seen substantial activity related to the automobile and air pollution. In particular, there has been much investigation into how to modify the internal combustion engine to minimize its undesirable effluents.

Along with this activity, there has been a resurgence of publicity relating to battery powered automotive vehicles as a means for alleviating the adverse air pollution effects of the present IC engines, conventional batteries as well as some novel types which have been demonstrated under laboratory conditions.

There have been a variety of prestigious studies and conferences relating to this particular problem—for example, (1, 2).[1] Some of these studies have been somewhat narrow in their scope when looking at alternates for the propulsion system of an automobile vehicle.

A recent study completed under the auspices of the technical advisory board of the U.S. Department of Commerce (3) did not follow the pattern of the preceding studies and examined the total automotive system as a part of a transportation system.

In examining various alternates to the internal combustion engine, the study included Rankine cycle heat engines, more commonly known as steam engines. One can conclude from the results of this particular study (3), others in progress (4), as well as other published literature (5), that at this point in time there is a completely acceptable economically feasible alternate to the internal combustion engine as an energy conversion device for many automotive propulsion applications, and it is the closed cycle reciprocating steam engine.

However, the fact that it may be a completely adequate alternate in terms of its meeting the technical requirements of an automotive powerplant, that in production its cost would be competitive with, if not less than present internal combustion engines, and that because of the lower temperature steady external combustion, it would meet air pollution requirements for some time into the future without any additional development, are not enough to see such an engine produced for and employed in automotive vehicles. There are many other forces and constraints which enter the picture in deciding whether or not such a device will be produced.

BASIS OF EVALUATION

It would be impossible to make any evaluation of alternates to the internal combustion engine without first establishing some ground rules. Thus the evaluation is restricted to Rankine cycle engines

[1] Numbers in parentheses refer to items in bibliography.

providing shaft work for propulsion of the present medium-size American automotive vehicle rather than some other type of vehicle of limited acceleration performance, range, size, or weight.

This restriction is especially important. A number of recent papers, symposia, et cetera, dealing with electrically powered vehicles have not always identified the market for the type of vehicle they were proposing.

In addition to prescribing the type of vehicle, one must examine the entire automotive vehicle in a manner similar to that of Hoffman (6–9), that is, its weight distribution, the function of various components, et cetera.

Fortunately, such a study was not necessary, in that the results were already available in the literature (10–14). All that was required was to look at these results and interpret them in terms of substituting steam engines for the internal combustion engines.

AUTOMOTIVE VEHICLE PROPULSION REQUIREMENTS

The automotive propulsion system must provide for acceleration, cruising, and auxiliary power. If consumer choice is not allowed, it is in the area of acceleration power that we have the most flexibility in the size of powerplant to be installed in the vehicle. Two reasons why present automotive vehicles have such a large power-to-weight ratio are first, the acceleration performance demanded by the consumer is nearly that of the sports car and second, the torque-speed characteristics of an internal combustion engine are not well suited to its use.

One might control the acceleration rate to be allowed. For example, present automobiles have the capability of going from 0 to 60 miles per hour in the order of 10 seconds, but such control of the acceleration rate is not likely to meet with acceptance on the part of the consumers. However, this acceleration performance has a large bearing on the type of powerplant which might or might not be useful as an alternate to the present internal combustion engine. In addition to the power requirements, one should examine the torque-speed characteristics required as the latter is the more meaningful output of a powerplant for an automotive propulsion. It is an important performance parameter in the comparison of alternate powerplants.

In the evaluation of any alternates to the internal combustion engine, one must keep in mind that there are two requirements placed on the engine which are difficult to achieve in the same device. One is high power per unit weight or volume which is a measure of the system's ability to provide acceleration power, and the other is high energy storage per unit weight or volume which is proportional to the range of the vehicle.

Figure 1 (9), indicates how the horsepower-to-weight ratio has been changing with time for full-sized American cars. Figure 2 represents one forecast of how the fuel economy at 60 miles per hour will vary with 0 to 60 miles per hour acceleration performance for various classes of vehicles in the 1970's (9).

It is one thing to think in terms of performance indicated by the potential mean of small or compact cars. It is quite another to meet the potential performance of luxury cars when one is thinking in terms of alternate powerplants to the present internal combustion engine.

The numbers indicated in figure 2 represent an improvement in specific power over what is available today. The projections used to obtain figure 2 assume increasing use of lighter materials, improved aerodynamic design and improved rolling friction characteristics. What is important here is that the car of the next decade will require slightly less powerplant to achieve the same performance as an equivalent car of this decade.

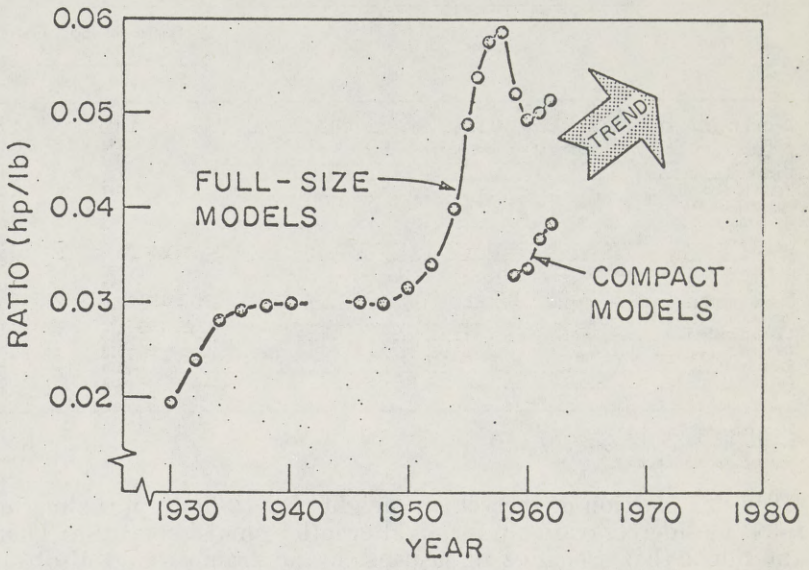


FIGURE 1.—Trends in Specific Horsepower of U.S.-Made Passenger Automobiles (Ref. 9)

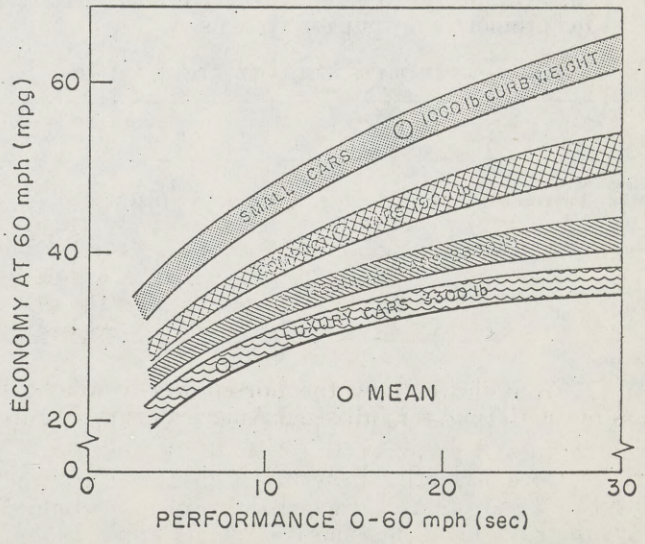


FIGURE 2.—Economy and Performance of Automobiles in the 1970's (Ref. 9)

COMPARISON OF VARIOUS PROPULSION SYSTEMS

Table I, prepared by Hoffman (7), is useful in evaluation of possible alternates to the internal combustion engine for automotive propulsion. The mean value items in table I marked with an x sum to 0.325 of the vehicle weight.

TABLE I.—WEIGHT APPORTIONMENT OF 1966 MODEL PASSENGER CARS [1]

	Component	Component weight divided by curb weight	
		Mean value	Least value
	Body	0.330	0.243
	Trim	.142	.106
	Glass	.032	.022
X	Engine	.151	.118
X	Transmission	.047	.039
	Suspension: [2]		
	Front	.033	.025
	Rear	.027	.016
	Wheels	.025	.016
	Tires	.032	.026
	Brakes	.038	.031
	Steering unit	.016	.012
X	Rear axle, driveline [2]	.043	.036
X	Exhaust system	.013	.008
X	Battery	.013	.010
X	Radiator [3]	.014	.007
X	Fuel tank	.044	.035

[1] From reference 7.
[2] Front-engine, rear-drive models only.
[3] Water-cooled engines only.

It is this fraction of the vehicle weight that to first approximation can be considered available for an alternate propulsion system. There is no doubt that a change in suspension and frame would also take place for the new propulsion system but probably not to a significant extent.

Table II is a comparison of representative energy converters for possible use in automotive propulsion systems.

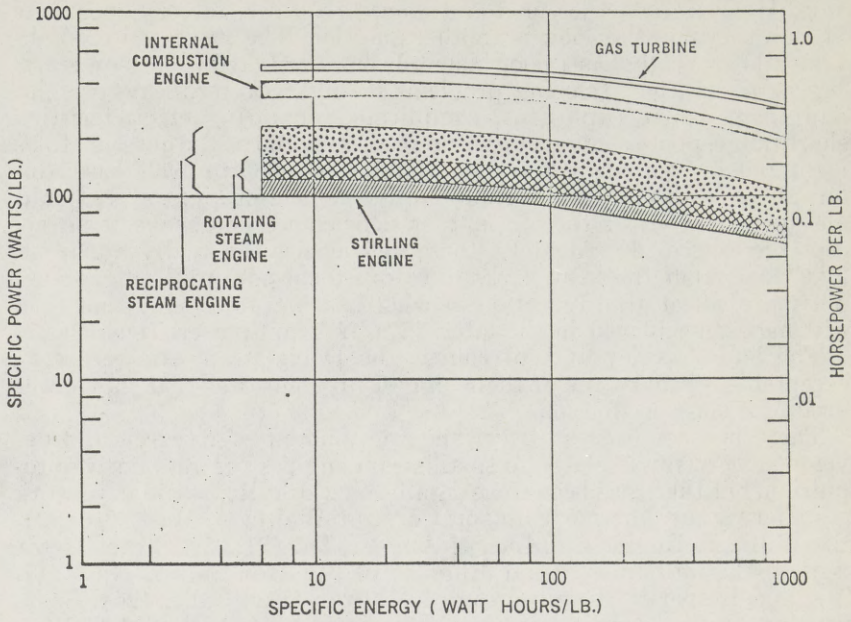
TABLE II.—COMPARISON OF REPRESENTATIVE CONVERTERS [1] (3)

Converter	Specific weight lb/kw	Specific fuel lb/kw-hr	Specific cost $/kw
Nonregenerative gas turbine [2] (Brayton cycle)	1–2.5	1.0	3–5
Rotary I. C. engine [2] (Wankel engine)	1.34	.67	4(?)
Gasoline engine [2] (Otto cycle)	2.7	.6	2.5–4
Regenerative gas turbine [2] (Brayton cycle)	2–5	.6	5–10
Steam engine (reciprocating) (Rankine cycle)	6.7	.67	4–(?)
Diesel [2] (Diesel cycle)	8	.4–.55	3–6
Free piston	9	.67	(?)
Steam engine (rotating) [2] (Rankine cycle)	10	1.34	5–6.7
Stirling engine (Stirling cycle) [2]	10	.6	6.7(?)

[1] From various sources.
[2] Needs transmission.

Figure 3 (3) compares specific power versus a specific energy for combustion engines of various types. It indicates that the gas turbine is potentially more attractive in terms of these two parameters, but its potential cost and other characteristics probably would not allow it to be competitive in an automotive vehicle application for other than the luxury type of car.

FIGURE 3 - SPECIFIC POWER VERSUS SPECIFIC ENERGY FOR COMBUSTION ENGINES.(3)



What is clear is that the reciprocating steam engine comes closest to the internal combustion engine. If one were to put other types of energy source-converter combinations such as fuel cells and batteries on the same type of plot, they would be less favorable in comparison to the combustion engines. A possible exception is the fuel cell, which may have a lower specific power but which might have adequate specific energy.

THE STEAM ENGINE LOOKS BEST

At this point, the reciprocating steam engine appears most attractive as an alternate to the internal combustion engine for automotive propulsion on a specific energy and specific power basis as well as a potential cost basis, provided we restrict ourselves to powerplants of the order of 100 to perhaps 150 shaft horsepower output.

However, if we were to open our consideration to larger vehicles such as trucks and buses, we may find that Stirling engines, gas turbines, and perhaps partially open-cycle reciprocating and rotating steam engines might become attractive.

A 100 to 150 horsepower shaft power output engine was chosen because this actual shaft power output from a steam engine with its superior torque-speed characteristics for vehicle propulsion would be a formidable powerplant and could adequately meet the propulsion requirements for all but the luxury-size automotive vehicles.

ADEQUACY OF STEAM ENGINE FOR AUTOMOTIVE VEHICLE PROPULSION

The best estimates of what could be accomplished today in terms of weight, fuel consumption, and cost tabulated above, indicate that

from a technical point of view the steam engine is an acceptable alternate to the internal combustion engine for automotive vehicle propulsion. However, whether or not it would be a satisfactory substitute from a user point of view is another question. The steam-powered automobile generally has a poor image. It has attributed to it: slow starting in all weather, freezing problems in cold weather, heavy weight, danger of boiler explosions, complicated operating characteristics, short range, poor economy, high cost, et cetera, and so the question to be answered in comparing the steam engine to an Otto cycle based internal combustion engine for automotive vehicle propulsion is, Could one overcome all of these apparent deficiencies and make it an acceptable device? Fortunately, these deficiencies are really apparent, and stem from the very early days of steam-powered automobiles. They are not at all a reflection of what is achievable today; not even of what was achieved in the later days of steam-powered vehicles.

The later Stanley and, of course, the Doble steamcars were very acceptable. Perhaps one of their biggest problems was that they never set up for mass production.

There has not been an overwhelming amount of research and development activity related to small steam engines for automotive propulsion, but there has been some significant work. Representative work is underway at Thermo Electron Corp. of Waltham, Mass. (16. 22), the Williams Engine Co., Inc., of Ambler, Pa. (21, 23), Steam Motor Systems-Ellipttocline Steam Engines of Winston-Salem, N.C. (17, 24), and Emperical Engineering of Midway City, Calif. (24). Some very interesting development work was undertaken by the McCullock Corp. in Los Angeles, as reported by Dooley & Bell in 1962 (16).

Thermo Electron Corp. is developing a novel steam engine in which the working fluid inside of the engine is hermetically sealed from the crankcase of the engine so that no steam ever gets into the crankcase and no crankcase or other lubricant ever gets into the steam side of the engine. All lubrication on the steam side of the engine is done with steam and the aid of solid-state lubricant cylinder liners. An ingenious in-cylinder valving mechanism eliminates the conventional camshaft and valve lifters normally associated with reciprocating steam engines. In particular, this novel valving arrangement leads to excellent performance at small power levels. Actual indicator diagrams have indicated unprecedented valve performance at this power level. This hermetically sealed engine will operate in the neighborhood of 1,000 pounds per square inch with 1000° F. steam.

Hermetical sealing of the working fluid side of the engine also eliminates the presence of any noncondensable gases in the condenser. This improves condenser performance, keeps it high over the life of the unit and makes possible a smaller condenser. In addition, careful design has brought the working fluid inventory to a very low level, enabling very rapid startup. By arranging for condensation to take place in a preselected area, all freezing problems can be eliminated. The New York Times recently, March 16, 1968, announced a joint development effort between Thermo Electron and the Ford Motor Co. to develop steam engines for perhaps boats and golf carts.

The work of Gibbs and Hosick on their elliptocline steam engine represents another novel development. This engine was described in a recent article in Popular Science magazine. February 1966 (19). Their

engine is inherently balanced even though the action of pistons is reciprocating and the output motion of the engine is rotary, very much like a revolving block internal combustion.

One of its very big advantages is that one valve mechanism feeds steam flow to nine opposing pairs of cylinders. This leads to some mechanical simplification in terms of valve mechanism and a great reduction in engine volume and weight for a given displacement.

Work by the Williams Engine Co. is along more conventional lines in that the engine is not much different in appearance from other reciprocating engines. Thermal efficiencies of 29 percent have been reported for the Williams engine; whereas Thermo Electron is attempting to achieve efficiencies of 26 percent. The work of Gibbs and Hosick has not gone far enough to obtain reliable efficiency data; but there is no reason to assume that the engine will not have good thermal efficiency characteristics.

The work of Smith and Peterson at Empirical Engineering has been along conventional lines, modifying existing reciprocating engines and improving steam generators. Both the Williams Engine Co. and Empirical Engineering have been operating monotube boilers; that is, once-through, high-flow, velocity-heat-transfer steam generators.

Both the Williams people and Empirical Engineering have lubricant added to the working-fluid side of their engines and operating data in sufficient quantity to indicate that there is no detrimental effect on boiler or condenser life due to the presence of lubricants. High-velocity flow through the boiler tube prevents scale from accumulating.

Another important aspect of modern steam engine technology is that of controls. The state of the art today is such that very simple and reliable fail-safe control systems can be designed to limit the temperature and pressure level in the boiler to safe, predetermined conditions.

When little or no shaft power is being withdrawn from the engine, such as in idling or low-velocity cruising, these controls are sensitive and reliable enough to shut off the burner and allow the engine to operate off existing steam head until the pressure falls to a predetermined level, at which time the burner comes back on. Doble steam cars had this feature.

Even though the steam engine has attributed to it boiler explosions and other dangers associated with the boiler, it is difficult to find any documented evidence of any actual monotube boiler explosions in automotive application. There have been failures of boiler tubing, but this usually leads to a melting of boiler components—if enough of the working fluid leaks out—and if combustion is maintained, perhaps to some kind of fire.

Most modern engine developments deal with steam pressures of the order of 1,000 pounds per equal inch or above, with inlet steam temperatures of the order of 1,000° F. or above. In all engines currently under development, the working fluid is water.

The engine weights are the order of 4 to 5 pounds per horsepower for complete engine, including boiler, condenser, controls, et cetera, in units up to the order 200 horsepower. Completely closed-cycle engines become heavier as the power level goes up because of rapidly increasing condenser size and weight.

Thus some of the larger engines are partially closed cycle; that

is, when one draws large amounts of power, the condenser does not handle the complete load and the excess vapor is vented overboard. This means that the working fluid must be periodically replenished. However, under normal kinds of operating conditions, one can still easily have a vehicle range of 500 miles and add water which has not been given any special treatment.

Since the basic types of components that go into an automotive steam engine, pistons, cylinders, crankcase, and valves, are not unlike their counterparts in an internal combustion engine, it is not anticipated that the cost of a steam engine would be in excess of that of the internal combustion engine once comparable levels of production were achieved. The steam engine in an automotive vehicle leads to other simplifications in design of a propulsion system in that transmission and clutch requirements are minimal or even nonexistent. The steam engine does not require a carburator, and the ignition system can be simpler.

There are, of course, components which must be added, such as the boiler, controls for the combustion chamber, et cetera, but an overall balance of the numbers of components and their weight requirements indicates that a 125-shaft-horsepower output steam engine would be competitive with the internal combustion engine on a weight and volume basis, meeting all the heating and cooling requirements of the medium-size vehicle in which it was installed.

Steam-powered vehicles have other flexibilities that an internal combustion engine does not have. It is possible to design an engine so that it is not burning fuel when idling at stop lights or in traffic. That is, one shuts off the steam engine and for a reasonable length of time there is enough pressure to start moving again.

After this, the engine is restarted automatically. In addition, the engine can be designed with thermal capacity in the boilers so that for short periods of time one can withdraw perhaps double the steady-state power rating of an engine.

This can lead to valuable safety considerations for emergency passing, et cetera. Of course in a completely closed-cycle engine one may not be able to make use of such capacity unless the condenser has been designed with excess condensing capacity. In a partially closed cycle, excess exhaust vapor would be vented overboard during short periods of emergency power.

There are two pieces of evidence from the steam engine people themselves that indicate that the air pollution characteristics of an external combustion engine are highly desirable. Both Thermo Electron Corp. (22) and the Williams Engine Co. (2) have had the exhaust gases of their engines analyzed by independent laboratories.

The result of the Williams engine exhaust gas test have been reported by the Steam Automobile Club of America. The tests were conducted at the Mobile Testing Laboratory in Paulsboro, N.J. In both cases the exhaust gas composition was extremely attractive in terms of future emission requirements for automotive vehicles. Of course, these findings, for steam engine exhaust are backed up by findings at the General Motors Research Laboratory in the operation of their Stirling engines, which are also external combustion devices.

SO WHY NOT THE STEAM ENGINE?

If one could, in fact, build a steam engine that would adequately propel a medium-sized automotive vehicle, provide the kind of acceleration performance desired by the consumer, meet all the auxiliary power requirements at a cost competitive with that of an internal combustion engine with no undesirable operating characteristics, why don't we have one?

I am not prepared to supply an answer to this question, except to point out that resistance change is enormous and that the capital requirements for the scale of manufacture required would be very large. Even though the engine would ultimately be competitive in price, changing over to a new engine would, undoubtedly, reduce profits for a period of time.

However, because modern steam engines appear so attractive for many reasons, including very desirable air pollution characteristics, it may be easier to introduce them in some application other than for automotive vehicle propulsion. For example, they might be more easily introduced in special purpose vehicles such as post office trucks, delivery vans, taxis, or in certain size farm tractors, or perhaps in boats where not only would its air pollution characteristics be desirable but its noise pollution characteristics would be outstanding in comparison to most outboard and inboard boat motors.

Senator Muskie, that completes my prepared statement. I will submit the references attached to my statement since I alluded to them as I progressed through my reading.

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Senator BAKER. Professor Gouse, thank you very much for your statement.

Much of what we have discussed in interrogating the witnesses who preceded you dealt with the ultimate question of how internal combustion engines may be adapted to a lower level of exhaust emissions versus the desirable characteristics in this respect of steam engines.

Would you care to hazard an estimate of how the complexity of a steam engine would stack up against an internal combustion engine that was modified and contrived to reduce emission levels to, for the sake of an example, the range of 35 parts per million of unburned hydrocarbons?

Mr. GOUSE. Based on the present technology of both engines I would say the steam engine would be simpler. It is possible there may be something under development that I am not aware of that would lead to an internal combustion engine that is simple enough. However, if you look under the hood of a new car, the number of new valves and devices added for exhaust emission control are not negligible, and the next year or two may bring more.

Another problem is to keep the control devices operating the way they are at the factory. The consumer can usually disconnect them and is prone to, because the tuning of the engine becomes reasonably critical with the new devices and they may detract from the performance of the vehicle.

The steam engine has built-in emission control from the start. Present emission characteristics haven't really been developed for the steam engine to the point that they might be. These are fairly ordinary burners that are giving these desirable characteristics. They might be able to do better if one tried to improve them.

Senator BAKER. I take it it is axiomatic that if the internal combustion engine were modified or changed in order to bring it down to levels even generally comparable to the emission levels of steam en-

gines, that the internal combustion engine would be far more expensive and far more complex.

Mr. GOUSE. In my opinion, it would be right now. I would like to add something which I should have said earlier. When I said the engine is completely acceptable, I didn't mean that tomorrow you can start building cars with steam engines. Although they seem to be completely technically feasible and adequate, a great deal of money will have to be spent to take them to the point where they have the reliability of present automotive engines.

Senator BAKER. I have listened to the testimony of all the witnesses this morning and I don't believe I heard anybody refer to the concept of steam-electric propulsion systems. Has that been seriously explored by investigators?

Mr. GOUSE. I don't know of anyone who has seriously looked at it. It could be used in a hybrid system in the same manner as the General Motors Co. is looking at the hybrid system, using a small Stirling engine operating at nearly constant load at maximum efficiency in conjunction with batteries.

Senator BAKER. I noticed in your statement that you speak of thermal efficiencies in the range of 29 percent. The published data that one can find for the Williams engine can lead to that calculation?

Mr. GOUSE. That is very skimpy information. I wouldn't want to stake my life on that. I don't know why you shouldn't be able to achieve overall efficiencies of 25 percent with one of these engines.

Senator BAKER. Efficiencies. Would thermal efficiencies in this range be comparable to a percentage efficiency, computed on the fuel input versus power output as testified to earlier?

Mr. GOUSE. Yes. Fuel input over work output. I don't know why you couldn't, using modern techniques, have design point operation around 25 percent with the order of a hundred horsepower steam engine.

The steam engine, during operation, would probably have a higher average efficiency than an internal combustion engine actually used in the automobile. In city driving, you have to do a lot of accelerating of the automobile up to reasonable speeds to get torque output to drive it. This is a very inefficient and costly way to operate in terms of fuel. The steam engine torque speed characteristics are such that in heavy city driving, the average efficiency can be better than for an internal combustion engine even if the peak efficiency is lower.

Senator BAKER. What are the prospects or developmental efforts that you know of for steam turbines as distinguished from reciprocating engines for automotive applications?

Mr. GOUSE. For the small sizes, say 100 horsepower or so, water has too low a molecular weight to lead to a good turbine design. You have to go to larger powerplants. It is possible to use a turbine powerplant using the vapor of one of the refrigerants at this power level.

The turbine car doesn't have as attractive operating characteristics from the driving point of view as the reciprocating engine. There is a delay time in the accelerator.

I don't know if you have ever driven a gas turbine powered car. The car doesn't respond as well to the accelerator, at least the ones that have been available to now. It doesn't mean it has to stay that way.

Senator BAKER. Professor, you spoke of the fact that as far as you can document, you know of no explosion of steam generators or boilers.

Mr. GOUSE. For cars?

Senator BAKER. For automotive application. Can you say with reasonable assurance that whatever danger of boiler or tubing explosions remains has been substantially reduced since the Stanley days, and the Doble days?

Mr. GOUSE. Yes, this is because you can build an engine today with very little liquid in it, so that if something were to rupture, the amount of gas that would have to escape that would lead to an explosion would be small.

Senator BAKER. Metallurgy improvements would also reduce that hazard. What would happen if a steam automobile were involved in a highway accident? What would the probable result be? What would happen as a result of the rupturing of lines or boilers in engines?

Mr. GOUSE. It would depend a lot on the accident. I suppose the worse case would be the same as with an internal combustion engine. The fuel would burn. You would have a fire. I don't think the fact that you had steam under pressure, a small amount of it, would add appreciably to the danger. You could get the fire for the same kinds of reasons you get fires with internal combustion engines.

Senator BAKER. To put that in a nutshell: Would you hazard an estimate of the relative danger in the steam driven automobile versus an internal combustion automobile from a highway accident, as I have described it?

Mr. GOUSE. I think they would be very similar. I don't think there would be any appreciable difference.

Senator BAKER. As I understand it, the usual steam application for automotive purposes is fueled with kerosene?

Mr. GOUSE. Yes.

Senator BAKER. Or less volatile fuel than gasoline?

Mr. GOUSE. Yes.

Senator BAKER. Might that not reduce the hazards of fire?

Mr. GOUSE. It might. But it burns also, especially if it gets onto the upholstery materials.

Senator BAKER. Do you have an estimate you care to make on the difference in cost to the consumer or the owner of a steam propelled automobile versus an internal combustion automobile, assuming the usual cost of fuel, maintenance, upkeep and repairs?

Mr. GOUSE. Assuming you got to similar levels of production, I don't know why it should cost any more. In fact, it might even be less when you consider the complexities that have to go into the present internal engine to meet the air pollution requirements.

Senator BAKER. Is there anything you see about the configuration of the steamplant as now developed or as you might reasonably foresee for the future, that has posed problems of automotive design, the body shell, or engine compartment?

Mr. GOUSE. No, I don't know why you have to change the appearance of the car at all. I think you would have trouble powering the very largest automobiles with a steam engine, such as the Cadillac or the big Lincolns. Up to the medium sized cars, such as the Ford, the little Chevy, I don't know why you would have to change much of anything. That is assuming someone was willing to put up the development funds to proof-test all this equipment to get it to the necessary reliable state.

Senator BAKER. There was a good bit of testimony this morning about collateral difficulties with steam applications, particularly for driving the accessory units, generator, alternator, compressor and the like. Do you have any thoughts along these lines as to how these problems might be solved for steam application?

Mr. GOUSE. There are a variety of alternatives. It would depend on the particular vehicles system design you wanted to have. You could put in a separate smaller powerplant, you could take a power take-off to drive the generator much as you do in a regular car, or you could use a storage battery. You have heating capability from the condenser. By using absorption refrigeration techniques you have cooling. There are also automotive air-conditioning units under development that could operate using waste heat. They are not available on any cars now, but people are working on them. You probably would have to run your windshield wipers, lights, and radio off your battery.

Senator BAKER. We have been told that freezing is not an insuperable problem, or startup isn't an impossible obstacle.

Assume for the moment that something did go wrong. Assume that the burner didn't function properly or the heating device or the pilot light or whatever, failed to operate. How serious would the incident be in terms of damage to the unit if it did freeze?

Mr. GOUSE. It would depend on what means you used to avoid the freezing. I would say the simplest way to avoid the freezing problem is to design the engine so that the water could freeze in it. If you locate your water reservoir appropriately, in a closed system engine, so that water collects in it as a liquid when you shut the engine off, you just design the reservoir strong enough to withstand freezing. This is possible if you use a small fluid inventory engine. It is not feasible if you have to have a tank to hold 20 gallons of water.

Senator BAKER. We have heard testimony once again this morning about the necessary size of the radiator condenser. Fan sizes and arrangements for the fan, and the like. During the noon recess we went down to the garage and looked at two automobiles on display. If I am not very much mistaken, one of them didn't have a fan on its condenser.

Do you have any comments to make on this difficulty in the design and operation of steam engines?

Mr. GOUSE. I didn't really notice that.

I would like to have a fan, I think, of some sort. I don't think it is an insurmountable problem. As long as you don't try to build a closed-cycle engine that is too large. As the power output of the engine goes up, it goes up approximately with the cube of the dimension of the cylinder, the heat rejection goes up with the same cube of the dimension, but the area available for heat transfer goes up with the square. So that if you double the engine size you need eight times the area for heat transfer.

If you go to a large engine, you have a large condenser. If you stick to 100 to 125 horsepower you can manage a condenser about twice the size of a normal radiator.

Senator BAKER. Was this same relationship generally so with other fluids?

Mr. GOUSE. Yes.

Senator BAKER. The same relationship.

Is water supply a substantial problem, or should it be a substantial problem with properly designed steam engines, especially for warm weather operation?

Mr. GOUSE. I don't understand that.

Senator BAKER. The supply of feed water to the boiler.

Mr. GOUSE. I would like to see an engine with a supply of water built in once and for all, that you never added after you built the engine.

Senator BAKER. Closed cycle, hermetically sealed.

Mr. GOUSE. Yes. It is not necessary, but it leads to a number of advantages for maintenance and things like that, if you can achieve it.

It is just something that no one ever tinkers with.

Senator BAKER. It also leads to the restriction on the amount of available emergency power.

Mr. GOUSE. Yes, sir. There is a tradeoff here as to how you are going to do this. There are a variety of ways that you can do these things.

Senator BAKER. Would you assume for the moment, for the sake of illustration, that you would like to eliminate any concerns of a social nature such as the relative emission values of internal combustion versus the steam engine. Try to balance for me the respective appeals of an internal combustion and a steam engine from a pure economic consumer standpoint.

Mr. GOUSE. I don't really know if I can. To myself I would like a steamcar if I could buy one at an appropriate price, for a variety of reasons. One is I am a mechanical engineer. How other people would feel about this, I don't know.

I have driven some. As far as drivability goes, I don't see why anyone would object to it.

The silence is wonderful. You can ride along at 35 miles an hour hearing the birds.

Senator BAKER. And your wife and children. [Laughter.]

Mr. GOUSE. You may want that background noise to drown them out.

There are a lot of things to consider.

That is a tough question to answer without having any personal opinion.

Senator BAKER. Let me put it a little differently.

If we had no mass-produced vehicles, either internal combustion, steam electric, or otherwise, and you were in this hypothetical situation, commissioned to design one for mass production and consumption, would you judge our chances of producing the most satisfactory car to be in the field of steam, starting from scratch; internal combustion, starting from scratch; or electrical units, starting from scratch?

Mr. GOUSE. Assuming we had no cars, but we had our present level of technology, I would pick steam.

The internal combustion engine has a very complicated carburetor that took years to develop. And the ignition system is very complex. Those two together cause a lot of trouble as far as one has trouble with the internal combustion engine. And they are missing in the steam engine.

Senator BAKER. One more hypothetical case.

If you were starting from scratch today, and the question of the ambient air quality was the determinating factor, and our objective

was not just to arrest pollution but to improve the quality of the air, with the present state of the development of the steam engine versus the present state of the development of the internal combustion engine, which would get there first in terms of the emission of, say, 35 parts per million hydrocarbon?

Mr. GOUSE. I know the steam engine can get there right now.

The problem is, will someone invest to develop the reliability necessary for consumer use?

Senator BAKER. Do you doubt that the internal combustion engine can get there at all?

Mr. GOUSE. Not unless something new happens in the internal combustion, or we find something new in the basic engine, it will be very difficult. It will add a lot of equipment to your engine to get there.

Senator BAKER. Do you think that with the present level of technological sophistication, and that reasonably in prospect, that you could build an internal combustion engine with whatever additions and variations are necessary to produce emission levels in this order?

Mr. GOUSE. Yes. But I think the steam engine would be simpler and less costly.

Senator BAKER. That was my next question.

If you assume that both can reach this point at some future date, which one would be less expensive from the development standout and from the standpoint of the finished product, in your judgment?

Mr. GOUSE. Based on what I know now I would say the steam engine.

Senator BAKER. Oxides of nitrogen are also a substantial contributor to atmospheric pollution, especially in some areas where photochemical smog is a problem, such as in the Los Angeles Basin. As I understand it, the general approach to the reduction of the level of unburned hydrocarbons is the introduction of additional air, higher combustion temperatures, which then axiomatically produce more oxides of nitrogen.

Is there a comparable problem in the field of oxides of nitrogen contamination with the external combustion engine?

Mr. GOUSE. If you keep the combustion temperature reasonable, the oxides of nitrogen produced in the steam engine are substantially less than in internal combustion engines, and any device that you might develop to further reduce them from internal combustion engines would probably work on the steam engine.

It is possible by looking into the burner design,which hasn't really been done for steam engines, to further reduce the undesirable nitrogen compound in the steam engine exhaust.

Senator BAKER. I find the last questions always inevitably produce other questions. I have one more.

Speaking of burners, and heat generators, do you know of, or foresee any new techniques in heat production which might be adaptable to the steam concept for automotive propulsion?

Mr. GOUSE. Yes. All of my conclusions are based on the assumption you do this. I looked briefly at the Williams engine, and I thought things could be much better, at least in terms of the size that they are using. I couldn't see under the cover. If that represents the steam generator, they ought to be able to do much better.

We have done an enormous amount of work in the space and nuclear power program relating to boiling heat transfer. You can really do a much better job on these today compared to 15 years ago.

Senator BAKER. As compared to one mentioned this morning, using radioactive salts in the closed system?

Mr. GOUSE. There is a lot of existing technology we didn't have 15 years ago. The people developing engines have generally dealt with the engine rather than the boiler.

Senator BAKER. Mr. Gouse, we thank you very much. It is a very fine statement. We are grateful.

The hearings will stand adjourned until 9:30 tomorrow morning in this room.

(Whereupon, at 3:35 p.m., the subcommittee was adjourned, to reconvene on Tuesday, May 28, 1968, at 9:30 a.m.)

AUTOMOBILE STEAM ENGINE AND OTHER EXTERNAL COMBUSTION ENGINES

TUESDAY, MAY 28, 1968

U.S. SENATE,
COMMITTEE ON COMMERCE, AND THE
SUBCOMMITTEE ON AIR AND WATER POLLUTION
OF THE COMMITTEE ON PUBLIC WORKS,
Washington, D.C.

The joint hearing was convened at 9:30 a.m. in room 5110, New Senate Office Building, Senator Howard H. Baker, Jr., presiding.

Present: Senators Baker, Moss, and Scott.

Senator BAKER. The committee will come to order.

The first witness this morning is Congressman Richard L. Ottinger.

You may proceed, Congressman.

STATEMENT OF HON. RICHARD L. OTTINGER, A REPRESENTATIVE IN CONGRESS FROM THE STATE OF NEW YORK

Mr. OTTINGER. Mr. Chairman and distinguished members of this joint committee, I appreciate the opportunity to appear before you once again to testify on a matter of great interest to all of us: how to enjoy the convenience and utility of the automobile, while avoiding the flagrant errors that we have been led into the name of convenience and necessity.

It was to this end that I, appeared before this same committee last year during its hearings on the electric car—hearings which produced dramatic effects, not the least of which was the intensified research culminating in the recent Morse report of "The Automobile and Air Pollution." There is no need for me to go over the details of this excellent report: you are all as familiar with it as I am. One of its most startling conclusions, however, was its flat statement that "no major obstacles are seen as to the development of a modern steam engine," capable of powering an automobile today.

This startled me. Until recently I had thought of the steam car as one of those luxurious animals that had fallen by the wayside, a victim of the Darwinian laws of automotive natural selection. I was aware that some experimentation was still taking place, and it was for that purpose that I drew up my automotive study bill, H.R. 2899, to direct research into the electric car or "other alternatives to the internal combustion engine."

But what I did not know was how far we had advanced since the early days—what pioneers such as Charles Keen, the Williams brothers and Charles Gill and his engineers had come up with.

Mr. Chairman, I am vastly encouraged by the information that the Morse report contains: it has been developed as a direct result of the interest and concern of this committee. It calls to the attention of this Nation, heretofore so much concerned with the speed with which it could travel, the costs of getting there.

Principal among those costs, of course, is air pollution. The contribution of the automobile to our national pollution levels is formidable. It has been estimated as producing over 60 percent of the atmospheric air pollution in the United States today. There are between 95 and 100 million vehicles on the road here today. Each of these produces a rough average of slightly less than one ton of pollutants in a year. The pollutants include carbon monoxide, nitrogen oxides, hydrocarbons, sulfur dioxide and particulate matter.

I have heard that the number of vehicles on our roads is expected to double by the year 2000. If uncontrolled, resulting pollution levels in our cities would rise to the point that they would become virtually uninhabitable. Driving in the country would, of course, be much more pleasant—about like driving in the cities today.

None of us could tolerate that state of affairs—and I do not think that it will come to pass. But it could, if we did not take steps to prevent it.

That, in essence, is what we are about today—to explore some of the alternatives that are available.

The automobile companies suggest that automobile air pollution can be cured by control of emissions from internal combustion engines. The Air Quality Act, enacted by this Congress last year, permitted the establishment of Federal standards for vehicle emissions. The pollution control devices presently in existence cannot keep pace with the anticipated increase of automobiles on our roads.

I do not mean to claim that the Air Quality Act has no value—clearly it does. But it is not the answer to the air pollution problem, and its proponents have never claimed such a role for it.

One problem in the setting of emission standards has been what standards to set. It appears that the standards set in California may have been arbitrarily set, with no reference to levels of health or discomfort. Indeed, the Morse panel suggests that the national standards may be the best we can do today, but that additional controls are going to have to be imposed in the future.

I don't see how it is possible to argue with this conclusion. Even if national standards are appropriate for new automobiles, they don't touch cars on the road, and there remain the far knottier questions of continuing enforcement and monitoring of engine performance that effective control devices require once the new cars are on the road. Many of these devices require careful tuning of engines and air-to-gasoline ratio for proper performance. What happens when the engine gets out of tune and engines do this with distressing regularity? I can tell you—instant pollution. The Morse report bears this out.

Again—what to do with the older car? The Morse report indicates that the national rate of auto turnover is about 10 percent per year. In other words, 3 years from now less than one-third of the cars on the road will be required to have control devices. Moreover, the older ones will be of questionable effectiveness—those that have not been disconnected by their owners to improve engine performance.

In talking about devices to control emissions, we are only discussing what the TV commercials call symptomatic relief. This is not good enough. It is critically important, in my view, to readjust our thinking—to look at the root cause, and having found it, to change it.

The root cause in this case lies in the nature of the internal combustion engine. The studies indicate that air pollution from this engine stems inevitably from the nature of the combustion process—that a noncontinuous combustion process necessarily produces pollution, because combustion is not and cannot be complete in the microseconds available before the next step in the cycle must be taken.

The problems of the internal combustion engine are built into it, you can engineer it a little better, and it will perform a little better, so long as it is in proper repair. But let anything go wrong and you have trouble.

It is the feature of continuous combustion that produces the extraordinary pollution-free performance of the steam or vapor engine. In tests, the Williams steamcar did consistently better than the standards that the Morse report ultimately envisions. In hydrocarbons, 20 parts per million, compared to 25 parts per million in the Morse report; in carbon monoxide, .05 percent, compared with .25 percent—80 percent better than the best that can ever be hoped for from the internal combustion engine.

The electric and steam cars are essentially nonpolluting, and it is for this reason that they appear so attractive as alternatives. I drove an electric car to your hearings last year; I drove a steamcar here today. Both are very promising and exciting solutions to pollution-free driving.

The steamcar I drove was built by Mr. Charles Keen, a pioneer in the industry; it was further perfected by Mr. Charles Gill, of Thermal Kinetics Corp., in Rochester, N.Y., and his associates. He and they are here today and can give you any details on its operations that you may wish. I can only give you my layman's reaction: It works. It is easily and quickly started, easily driven, easily stopped, and it is a pleasure to drive.

Mr. Gill is here to tell this committee, and he is in a position to know, that with only a very modest expenditure for research on refinements of existing technology a vapor automobile could be constructed in a short period and marketed competitively with the internal combustion automobile. I am anxious that he be able to tell you this himself, since I think that this is very important and exciting news.

It means essentially that the solution is within our grasp now, today. and not at some indefinite time in the future.

In my view, the car that I drove to the hearing today, and its counterparts, of which you have already heard, represent a real challenge and opportunity to us as citizens and to us as legislators:

As citizens, because they show us that traffic need not be noisy and filthy.

As legislators, because they encourage us to look for means of persuading the industry to do the right thing—and to look more carefully and seriously into the problems of pollution-free driving.

I will repeat my warning of last year: if the American automobile industry is unable to come up with a pollution-free car, its foreign

competition will beat it to the punch, just as the foreign-made compacts hurt industry several years ago because of its reluctance to accommodate to change.

The American automobile industry has a tremendous stake in coming up with a feasible alternative to the internal combustion engine. It appears that they are reluctant to do so, and that some specific stimulus may be necessary to help them along. In this respect, Congress may be able to be of some assistance.

I have already introduced a bill to provide financial assistance toward research and development of one or more alternatives to the internal combustion engine. I was pleased to vote for the Air Quality Act of 1967, imposing controls on vehicle emissions, and will join the fight to strengthen those controls, if and when this becomes necessary.

I think that we can and should do more. One thing that the Federal Government can do is to put our money where our mouth is—to spend hard cash on nonpolluting automobiles as an incentive to the industry to meet the clear need. The Federal Government currently purchases around 30,000 automotive vehicles per year, at a total cost of some $175 million. I am currently drafting legislation which will require these purchases to be made for non- or low-polluting automobiles, wherever feasible. My hope is that the certainty of a market will serve as a powerful incentive for the development of a nonpolluting automobile that will be as far ahead of its competition today as the jet is of the plane flown at Kittyhawk by the Wright brothers.

I hope that the Congress will concur and that the necessary laws will be passed. But my real hope is that the American automotive industry will pick up the gauntlet and will make the effort on its own initiative to solve the problems confronting us all. If they will do this, I am confident that we will see the outline of a solution by 1970, and will have the problem licked by 1975. I do not feel that my confidence is misplaced

Now it's up to them.

Thank you.

Senator BAKER. Thank you, Congressman. We all know your continuing interest in this subject.

We will now proceed with the testimony of Dr. Richard S. Morse, of the Alfred Sloan School of Management, Massachusetts Institute of Technology.

Dr. Morse, welcome to the committee.

STATEMENT OF RICHARD S. MORSE, ALFRED P. SLOAN SCHOOL OF MANAGEMENT, MASSACHUSETTS INSTITUTE OF TECHNOLOGY, CAMBRIDGE, MASS.

Dr. MORSE. Thank you. I very belatedly wrote some testimony which I brought down this morning. If I may, I will read from this.

Senator BAKER. Dr. Morse, you may indeed.

As a matter of fact, we will appreciate it. The Senate will convene in the morning at 10 o'clock. We don't expect to have an order permitting us to continue with the hearing. With your permission, we will include your entire statement in the transcript as if read.

Dr. MORSE. In January 1967, the Secretary of Commerce established a study panel of 15 members, drawn from the industrial and

academic community, with a request to examine the technical and economic feasibility of present and future automotive power sources and to recommend an appropriate role for the Federal Government.

This panel, of which I was appointed chairman, was also requested to compare the performance characteristics of electric vehicles with other types of vehicles, especially with respect to the air pollution problem. The Department of Commerce assumed the initial responsibility for this study which was conducted in cooperation with the Commerce Technical Advisory Board and a joint support agreement with the Departments of Defense; Health, Education, and Welfare; Housing and Urban Development; Interior; Post Office; Transportation; and the Atomic Energy Commission; and the Federal Power Commission. We obtained fine cooperation from Government and industry in our efforts to develop technical information and to analyze the wide variety of technical and economic problems associated with the auto industry pollution problem.

The results of this study, including a summary of findings and recommendations, were made available in a report, "The Automobile and Air Pollution—A Program for Progress, Part I," in October 1967. Part II of this same document was published in December 1967, and included a summary of more detailed reports prepared by a variety of experts upon whom our panel called for advice and counsel. These documents are now available from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C.

Subsequent to publication of these reports, additional information appeared upon the horizon both in this country and abroad with regard to isolated development work and advanced technology of potential usefulness in the steam engine field. Most of these experimental activities were centered around the efforts of individuals, small technically based companies, or within large corporations not associated with the automobile industry.

In order to have a mechanism to examine new innovative ideas, undertake detailed engineering studies, and initiate development work, a group of experienced technical people in the Boston area, Dr. David Ragone, professor of metallurgy and materials science at Carnegie-Mellon University, and nine organized Energy Systems, Inc. This company has to date been financed with private venture capital sources, and, during the past year, examined a variety of new technical developments, potential markets, and patents applicable to steam propulsion systems. In this activity we have had cooperation from several segments of American industry, such as producers of fuels lubricants, chemicals and materials, who view the commercial introduction of steam systems as potentially profitable business opportunities.

Through use of a patented rotary valve mechanism, first developed and successfully demonstrated by a Dr. Robert B. Black, for example, it appears feasible to modify existing two cycle internal combustion engines for steam operation. By such a procedure, fairly good efficiency can be obtained, starting and reversing operations are solved, and continuously variable torque can be obtained over a wide range of operating speeds—essential features for many vehicle propulsion requirements.

Preliminary design studies also suggest that unconventional engine configurations, not applicable to gasoline or diesel internal combustion

operation will lend themselves to the steam cycle. The design and development of such advanced engines will obviously require a substantial effort, but the prospects appear good for steam units with excellent horsepower weight ratios and specific fuel consumption, and with characteristics superior to the diesel engine in terms of noise, odor, air pollution, and torque.

The attainment of such objectives will require the application of a number of new technologies in the fuel, lubricant, and materials field. Preliminary development work undertaken by Energy Systems, Inc. suggests that novel steam generator designs will permit boiler efficiencies of over 90 percent and a reduction in size of perhaps a factor of two to three as compared with the best existing equipment today.

Within the Department of Defense, we already have technical and management competence in the field of propulsion. With the improved base of knowledge now available in this field, there is no reason why the development of steam technology could not be expedited by the normal route of R. & D. contracting or the purchasing of demonstration units. Other agencies of the Federal Government, and particularly those charged with the establishment of emission standards and investigation of the important and complicated problems of health factors associated with pollution, perhaps suffer from a lack of those specific scientific and engineering skills necessary for the appropriate evaluation of engine development activities.

The Department of Transportation and the Department of Housing and Urban Development obviously have an interest in the steam field. The use of Federal funds for demonstration programs, while perhaps inconsistent with the usual concept of an orderly research and development effort, would undoubtedly serve to highlight the feasibility of steam propulsion. By such a mechanism, industrial interest in the field could be expedited and commercially funded programs initiated with prospects for ultimate profitable exploitation in the marketplace.

Very little work has been done to develop any steam engines of advanced design either in Government or industry. It has become recently apparent, however, that a number of individuals and a few major corporations have suddenly recognized the inherent advantages of steam as a propulsion mechanism, and work in this area may be accelerated in the next few years.

The Air Quality Act of 1967 has now been enacted with many features consistent wtih the findings and recommendations of the recent Commerce Department study. Both recognize that the use of Federal standards is essential to continued progress in the reduction of harmful emissions from automotive vehicles. The establishment of a Presidential Air Quality Advisory Board under the Air Quality Act is consistent with Recommendation 13 of our study suggesting a requirement for improved coordination of all Federal activities relating to air pollution at a high level within the executive branch. No action, however, has been taken on this subject by the Government.

Endorsement of a limited Federal-funded research program was included under recommendation 7 of the Commerce Department study which suggested that:

> The Federal Government should increase its support for mass transportation research, development, and demonstrations related to the reduction of air pollution.

Recommendation 14 stated that:

> The Federal Government should initiate a five-year program, in total amount of approximately 60 million dollars, to support innovative developments useful in the establishment of future emission standards in the following areas:
> (*a*) Energy sources for vehicles;
> (*b*) Vehicular propulsion systems;
> (*c*) Emission control devices;
> (*d*) Special-purpose urban cars; and
> (*e*) General-purpose cars.

I am sure that many of us do not enthusiastically endorse the concept of the Federal Government engaging in research activities which can normally be more appropriately undertaken by private industry. It was against this philosophy that the above recommendation was clearly limited to the support of innovative developments and only those useful in the establishment of future emission standards. The Federal Government should not compete with the private sector; but it would appear that some stimulation from the Federal Government will be necessary, if, in fact, we wish to expedite the introduction of new and novel propulsion systems, which can materially contribute to a reduction in harmful emissions in the atmosphere. As far as I am aware, no specific action has been yet taken by the Government to implement any of these recommendations.

Recommendation 6 suggests that the Federal Government should set standards for emissions including smoke and odor of gasoline- and diesel-powered trucks and buses. Because of the unique operating characteristics of steam engines, they are admirably suited to truck and bus propulsion. The establishment of more stringent standards, with respect to smoke and odor, would obviously expedite the introduction of relatively noiseless, smokeless, and odorless external combustion engines.

Recommendation 15 stated that:

> Federal, State, and local government should incorporate low-emission performance criteria as factors in the purchase of vehicles for their requirements.

This recommendation, which perhaps has not been fully understood, does not suggest that Government agencies should immediately purchase electric or steam autos, for example. It did suggest that low-emission performance be included as criteria in the purchase of vehicles. By such a mechanism, the Government would, hopefully, use its purchasing power as a means for forcing innovation. Incentives would be available, particularly for the smaller manufacturer, to introduce new and novel concepts for emission control and/or new propulsion systems. Through use of such Government purchasing power, new developments would be demonstrated. By such a procedure, incentives would be available for industrial R. & D. activity. The demonstration of new devices would serve as an example both for Government and industry and permit earlier and more strigent standards setting.

Current technology probably now permits the development, manufacture, and sale of steam engine systems which have relatively low-pollution characteristics, weight/horsepower ratios comparable to diesel engines, and greatly superior torque characteristics. Such units will be inferior to both gasoline and diesel engines in terms of fuel economy, startup time, and antifreeze characteristics. However, current available technology can now offer a viable solution to several present

propulsion requirements where noise, pollution, safety, and torque represent significant factors.

A city bus represents a fine potential application for steampower with its resulting low noise and air pollution. Of even greater importance, however, is the fact that piston-type steam engines have very remarkable torque characteristics, particularly at low speeds. This feature is particularly useful for stop-and-start driving. This same characteristic, or course, makes the steam engine admirably suited to a number of other nonpersonal vehicles, such as tractors, lift trucks, earth-moving equipment. It is not unreasonable to assume that it will be in fields other than that of the automobile where steam will be first applied because of such technical factors and the greater ease with which they may enter the market.

At the request of the Department of Housing and Urban Development, a study was recently made by Energy Systems, Inc.—not funded by HUD—to determine the feasibility of replacing the diesel engines currently used in large metropolitan city buses with a steam engine system. This study was based on the typical large General Motors bus that is used in Washington, Boston, or New York. This engineering analysis showed that by employing a steam engine of the same displacement by converting the existing General Motors 6V–71 diesel engine and operating at 1,000 p.s.i. steam pressure, it would be possible to obtain a maximum torque capability of 4,800 foot-pounds. With a 35° cutoff in terms of crank angle, i.e., the portion of time in which steam is admitted to the cylinder this same engine would develop an average torque of about 1,900 foot-pounds. This compares very favorably with the currently used diesel engine which had rated torque of about 550 foot-pounds. At a 1,000 revolutions per minute the converted diesel had approximately twice the horsepower output of the corresponding diesel unit. Of course, this discrepancy was even more marked at lower speeds where all internal combustion engines, diesel or gasoline, must depend upon some form of torque converter or transmission to effectively meet operating requirements.

Because of the torque characteristics of a steam conversion unit, the usual transmission could be eliminated and the very superior low speed and reserve power characteristics of the steam conversion system fully utilized. Figure 1 shows the relationship between torque and horsepower for a 6M 6V–71 diesel and as converted for steam operation based on this study. Neither a diesel nor a gasoline engine has any power at zero speed. Consequently, you have to have a clutch, torque converter or transmission to operate effectively.

And by employing a continually variable cutoff system, it is possible also to have substantial reserve power. As indicated in figure 1, steam conversion units will have approximately 25 percent greater horsepower and many times the low speed torque of the corresponding unit. In working with one of the major metropolitan transit companies we learned that they burn out some three or four transmissions during the life of one engine. This is an important factor in terms of down time and maintenance.

The need for both a steam generator and condenser and the power requirements of the associated auxiliary equipment, such as the fan required for condenser cooling must be recognized. I don't want to say that the problem of developing a steam conversion diesel is going

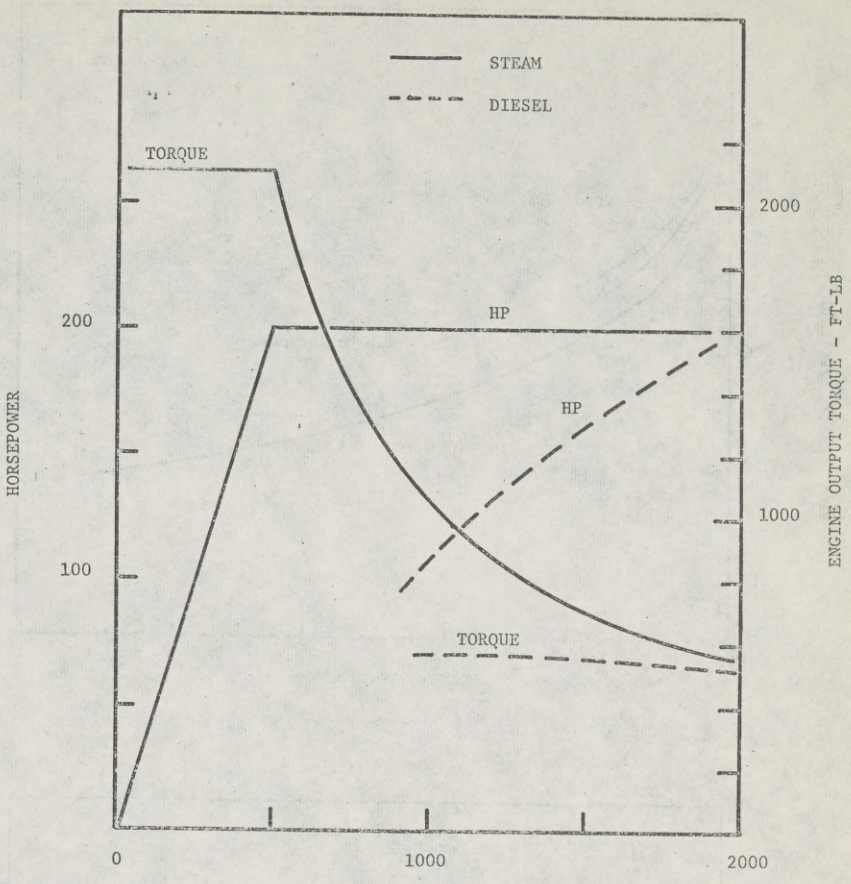

FIGURE 1 COMPARISON OF HORSEPOWER AND TORQUE CHARACTERISTICS - DIESEL ENGINE AND STEAM CONVERSION. (G.M. 6V-71)

to be simple but it is technically feasible to do this job now. Operating efficiency in terms of specific fuel consumption of steam conversion units will not be as low as for a diesel. Preliminary studies suggest that advanced steam engine designs will eventually permit operating efficiencies comparable to diesel units.

Thermal efficiencies as a function of condenser pressure are given in figure 2 for various steam pressures on the basis of a simple cycle steam system. Higher efficiencies are, of course, possible with multi-stage Rankine cycle systems.

In figure 3, information is given for calculated specific fuel consumption as a function of condenser pressure, again for a single stage steam cycle system. This data, developed by Energy Systems, Inc., was based on a boiler efficiency of only 75 percent and a single stage steam cycle unit. A study which we have made of more advanced engine designs suggests that we would be directly competitive with the diesel on fuel consumption. Since this information was prepared, de-

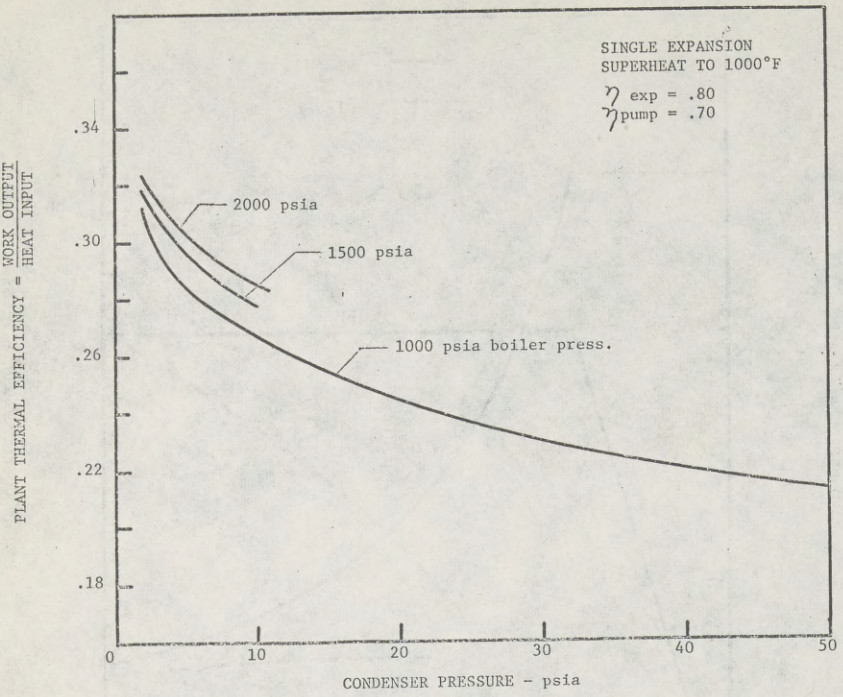

FIGURE 2 THERMAL EFFICIENCY OF SIMPLE CYCLE STEAM PLANT

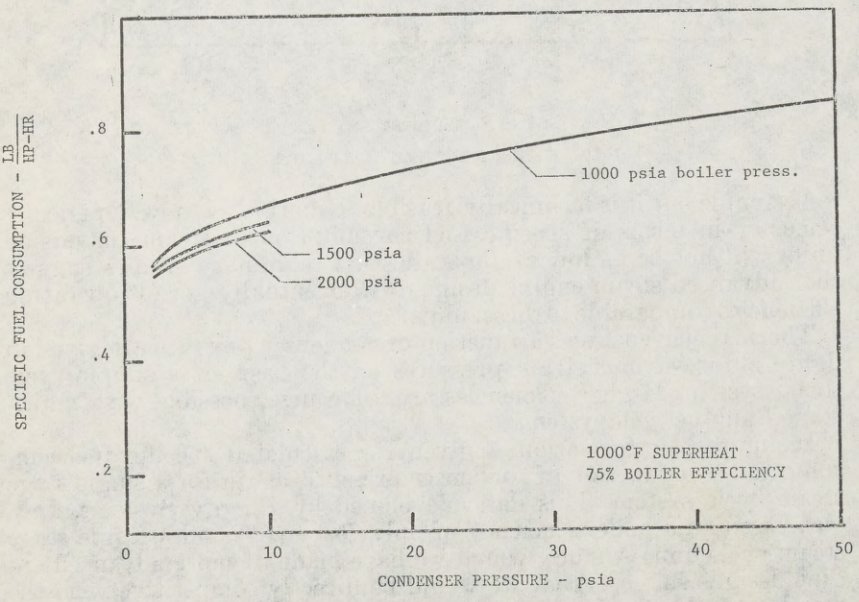

FIGURE 3 SPECIFIC FUEL CONSUMPTION FOR SIMPLE CYCLE STEAM PLANT

velopment work and boilers of unique design suggest that steam generator efficiencies of 90 percent will be possible.

As more stringent standards are established to control emissions from the gasoline engine, fuel efficiency will undoubtedly be impaired, particularly if the solution involves the exhaust re-cycle principle and mixture control as the mechanism for emission reduction. If standards are imposed upon the auto industry which necessitate more radical improvement in emission reduction, the relative cost advantages of the steam unit may become more apparent as its emission characteristics, even without any development work to date, are superior to even the most appropriately modified gasoline engine.

From the viewpoint of the country's basic position with respect to available energy for transportation systems the external combustion engine has many significant advantages because of its flexibility with respect to fuel requirements. It is currently feasible to operate a steam generator on a wide variety of liquid fuels without regard for octane or cetane rating or exact fuel composition from a chemical constituent viewpoint. Basically, an external combustion engine can burn cheaper fuels on a BTU basis than either the gasoline or diesel engine. Furthermore, the capital investment in terms of refinery costs, and the oil and gasoline industry is a heavy capital industry, will be considerably less for the production of fuels for an external combustion boiler as opposed to use with an internal combustion gasoline or diesel engine. The reduction in capital investment is quite substantial for producing the kinds of fuels which would be used in external combustion boilers. Such fuels flow through current and existing distribution channels and none of the complex problems associated with the distribution of energy for the electric car exist.

By the use of monotube boilers of advanced design, and a closed cycle steam system with relatively limited quantities of steam and water, safety characteristics of a steam engine seem to be well in hand. A substantial number of automobile accidents have associated injuries which result from gasoline fires and explosions. Boat owners have long recognized the need for using less volatile and explosive fuels, such as diesel oil, as will be employed in steam propulsion systems. This important feature of the steam cycle might be the subject of more intensive investigation by the Department of Transportation with its current emphasis on highway safety.

The noise characteristic of steam cycle engines will undoubtedly become of greater importance as we become more aware of the increasing tempo of urban life and the degradation of our "noisy society." As a recent Department of Commerce study panel indicated, this country is also rapidly approaching a crisis with respect to the use of the limited bandwidth available in the radio frequency spectrum. We are long overdue in attacking the problems of man-created "electromagnetic noise" which is being introduced into the frequency spectrum. Standards will be required for the suppression of electromagnetic interference such as is created by spark ignition engines and, here again, a steam cycle unit has much to offer.

In the military area the multi-fuel, low-noise features inherent in steam design have direct application in Vietnam. The superior torque characteristics of a steam unit has much to offer as a propulsion mechanism for large military transport vehicles, earth-moving equip-

ment and tanks. The Department of Defense has undoubtedly made the greatest contribution to the investigation and development of new and novel energy conversion devices, particularly for vehicle and auxiliary power use, but to date, little effort has been expended in the steam area except for the limited work in very small constant-speed auxiliary power units in the 1 to 5 horsepower range.

The automobile industry has periodically turned its attention to radical propulsion systems such as gas turbines, which at least in the larger sizes may offer attractive alternatives to the gasoline and diesel engine particularly for long-haul trucks. Pioneering work originating in Holland, in the Stirling cycle field has been closely followed and perhaps expanded by one major automobile producer. It appears that the auto industry has devoted essentially no effort to the steam cycle as a viable concept with potential applicability for personal vehicle transport.

Many of the limitations often expressed with respect to steam are perhaps even more applicable to the more recent novel and unique contributions of the auto industry in the battery field. The sodium sulfur and lithium chlorine battery systems both represent major technical contributions to higher efficiency battery development but have obvious safety problems associated with their use. They must be maintained at high temperatures while the vehicle is not in use and, in addition, neither unit fits into the well-established industrial distribution complex for its fueling.

On the basis of an informal survey of some dozen engine manufacturers, it appears that this industry—speaking now of the engine manufacturers, not the automobile industry—has given no serious consideration to steam. Essentially all enthusiasm for steam currently resides within a small group of so-called "steam car buffs"—inventors and mechanics—who, unfortunately by and large, have not had access to advanced technology nor are associated with any management and industrial base essential to effective implementation of a development activity.

A unique characteristic of the American free enterprise system is our environment which nurtures the innovation process. History suggests that innovative ideas in the steam field will probably come from outside the automotive industry. This should not be viewed as an unusual phenomenon as well-established industries tend to become less innovative. In this era of growing interest in enterpreneurship, many of our large corporations are viewing with concern their ability to attract and effectively exploit the talents of really innovative people within their own organizational structure.

A recent survey, for example, of the country's 200 largest industrial concerns—taken from the Fortune's list of 500 companies—established the fact that 56 percent of these organizations were concerned with the effectiveness of their own internal Research and Development establishment. A comparable percentage either had, or were contemplating, development of financial relations with small technical enterprises as a mechanism for expediting their new product development function.

As was reported by a recent study of the U.S. Department of Commerce, "Technological Innovation: Its Environment and Management;" synthetic fibers came from the chemical industry, not the textile; improvements in high speed ground transportation are coming

from the aerospace and electronic industries, not the automotive or railroad; instant photography was not developed by the photographic industry; and the electrostatic copier was not developed by the office equipment industry.

In the final analysis, incentives within the industrial complex of this country, perhaps expedited by such hearings as these, should provide a mechanism for more rapid development of a commercial steam engine and the auto industry itself will no doubt then enter the business. This will require a long term program because of the high capital costs associated with mass production of a new energy conversion system and the associated problems of distribution, spare parts, testing, warranty and customer acceptance.

Incentives certainly now exist for the country's fuel and lubricant producers to assist in such developments as the use of electric vehicles ultimately depending upon nuclear fuel as an energy source certainly represents a less attractive future for their business.

Potential suppliers of chemicals, advanced materials, high temperature alloys, and auxiliary components also should view the steam engine market with interest because of its tremendous potential.

Thank you.

Senator BAKER. Dr. Morse, thank you very much. I will order placed in the record a copy of your biographical sketch.

(The exhibit is as follows:)

RICHARD S. MORSE [1]

Mr. Morse has been engaged in industrial research and the organization and management of technically based enterprises. As president of National Research Corporation in Cambridge for twenty years, he was responsible for the first industrial application of high vacuum technology in such fields as the large scale vacuum melting of metals and alloys, production of low reflection optical coatings, mass dehydration of penicillin, and initiated the organization of Minute Maid Corporation to pioneer the frozen citrus concentrate business.

He has been continuously associated with Defense activities since his association with OSRD during World War II and entered public service in 1959 as Director of Research and Assistant Secretary of the Army during both the Eisenhower and Kennedy Administrations. For the past six years, he has been a member of the Technical Advisory Board of the Department of Commerce and was Chairman of the interdepartmental Federal Study established by the Secretary of Commerce which dealt with the auto industry pollution problem last year. This activity with its recommendations and analysis resulted in the government publication "The Automobile and Air Pollution—A Program for Progress, Parts I and II."

Mr. Morse is now senior lecturer at the Sloan School of Management, MIT and is engaged in technical and management consulting for industry and government. He is director of: Japan Fund, Inc., Energy Systems, Inc., the New England Council; director and chairman of the executive committee of Dresser Industries, Inc.; Trustee: Midwest Research Institute, Research Analysis Corp., Marine Biological Lab.; Board of Visitors, Air Force Systems Command.

Senator BAKER. I would like to say now, as I should have said earlier, that Senator Muskie asked that I apologize to you and to the other witnesses for the fact that he couldn't be present at these hearings. He is chairing another committee hearing, which says something for efficiency of planning in the Senate.

Mr. MORSE. I was in Washington for 4 years and appreciate this problem.

[1] Sloan School of Management, MIT, 50 Memorial Drive, Cambridge, Mass.

Senator BAKER. The historical suggestion that innovation frequently comes from industries other than those directly related to the enterprise, citing the office equipment industry, the photographic industry, and the automotive industry, would suggest also, it seems to me, that if there is to be a program of incentives through procurement or otherwise to accelerate the pace of development of new energy conversion systems, that it might not be a system of incentives designed for the existing transportation industry. Do you agree with that or not?

Mr. MORSE. I would hope that any Government support, regardless of the form it might take, would go to the most competent people who can get the job done, whether in the big or small companies.

Senator BAKER. How would you visualize the arrangement or structuring of these incentives?

Mr. MORSE. As you may remember, in our study dealing with the automobile and air pollution we suggested several mechanisms.

Senator BAKER. The procurement program?

Mr. MORSE. A procurement program in the sense that the Government is a major, potential purchaser of vehicles, for example. We didn't suggest that the Government go out and buy steam cars or electric cars. We suggested that in the procurement process the Government could incorporate emissions as one of the criteria for evaluating the bids. If two companies came in at roughly the same price and essentially met the same specifications for a truck, for example, the company which would guarantee a substantially lower emitting vehicle would get the contract.

This does several things. It is an inducement to the more innovative companies and perhaps the smaller company, to go out and really do the best job on emissions.

However, once a company has demonstrated that a lower emission engine can be built, the Government—in this case I assume HEW—would be in a much stronger position to know that tougher standards could be set. You would have demonstrated that industry had the capability of meeting better standards.

The Government obviously and properly doesn't want to upset the normal production lines of the auto companies. On the other hand, they would like to have as tough an emission standard as they can for the public. The Government for several reasons, such as lack of experience and qualified technical people, doesn't really know what the automotive industry can do and has no way of really finding out. Such a demonstration could serve to solve this problem and speed up the innovation process.

Senator BAKER. Would you have in mind that you would publish and solicit bids for a car based entirely on emission characteristics?

Mr. MORSE. No, sir; we didn't have that in mind. All other things being equal, the person who would guarantee the lowest emissions would get the business.

Senator BAKER. So you would include such items as power, horsepower, torque, fuel consumption, and fuel cost as well as size, weight carrying capacity, emission levels, and the whole range of characteristics that ordinarily would bear on the judgment and evaluation of the usefulness, utility, and desirability of the vehicle?

Mr. MORSE. With the added incentive of emphasis upon emissions.

Senator BAKER. Wouldn't this necessarily create some problems in evaluation since, as witnesses yesterday and you today have either testified or implied, there is an inevitable tradeoff of characteristics such as fuel cost versus torque, emission standards versus fuel economy, and the like. How would you go about writing specifications to accommodate these purposes without making it a separate solicitation of a low emission vehicle?

Mr. MORSE. When we contemplated this specific recommendation during our study last year I don't think we were envisaging the concept of buying electric cars or steam cars. We were directing our attention more specifically to the more or less conventional gasoline powered vehicle. Even in this area the Government has difficulty in knowing just how stringent standards are reasonable without upsetting the engineering, design, and development factors within the automotive industry.

Senator BAKER. You have made it clear in your statement I think, that you think it improper for the Government to compete directly with private enterprise in manufacturing and presumably in the development field as well. On the other hand, I wonder if you would elaborate a little on the idea that the Government, through its various agencies, including perhaps the national laboratories under the auspices of AEC, might be engaged profitably and desirably in basic research in advanced energy conversion systems.

Mr. MORSE. Assuming you and I are using the words "basic research" in the same sense, I think this country has more basic research at the moment than it knows what to do with. We need to have management decisions forthcoming and implement the use of existing technology more effectively in this area than has been the case to date.

For the past several months a company with which I am associated, found no difficulty whatsoever in having complete collaboration with a large number of companies, large and small, particularly oil and fuel producers. I don't think we need much basic research in this area. We need development work, somebody to decide to go ahead and spend money and proceed with a well-planned development program.

Senator BAKER. What bothers me is whether or not we are ready to say now that steam or electric cars are the transportation system or energy conversion system that we ought to look for in the distant future, and that we are ready now to jump from internal combustion, on a mass produced basis into steam, electric, or some other type of engine without first exploring the possibility of other alternatives, even other exotic alternatives.

The reason for my question on basic research was to identify whether or not we established an alternative, even a specialized alternative, to the internal combustion engine.

Do you feel that in the space of the next 20 years, say, in view of the increasing requirements for emission control, that either steam or electric cars represent a better alternative than the internal combustion engine and a better alternative than anything else you have seen in the developmental stage?

Mr. MORSE. First let me say that I don't think this country or any other country is going to suddenly jump into a conversion of trans-

portation from, say, gasoline or diesel to steam, electric or anything else. Things don't go that way.

There is adequate engineering information available today, in my opinion, based on my own experience in research, to warrant a substantial effort to make demonstration units, both steam engines and complete transportation systems. There is essentially no research and development work being done in this country at the present time in the steam engine field—until this is done, and we make the usual improvements as one does in research and development activities, we will never know just how effective the steam engine will be as a competitor to the gasoline engine.

I do not feel competent to sit here today and predict that a steam engine could, on all counts, that is, operating costs, capital investment, et cetera, replace the existing internal combustion engine within 10 years. On the other hand, I am convinced that if we find it necessary to go to more stringent emission standards—referring particularly to oxides of nitrogen—in combination with CO and hydrocarbons—I think we are going to find that the steam engine will become more competitive.

There are a number of other subtle features associated with steam which did not occur to me until a few months ago. The torque characteristics are very significant as has been indicated before.

A gasoline engine, operating at reduced power, has a very poor efficiency. The steam engine with continuously variably "cut-off" has much better relative efficiency over a wide power range.

Furthermore, a steam engine has excess power available in terms of its rated power while the maximum power output of a gasoline engine is determined essentially by displacement. Until such an engine is actually put in a bus, tractor, or automobile, it is difficult to evaluate all of the advantages of steam as well as the difficulties.

If you look at the basic problems of the country in terms of energy sources and the capital investment associated with, the production of relatively high octane gasoline versus something that will just burn, we have another economic factor. I don't think anybody has examined this subject in great detail but the basic economics of external combustion engines are favorable to its use.

Senator BAKER. So you are suggesting incentives through the procurement programs or otherwise to build development models so that we can make these comparisons on a more valid basis?

Mr. MORSE. Yes. If the Government wishes to expedite a solution to the emission problem you will probably have to move that way. I would also hope that the straight business incentives to move into steam are adequate to get something done by certain segments of industry. It is inconceivable to me how anyone would spend a million dollars on, say, a liquid hydrogen oxygen fuel cell demonstration car as opposed to working on novel steam systems today.

Senator BAKER. You haven't touched directly on this, but would you care to give us your judgment on where the end of the road lies for internal combustion engines in terms of emission characteristics, from a practical rather than a theoretical concept? How low do you think emission levels can be reduced for internal combustion engines relating to, say, unburned hydrocarbons?

Mr. MORSE. I think the best I can do is refer to page 42 of part II

of our Commerce Department report. We made a great effort to not only determine what was currently being done within the automobile industry—and I might say the industry was very cooperative—but also, in our technical judgment, guess what might be done.

In that report we stated that in 1970 it would be commercially feasible to have unburned hydrocarbons as low as 275 parts per million, with oxides of nitrogen reduced to 350 parts per million. This point is perhaps not too well understood. Once we start playing with the oxides of nitrogen problem—it becomes difficult to reduce the hydrocarbons—at the moment we don't have any technical method for both reducing oxides of nitrogen and unburned hydrocarbons in the internal combustion gasoline engine. If you want to leave the oxides of nitrogen in the range of 600–800 you can reduce hydrocarbons to 180–200. If you want to reduce the nitrogen oxides to 350 you probably will run up carbon monoxide and also increase the hydrocarbons to 275 parts per million.

We also estimated that by 1975 it should be commercially feasible to have hydrocarbon emissions down to 50 and oxides of nitrogen down to 250 parts per million. We didn't say what this might cost, or do to the operating efficiency of the engine.

I haven't seen any information to suggest that these numbers are still not appropriate.

Senator BAKER. You think they are?

Mr. MORSE. It is a matter of judgment, but this data was based on a pretty detailed technical study.

I note you have another column, "Ultimate feasibility," with hydrocarbons in the range of 25 and oxides of nitrogen in the range of a hundred.

Mr. MORSE. Those numbers were prepared as a sort of technically educated guess assuming cost was no object, but indicate what you would be able to do if you put enough gadgets on the gasoline engine.

Senator BAKER. Do you have a time estimate on that?

Mr. MORSE. No, sir.

Senator BAKER. I assume it would be post-1975?

Mr. MORSE. Well, we made the atomic bomb in a relatively few years. That isn't the way you do things in peacetime with problems of customers, competition, and costs.

Senator BAKER. Are you aware of technology available now to achieve these ultimate feasibility standards which produce hydrocarbons in the range of 25 parts per million and at the same time reduce oxides of nitrogen to the level in the range of a hundred parts? The question was obviously prompted by the second column under heading "Commercial feasibility" where it shows an increase in hydrocarbons as a trade-off for increase in oxides of nitrogen.

Mr. MORSE. This gets into a very difficult semantic problem. We define commercial feasibility as "emission control at a given level attained on a vehicle which performs the required transportation function, is manufacturable, and is acceptable to the public in all respects, including economics, durability, performance, convenience, esthetics, and psychology, and so forth."

In talking about "ultimate feasibility," I would say that you can do it scientifically. Whether you can possibly introduce it into a production line in Detroit and have an economically viable product at the

end of the line, I don't know. This does not look too promising today.

Senator BAKER. The 1970 regulations on air pollution by automobiles would limit carbon monoxide emissions to 1 percent of exhaust volume. Sunday's Washington Post contained an article which quoted Charles Heinen, Chrysler chief engineer for emission control, as saying that in order to reduce these emissions further to 0.5 percent of exhaust volume, it would require an afterburner costing a hundred dollars per car. Do estimates such as that suggest that if we are to develop low-emission automobiles at reasonable cost we would be better off to expand research on steam propulsion rather than to continue to complicate the internal combustion engine?

Mr. MORSE. I think I touched on that in my earlier testimony. All of the things which you are going to do to an internal combustion engine to further reduce emissions will cause added difficulties in terms of cost, fuel efficiency, operating characteristics of the vehicle, and available gasoline supplies.

It is a matter of degree. People are used to a good, snappy, high-horsepower car. As you start adding things to it, you introduce both operating and economic problems.

(The complete article from the Washington Post of May 26, 1968, follows:)

U.S. REVIEW OF CAR FUME LAWS URGED

(By Robert W. Irvin, Washington Post Staff Writer)

DETROIT, MAY 25.—The Federal Government should re-assess the automobile's role in air pollution in the light of new research on photo-chemical smog and carbon nonoxide outpouring from cars, according to the Automotive News.

The trade paper suggests that a new examination of the problem might prove proposed new stringent exhaust regulations unnecessary and save as much as $20 billion.

Charles Heinen, Chrysler's chief engineer for emission control, was quoted saying the Government should stick with its planned 1970 regulations to control carbon monoxide from automobiles.

The regulation would limit carbon monoxide emission to one per cent of exhaust volume. But there have been suggestions this be cut to 0.5 per cent.

Heinen said this would require an after-burner costing $100 per car.

The paper said further reduction isn't needed because there is no evidence of a street-level carbon monoxide problem anywhere in the country, even in New York City.

"Los Angeles does have a photo-chemical smog problem due to its unique geography and climate, but there is little evidence that photo-chemical smog is becoming a problem in other cities," Automotive News said.

"Federal legislation singling out the automobile as the major source of the Nation's air pollution was rushed through before the evidence was in" and the matter ought to be delved into again," it continued.

Senator BAKER. The question that was put to most witnesses yesterday I would like to put to you now. It clearly is of the most hypothetical type. I would appreciate your best estimate if you care to give it.

If we were starting from scratch, so to speak, with the development of either a steam engine or an internal combustion engine that would produce acceptable levels of emission, is it your judgment that it would be cheaper to produce the steam engine or the internal combustion engine for these purposes at some predictable future day?

Mr. MORSE. May I define what you mean by emission. Would you say 1970 standards, or the best you can get?

Senator BAKER. I will leave that to you. I have in mind something better than 1970—certainly 1975 and possibly beyond that.

May I add this, although I don't require or ask that you include it in your answer to the hypothetical question. This committee took testimony in Los Angeles a year ago to the effect that in the field of unburned hydrocarbons the emission level would have to be reduced to something in the range of 35 parts per million if we were to accomplish a cleanup of the atmosphere as distinguished from stabilizing the level of pollutants from this source. This is in my mind when I put the question. I don't insist that you use that as a basis for your judgment.

What I am after is, which engine, steam or internal combustion, is more likely in the future to produce an economical, practical engine of acceptable emission levels?

Mr. MORSE. If a group of innovative, competent engineers were charged with the job of meeting the lowest emission standards they could, consistent with reasonable operating performance, capital investment, and operating cost, they would elect to put their own personal bets on some form of external combustion engine. I carefully use the words "external combustion" as opposed to steam. This might include steam, or it might include nonaqueous vapor fluids which would not have the problems of freezing, for example.

Senator BAKER. Of course I take it that in the case of the internal combustion engine that there is a determinable falloff in effectiveness or efficiency of the engine as you apply smog control or emission control devices.

Mr. MORSE. The internal combustion engine, especially the gasoline one, is a complicated mechanism. It is very cheap because we have a heavy capital investment in the industry and the auto industry has made a great contribution to the American way of life. If we were to start over again this is a hard way to solve the country's transportation problems.

Senator BAKER. A few more questions.

First, how easy is it for a car owner to change the effectiveness of one of the present smog suppressing devices?

Mr. MORSE. The auto industry is concerned with this problem, but I am not an expert on this subject. I think as we move toward more rigorous emission control and have to introduce more complicated devices such as catalytic mufflers and various types of exhaust recycle devices, there will be maintenance problems and deterioration as it has already demonstrated in California.

Senator BAKER. I think there has been some history of California residents in particular disconnecting some of the exhaust suppression devices in order to allegedly improve the performance of their automobiles.

Yesterday General Motors testified that once the test had been completed it would take 10 years leadtime to produce a steam automobile. Do you believe this to be a reasonable estimate?

Mr. MORSE. Ten years after a prototype had been tested?

Senator BAKER. Yes, sir.

Mr. MORSE. No. General Motors should be able to answer their problems for themselves. I don't think it would take some companies that long.

Senator BAKER. Do you believe it is likely that a company not currently producing automobiles could break into the automobile market with the steamcar?

Mr. MORSE. I guess my philosophy of life has always been you can do anything in this country if you want to. We have independent engine manufacturers at the moment who are doing pretty well. We have some independent producers of special-purpose vehicles.

When I was in public service in the Pentagon, I was involved with a number of large R. & D. and procurement programs, substantial ones with vehicle manufacturers; and it was very common to buy special-purpose vehicles from people other than Detroit with excellent results.

Senator BAKER. Yesterday General Motors testified that they have been having discussions with your company, Energy Systems, Inc. Can you tell us what form these discussions have taken?

Mr. MORSE. I would say the dialog to date has not been very exhaustive. Dr. Hafstad heard that a group of us were doing detailed design studies and development work suggested that some of General Motors people might meet with Energy Systems to determine whether there might be some manner in which we might work together. That is the complete content of our discussion. We have no arrangement with General Motors of any kind.

Senator BAKER. A final series of inquiries.

As I said earlier, I think an appropriate part of these hearings and this inquiry is whether or not steam offers an attractive alternative to specialized or general applications of the internal combustion engine in consideration of exhaust emission control and in consideration of other characteristics of the two engines. I think we also should inquire into whether or not there are other alternatives that offer some or all of these advantages or different tradeoffs of advantages, or as much or more promise as you have described for the external combustion engine, especially the reciprocating steam engine.

I don't necessarily limit this question to these subjects but I am thinking particularly of, first, the electric automobile, which you have touched on briefly in your statement, and then a variation in the form of the steam-electric automobile, fuel cell applications, Stirling engine, constant and variable speed turbines and the like.

The question I am trying to shed light on is whether or not we are overlooking other good bets, so to speak, even fuel conversion systems that might be adaptable to the transportation industry and the automobile in particular.

Mr. MORSE. I have tried in this testimony not to use the word steam in the narrow sense. That is why I prefer the term external combustion device, as that is the aspect of the system which relates to the pollution problem.

I think steam is perhaps the most promising working fluid to which we might direct our attention as far as the Rankine cycle engine goes. On the other hand, if I were in the automobile business, or the engine business, or a consumer of engines in the vehicle business, I would not overlook a number of other working fluids for use in noninternal combustion engines.

We have had a lot of advances in chemistry in the last 10 years. We have some organic fluids which are useful up to about 750° F., which was not true at the time of Mr. Stanley. There is great progress being

made in lubricants, in the test tube research phase, all of which have to be looked at in the light of a total systems approach to the development of an innovative solution to this problem.

By going to a variable torque, rotary valve system—steam conversion unit—you can get into the business fairly easy and make a demonstration. You don't have to tool up to make crankshafts, castings, and involve the tremendous investment associated with new engine design.

The second stage in such a development program would involve a detailed look at some radical new engines which, while not useful in the internal combustion field, look very promising for steam or vapor use.

I think there is enough economic and engineering data available right now so that you can pinpoint the ones to work on first and also project the R. & D. for the next phase. I believe it is possible to greatly improve operating characteristics, and reduce both fixed and operating costs by new designs.

Senator BAKER. So you don't foresee anything that is presently and reasonably available for future development that might offer the combination of advantages that steam offers, or external combustion engines offer, as an alternative to internal combustion engine?

Mr. MORSE. You have to always look at the application. If somebody wanted to, I am sure one could make relatively smokeless, quiet diesels; but nobody seems to be working on such problems.

Senator BAKER. Do you think that is a better development than steam?

Mr. MORSE. No; because it doesn't have as good operating characteristics. For certain uses such as stationary power, it may well be better.

Senator BAKER. Do you think the dual concept of the electric motor offers more advantage or promise than the steam concept?

Mr. MORSE. I am not impressed with fuel cells, except for very special purposes. It is inconceivable to me that anybody will run around in the street with liquid hydrogen or liquid oxygen, for example, as fuel.

Senator BAKER. There was a time when it seemed unlikely that you would sit on top of a tank of gas.

Mr. MORSE. I agree.

Senator BAKER. Do you see a prospect that battery development and motor technology might offer the prospects of a better electric car than the advantages you see for steam?

Mr. MORSE. I am certain there will be improvements. This is a changing world. We took a position in our study that at the moment, even with more advanced battery development, the electric car would have limited range special purpose use. That doesn't mean we will not develop this business in the future or fairly soon for special requirements.

Senator BAKER. The question is, do you see more promise or potential in the electric automobile than you do in the steam automobile at the moment?

Mr. MORSE. No; I do not and certainly not for general use vehicles. Steam still is the only approach which will permit the kind of characteristics that you need for a large auto or for a long-range auto.

Senator BAKER. Thank you very much.

Senator Scott.

Senator SCOTT. Dr. Morse, what are the entities engaged in saying that this cannot be done, as against those entities and the like which say it can be done. Who is against it and who is for it?

Mr. MORSE. I am not sure I understand. Who is against what?

Senator SCOTT. The concept you spoke of, with regard to the widespread use of steam for day-to-day transportation in an expanding cycle engine or other variables?

Mr. MORSE. I don't know. We are talking about individuals, it seems to me. Energy Systems has met with a large number of companies in the last few months. Without exception everyone has come away saying, "Maybe there is something here," once they see the technical and economic data. There hasn't been much data available until recently, that is, engineering information, developed by competent people who know thermodynamics, and who have some feel for the cost of the tooling and production of new steam devices.

The fact remains that there is almost no one in this country doing extensive research on steam engines. There certainly isn't any major corporations in the United States or abroad in the field in a serious way.

Senator SCOTT. Would there be any interest in extending or expanding such programs through research activities without involving the Federal Government?

Mr. MORSE. I think there is adequate incentive right now for a progressive American corporation to spend money on steam cycle engines. There is also incentive for anybody in the fuel and lubricant business. It is not very logical for an oil company to support battery research. They want to sell fuels and these generate steam. There is plenty of incentive for American management to do something today and make money in this new field.

Senator SCOTT. Would the large automobile companies, in your opinion, seek to deter or delay the development of steampowered automobiles?

Mr. MORSE. I have no reason to believe anybody is delaying progress—it is just that no action is underway in the auto industry.

Senator SCOTT. I wasn't making a charge. I was speaking from the aspect of every new idea which runs into people who are committed to old ideas. I wondered what was the attitude toward the new ideas from those who are making money from the old ones.

Mr. MORSE. I think it depends on who you talk to. I think this country should stop saying the auto industry. I think you will find greater differences between the companies and management attitudes within the automobile industry than you will between the so-called "automobile industry" and, say, the electronics industry.

Senator SCOTT. I take it what you mean is that within the auto industry there are some companies which might be open to the possibility of using their facilities for research in the development of an economically feasible engine which would also offer advantages in other areas, that is, seeking better transportation solutions to pollutants and so forth.

You believe that within the auto industry there exist some group or groups that might be favorable to the development of this newer idea or the survival of an old one.

Mr. MORSE. I do, but we have to recognize that the auto industry is a pretty competitive business. Those segments concerned with increasing their return on investment, obviously, should undertake innovative programs and I believe some progress is being made in this area.

Senator SCOTT. You have mentioned the Black patented rotary valve mechanism, and you said it appears feasible to modify certain available two-cycle combustion engines for steam operation. What would be involved from the standpoint of cost and time in the development of such a system?

Mr. MORSE. I gave that merely as an example of an approach to permit fairly rapid introductions of a steam cycle system.

Some years ago, Dr. Black did some development work, which was privately financed. He is more or less a lone inventor, and operated a 25-horsepower, three-cylinder engine some years ago to demonstrate the rotary valve principle, on which he has some patents. This permitted a continuously variable torque characteristic for his engine which is quite important and the results look quite promising.

You don't need such a device if you are running at constant speed, as for an auxiliary power source. It was a method of taking an existing engine, using the block, crankcase, pistons, and so forth, and with a relatively simple add-on device to the top of the cylinders, he produced an engine which would start, stop, reverse, and developed variable cutoff very easily.

Since that time, Energy Systems has designed and built a unit of that type. I wouldn't brag about the current operating characteristics of this first unit, but it is running, and we did the job in 6 weeks. It is not a finished design, but we have proved the principle.

Senator SCOTT. Perhaps that is a question of perfection through investment and promotion.

Mr. MORSE. Yes; we still have many problems of engineering, tooling, production, and so forth.

Senator SCOTT. Thank you, Mr. Chairman.

Senator BAKER. Thank you very much, Dr. Morse.

I would like to call next Mr. Calvin E. and Mr. Charles Williams, who are with the Williams Engine Co., of Ambler, Pa., only 3 miles from Senator Scott's hometown.

Senator SCOTT. I am 3.4 miles away from you.

STATEMENT OF CALVIN E. AND CHARLES J. WILLIAMS, WILLIAMS ENGINE CO., INC., AMBLER, PA.

Mr. CALVIN WILLIAMS. Senator Baker, Senator Scott, and members, my name is Calvin E. Williams, and my brother Charles and I own the Williams Engine Co., of Ambler, Pa. This company has been engaged in the design and development of steampower systems for automotive use for over 30 years. We believe our engines, in any of several displacements, can meet the entire range of car, bus, and truck applications required by the American motorist and American industry.

Although my brother and I were not present at yesterday morning's session, we are very familiar with both the positive view of steam's potential described by Dr. Ayres and with the somewhat less enthusiastic position taken by Ford and General Motors.

The short time allotted to me this morning suggests that I should

speak directly to the principal shortcomings alleged to make steam impractical as a viable alternative to the IC-powered car. I will be happy to answer questions at any time, but I would like to take up, in order, safety, complexity, emission, and efficiency.

SAFETY

Modern steampower is very safe; the old-fashioned steamer was never as dangerous as some testimony would suggest. It is impossible for "explosion" in the catastrophic sense of the word to take place in a modern monotube boiler; I have never heard of an authenticated explosion taking place with the oldtime steamcars.

Let me state exactly what is likely to happen and what might happen if a steamcar was 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.

Suppose it ruptures—what happens? First, only a small piece of tubing, three-eighths 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.

COMPLEXITY

Industry testimony would lead you to believe that a modern steam system is difficult to build, to drive, and to maintain. This is untrue. We think we know better, after 30 years.

The IC system seems simple, because it is easier to visualize what happens. Gasoline and air are mixed in a closed space, it is ignited, there is a "bang" and power to the crankshaft results. Unfortunately, a lot more—and a lot more complexity—takes place, in the form of a clutch and transmission, before that power is usable. As you know, even when it is usable, it is best used at relatively high revolutions per minute.

Steam is a little harder to describe—but a lot easier to use. Water is heated outside the engine to make steam, the steam is led into the cylinder, it expands—without any bang—and usable power is immediately created, without the need for a clutch and transmission. This power can be created in equally useful fashion at either low or high revolutions per minute, but no other system can give comparable low-speed torque as efficiently. From your friendly neighborhood mechanic's point of view, working on a steam unit is the same or easier; in any event, there are many fewer parts to deal with. The engine only needs four cylinders to give the same power impulses as a V–8 IC engine, and the steam engine is more durable because it doesn't require high revolutions per minute to obtain maximum horsepower.

You have heard that steampower requires specially treated water. That is not true when monotube boilers are used. The car you saw downstairs runs on tap water, and it can do so because the modern boiler utilizes very high flow velocities through the tubing—1,000 pounds per square inch and 1,000° F. are standard operating conditions. We have run systems for 100,000 miles with zero corrosion.

It has also been alleged that the boiler water can be contaminated with oil or that the crankcase oil can be contaminated by water. I state to your two committees that we have completely eliminated the first problem, which is a proprietary matter with us. The other problem is not a problem for any modern steam designer because the design isolates the two fluids.

Lastly, on the matter of complexity, the accessories or minor components hardly challenge industrial ingenuity.

Our water pump is about the size of a large head of lettuce, but it is designed to meet the requirements of a 500-horsepower system—technically, it's just another pump.

Detroit also appears to be worried about the condenser. They shouldn't be; ours is made from a standard auto radiator core and costs—handmade in our own shop—about $150. In mass production, they might cost $25.

EMISSION LEVELS

The mobil test results, using the standard seven-mode, cal cycle which, incidentally, were requested by Ford, speak for themselves. They were run on the 8-year-old car you saw downstairs. But the 20 parts per million unburned HC, 0.05 percent CO, and 40 parts per million NOx don't begin to tell the whole story.

Incidentally, in "The Automobile and Air Pollution Report" by Dr. Morse's committee, part I, a chart on page 22 shows emissions for 1–C engine after 1980 to be: 25 parts per million hydrocarbon; 0.25 percent CO, and 100 parts per million NOx.

Low emission is not an option with steam power. It is built in, requiring no "clean air packages," expensive catalytic mufflers, or other devices whose complexity requires tuning and maintenance. Nobody can remove steam's inherent superiority with a 39-cent screwdriver—as is often done by a disgruntled customer or dealer, who doesn't like the driveability price which must be paid when these devices are installed and used correctly.

Above all, gentlemen, we don't hope to reach these figures sometime in the 1970's; we know that we can begin to reduce Lon Angeles' motor vehicle smog level not to 1940, but to almost zero—tomorrow—given the opportunity.

EFFICIENCY

We did not build our system to curb smog; that's a happy plus. We built it because we know that modern steampower is a better way to run cars, trucks, and buses.

After many years of argument, we think it is fruitless to debate basic thermodynamic concepts with IC proponents before this committee. We propose that the Federal Government underwrite and carry out an objective test program, both on the dynamometer and over the road, of comparable IC and steam systems.

We are confident the result will vindicate steam. To put it in plain language, steam will give you more power for your money.

CONCLUSION

Before answering questions, I would like to conclude, at your staff's direction, with a brief and very amateurish movie, showing a few of our engines in action. I stress these last words, because we believe our system is ready to help solve this Nation's air pollution problem.

The only problem remaining for steampower is finding the capital necessary to emulate Detroit's mass production and marketing. Thank you for inviting us to testify. We look forward to further Federal interest in steampower for automotive use.

Senator BAKER. Thank you very much. Yes, indeed. We would be happy to have you comment on the movie.

(Motion picture presentation.)

Mr. CALVIN WILLIAMS. This is a 21-foot cabin cruiser propelled by a 140-horsepower steam unit. It would propel this boat at 28 knots. It is not a very clear picture. This is a 30-passenger bus propelled by a steam unit.

It was formerly propelled by a 300-cubic-inch V–8 IC engine. We replaced it with a 56-cubic-inch displacement steam engine. We drove this bus with no clutch, no transmission, direct drive, and we could propel the bus at speeds up to 65 m.p.h.

Now you see the steam coming out of the rear. This is because the exhaust from the engine is going right out to the atmosphere so that we can show that it is being propelled by steam. Normally this is connected into the condenser system and this steam would not appear on the road when you are moving.

I might add this bus weighed 15,000 pounds and the 56-cubic-inch displacement engine that propelled it was connected directly to the driveshaft. This is a 1950 Ford car powered by a steam unit. This car we drove to Detroit in 1957 and demonstrated to the Chrysler Corp.

This is a homemade body, an experimental car.

This is the car that you saw yesterday, before it was completed. These pictures were taken in 1960. This car has a 43-cubic-inch displacement engine and it is run without a clutch or transmission. The speed range is controlled by the cutoff lever and your accelerator pedal.

This is the car that ran in the Mobil Test, seven-mode California cycle test—in the Mobil Corp. test, in December 1966. This car could be started from a cold start in from 15 to 30 seconds. After the initial cold start it can be started instantly at any time.

My brother Charlie is on the left, and my dad who passed away in January of this year, spent his entire life on the research and development of steampower systems. That is it. Thank you.

Senator BAKER. Mr. Williams, thank you very much. I am sure we do have questions, and I would like to start with Senator Scott.

Senator SCOTT. Thank you very much, Mr. Chairman. I take it, Mr. Williams, that you feel that you have overcome the disadvantages of bulky boiler, high-water consumption, and slow starts. Do you feel that you have overcome or are overcoming those? Where do you stand?

Mr. CALVIN WILLIAMS. We feel that we have overcome basically these objections, although we do say that bulkwise we are taking up

more space in the present day car than an IC engine would. Advanced designs wouldn't do this.

Weightwise we are lighter in weight than a comparable IC engine. We have the steam generator which you saw yesterday installed in the trunk, taking up the trunk space. In future designs we would incorporate this in the front engine compartment, with the engine, so that you would have a trunk space.

Senator SCOTT. And your high water consumption you have reduced to 500 miles on 12 gallons?

Mr. CALVIN WILLIAMS. Yes. With 10 gallons of water in hot weather—that is a conservative figure—we can give 500 miles. In cooler weather we can up that to a thousand miles. I might add this is with a condenser that is nothing more than a typical automotive IC engine radiator that we are using for a condenser, which is certainly not the ultimate.

We have designs for a condensing system which would up the water mileage for 8 gallons to no more than the water you add to your present IC engine. I might add that a 1968 Lincoln Continental carries 5¾ gallons of water in its cooling system.

Senator SCOTT. How do your cars compare with the IC vehicles in fuel mileage?

Mr. CALVIN WILLIAMS. We get better mileage. On this particular car, tested at the Mobil Oil Corp., with the 43-cubic-inch engine, is a full-sized car with a 114-inch wheelbase and a weight of 3,400 pounds.

In running the seven-mode California cycle tests with stop and go driving, we averaged about 20 miles a gallon on low-grade fuel, which was kerosene.

Senator SCOTT. Would lubrication costs be comparable?

Mr. CALVIN WILLIAMS. I believe they would be about the same. In the lower part of our engine we use regular automotive type oil. We do inject a special oil into the steam cylinders for lubrication. This is a very minute amount. A pint would carry you for about a thousand miles. This is not an expensive oil.

It is about the same price as we pay for a quart of 10–20 oil.

Senator SCOTT. How long have you been working on the development of steam-propelled vehicles?

Mr. CALVIN WILLIAMS. My brother and I started with our dad in 1936. We built our first steam car in 1940, which I might say was not a success. We feel that our first successful car was built in 1954.

Since that time we have propelled vehicles like this 30-passenger bus, several standard-type cars, several home-built cars, pickup trucks, and we have accumulated quite a bit of mileage over the road since 1954.

Senator SCOTT. Aside from being a closed-cycle concept, in what other ways does your car differ from the old Stanley Steamer?

Mr. CALVIN WILLIAMS. The main difference, I would say, Senator, is in the efficiency. We have efficiencies that are four times better than what the old Stanley Steamer was. This in turn would be interpolated in mileage, fuel consumption. There again, with an efficient engine for a given amount of power you are going to put out less emissions.

Senator SCOTT. In size, do you have a substantial difference from the Stanley Steamer?

Mr. CALVIN WILLIAMS. A Stanley Steamer was rated at 20 horsepower, and it was a 4-inch bore and 5-inch stroke, about 250 cubic

inches. We are running a car with a 43-cubic-inch displacement, so there is quite a difference in size.

Senator SCOTT. Have you received much outside support?

Mr. CALVIN WILLIAMS. I would say none.

Senator SCOTT. What has been the attitude of the automobile companies to your project during your experience?

Mr. CALVIN WILLIAMS. As I say, we were invited by Chrysler to take the steampowered Ford car out there, the one in the movie. We spent a day with their engineers and went over our thermodynamics and engineering and detailed drawings.

We left them with them. To this day, we understand they are still studying them. They tell us we have interesting power. In 1966, through efforts of the Steam Automobile Club of America, Robert Lyon, president—I believe he is with us today—we worked up a little brochure and started taking orders for our latest steam unit, 105 cubic inches.

And we did receive orders for 10 of these units. Nine were to be installed in Chevelle automobiles, one an order from the Ford Motor Co. to be installed in a Ford Fairlane. Naturally, they didn't want it in a Chevelle. We started to build these steam units, ordering in small quantities, say 10 of each.

With the economy as it is today, we just couldn't get any kind of deliveries on castings, steel, bearings, and the cost of things skyrocketed. For example, we use three timing chain sprockets to drive the camshafts. We had purchased these sprockets in small quantities before.

Came time to order them for these 10 units, the price jumped from $24 a sprocket to $77 a sprocket. We thought that was quite a jump. It has been that way practically on every item that we use. It seems if you want something in small quantities, it is very difficult to get a good price for it.

It took us a year to get castings, which we had anticipated we would get in 12 to 14 weeks. We ran out of working capital and had to stop manufacturing operations.

Senator SCOTT. It is not possible for you to estimate what the unit cost of one of your vehicles would be, assuming a given production, because of this fluctuating cost of materials?

Mr. CALVIN WILLIAMS. That is true. Originally we took these orders base on minimum quantities of 10 to 50 at $10,250 each, which is a very high price. When you understand that these were practically hand built, we didn't anticipate making any profit.

This should not give you the picture that steam is expensive. In mass production, we say a steam automobile comparable to what Detroit is building could actually be sold for less because there are fewer working parts that go into the steam system.

Senator SCOTT. One last question: We ask a great many questions about what is going on in this country and find in some other country they are doing it. Is there a comparable investment going on, to your knowledge, in Japan, West Germany, Great Britain, or even France?

Mr. CALVIN WILLIAMS. Not as far as we know.

Senator SCOTT. You have no contacts which would tell us whether or not our Japanese friends are already moving along over the highways in a steamcar?

Mr. CALVIN WILLIAMS. No. There is a magazine published in Eng-

land, on the Isle of Man, called Light Steam Power. They try to cover steam over the entire world. I have never seen anything in there about developments in Japan. Most of the developments covered in this magazine go back to the old work.

Senator SCOTT. Pritchard?

Mr. CALVIN WILLIAMS. Pritchard is in Australia. That is the one designed today. I know about the Pritchard unit from what I have read in this magazine.

Senator SCOTT. Mr. Chairman, it might be of interest to mention here, that this area historically has had a great deal to do with automotive development. Only 5 or 6 miles away, the autocar was developed at Ardmore, and the first feasible automobile was developed near where you are working, the old Stephens-Duryea.

You wouldn't remember the Stephens-Duryea, Mr. Chairman, but it was the first feasible automobile of the 1890's. It was developed in the same area. Around Philadelphia we get good ideas, and then wait for Detroit to provide the money.

Thank you.

Senator BAKER. I thank you very much, Senator Scott. I think clearly you have demonstrated with these massive accomplishments in the automotive field and your contribution in the political field that there must be something in the water. [Laughter.]

Mr. Williams, thank you very much. I would like to ask one or two questions, if I may. First, I would like to thank you for the demonstration of this prototype automobile yesterday in the Senate garage. I found it intriguing and fascinating.

Some testimony was taken yesterday on the difficulty of supplying auxiliary power, such as for heating, air conditioning, electrical power at idle conditions, windshield wiper power, and the like.

How have you accommodated these problems?

Mr. CALVIN WILLIAMS. Of course, the auxiliaries are run by the engine, and as you know when you stop at a traffic light, the engine stops turning, so naturally you get no power. This is all right. We had no trouble with this ourselves.

We feel that a car would run continuously in city driving, like around Washington, where you wouldn't get up to any good speed, that you could build up a reserve with your regulating system. Let's assume that a car is stuck in traffic at a traffic light.

Sometimes you have to wait 5 or 10 minutes or so. It may be that you would have something so that the engine could run at a reduced revolutions per minute just to run the auxiliaries. This could be done easily.

Senator BAKER. You don't foresee this as an insuperable technical problem?

Mr. CALVIN WILLIAMS. Oh, no. Not at all. Not at all. Another thing. Of course let's assume that you have a car with an air conditioner and the compressor is run by the engine. and the windows are closed and you should have to stop at a traffic light for 3 or 4 minutes.

I don't think the car will get like an oven in that short time if the compressor was shut off.

Senator BAKER. You wouldn't necessarily have to use the compressor for air conditioning?

Mr. CALVIN WILLIAMS. That is right.

Senator BAKER. One other question. In the material I have here, the research report from the Battelle Memorial Institute, in dealing with emission data for the internal combustors, at page 33 of the report there is a footnote A which says:

When comparing the data in this table

Speaking of emission levels—

with those for gasoline engines on a relative mass emission rate basis, the data in this table should be roughly doubled to account for the higher air-fuel ratio generally used with external combustors.

I am looking now at the "Williams Steam Power Report," which was submitted to the committee before you testified, dated May 15. On the first page is a schedule of emission results from the Mobil Oil Corp. seven-mode testing, which shows hydrocarbons at 20 parts per million, carbon monoxide and oxides of nitrogen.

Are these figures shown in your report double the figures that the Battelle report suggests, or are they the raw figures? In order to get the realistic actual emission levels from the external combustion engine, your engine, do we read them literally as you have shown them in this report, or must we double them?

Mr. CALVIN WILLIAMS. I would say literally as in the report, because it says at the bottom of the first page of the Mobil Oil Corp. test report that "These figures were measured during seven-mode California cycle operation."

They give the figures of the 20 parts per million, 0.05, and they have here 70 parts per million on nitrogen oxides. On the chart on the other page, where this was taken at constant speed, you would have to take 1/20 of that, because the boiler actually fired only 20 percent of the time.

We took an arbitrary figure in our written presentation of 40 parts per million. Actually on some of these tests it was down to 35 parts per million of nitrogen oxides.

Senator BAKER. Thank you very much.

The exhibits attached to your statement will be placed in the record at this point.

(The exhibits are as follows:)

WILLIAMS ENGINE COMPANY, INC.,
Ambler, Pa., May 15, 1968.

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

MR. CHAIRMAN AND MEMBERS OF THE COMMITTEE: The Williams Engine Company, Inc. is a small research and development firm engaged in the limited manufacture of steam powered road vehicles.

We have invested over 30 years and $2 million dollars in the design, research and development of steam power systems for motor vehicle use.

From thousands of dynamometer tests and over 100,000 miles over all types of roads, including turnpikes, we have empirically proven that modern steam power is practical and feasible for cars, buses and trucks—Right Now!

In December 1966 one of our prototype steam cars ran the 7—Mode California Cycle Tests at the Mobil Oil Corporation Testing Laboratory, Paulsboro, New Jersey. Kerosene fuel was used.

The very low emission results were as follows:

Hydrocarbons: 20 p.p.m.
Carbon Monoxide, (CO): 0.05 percent.
Nitrogen Oxides, (NO_x): 40 p.p.m.

These results were obtained on an unoptimized car with over 25,000 miles on it. This car is full sized with 114" wheel base and a weight of 3400 lbs. It has a top speed of 100 MPH, with our 43 cubic inch steam engine.

Our 1968 models will reduce these low emissions to even lower levels.

The Williams basic designs cover a range from 10 HP to 800 HP in 14 cubic inch to 262 cubic inch displacements. Kerosene, fuel oil, Diesel fuel or gasoline can be used with equal facility.

They will provide smog-free power for vehicles ranging in size from golf carts, mini-cars, compacts, full sized cars to buses and truck tractors with performance equal to or better than the internal combustion engine.

No clutch or transmission is required to apply the power to the driving wheels. Our steam engine can be reversed at any speed to provide dynamic braking.

We presently have the technology, background and know-how in the field of steam power systems to provide a steam powered vehicle (car, bus or truck) at minimal development costs that will be equal or superior to the internal combustion engine, Plus the Advantage of 95 to 98 percent Less Harmful Emissions.

In mass production our steam powered vehicles can be built for less than internal combustion vehicles.

Financial aid is all that is needed to get the Williams Steam Car, Bus and Truck on the road in quantity.

It would give us pleasure to show to the Committee a short amateur movie film of several of our steam vehicles in operation.

Sincerely yours,

WILLIAMS ENGINE CO., INC.,
CALVIN E. WILLIAMS,
President.
CHARLES J. WILLIAMS,
Vice President and Secretary.

POLLUTION COMPARISON

	Internal combustion National Standards 1968	External combustion Williams Steamer no smog device tested December 1966 by Mobil Oil Corp.
Hydrocarbons	275 p.p.m.	20 p.p.m.
Carbon monoxide	1.5 percent	0.05 percent
Nitrogen oxides	1,500 p.p.m.	40 p.p.m.

STAMP OUT SMOG—BUY A WILLIAMS STEAM CAR

The Williams Engine Company, Inc. of Ambler, Penna. is producing both complete package steam power units to install in a car of your choice and the complete all fully automatic modern steam automobile.

Internal combustion engine cars emit over 1000 parts per million of hydrocarbons, which will no longer be permitted. The 1968 cars with smog attachments are permitted by law to have 275 parts per million of hydrocarbons emission. Permissible carbon monoxide (CO) emission for 1968 is 1.5%.

A Williams steam roadster with over 25,000 miles on it was tested for smog emissions at the Mobil Oil Corporation Test Laboratories, Mobil's test report of January 6, 1967 disclosed the following results:

Hydrocarbons: NDIR—20 p.p.m.
FID—20 p.p.m.
CO: NDIR—0.05 vol. %

In city traffic, internal combustion engine cars, while idling, continue to foul the air with pollutants even when standing still at a stop light or stop sign.

Emissions, under the same conditions, for the Williams Steam Car are zero.

On deceleration (such as slowing from high speed to a slower speed or going down a hill)—the internal combustion engine car has maximum emissions of foul pollutants.

In deceleration—the Williams Steam Car emits nothing.

Maintenance to keep internal combustion engine cars at required levels of emissions—exorbitant.

Maintenance to keep Williams Steam Car at required levels of emissions—none.

Williams Patented Steam Engines

Four cylinders in line—single acting—Uniflow operating on 1,000 p.s.i. and 1,000° F. steam

	Torque at 0 r.p.m. (pounds per foot)
Model 2288 1¾-inch bore by 1½-inch stroke—14 cubic inches	150
Model 2280 2-inch bore by 2-inch stroke—25 cubic inches	260
Model 2329 2⅝-inch bore by 2-inch stroke—43 cubic inches	450
Model 2071 3-inch bore by 2-inch stroke—56 cubic inches	589
Model 2279 3½-inch bore by 2¾-inch stroke—105 cubic inches	1,105
Model 2036 4-inch bore by 3⅝-inch stroke—182 cubic inches	1,898
Model 2178 4¾-inch bore by 3$^{45}/_{64}$-inch stroke—262 cubic inches	2,734

Horsepower range: 10 to 800.
RPM range: 0 to 5,000.
Overload capacity: 100 percent on all models.
Engine weights: 50 pounds to 500 pounds.
All engines instantly reversible—no clutch or gear box required.

Steam generators:
Mono-tube, once through, forced circulation type.
Steam in 10 seconds from cold start.
Fuel: kerosene, number 1 or number 2 fuel oil or Diesel fuel.
Size and weight of steam generator varies according to horsepower.

Complete steam power package units for: Stationary, automobiles, trucks, buses and marine applications.

Williams Steampower Package List

SPECIFICATIONS

Steam engine

Four cylinders in line, 3½-inch bore by 2¾-inch stroke—105 cubic inches:
single acting—Uniflow—Williams Steam Cycle.
crankshaft pressure lubricated.
steam cylinders pressure lubricated.
ball bearing camshafts and roller tappets.
alloy steel poppet valves.
allow steel pistons.
aluminum crankcase.
alloy steel cylinder block.
cylindrical crossheads.
valve cut-offs, lever operated.
Dimensions:
Height above crankshaft centerline—19 inches
Length—25¾ inches
Width—12 inches
Weight—300 pounds, approximately
Operating conditions: 1,000 p.s.i. and 1,000° F. superheated steam

Steam generator

Williams mono-tube forced circulation:
automatically controlled by temperature and pressure.
stainless steel tubing within a stainless steel housing.
controls operate on 12 volts d.c.
burner is forced draft atomizing type.
fuel: kerosene, No. 1 fuel oil or Diesel.
Dimensions: diameter—21 inches; length—31 inches; weight—250 pounds, approximately.

Feed water heater

Dimensions: diameter—5 inches; length—16 inches; weight—26 pounds, approximately.

Feed water pump

3 cylinder high pressure; weight—25 pounds.

Condensate pump

Gear type; weight—7 pounds.

Throttle valve

Balanced for foot operation; weight—9 pounds.

A schematic wiring and flow diagram will be supplied purchaser at time of delivery.

Following items are to be supplied by purchaser: Condenser; fuel and water tanks; wiring; connecting piping and hoses; 12 volt battery; and alternator. The right is reserved to make changes at any time, without notice in prices, materials, equipment, specifications and models, and also to discontinue models.

Senator BAKER. We are going to have to recess now. The last signal was a vote on the Senate floor. The committee hopefully will reconvene in 15 minutes.

(Whereupon a brief recess was taken.)

Senator MOSS (presiding). If you will resume your seats we will continue with the hearing.

Our next witness is Theodore R. Johnson, executive vice president of the Thermo Electron Corp.

Mr. Johnson, would you come forward, please.

Mr. Johnson, would you identify your companion, and then you may proceed.

As you know, we are somewhat pressed for time. We can include your statement in full in the record, and if you care to highlight or summarize it you may do so. If you prefer to give it in full, you may read it, except I want to indicate we must hurry. As another device, we will probably forego oral questioning and would perhaps like to submit written questions to you later that you might answer and we can put the answers in the record, if that is satisfactory.

You may proceed.

STATEMENT OF THEODORE R. JOHNSON, EXECUTIVE VICE PRESIDENT, THERMO ELECTRON CORP., WALTHAM, MASS.; ACCOMPANIED BY SOTIRIS KITRILAKIS, MANAGER, DYNAMIC SYSTEM DEPARTMENT

Mr. JOHNSON. I am accompanied by Sotiris Kitrilakis, who is in charge of our steam engine work, and technical questions, if any, can be addressed to him.

Thermo Electron Corp. was founded in 1956 by Dr. George N. Hatsopoulos, president of the company, and the late Dr. Joseph Kaye, both of the Massachusetts Institute of Technology. The principal business of the company is the design, development, and manufacture of advanced energy conversion systems. Thermo Electron is a recognized leader in the field of thermionic conversion, a technique for producing electricity from heat directly without the use of moving parts. Dr. Hatsopoulos is today in Italy representing the United States at the Second International Conference on Thermionic Elec-

trical Power generation, which is why he was unable to appear in person.

Located on route 128 in Waltham, Mass., the company employs about 175 people, 40 of whom are graduate engineers and scientists, and has a current level of sales of about $4,000,000. Among the members of the board of directors are Dr. Edward Teller, professor at large at the University of California; Joseph H. Keenan, professor emeritus of mechanical engineering at Massachusetts Institute of Technology; Robert A. McCabe, a partner of Lehman Brothers; and Charles B. Smith, an associate of Rockefeller Family and Associates.

HISTORY OF THERMO ELECTRON'S STEAM ENGINE PROGRAM

Thermo Electron began the development of an advanced steam engine in 1963 when a staff member suggested that a small steam engine generator might fulfill military requirements for a silent electric power supply. As an initial step, members of the company's technical staff met with Professor Keenan of MIT, a recognized authority on steam engines, to determine the specific technical reasons why the steam engine was displaced by the internal combustion engine. He identified three major problems:

1. The oil required for cylinder and value lubrication contaminated the working fluid resulting in boiler failures caused by the oil decomposition products.
2. Loss of water at various points in the system required the addition of makeup water from "roadside" sources which contained impurities harmful to the engine and boiler.
3. The size and weight of the system were excessively large primarily because of the poor heat transfer characteristics of the boiler and condenser.

Thermo Electron has found solutions to these problems by applying technology and materials developed in the last 20 to 30 years, including recent results of space, atomic energy, and military research programs, and by making a number of design innovations which depart significantly from conventional practice.

Our design approach is based on the concept of a hermetically sealed system in which no makeup working fluid is required and which is permanently lubricated for the life of the engine. Unique internal valving, on which two U.S. patents have already been issued, eliminates the need for external actuators and contributes to increased efficiency, which Professor Gouse commented on yesterday. This higher efficiency reduces the required size of the boiler and condenser. Piston and cylinder wall materials have been chosen which keep frictional losses to a minimum, are lubricated by the working fluid and last almost indefinitely without measurable wear. The use of a hermetically sealed system, which is evacuated prior to charging with working fluid, greatly increases the effectiveness of the boiler and condenser, thereby permitting significant size reductions. A new method of heat transfer has been applied to the boiler, resulting in further size reduction of this component. The major characteristics of Thermo Electron's approach are summarized in figure 1.

FIGURE 1. MAJOR CHARACTERISTICS OF THERMO ELECTRON STEAM ENGINE

1. Hermetic system from which all external contaminants are permanently sealed.
2. Permanent charge of working fluid and lubricant adequate for the life of the system.
3. Internally actuated poppet valving which provides increased efficiency and reduced size and weight.
4. Compact boiler, resulting from use of improved heat transfer technique.
5. Compact condenser, resulting from the complete exclusion of non-condensibles from the system.
6. Efficient operation at relatively high speed (up to 4000 rpm) resulting in reducing size and weight.

This approach has been applied to the development of a series of steam engine generator sets, photographs of which are provided in figures 2, 3, and 4. These generator sets are silent in operation, use a variety of liquid hydrocarbon fuels, and offer the potential of a maintenance-free operating life which far exceeds that of internal combustion engine generators. Operation of these systems for many thousands of hours has demonstrated the feasibility of our approach in providing attractive performance and reliable operation. Performance figures for our 1.5-kilowatt generator set, which has been delivered to the U.S. Corps of Engineers at Fort Belvoir for evaluation, are provided in figure 5.

The measured thermal conversion efficiency of this engine is 17 percent, which compares favorably with the efficiency of the standard internal combustion engine used in conventional generators of this type.

(Figs. 2 through 5 follow:)

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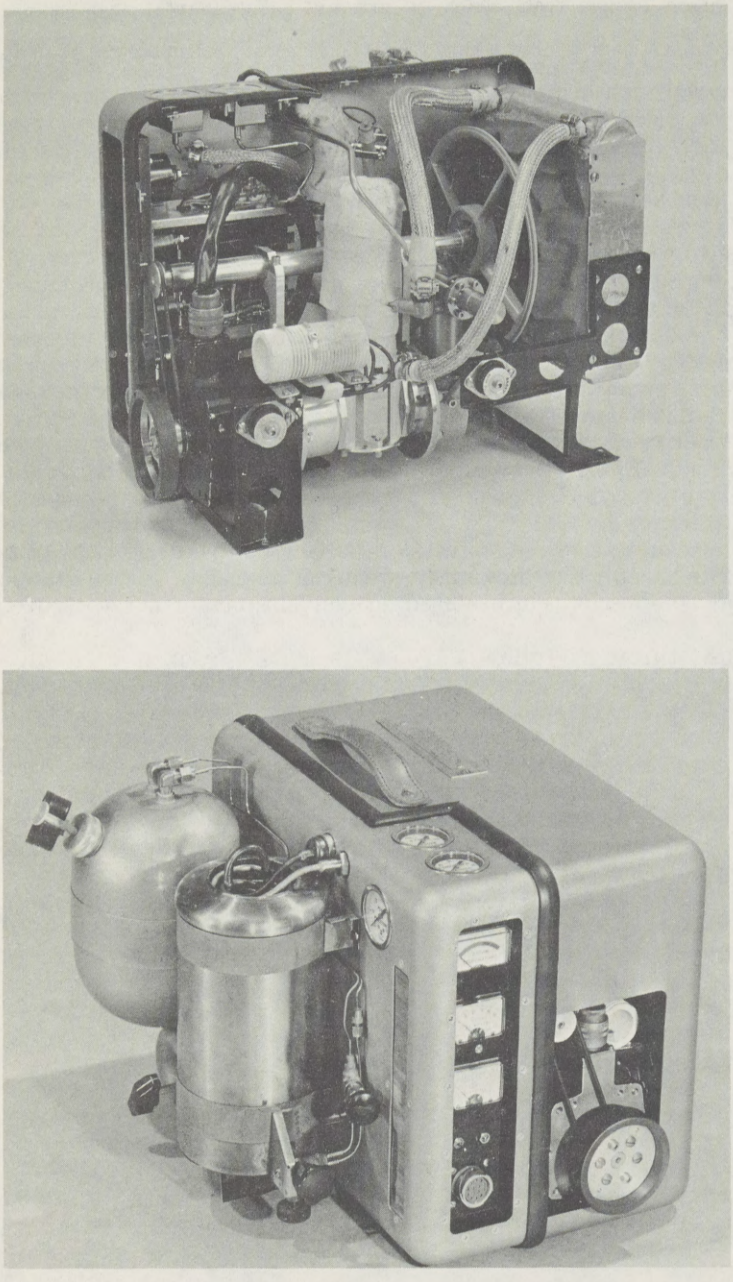


Figure 2 100-Watt Steam Engine Generator

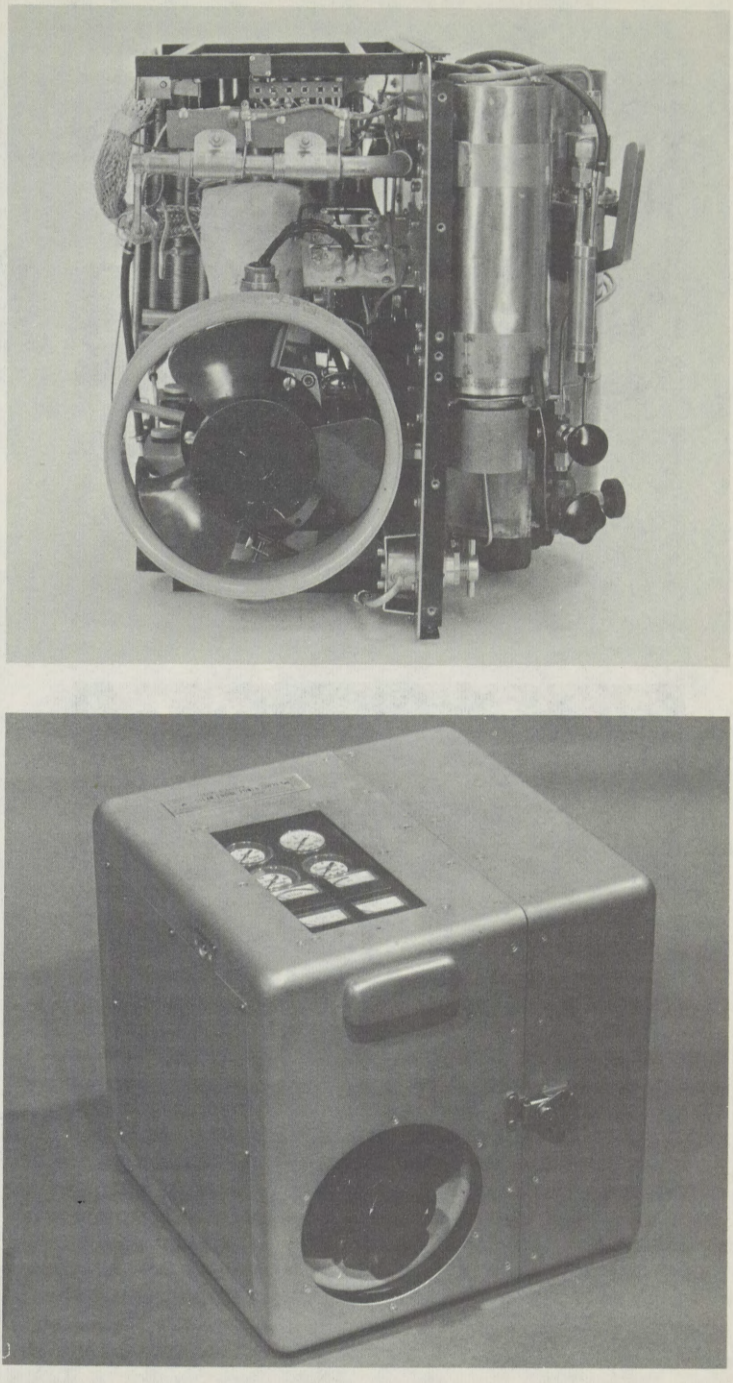
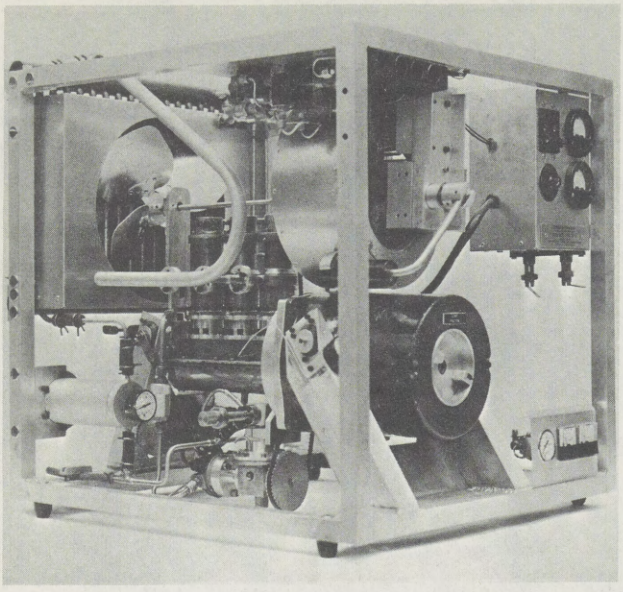


Figure 3 300-Watt Steam Engine Generator



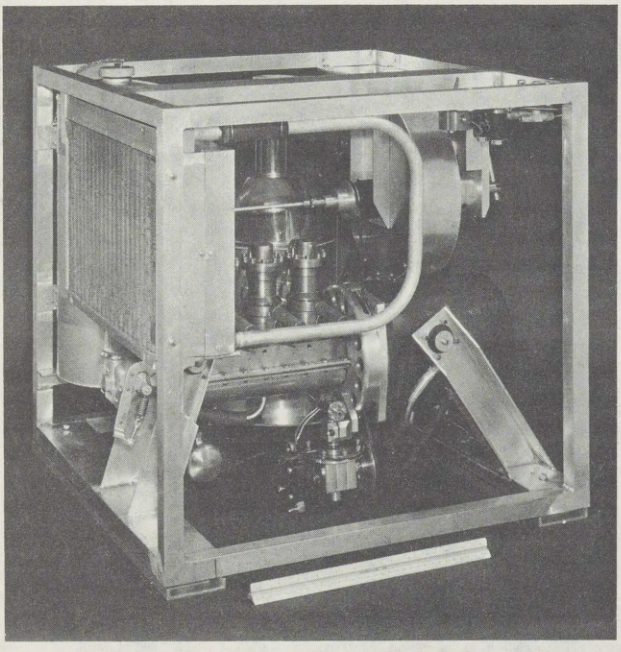


Figure 4 1500-Watt Steam Engine Generator

FIGURE 5. MEASURED CHARACTERISTICS OF 1.5 KW. ENGINE GENERATOR SET

Electrical Output Power: 1.5 kW at 28 V dc, Regulated.
Engine Shaft Power: 3 hp at 3600 rpm.
Volume: 2 x 2 x 2 ft.
Weight: 125 lbs.
Fuel Consumption at Rated Output: 3.6 lbs/hr.
Fuel: Gasoline, Jet Fuel, Kerosene.

Mr. JOHNSON. In addition to the development of silent generators for the Army, Thermo Electron is also working on an implantable power supply for an artificial heart, based on a miniaturized version of the same engine. Two types of power supplies are being considered; one which is recharged periodically and one which can operate for several years on a single loading of a radioisotope such as plutonium 238. An artist's view of the complete implantable circulatory support system, showing the location of the prosethetic assist pump and power supply, appears in figure 6, and I have here in my hand one of the first prototypes of the device which is being tested in our laboratory. This work is being sponsored by the National Heart Institute of the National Institutes of Health and by the Atomic Energy Commission.

Senator MOSS. That would be implanted within the abdominal cavity?

Mr. JOHNSON. Yes, sir. Figure 6 shows the proposed location of the power supply within the body.

Mr. JOHNSON. As you know, a few weeks ago Thermo Electron and the Ford Motor Co. announced a joint program to further develop the unique steam engine concept which I have described. The objective of this program is to apply our technology to a variety of commercial applications with assistance from Ford in production engineering, cost reduction, production planning, and manufacturing. The specific product objectives of this program have not yet been defined in detail; however, among other possibilities, we are considering a number of vehicular applications which I will discuss in a moment.

As several other witnesses have pointed out, there are quite a few working fluids other than water available to the designer of a Rankine-cycle reciprocating engine. For automotive applications we feel that an organic working fluid is a better choice than water.

Organic fluids are carbonbearing compounds, one class of which, the freons, is commonly used in refrigerators and air conditioners. Several new organic working fluids with properties suitable for Rankine cycle engines have become available during the last 10 years. These fluids are capable of operation at temperatures up to 600° F. and have freezing points well below the minimum ambient temperatures normally encountered in the continental United States. This would avoid the freezing problem discussed by a number of witnesses this last day.

Thermo Electron has built and tested engines using these working fluids with measured conversion efficiencies at 550° F. comparable to those achieved with steam at 900° F. They are compatible with the new fluorocarbon lubricants which can be circulated throughout the system, thus eliminating the need for seals between the cylinder and the crankcase. As shown in figure 7, no cross-head piston, of the type used in conventional steam engines, is required, which makes the configuration of our engine very similar to that of the internal combustion engine.

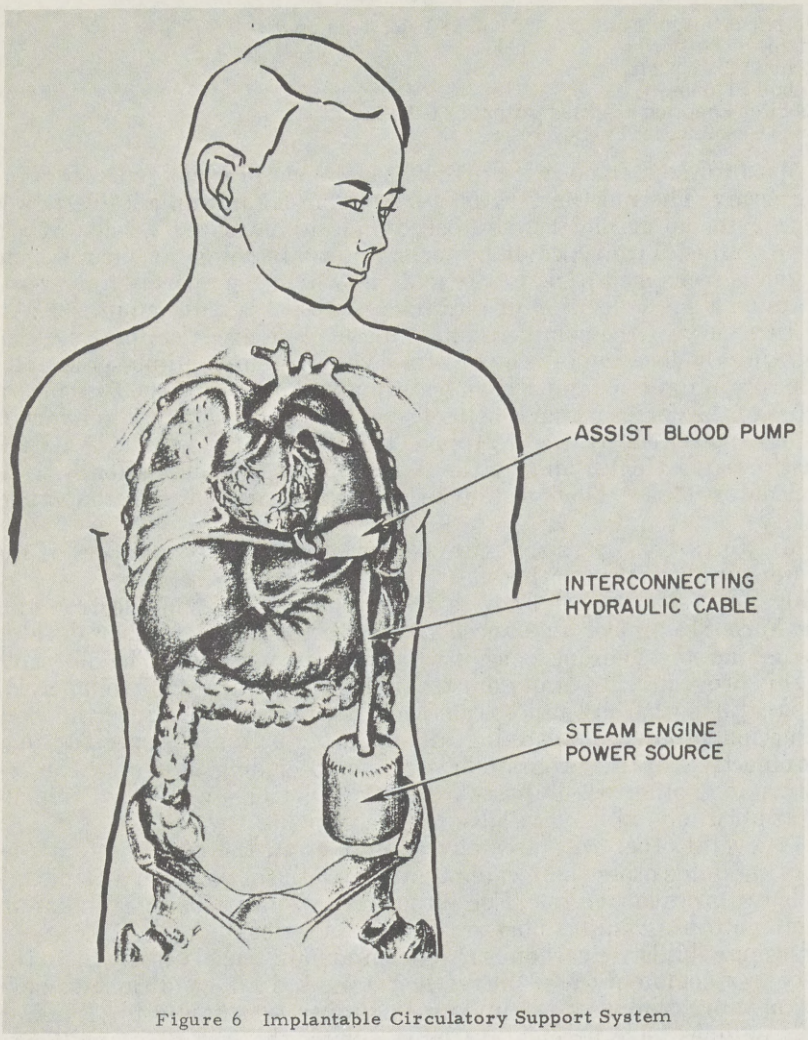


Figure 6 Implantable Circulatory Support System

I think it is worth a moment to look at this figure. Although it is greatly simplified, you can see that the elimination of the seals conventionally used to separate water from lubricating oil makes the configuration of this particular engine very similar to that of an internal combustion engine. And this has very great advantages, as you will see in a moment.

The maximum temperature encountered at any point in the engine is considerably below the normal operating temperature of the exhaust valves of an internal combustion engine.

This fact, plus the similarity of configuration, permits the use of standard materials and processes currently used in the manufacture of both refrigeration compressors and internal combustion engines. Thus, the technology developed over the last 50 years by these industries can be applied to the production of our engine.

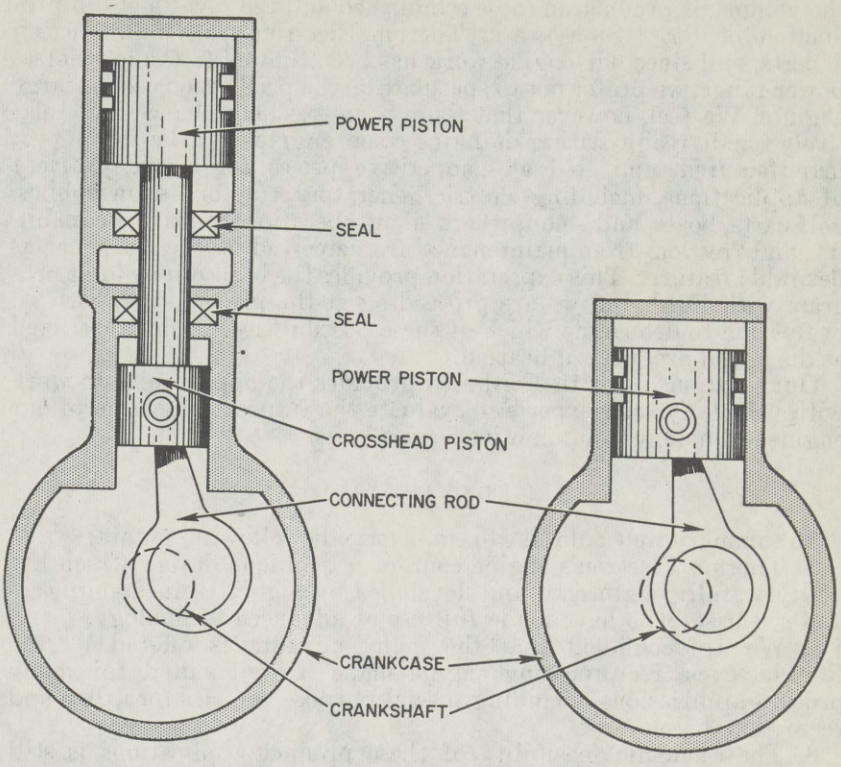


Figure 7. Comparison of Conventional Steam Engine with TECO Engine Using Organic Working Fluid

There are basically three approaches to the design of a pollution-free vehicle utilizing an external combustion, Rankine-cycle reciprocating engine:

1. A hybrid vehicle whose propulsion system includes both storage batteries and an engine generator set of 5–20 kilowatt output.
2. A relatively low-performance vehicle with an engine of 20 to 40 horsepower without batteries, suitable for intraurban use as a delivery truck or taxi.
3. A vehicle whose performance characteristics are comparable to the present passenger car, utilizing an engine of 100 horsepower or more.

The pollution characteristics of each type of vehicle are, of course, determined by the design of the external combustion system as opposed to the engine, per se. Although our experience to date has been confined to relatively small systems, we are confident that the excellent mission characteristics of these units will be duplicated in larger powerplants. Previous witnesses have provided ample documentation of the pollution-free exhaust of external combustion systems.

From an engineering standpoint, all three of these approaches are technically feasible. That is, the advanced design features of our engine can be applied at any power level. We are confident that engines can be designed and built.

It is impossible to say at the present time whether any of these approaches are economically feasible. This will depend primarily on the volume of production to be established and the investment in production facilities. Since we at Thermo Electron are not production experts, and since our engine work has been limited to the low horsepower range, we prefer not to speculate on the production cost of large engines. We feel, however that there is an excellent chance that relatively small reciprocating Rankine-cycle engines can be developed, manufactured, and sold at competitive prices for a wide variety of applications, including electric generators, tractors, snowmobiles, golf carts, boats, and so on, where silent operation, multifuel capability, and freedom from maintenance are perceived by the consumer as desirable features. This expectation provides the basis of our joint program with Ford, and we are proceeding at the present time with an evaluation to determine which of these possibilities should be selected as the initial product application.

Our relationship with Ford also provides the opportunity to work with vehicle systems experts to evaluate the future application of our engine technology to automotive powerplants.

CONCLUSIONS

In summary we would like to emphasize the following points:

1. Thermo Electron's engine concept is a unique design which has been carefully engineered and developed by highly trained engineers and scientists who have made full use of advanced technology.

2. We are confident that the many advantages offered by the Rankine-cycle reciprocating engine make it well suited for many product applications, including special purpose vehicles for urban and recreational use.

3. The economic feasibility of these product applications is still being investigated. An important aspect of this investigation, in which we are receiving considerable assistance from Ford, is the application of current high-volume production techniques and the use of existing components from internal combustion engines and refrigeration compressors. We feel this is the path to follow to achieve competitive manufacturing cost.

4. In the absence of substantial Federal support for the development of pollution-free vehicles, we will focus our attention initially on military applications and commercial products in which the special features of our engine may lead to realize profitable sales.

5. If Federal funds were available, the developments of such vehicles could begin immediately. This would make possible a definitive and objective evaluation of their performance characteristics, economic feasibility, and public acceptance.

If I might add another point, in connection with Dr. Morse's responses to Senator Baker's questions.

I would like to draw an analogy with the artificial heart program. In that program the reduction of the annual death toll from heart disease has been identified as an urgent social goal, and therefore Federal funds have been appropriated to pursue a number of alternative paths to meet this objective.

A considerable amount is being spent on research to prevent heart

disease; heart transplants are being sponsored by a number of grants, and the development of artificial heart devices, such as we are engaged in, is a third approach.

It seems to me that, if the elimination or reduction of air pollution is also regarded as an urgent and important social goal, then the Federal Government should be willing to examine a number of alternative solutions to this problem.

While the automobile manufacturers are apparently devoting a large effort to modifications to the internal combustion engine, and, as indicated in the testimony before your committee last year, the development of electric batteries for automotive use is also being vigorously pursued, it seems that the steam engine, or as we have defined it the organic Rankine-cycle reciprocating engine, is receiving relatively little attention. As other witnesses have stated, there is very little development work in progress on this method of vehicle propulsion. If the private sector is unable or unwilling to explore this approach to pollution abatement, the Government should give serious consideration to doing so if for no other reason than to assure a proper evaluation of the potential merit.

Thank you very much.

Senator Moss. Thank you, Mr. Johnson, for that very fine statement.

I had indicated I wouldn't have any questions. I have two or three. It appears we will have to recess for lunch shortly, anyway, so perhaps we can have a few oral questions.

I am wondering if there is any real danger from explosion of a steam generator. Is that really a problem now?

Mr. JOHNSON. Let me ask Mr. Kitrilakis to answer that.

Senator Moss. All right.

Mr. KITRILAKIS. Perhaps the best way to answer this question is to point out that the extent of the hazard will depend on two factors: the amount of energy available for release and the rate at which this energy is released.

I think Mr. Williams touched upon the first factor when he commented that monotube boilers contain very little working fluid, as opposed to, say, a system where you have a large reservoir of water and steam. Therefore the total amount of fluid that could be released in this type of system is very small.

Since we are talking about a boiler made up entirely of tubing, the worst type of accident that can occur would be a complete rupture so that the total cross-section of the tube is available for releasing the energy in the working fluid. The relatively small diameter of the tubing used in modern boilers limits the rate at which energy can be released so that there is virtually no possibility of an explosion.

There is really no danger associated with this. The danger associated with the fuel that one carries, that could explode and start a fire, is far greater, and in this respect a steam engine vehicle would be less dangerous than present autos, since the fuel, kerosene, is less volatile and, therefore, much less likely to ignite.

A situation similar to that encountered with a steam engine exists in the home, where the electric refrigerator contains working fluid at substantial pressure. While it is quite inconceivable that the coil containing this working fluid could rupture, the refrigerator is not thought of as a dangerous device.

Senator Moss. You would say the hazard would not be greater than we are experiencing now with the mechanical refrigerators we have?

Mr. KITRILAKIS. Those can be ruptured, and there is a hiss and release of gas but it doesn't represent serious danger to anybody because the release rate is limited by the principles I spoke of.

Senator Moss. Isn't it true that the existing pollution control devices on internal combustion engines lose their effectiveness over a period of time as the engine wears?

Mr. KITRILAKIS. One would expect this to be the case. For one thing, these engines require accurate tuning of both carburetion and ignition.

Also, any catalytic device by its nature implies use or exhaustion with time.

Senator Moss. Is that problem eliminated in the external combustion engine we are talking about?

Mr. KITRILAKIS. Definitely. Occasionally you would have to clean certain parts of the burner, but these, when dirty, would not particularly contribute to pollution. Dirt might contribute to some inefficiency.

Senator Moss. Is the condenser so large in your closed-cycle engine as to make the engine unmanageable?

Mr. KITRILAKIS. Not at all. Perhaps a valid comparison might be made on the system which we have delivered to the Army at Fort Belvoir. The weight and size of the Rankine-cycle system were smaller than that of the comparable gasoline engine generator set. So, in fact, in spite of the need for a condenser and boiler, the total system is smaller and lighter.

Senator Moss. You said the advantage of the closed cycle is that you have no loss of fluid.

Mr. KITRILAKIS. That is correct.

Senator Moss. Does this affect the engine's performance in any way?

Mr. KITRILAKIS. Yes, it does, in a number of ways. One important way is that the size of the condenser is reduced because the system is totally hermetically sealed, it cannot communicate with the environment, and you do not have the problem of collecting noncondensibles in the condenser which reduces its effectiveness.

Another important aspect here is the fact that having the same charge of working fluid throughout the life of the engine avoids the introduction of contaminants from whatever source one might obtain additional working fluid. You would not always have high quality working fluid available if you had to replenish the system every so often.

Mr. JOHNSON. It is worth making the distinction between the phrase "closed-cycle" on the one hand, which is descriptive of all the steam engines that I am aware of today, and the phrase "hermetically sealed," is applicable only to our engine.

Our engine, being hermetically sealed, makes it impossible for any of the working fluid to escape. The conventional closed-cycle steam engine, however, returns a major fraction of the working fluid to the boiler, but a certain amount of it is lost to the atmosphere and therefore must be made up.

Senator Moss. Do you lose reserve speed capacity with this closed cycle?

Mr. KITRILAKIS. On the contrary, sir. What we have attempted to do is to have instantaneous response to whatever power demand we experience. This relates to a point that was made yesterday, where the implication was made that the high torque characteristic of the steam engine at low speeds is a result of a large amount of reserve steam in the boiler. This is not true at all.

The steam engine is capable of high torque as long as it is supplied with the required amount of steam, and a well-designed monotube boiler can easily match the demand rate of the engine over a wide range of output.

Senator Moss. What is the startup time for your engine?

Mr. KITRILAKIS. This again is a function of design. In the particular system that we have developed for the military, it is of the order of 20 seconds or so.

There we have to have a manual start because a battery is not acceptable in the system. So the startup time is somewhat slower than one might expect. You could do much better with an automatic starting system.

Senator Moss. If your engine were used in an automobile, could you get an instantaneous start then?

Mr. KITRILAKIS. With a battery to provide power for ignition and pump fuel and air for combustion, startup could be accomplished within a few seconds except in the very coldest weather.

Senator Moss. I think Mr. Johnson said the problem of freezing could be met by using a fluid which is not susceptible to freezing in the temperate climates.

Mr. JOHNSON. That is correct.

Senator Moss. We do thank both of you gentlemen, Mr. Kitrilakis and Mr. Johnson, for coming here and giving this very interesting testimony.

It has been helpful to our record and we appreciate it very much.

Mr. Charles Gill, president of the Thermal Kinetics Corp. of Rochester.

Mr. Gill we are glad to have you here. We would appreciate it if you would proceed.

STATEMENT OF CHARLES L. GILL, PRESIDENT, THERMAL KINETICS CORP.; ACCOMPANIED BY HAROLD M. YANOWITCH, ATTORNEY

Mr. GILL. I have with me an associate, Mr. Harold M. Yanowitch. He is with me primarily because I have a laryngitis problem. He is an attorney and he will speak for me in the event my voice gives out.

It is indeed a great pleasure and privilege to testify before this committee. I have been most impressed by the credentials and the testimony of the people who have preceded me, and I wish to state that my technical background is primarily as an optical physicist.

It was not until several months ago that I became interested in anything associated with steam propulsion. For some time a group of Rochester, N.Y., businessmen have been interested in the general air pollution problem and specifically in the contribution of the in-

ternal combustion engine to the problem. Our interest was further stimulated by the work and the report of the Panel on Electrically Powered Vehicles to the Commerce Technical Advisory Board. The conclusion reached by the Rochester group was that a sealed vapor engine provided the most practical solution to vehicular air pollution when viewed from the state of current technology, cost of manufacture, and operational considerations including efficiency, maintenance, and low noise level.

Upon completion of our survey, a private corporation—Thermal Kinetics Corp.—was formed with the following objectives.

1. To acquire a "modern" steampowered automobile to determine the current state of the art of presently available steamcars and to evaluate the technical and economic feasibility of potential solutions to the anticipated problem areas.
2. To determine the current interest of existing industries in development of a sealed-cycle vapor engine power system for automotive applications.
3. To determine whether sufficient profit incentive exists to encourage development of a useful system with private capital.
4. To undertake the development of a vapor system which would be competitive with the present internal combustion engine, assuming the results of the above investigations were favorable.

The first objective resulted in the acquisition of a steamcar developed by Mr. Charles Keen of Madison, Wis. This automobile is the third generation of a series of steamcars built by Mr. Keen and incorporates the combined experience of Mr. Keen, Mr. Abner Doble, Mr. Alex Clarkson, Mr. William Besler, and others who consulted with Mr. Keen during its development.

While we consider this automobile to be representative of the best steampowered system available today, improvements are necessary in several areas before the mechanical sophistication and reliability of the present internal combustion engine can be approached.

While all the required improvements are possible within today's technology, development effort is required to adapt the available technologies to the necessary system components, and to integrate the components into an optimum vapor system for automotive application.

The resultant system conceivably could be superior to the internal combustion engine by many standards of comparison in addition to the well-publicized decreased atmospheric pollution. These potential benefits include lower noise levels, decreased operating costs and relative mechanical simplicity with the accompanying increased life and decreased maintenance.

While the opportunity exists for technical improvements of all system components, the following comments are considered indicative of the possibilities wihch exist for adapting current technology.

1. VAPOR GENERATOR

One of the major obstacles to the development of an acceptable vapor engine automotive system is the space requirement of the vapor generator. Adaptation of current heat pipe technology as a means of heat transfer will not only reduce this space requirement very significantly, but also should increase heat transfer efficiency and reduce cold startup delays.

2. ENGINE

The more uniform pressure distribution within the expansion chamber of a vapor engine makes the choice of a rotary vapor engine attractive. We believe that application of present materials and technologies can eliminate the sealing and lubrication problems formerly associated with rotary engines.

3. WORKING FLUID

Water has been used traditionally in vapor engines because of its abundance and chemical stability. Responsible technical people of leading chemical industries have indicated that superior working fluids are possible within today's technology.

As the gentleman from Thermo Electron and others have testified, freon and other organic fluids presently available can be used at relatively low operating temperatures and compare favorably with water. We have been assured by some of the chemical companies with whom we have talked that a superior fluid can be developed at relatively low cost.

As a result of our conversations with many management people, we believe that industry generally has a negative attitude toward the development of an external combustion vapor engine system for automotive use. The following reasons for the negative attitude are among those most frequently cited.

1. There is little profit incentive to nonautomotive industry to develop a system, since few basic inventions are required and any patent protection which might evolve would be easily avoidable.
2. No successful alternative power system can be produced economically without the design, manufacturing, marketing and servicing capabilities of the present automotive industries.
3. The present internal combustion engine has attained a high degree of reliability. No alternative system will be publicly acceptable until a similar degree of reliability can be guaranteed.

We at Thermal Kinetics are convinced that an external combustion vapor engine utilizing present automotive accessory systems, body designs, and fuels and which will compete successfully with the internal combustion engine, can be developed in a reasonable timespan at a relatively low development cost.

However, because of the above deterrents, we believe the development will be evolutionary over a relatively long period unless development money is provided. We further believe that once such a system is developed, the present automotive industry will economically produce, market, and further refine the system.

Because of these convictions, we are restricting our present activities to the following:

1. We plan to continue our experimental work with the Keen car to develop innovations which will improve the operating efficiency, reliability, and to reduce the maintenance requirements.
2. We will maintain and strengthen our technical and industrial contacts so that if and when development money becomes available, we will be able to make a technical proposal supported by a competent technical team which in turn will be supported by necessary related industries. Thank you.

Senator Moss. Thank you, Mr. Gill. That is a very interesting statement. Is this group of Rochester businessmen doing this research with a profit motive, or are you motivated simply by a desire to find an answer to the pollution problem?

Mr. GILL. They are profit-motivated. I thought the word "businessmen" implied that. While some of our ventures have proven to be nonprofit, they were not designed that way.

Senator Moss. What is the size of this venture? How large a staff do you have?

Mr. GILL. We operate a small manufacturing facility in Rochester. The facilities and people of Thermal Kinetics are common to the other company.

We are not a large group and we do no manufacturing at this time at Thermal Kinetics. We are research-oriented. We have, through telephone and personal contacts, talked with related industries. By this I mean large and small chemical houses, manufacturers of compressors, air motors, who have the technology to readily build components of a vapor engine on a mass scale.

We talked with people who currently manufacture boilers for various applications. All of these people agree that a vapor engine is practical and less expensive to operate, if it is manufactured in large volume.

But all of them have the same negative attitude as to the success of a group attempting to enter the automotive manufacturing field without paying the very high price of admission, which was quoted yesterday at $300 to $500 million.

All of these companies are willing to work in the development of the necessary components of a vapor system, if adequate money is provided. Our intention has been to bring together these groups and to work as a team using their resources in addition to our limited resources to develop the components and to integrate these into a workable system.

Does that answer your question?

Senator Moss. I think so. I take it that your group believes that the economic advantages of manufacturing and maintaining a steam vehicle can be established so clearly that you might then attract capital in order to become competitive with the internal combustion engine. You would win the race if it was more economical to operate an external combustion vehicle.

Mr. GILL. I believe that we can develop a system which will prove to be superior to the present internal combustion engine. However, I do not believe that once this has been demonstrated that the automotive industry will be reluctant or incapable of improving. I suspect that if steamcars become the accepted mode of public and private transportation, that the vehicles will wear General Motors', Ford's, and Chrysler's insignia.

Our contribution would be in the development and the introduction of the system. However, there are many other commercial applications for specialized vehicles, which would remain with the smaller companies. I am sure a small company would be able to compete with the automotive industry in these low-volume applications. We have no illusion of toppling the automotive giants.

Senator Moss. They simply will adopt and utilize what is developed and continue to manufacture under the large corporate names that are now building internal combustion engines. Is that what you are saying?

Mr. GILL. I am saying that their mass manufacturing, marketing, and servicing capability is required in order to compete in that marketplace.

Senator Moss. How do you think that we should proceed in getting these vehicles—the kind that you are developing and working on—tested and, if warranted, into mass production?

Mr. GILL. The military, as the preceding gentleman has indicated, have funded the development and evaluation of small size sealed vapor systems. The automotive application is obviously an expansion of these systems.

I believe that the Government could best suit their purposes, if they wished to develop external combustion automotive sources, by funding the research and development of vehicles capable of fulfilling the automotive requirement.

The development cost of such systems should be minimal. Once the Government takes a positive action, I am quite confident that all industry will be stimulated into using their own capability to climb on the bandwagon.

Senator Moss. Is it your observation that the large corporations which make the internal combustion engine have conducted some degree of research on external combustion but have not pressed forward with any seriousness up to this point?

Mr. GILL. This is what was stated yesterday. They have invested, as stated, tens of millions of engineering hours in bringing the internal combustion engine to its present high reliability. My automobile comes to me with a 50,000-mile, 5-year guarantee.

If I were manufacturing that automobile, I would be very certain that any substitute power package I introduced would have equal reliability. I think that for this reason the automotive industry may appear to be reluctant. I am afraid, as a businessman, that I would be reluctant also.

Senator Moss. Would it be possible for a large conglomerate corporation, or a combination of component suppliers, to get into the market now with an external combustion engine vehicle which would be competitive?

Mr. GILL. I think history has shown that it is very difficult. Others have tried to penetrate the automotive market. Mr. Kaiser and Mr. Tucker, with great capital investment, failed. I think that it will continue to be a difficult market to get into because of the marketing and servicing that is required.

Senator Moss. Thank you, Mr. Gill. We surely do appreciate your testimony and your observations. We also appreciate learning about the research work you are doing in this most important field. Thank you indeed for coming.

We will now take our luncheon break and resume promptly at 2.

(Whereupon, at 12:31 p.m., the luncheon recess was taken.)

AFTERNOON SESSION

Senator BAKER (presiding). The committee will come to order.

The next witness is Mr. Edward Pritchard, chairman of the board of directors of Pritchard Steam Power, Victoria, Australia.

Mr. Pritchard, we welcome you to the committee. May I apologize now for myself and for the committee for the inconvenience we have caused you this afternoon. But I trust you will have at least some degree of forgiveness in view of the fact that we are in session here while the Senate is also in session and these conflicts are sometimes inevitable.

I understand you have a statement, and if you would continue with that in your own manner now, we would appreciate it.

STATEMENT OF EDWARD PRITCHARD, CHAIRMAN OF BOARD OF DIRECTORS, PRITCHARD STEAM POWER PROPRIETARY, LTD., CAULFIELD, VICTORIA, AUSTRALIA

Mr. PRITCHARD. Thank you.

Mr. Chairman and gentlemen, I might have an accent problem here and I would appreciate it if you tell me whether I am speaking too quickly or not loudly enough.

Senator BAKER. Coming from Tennessee, I have sometimes been charged with an accent problem, too. So I am sure we will get along quite well.

Mr. PRITCHARD. I am Edward Pritchard, and I am a member of the Institute of Engineers of Australia and a fellow of Melbourne Technical College in Mechanical Engineering and Automotive Engineering, and chairman of directors of the Pritchard Steam Power Proprietary, Ltd.

It has already been shown that the amount of poisonous exhaust gas emission from a steam-engined automobile can be brought to a low level. For the steam engine to be a serious competitor to the petrol engine, it then needs to offer reasonable competitive performance, be able to be produced at a reasonable cost and to take up no more than a reasonable space in the vehicle.

I will try to say internal combustion engine rather than petrol engine.

With regard to an opinion on the steam and gasoline engine, I would like to quote the words of Mr. Alec Issigonis, technical director of the B.M.C.—British Motor Corp.—and this car company is the fifth largest in the world and the second largest in Europe. B.M.C. is a merger of Austin and Morris.

Talking with the editor of the English Motor, Mr. Issigonis says, "In modern cars we have almost reached the stage of accepting some sort of automatic transmission. In the old days this requirement was not there at all, was it? So there is something to be said for restoring the steam movement." Issigonis added some qualifications regarding fuel consumption and costs.

Now that air pollution has become more important, it could be fairly stated that a lot more could be said for restoring the steam movement.

I would like to discuss some points regarding exhaust emission, and also the economy and power requirements of a modern automobile.

These figures are usually overrated or exaggerated in the case of the internal combustion engine automobile.

I would then like to mention some points on steam engine design and on steam generator performances. Reference will be made to the Pritchard steam truck prototype unit and also the new steamcar prototype.

As I hope you will understand, I have to protect some of the findings of my company and I cannot speak quite as freely as I would otherwise wish.

I will now discuss some engineering points regarding exhaust emission:

In comparing the burning of fuel in gasoline and steam engines, several points come to mind:

(*a*) Mixture next to wall. It is thought that some of the petrol air mixture next to a relatively cold cylinder wall cannot burn properly. On the other hand, the burner tube of a steam unit, of light gage heat-resisting material, is maintained at a relatively high temperature such as red heat. This avoids the above chilling problem except, perhaps, for 15 seconds after the first cold startup.

(*b*) Mixture ratio. The internal combustion engine normally gives its maximum power at mixtures chemically overrich. Carbon monoxide is produced under these conditions. However, at maximum economy setting, the mixture is lean enough to enable the suppression of carbon monoxide on these grounds alone.

With the steam engine, a typical burner mixture would be 10 percent lean. In other words, there is 10 percent more air in the mixture than is chemically required for combustion. With the car stopped as at a red traffic light, the steam engine is stopped. There is no idling and the burner, if of the on-off type, is normally off. The whole system is dead when you stop so there is no exhaust emission at all.

A third point: (*c*) The gaging of the mixture ratio. An instrument is used to measure the mixture ratio of an internal combustion engine. Carbon monoxide can be present and the mixture overrich even with invisible exhaust gases. What I mean by that is you couldn't tell by just looking at the exhaust. However, with a good burner, using kerosene or light fuel oil, there is a clear "line" between smokeless and smoky operation with the steam unit. This is a ready indication of mixture strength. This means there is a visual indication of the mixture. You don't have to have an instrument. Anybody can check it easily for himself.

There are several other points that are helpful to the reduction of exhaust poisonous emission. I will briefly mention some of them.

There is more space for combustion, and this gives more time for the mixture to burn. Also, I think this was mentioned earlier, that you don't need lead tetraethyl in the fuel.

Before detail work was begun on our steamcar engine, some estimates were made on economy and power requirements. Some of our estimates were referred to in "The Steam Revival," Joseph Lowrey, Automobile Quarterly, summer 1963, and also in the English journal, "Light Steam Power," January–February 1968. This has become rather important, this question of economy, because yesterday one of the witnesses said the estimates on the petrol engine showed fuel consumption on the order of 0.4 to 0.5 and for the steam engine 0.7. All I can say is those figures are entirely misleading.

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The figures given in the table for the petrol engine are for full load. In Australia, it is 0.5 to 0.6 pound, rather than 0.4 to 0.5. These figures are for full load, generally with the engine stripped of all auxiliaries such as fan and corrections allowed for favorable atmospheric conditions, and a correction formula applied for humidity.

As few automotive engines would run at full torque or power at, say, three-quarters maximum revolutions for longer than 10 hours without blowing up or otherwise breaking down, the above figures can hardly be said to be representative of what is obtained in typical automotive applications.

What is required for comparison purposes is data on fuel consumption obtained when the engine is driving a car on the road. Miles per gallon is the yardstick of economy performance. Appendix 1 shows graphs of fuel consumption in pounds per BHP hour as follows—maker's figures and—at actual road loads worked out from miles-per-gallon tests and assumed rolling and air resistance data for steady speeds on level roads.

Referring briefly to the chart which is appendix 1, you can see that the actual brake horsepower per hour for road loads are considerably higher than the figures usually quoted, nearly double in some cases. The other graph was calculated by using miles-per-gallon figures obtained by "English Motor" magazine. The estimates were worked out in 1962, and the car was an Australian Holden. This is a GM product.

You will notice that at the righ-hand end of the graph the two lines nearly come together. All this means is that at the top speed of a car, road load is full throttle load and that is why these two come together at that point.

Note that actual economy of the petrol engine under loads varies from approximately 0.75 to 1.0 pounds per brake horsepower hour. This is the economy the steam engine has to compete with; that is, .75 to 1.

The engineering term "brake horsepower" originally referred to an actual measurable horsepower that could be measured on a friction "brake" dynamometer. The quantity currently used, "Gross SAE brake horsepower"—is not a true brake HP and this quantity cannot be shown on a dynanometer. The figure is boosted by several factors.

It seems that approximately two-thirds of the "Gross SAE brake horsepower" figure can be reached at the rear wheels in a manual transmission car at certain speeds and 50 percent of the "Gross SAE brake horsepower" can be reached with a car with automatic transmission.

The engine power required to enable a six seater modern car of 2,500 pounds tare weight—"Tare" means unloaded—to travel at 80 miles per hour on level road is approximately 45 brake horsepower. To enable a large American modern car to travel at 100 miles per hour, approximately 90 engine brake horsepower is required.

If extra power is required for acceleration, this can be supplied using reserve power from the steam generator.

Briefly, the design method used for steam power units is as follows:

The steam generator is designed to produce enough steam for the maximum sustained power required. The engine is designed to run satisfactorily at the desired maximum speed and of such dimensions;

for example, bore and stroke—that acceleration and hill climbing is adequate. For overload and for starting from rest, the valve timing may be altered manually or automatically to provide later cutoff in the cylinders. In other words, the high-pressure steam is admitted for a larger percentage of the stroke. Reverse is obtained by altering the valve timing.

I have to mention here that a double-acting steam engine is one in which both sides of the piston are driven. In other words, the piston is driven down the stroke by high-pressure steam, the steam is then exhausted, and then a valve admits steam under the piston pushing it back up the stroke.

Some people call the double-acting engine a one-stroke engine, as distinct from a two-stroke or single-action design in which power is applied in one direction only. The four-stroke engine is one in which power is applied once every four strokes; that is, once down every two revolutions.

The double-acting engine has a piston rod underneath the piston, and the piston rod passes through a seal at the end of the cylinder. The piston rod is connected to a cross head, which looks like a piston on an ordinary car, and there is a connecting rod to convert the straight motion to rotary motion.

This means the double-acting engine is somewhat lengthier in construction than the single-acting engine. In my opinion, the piston displacement of a double-acting engine need only be approximately 14 percent of that of the gasoline engine it replaces. The steam engine will replace the gear box also. Frictional torque drag of this engine would be found to be roughly 20 to 25 percent of that of the equivalent petrol engine.

CAR BODY DESIGN FOR USE WITH STEAM ENGINE

With a low drag engine unit, it can be seen that interesting possibilities open up on body design. It now pays to use a body of low air drag. It is possible to obtain 30 miles per gallon—25 U.S. m.p.g.—at 60 miles per hour with an efficient 6 seater body of 2,500 pounds empty weight using a well designed steam engine of medium efficiency.

Maximum cruising speeds of 80 miles per hour could be achieved with an engine output of 36 estimated horsepower. Sixty brake horsepower would be required for a large American type car—but with an aerodynamically efficient body—at 100 miles per hour.

Thus the use of steam engines would provide designers of the sedan car with a new interest. Although many would agree that current American body design is very smart, it could be a lot more functional.

The point has been raised that a car body designed for the function of low drag may not be beautiful. I would like to mention that it has been said of Ron Grainier, the Australian composer, that, earlier, he was floundering when endeavoring to compose "pure music." However, given a theme or "function," he produced such wonderful music as used for the TV series "Maigret" and "Dr. Who." My point is that, given a theme or aim, body designers could produce efficient and beautiful body designs.

TIRE DESIGNS

Tire drag has risen alarmingly over the past 20 years. Smaller wheels and the use of some synthetic materials are contributing factors. High drag means additional heat which has to be disposed of. High drag tires are a safety hazard at high speeds. However, the new radial ply tire designs assist in reducing this dangerous waste heat.

The use of a low drag steam engine would provide additional incentive toward the development of low drag tires. It is a good combination to use a low drag engine, low drag body, and low drag tires. It would show improvements in efficiency, miles per gallon, and speed, and would enable the use of a small power unit.

SOME FACTORS IN STEAM ENGINE DESIGN

(*a*) *Expansion ratio*

The steam engine designer must beware of basing much of his design on considerations of theoretical indicator diagrams.

A cutoff figure can be specified which will not work properly in practice. Cutoffs as early as 3 percent of the stroke have been specified. An example of the effect of cutoff, admittedly on a small engine using steam at only 420° F., is given on page 15, Light Steam Power, January–February 1955. The engine is the Ricardo "Colonial" unit. Sir Harry Ricardo is one of England's top engine designers. He was commissioned, I think, by the British National Research Council to design a small steam engine, portable, that would be handy in areas out of touch with, out of contact with electrical power. Now, results of some tests on this small engine were shown in this article referred to. The interesting point was that, as cutoffs were reduced below 40 percent, efficiency of the engine steadily deteriorated. This is due to many factors which are not yet properly understood.

Doble discusses expansion ratios referring to engines other than uniflow types in an interesting series of articles dealing with engine and steam generator design, beginning with the July 1937 issue of Engineering and Boiler House Review. Marks and others supply data on more modern large uniflow engines.

In my opinion, not enough research has been carried out on topics such as the "Missing quantity" in steam engines and the effect of throttling as against using earlier cutoff when full power is not required. However, it is known that the performances of well-designed uniflow engines is close to that "theoretically" expected, even when using rather early cutoffs.

(*b*) *Single-acting versus double-acting*

Perhaps because there exist so many single-acting four-stroke internal combustion engines, the designer who turns his attention to steam, often considers single-acting operation. There are a number of traps waiting for the designer with this type of engine.

The single-acting conventional petrol engine design lends itself to piston cooling by means of oil or oil spray on the underside of the piston. Cooling of a steam engine piston, however, can result in a serious loss of efficiency.

Some early history of single-acting versus double-acting is printed in "A Manual of the High Speed Steam Engine," by H. K. Pratt, 1914, London. Pratt says the single-acting principle was used earlier for high-speed dynamo engines for the reason of silence in the bearings, even when worn. Bearing pressures acted in one direction only. There would be no knocking even with a worn engine. With forced lubrication newly introduced, * * * "The double-acting engine gradually worked its way to the fore * * *." Pratt lists higher allowable speeds for double-acting engines rather than single acting. This is due to the cushioning action of steam on the piston toward each end of its stroke.

With double acting, two cylinders will do the work of four. With a 90° V twin layout, room is left under the hood for the steam generator and auxiliaries resulting in an acceptably compact layout.

SOME POINTS ON STEAM GENERATOR CONTROL

Yesterday some comments were made that the steam generator is dangerous. I disagree. In my country, in Australia, we had our steam generator design inspected by the Government authorities, and we have a written statement that no inspection is required for the steam generator. The police are satisfied with an ordinary driver's license. A person doesn't have to be a qualified mechanical engineer to drive the steamcar. As far as the comment that the boiler is still a hazard, is liable to blow up, I would say that that hazard is negligible. I have had personal experience on this. About 15 years ago in our first experiment with the steam generator, we were using a mild, low-carbon steel for the steam generator tubing, and, with temperatures over 800° F., mild steel will scale away. With this early design, we had a faulty thermostat design, and we were getting over 800° F. The superheater blew out while we were driving the car. It seemed like a burst tire. However, the steam generator pressure gage had gone down very rapidly. But there is no danger, because the tubing is housed in an insulating case. The insulating case was not affected in any way. The insulating case is under the hood. Thus, there are several protecting walls between you and the tubing.

This steam generator held 4 gallons of water, and the newer design holds 6 pints. So the danger of a rupture of the steam generator coil is negligible.

I wasn't going to mention that point, but it was referred to again yesterday.

The once-through type of steam generator is used on most modern designs. Satisfactory control of pressure and temperature of the steam is essential but has been difficult to achieve.

Some designs obtain fair control at moderate loads on the road after the unit has warmed up but fall down under some other conditions.

These are some constructive points I want to mention, because a modern steam generator must pass these tests.

One searching test is to proceed from light load to full load suddenly and to then check for satisfactory temperature control and power output under these conditions.

Another requirement of a steamcar power unit is that it should come up to a reasonable power after running 1 or 2 miles from a cold start.

Reasonable steam generator control is required during this period. The disposition of the steam generator tubing can affect the starting up performance of the power unit.

I mention that, because some authorities on this type of steam generator say you have freedom regarding the layout of the steam generator tubing.

While on the subject of starting up, it should be stated that the time to move away from a cold start with a steam unit is normally longer than for its rival. A cold starting time of approximately 60 to 80 seconds is expected with our new unit.

Naturally, this starting time from cold can be reduced by special design; but it may be difficult to bring it below 30 seconds. Williams has done well to bring it down to 20 or 30 seconds. We had thought of using thinner tubing. We might do that later.

PRITCHARD TRUCK ENGINE

In the 1950's and the early 1960's, A. M. Pritchard—my father—and myself designed, built, and tested a steam engine designed for 5-ton truck operation. See the report reprinted from "Truck & Bus Transportation, August, 1963. Sydney. A copy of the report is attached.

It can be seen that the performance is competitive with that of a petrol-engined truck of similar size. Note the favorable comments on acceleration.

PRITCHARD CAR ENGINE

Although there was a moderate amount of interest in the early 1960's in our truck engine, increasing interest was being shown in steamcar engines. We did not manufacture any truck units further to the prototype; but, instead, began to work out a new steamcar power unit. This was to be a heavy-duty unit of light weight suitable also for commercial work in taxis, light farm tractors, for small marine units, and so forth. Forty-seven shareholders in Pritchard Steam Power Pty., Ltd., are backing this new project.

The new car engine is installed in a 1963 XL Ford Falcon. See appendix 2 for photos. I must apologize, some of the copies of these photographs are not good. If I may, I would like to show you this photograph which shows it a bit clearer.

Perhaps while we are looking at the photos, I will mention the units. In appendix 2(a), the two-cylinder engine is just being installed. It fits at the back of the hood space, up against the firewall. In the latter photograph, the steam generating unit has been installed. In the foreground of the lower photograph can be seen the radiator-condensor. Immediately behind the radiator header tank is an exhaust steam rotary motor. Underneath the exhaust motor is the steam generator. On the right hand rear of the photograph in appendix 2(b) can be seen a small 6-pint lubricating oil tank. This holds cylinder oil, which is put into the engine at the rate of 1 pint to 2,000 miles.

The engine is 2⅜-inch bore by 2-inch stroke and is a 90-degree "V" full Uniflow, double-acting engine with one crank only, the crankshaft is supported by two roller main bearings. The big end bearing is also a roller type, I might mention with double-acting engine design, there is a steam seal at the end of the cylinder through which the piston rod passes. There is a further oil seal where the piston rod passes through

into the crankcase. In double-acting you thus can have two seals to prevent contamination of water into the crankcase.

Originally the steam engine was designed to offer competition to earlier Holden 6-cylinder engines which developed approximately 100 pounds-feet of torque. The Holden, as mentioned earlier, is a car made in Australia. It has a good reputation. Maximum design torque of the steam engine is 160 pounds-feet in normal early cutoff—14 percent—with 240 maximum pounds-feet available in midcutoff—33 percent—and 350 pounds-feet available in late cutoff—80 percent. A valve timing lever alters the valve timing controlling the cutoff percentages. Nearly all of the driving is intended to be done using normal early cutoff.

You will note the torque is higher than the Holden engine, and would be equivalent to the torque of the Holden in second gear.

Reverse is obtained by altering the valve timing. The uniflow engine design can offer safe drivewheel braking by the use of reverse valve timing if, for example, the normal braking system should fail.

It has been mentioned earlier this braking will only apply normally to the rear wheels.

The steam generator casing is 15 inches in diameter and 15½-inch-high-plus flanges.

The feed pumps and condenser fan are driven by a unique system using an exhaust steam positive rotary motor. No vacuum pumps are used. An electric motor drives the burner fan, fuel pump, and mechanical make-and-break for burner ignition.

No extra boost is applied to the electric motor driven burner fan to obtain extra power. Some designers use an exhaust turbine to boost this burner fan.

An earlier comment has been made on difficulties in designing a radiator-condenser large enough for steam engine operation. Well, the size of the radiator-condenser depends largely on what design principles are used. If a fan is used behind the radiator-condenser, and it is driven at the required variable speed, the radiator-condenser can be reduced in size compared with what may be required using other methods.

TESTING

It is planned to obtain performance figures for the new steam unit in the conventional body and also with an advanced body using a fastback and other modifications. For comparison purposes, it is intended to obtain a similar set of figures for petrol operation in both body types.

Some exhaust gas analysis tests will be run.

In concluding, I would say that the rebirth of the steamcar would give new interest not only to the mechanical side, but also to the body section of automotive engineering. What is wanted now in an automobile is an efficient vehicle, preferably of medium size, which produces a minimum of smog and it looks like it will be a steam automobile.

Later, after we have carried out satisfactory road tests on our new car unit, we would like a representative from the United States of America to come out and have a good look at the performance of our unit in Australia.

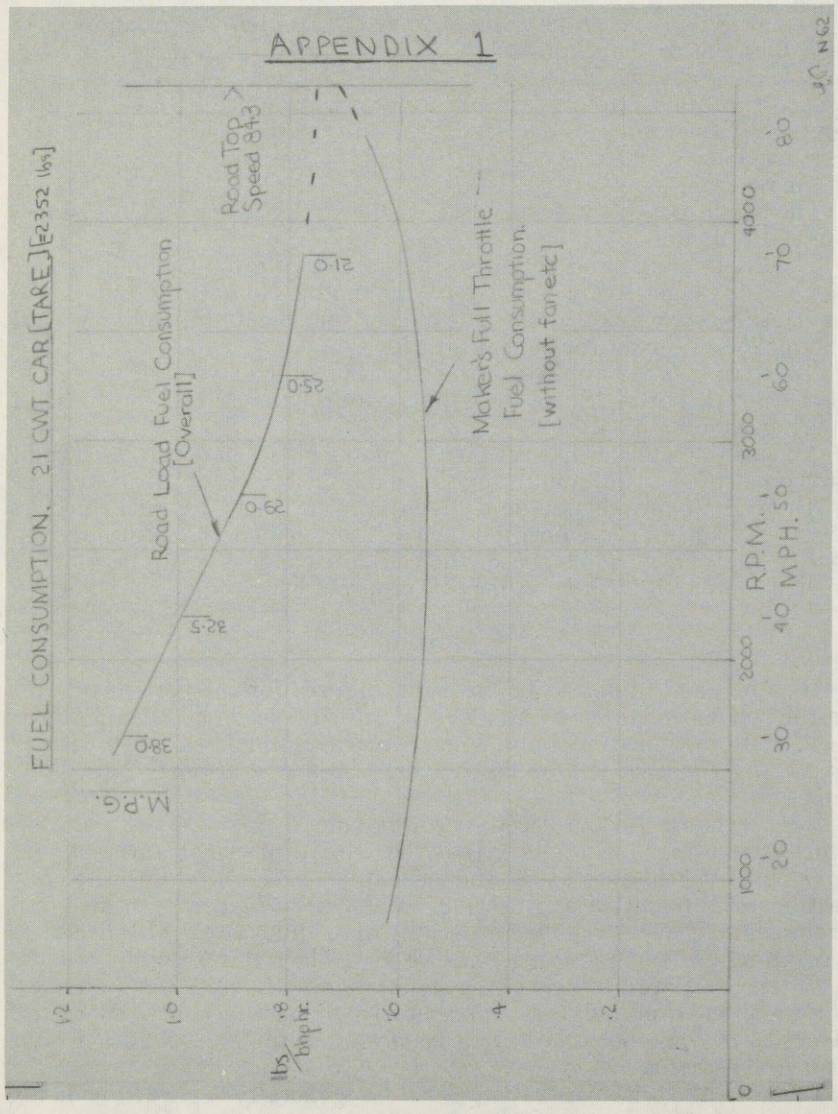
In Australia, the Australian Senate is generally regarded as being

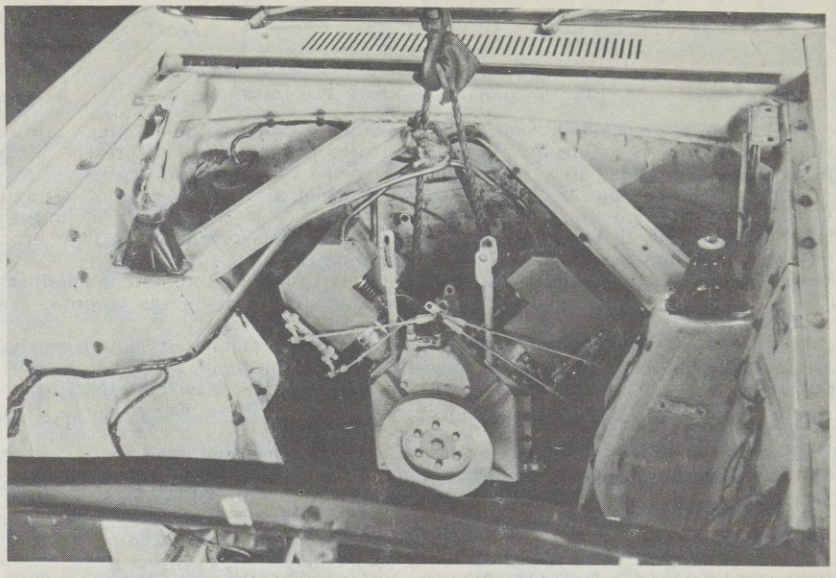
just a brake on the lower House. Australians could learn from the United States that Senate committees can be used as stimulating courts of inquiry.

Thank you. I would submit for your record the appendix exhibits to which I referred.

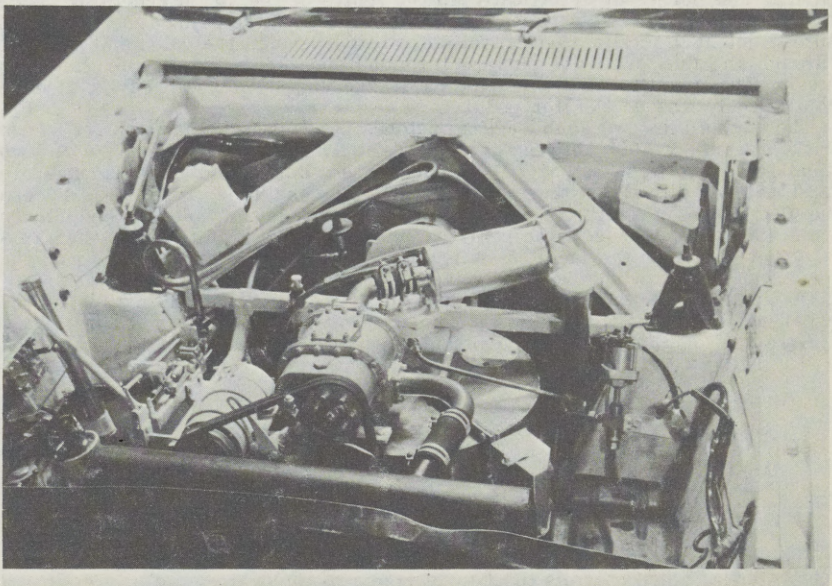
Senator BAKER. They will be printed as will the paper entitled "Independent Description and Test Report of Pritchard Prototype Steam-power Unit."

(The exhibits are as follows:)





Appendix 2a. Engine being installed.



Appendix 2b. Complete Assembly.

Independent Description and Test Report of Pritchard Prototype Steampower Unit

STEAMPOWER TESTS PROVE PROMISING

Will steam power make a come-back? A Caulfield (Vic.) firm is aiming to bring steam back into reckoning for automotive power purposes, and at present has a prototype engine fitted to a Lease-Lend Chevrolet 5-tonner.

Pritchard Steam Power Pty. Ltd., whose principals are Messrs. A. M. and E. Pritchard (father and son) are at the point of seeking financial backing to build a number of steam power conversion packs for trucks and buses. They even have plans for a steam power plant for cars and taxis.

The truck and bus model has been extensively tested, and numerous modifications have been incorporated, so that at the moment it is on the verge of the production stage.

Low operating cost, smooth and silent running, driving simplicity, and powerful acceleration are features of steam power. Although oldtimers such as the Sentinel had these attributes, their power packs were bulky. Large quantities of water had to be carried, and they were fed on solid fuels. Furthermore, they were relatively thermally inefficient.

The Stanley car power unit was relatively compact but sustained power output was low, efficiency was only moderate and starting time was lengthy. The Doble was reasonably compact and efficient but relatively complex.

Basically the Pritchard equipment consists of two units—a steam generator and a 2-cylinder engine. The generator occupies the space under the bonnet; the engine is located between the cab and the tray and is coupled direct to the drive shaft without clutch or gearbox. On the car design, both the steam generator and the engine are located under the bonnet.

Both the steam generator and the engine incorporate highly advanced design features.

NOT A BOILER

The steam generator is not a boiler. It uses a compact oil burner, developed from modern gas turbine practice, which sends hot gases through rows of steel tubing. The burner fires vertically up the centre of the steam generator inside a heat-resisting sheet steel firing tube. At the top of the firing tube, the gases spread out horizontally, then travel downwards through the coils, and pass out through the flue. Water is pumped through this tubing and is converted into steam. The quantity of steam passing to the engine is governed by a valve controlled by the accelerator pedal.

The engine uses two double-acting pistons operating in cylinders in "V" form with a setting of 90° between the cylinders. The engine is V-form, with two double-acting pistons set at 90° to each other. Roller and ball bearings are used, coupled directly to the propellor shaft. The engine is of the most modern "uniflow" type, in which the exhaust passes directly out of holes in the cylinder walls uncovered by the piston near the end of its stroke. With this system, unlike that of the conventional steam engine, the exhaust steam does not cool the passages through which hot inlet steam flows.

One pushrod-operated poppet valve is used to supply steam to each of the expansion chambers. Stainless steel poppet valves and piston rods are used.

Here are some of the more important statistics:

Estimated continuous h.p.: 90–100 h.p.
Estimated maximum torque: 1500 lb. ft.
Estimated maximum engine speed: 2000 r.p.m.
Engine bore: 4 in. Engine stroke: 4 in.
Cut-off positions: Forward 80%, 40%, 16%; reverse 80%.
Maximum engine working pressure: 700 p.s.i.g.
Dry engine weight: 300 lb.
Dry steam generator weight: 500 lb.
Cold starting time: Approx. 4 minutes.

The controls are relatively simple. There are two controls for the engine—a foot throttle, which controls the flow of steam to the engine, and a lever which controls "cut-off."

HOW CONTROLS WORK

"Cut-off" is that portion of the engine stroke during which high-pressure steam is admitted by the inlet valve. A cut-off of 80% is used to provide high

torque for starting. Immediately the vehicle moves off, the lever is moved to 40% cut-off. Over 12 m.p.h., the engine is run in early cut-off (16%), at which setting 750 lb/ft torques is available, and the engine is then controlled simply by the foot throttle. In late cut-off, 1500 lb/ft torque is available.

The cut-off control lever, which also actuates reverse, shifts the cams which operate the inlet poppet valves. The lever can be moved at any time and can, in fact, be shifted into reverse position for emergency braking. Thus rapid manoeuvring is possible. Cut-off is increased by shifting the lever if greater torque is needed for hill-climbing.

A dashboard switch is used to turn on the burner initially. Control then becomes automatic by means of a diaphragm operated micro-switch which controls the burner to maintain the steam supply at a working pressure of 700 p.s.i. or higher.

The burner fan and fuel oil pump are driven by a 24-volt electric motor. Fuel oil is pumped to a pressure-atomising jet that is lit by an electric spark, using heat-resisting steel electrodes with a ⅛" gap.

Starting time from cold is approximately four minutes. The steam generator itself develops full heat in 65 seconds, but the engine has to be warmed up and run gently for a few minutes in order to clear residual water from the exhaust before moving off.

The prototype uses a special mid-gear position in the two-speed rear axle to allow idling for warm-up.

An automatic temperature switch cuts out the burner in the event of the feed motor tank level or the water content of the steam generator being too low.

Exhaust steam is used to drive a positive-displacement rotary motor that drives the twin feed pumps.

Engine exhaust is piped to a radiator-type condensor in the same position as the normal vehicle radiator, and then back to the water tank. The condensor fan is driven by the exhaust motor at a speed in rough proportion to steam consumption. This is an important feature in hill-climbing, especially on a vehicle which does not change gears and where an engine-driven fan would slow-down with the engine itself.

LUBRICATION

The instrument panel carries the following items:

Master switch to actuate the burner.
Burner oil pressure gauge.
Steam temperature gauge.
Steam pressure gauge.
Ammeter.
Speedometer.
Cylinder oil pressure gauge.

The latter is important. The method of lubricating the pistons is by means of a slow-speed mechanical pump which forces small quantities of oil (approximately 1 drop per 80 revolutions) into the steam to act as an upper-cylinder lubricant. Approximately one pint per 500 miles is used in this fashion. The roller bearings on the main shaft are splash-fed from a 4-pint sump, and this oil should (especially with the prototype) contain a rust inhibitor. For instance, turbine oil may be used.

Design changes have been made to minimise the amount of condensate entering the sump. A piston rod sump seal is now specified and is preferred to the system used on the prototype. The latter uses a sealing ring on the crosshead.

Sump oil is changed "occasionally," according to the designers. No specific figure has been set, because being a splash feed, the condition of the oil is not very important.

Driving Impressions

(By Road Test Editor)

The Pritchard steam conversion is started by means of the master switch. Almost immediately a dull whirring sound occurs as the pressure-fed burner begins its work and sends its exhaust out the flue, running up the side of the cab.

Although the recommended warm-up period is 4 minutes. Mr. Ted Pritchard said that the vehicle can be got mobile in two minutes.

Once the necessary temperature and pressures have been obtained, the rear axle is engaged in either high or low ratio, and the cut-off lever moved to reverse or forward, according to the direction required.

As is to be expected, take-up is very smooth. In 40% cut-off there's real "punch" in the get-away, somewhat reminiscent of aircraft power. The cut-off lever is moved in quick stages to 40% and then 16% for normal running.

The silence factor was not what I thought it would be. In addition to the dull roar of the burner exhaust cutting in and out spasmodically as boiler temperature required it, there was a decided knock in the engine at around 25 m.p.h. This, I was informed, was tappet noise.

The designers state that tappet clearances increase by approximately .015" as the prototype engine warms up. Design alterations to reduce this noise include provision of a quieting ramp, enclosing of tappet gap in sump for silencing both by enclosure and by the effect of lubrication while maintaining the adjustment location external to the sump.

QUICK OFF MARK

Road performance was really nippy. With a tare of 3 tons 6 cwt., plus a 4 cwt. block over the rear axle, plus Mr. Pritchard and myself, acceleration was timed with a stopwatch. The vehicle reached 20 m.p.h. from stand-still in 4.2 secs. There was a comparative lag of almost 5 secs. in covering the next 10 m.p.h. to 30, making the 0–30 figure 9 seconds.

(Last month's road test of a laden Holden utility showed 3.3 secs. for 0–20, and 6.6 secs. for 0–30 m.p.h. This comparison will give readers some idea of the beefed-up performance of the old Chev. with steam power!)

Rolling along in mid cut-off (40%) at 10 m.p.h., it took only 3 seconds to reach 20 m.p.h., and 6.6 seconds to reach 30 m.p.h. There was so much power available in 40% cut-off that timed acceleration tests on moderate (1 in 25) gradients were little different from those on the level!

Although it takes four minutes to warm the engine from cold, re-starting is only a matter of seconds, with steam pressure in the tubes. Pressure will not drop to zero for three hours. With everything switched off, the vehicle can be run for more than half a mile before the steam gives out.

SOME QUERIES

Answering questions I put to him, Mr. Ted Pritchard gave the following replies:

Battery drain: 30 amps for the burner for 2¼ minutes, and 30 amps each time the burner operates whilst driving, which is approximately one-third of the time. A 24-volt, 50-amp generator is belt-driven by the engine. Whilst the vehicle is stationary, there is no battery input because the engine does not idle; neither is there any draw, because the burner is not required until steam pressure begins to drop when used for take-off.

Corrosion: Deposits in tubes not expected to be a serious problem. At approximately 50,000 miles, recommendation is for a blow-through with air or oxygen whilst the steam generator is hot. This would take 10 minutes, plus an hour for disconnecting and reconnecting. If deposits began to build up, steam would take longer to raise. But with superheated steam racing through the tubes at around 100 m.p.h., it would be difficult for any build-up to take place.

Stalling: Used in a 5-ton truck, the Pritchard steam power unit would climb a 1-in-4 grade fully laden. For a vehicle grossing 10 tons, Pritchard's recommend a step-down gear. They claim that a vehicle of 18 tons gross, equipped with one or two extra rations, would maintain a high useful wheel horsepower and even speed up all hills on interstate work.

NO SPECIAL TICKET

Special Licence: As the steam generator is not a boiler, the Victorian Mines Department does not require the driver to have a steam 'ticket' not does it stipulate any boiler inspection. There is, of course, a stainless steel safety valve inserted in the system to take care of any possible pressure build-up beyond the normal upper-working pressure. The steam generator components have been water-tested to 4000 p.s.i.

Fuel Consumption: Equivalent to a petrol-powered truck. With an all-up figure of 7 tons 2 cwt., and stopping every half-mile, the steam engine's consumption of fuel oil was 6.13 m.p.g. Running light, it was 9.55 m.p.g.

BUT—fuels which can be used range from kerosene to 75% sump waste and 25% kerosene. Pritchard's hope to further improve the consumption figure by fitting a light flywheel, thus allowing early cut-off to be engaged much sooner (around 7 to 8 m.p.h.) with reduced fuel demand. Futhermore, they anticipate being able to increase the sump-oil percentage to a figure around 100% with the use of a pre-heating coil and careful attention to filtration, thus getting basic fuel cost down around 6d per gallon.

Price: Approximately £1600 (plus tax if applicable) for complete power plant, including ramps, tanks, instruments, etc., replacing vehicle engine, clutch, gearbox, etc. (Further information is obtainable from Pritchard Steam Power Pty. Ltd., 339 Balaclave Road, Caulfield, Vic.)

Senator BAKER. Mr. Pritchard, we thank you very much. And I especially thank you for the implied comment on the status and relationship of the Senate to its peer group.

Let me start first by asking if there is a serious air pollution problem from automotive sources in Australia.

Mr. PRITCHARD. There is beginning to be an interest in this topic, and already we hear reports that, for example, carbon monoxide levels are becoming too high at some city street intersections. But compared to your problem it is only minor as yet in Australia.

Senator BAKER. Are there any national or local emission level controls in existence now, or as far as you know are any contemplated by local or national government authorities?

Mr. PRITCHARD. At the government level I don't think they are contemplated yet. But there is already a clean air committee, and I think the members are all honorary.

Senator BAKER. Would I be fair to infer from your interest in steam engines that your idea would be to try to promote and market steam automobiles and steam trucks and win acceptance for them solely on their superior performance characteristics rather than on their superiority from the pollution standpoint?

Mr. PRITCHARD. That is correct. We believe the modern steam engine can be competitive with the petrol engine regardless of pollution. And I might mention that, on a list of advantages for the steam engine prepared, I think, 4 years ago, lower poisonous emission was then about tenth on the list. But we have since pushed it up higher.

Senator BAKER. I notice the name of your company is Pritchard Steam Power Proprietary Ltd. Is the development of steam propulsion units for trucks and automobiles the sole and only business of this concern?

Mr. PRITCHARD. Yes.

Senator BAKER. Is this your full-time occupation and endeavor, the building of steam propulsion?

Mr. PRITCHARD. Yes.

Senator BAKER. Do you have a market for steam engines, or is the company devoting its entire efforts to development?

Mr. PRITCHARD. I should say we are mainly a development company. We are too small to handle production, but there will be eventual production by someone using our designs.

Senator BAKER. Is it your present plan then either to enter production yourselves or to try to encourage another company to enter production of a steam-propelled vehicle in Australia?

Mr. PRITCHARD. Well, we plan to complete the road testing, do some demonstrating, and see what interest is generated. We can't tell yet which way this will go.

Senator BAKER. Do you have any indication at all of public interest or public acceptance of this concept?

Mr. PRITCHARD. There is a great interest in this. Of course, engineers are particularly interested. There is an interest in applications not only for cars, but also in locomotives and other units. There are a tremendous number of applications for the steam engine.

Senator BAKER. Is there a corresponding interest in the development of an electric automobile in Australia?

Mr. PRITCHARD. I would say the interest is not high in electric automobiles.

Senator BAKER. Have any automobile producers in Australia yet expressed an interest in your developments, in the steam engine in general?

Mr. PRITCHARD. There is a design consultant from a major manufacturer who has contacted us. But from the leading car companies no interest at all. From the leading parts manufacturers in Australia a little interest.

Senator BAKER. Mr. Pritchard, you spoke in your statement of the availability of reverse torque for braking in terms of a standby braking system. Would you visualize that the production automobile with the steam propulsion unit would have a primary braking system similar to the presently used system and use reverse torque as an emergency or standby system?

Mr. PRITCHARD. Yes. I referred to the engine braking as used for mainly emergency purposes. I think until we come to perhaps four-wheel drive, to make use of the engine braking in the front as well as the back, I don't feel it would be much use for a passenger car. It could be for trucks, but I think not for passenger car use.

Senator BAKER. Of course the reverse torque converter is used in some truck applications now, as I understand it, internal combustion truck applications, for retarding downhill drive for instance.

Mr. PRITCHARD. Yes. Well, for braking at low rates of retardation, just the drive wheels could be used. But the braking required for an ordinary passenger automobile is often much higher than the rear wheels can cope with.

Senator BAKER. Now in the Ford Falcon conversion that you manufacture, I take it then you used the existing four-wheel hydraulic brake system as your primary braking system?

Mr. PRITCHARD. Yes.

Senator BAKER. Can you give us some estimate of how that braking system has performed with steam propulsion, compared to the reasonable brake performance and life expectancy in an internal combustion engine?

Mr. PRITCHARD. I can't tell you because we haven't begun the road testing. This unit has just completed shop testing and is due to go on the road. This is due now. But outside of the reduced drag, slightly more would be put on to the braking system, unless some extra provision was made to use engine braking.

Senator BAKER. What is the noise level of your engine in this Falcon? Can you give a description of the engine noise level?

Mr. PRICHARD. The engine noise is very low, and from our experience with the truck units, we have taken special steps to keep the noise of auxiliaries down for the new design.

I might mention that the silencing of engine exhaust is 100-percent effective in a condensing engine. There is no engine exhaust noise. This means that anything else will show up, and particularly noise has to be cut in the burner fan, in the burner exhaust tube due to resonance and due to the condensor fan operation.

The loudest noise from our truck prototype unit was from the condensor fan.

Senator BAKER. As I recall from your statement the water pump system on your motor is a turbine or continuous impellor-type pump instead of a reciprocating pump.

Mr. PRITCHARD. No. We use plunger pumps, but they are driven from a rotary exhaust motor.

Senator BAKER. Do you get much noise from the water pump?

Mr. PRITCHARD. On the new design; no. In the truck you might see a reference to some, which we thought might have been from the pumps, resonance or something, but the plunger pumps are quiet and the rotary motor is quiet.

Senator BAKER. What provision, if any, do you make for antifreezing of the system?

Mr. PRITCHARD. That question doesn't worry us so much in Australia. But I realize it is quite a big problem here. We only get to 32° Fahrenheit, usually on the grass, with a bit of a frost, and up comes the temperature again. I doubt if we ever get less than perhaps 50° during the day, even in the middle of winter. So it is not one of our problems in Australia. But we thought a little bit about methods of overcoming it. And in the water tank insulation, the Stanley people had sloping sides on the water tank. I believe this is used in some swimming pools today. The top slopes and a sheet of ice would climb up the side, rather than pushing the walls out.

Senator BAKER. In fact, you intend to just let it freeze?

Mr. PRITCHARD. Let it freeze in the water tank. This is one solution. And with our compact unit all under the hood, it is possible to use a small heater to keep the unit from freezing. There are quite a number of ways this could be overcome.

Senator BAKER. What do you do about accessory power loads, such as heating, air conditioning, windshield wipers and the like?

Mr. PRITCHARD. Well, this particular model Ford Falcon had vacuum wipers. The problem was satisfactorily solved by using electric wipers. They represent a very small load on the battery.

The heater problem is an easy problem to solve—not the air conditioning, but the heater problem. We intend to recouple the existing heater unit to the exhaust steam line so that exhaust steam can circulate. And this will mean the moment the engine is turning you will have powerful heater operation rather than having to wait a while—as in the case of some gasoline engine designs—for the water to warm up. You will have almost instant heating.

Regarding air conditioning, we haven't thought about it yet. I doubt there are more than two cars in Australia fitted with air conditioning at the moment. But we haven't thought much about this.

When the car stops, for perhaps a few minutes, I heard somebody say maybe you wouldn't roast or freeze in that short period. Does that answer the question?

Senator BAKER. I think it does, except from personal experience I challenge the idea that you may not roast or freeze. I have been stopped in Washington traffic and elsewhere a lot longer than a few minutes. I wonder if you have thought in terms of any sort of idling power that would be available for the auxiliary load?

Mr. PRITCHARD. Well, our particular engine is fitted with what I heard somebody call, I am not sure, but a free position. Our engine is able to idle if you require it. This is used in our applications for initial warming up for a few seconds and then the unit is then put out of action. But our units could be idled.

There are other ways, too. The stored power in the system generator system can be used in a steam ejector to make a vacuum for refrigeration equipment. So it is quite possible the storage steam in the system engine would be adequate to provide effective cooling.

Senator BAKER. Especially in Australia, where the pollution isn't yet significant, comparative costs of steam to internal combustion is significant. I wonder if you would care to give us your judgment of the comparative cost of production of a steam versus internal combustion engine, assuming both are produced in comparable mass production circumstances.

Mr. PRITCHARD. Well, it is my estimate that a well-designed system unit would cost more than a manual transmission internal combustion unit, but I think it would cost less than an automatic transmission internal combustion engine car.

I understand, according to Mr. Issigonis, that an automatic transmission costs the manufacturer as much as the engine. This might refer to English conditions, but I believe the automatic transmission costs as much as the engine, and a manual transmission apparently costs about 40 percent of the cost of an engine. I think the cost of the steam power unit would fall somewhere in between those two; that is, an engine plus manual generator and an engine plus automatic gearbox.

Senator BAKER. Would you care to give us an estimate or your judgment on the comparative operating costs of the steam versus the internal combustion engine of comparable size, under comparable circumstances?

Mr. PRITCHARD. Well, I believe that if the automotive body and the steam engine are designed for each other, making optimum use of the characteristics of the steam engine, then fuel miles per gallon will be competitive with the internal combustion engine.

Looking at the maintenance points of view, I will mention that our engine is intended for commercial work and is designed for 10,000 hours or 250,000 miles and we would be disappointed if the maintenance costs were as high as a petrol engine, or internal combustion engine.

Senator BAKER. Mr. Pritchard, this is the last question. Is there another firm or are their other individuals actively engaged in the development of steam propulsion units for automotive or truck applications in Australia that you know of?

Mr. PRITCHARD. Did you say other individuals as well as companies?

Senator BAKER. Yes, actively engaged in the developments of steam propulsion units for automotive and truck applications, or truck applications.

Mr. PRITCHARD. Yes, but they are running on very restricted budgets. We have a very strong steampower club. However, they have grave financial problems.

Senator BAKER. All right, sir. Mr. Pritchard, thank you very much.

I will now call on Mr. Gibbs, president of the Gibbs Machine Co., who is accompanied by Mr. Hosick of the Bowman Gray School of Medicine.

These gentlemen are appearing on behalf of the Gibbs-Hosick Trust.

You may proceed, sir.

STATEMENT OF R. A. GIBBS, PRESIDENT, GIBBS MACHINE CO.; ACCOMPANIED BY THOMAS HOSICK, RESEARCH CHEMIST, BOWMAN GRAY SCHOOL OF MEDICINE, ON BEHALF OF THE GIBBS-HOSICK TRUST

Mr. GIBBS. This memorandum indicates our unqualified support of any action you may take to encourage the development of steam- or vapor-powered automobiles as the only alternate form of power superior to the gasoline engine in regard to performance, cost, and freedom from significant air pollution.

In view of the fact that the automobile is responsible for as much as 85 percent of the air pollution in some areas, it is imperative that the problem of this particular pollutant source be attenuated with as much hase as can be mustered. Because of the insidious nature of the toxic buildup in many areas, it is difficult to assess how precious our time is before major disaster.

The closed-cycle steam engine has no emission into the atmosphere; the only emission comes from the external combustion of fuel within the steam generator. The properly designed steam generator has a combustion chamber of sufficient volume and dwell time for the reaction of combustion to complete itself before the gases come in contact with any cooled surfaces, thus insuring emission only of relatively inocuous carbon dioxide and water vapor. The internal combustion—IC—engine, however, attempts combustion at very high pressures within a few microseconds, and in close proximity of cooled cylinder walls. Cooling the reacting gases causes quenching of the combustion before completion, causing the release of unburned and partially oxidized hydrocarbons with insidious toxic properties, highly poisonous carbon monoxide, and the high combustion pressures cause release of various oxides of nitrogen, which are required for the photochemical process that produces smog.

The results of tests performed by Mobil Oil, sponsored by the Ford Motor Co., on a 6-year-old steam car built by the Williams Engine Co. gave impressive results, even though the system had not been optimized for low smog production. In comparison to a conventional Ford, hydrocarbon emission was cut to 4 percent, and nitrogen oxides were reduced an identical amount. Carbon monoxide was cut to 1½ percent of the IC emission. In contrast, a smog control device on the IC car cut emission of unburned hydrocarbon only to 25 percent of the former value. Furthermore, the IC reduction does not hold up as the car ages. Recent research indicates that, although much better reductions may be possible with the gasoline engine, it will be very costly, performance

will be impaired, and results probably could not approach what might be done with an optimized steam car.

The developer of a modern steam automotive power system starts with the realization that the passage of half a century since the demise of the original steam cars, and the unceasing evolution of the conventional Detroit product, almost totally obscure two important facts: First, from the standpoint of torque characteristics, overload capability, and power per cubic inch of displacement, steam greatly outperforms the IC engine. Second, and even less known, the power control, the steam generator—boiler—the condenser, and the engine components of the steam system have undergone a vast transformation since our grandfather's day. The result, today, is that any of several promising development efforts, including our own, could provide within a year or two, passenger car and truck power systems which would meet every test of consumer acceptance, while giving superior performance, economy, ease of operation, and virtually eliminating smog and noise as environmental hazards.

The attached table comprises a list of the more essential characteristics which must be considered in evaluating a power system for land vehicles. In the table an ideal power system is compared with (1) modern steam, (2) conventional gasoline IC power systems, (3) conventional diesel IC power systems, (4) gas turbines, (5) electric power, and (6) the Stirling external-combustion, hot gas engine. The tabulation is largely, but not entirely, self-explanatory. Characteristic No. 4, for instance, indicates the trend of efficiency and economy under widely varying load conditions. For example, when a vehicle is stopped or just beginning to move away under load, fuel consumption should be none or minimal. Steampower is the only system which equals the ideal in this regard. As to the other characteristics desirable in the ideal vehicular power system, steam can be seen to score much higher than any other power source under consideration, including the gas turbine.

Foregoing an extended engineering rationale at ths time, let us note some of the advantages of steampower, other than low smog emission, that will be of interest to the American consumer. As for performance—starting, acceleration, top speed, and manueverability—existing prototypes, and even antique steamers in some instances, can clearly demonstrate that steam will meet or exceed the requirements of commuter, trucker, or hotrodder.

Steampower does not require a transmission, a fact possibly of only incidental value to the ordinary motorist—until he has to pay for fixing one—but much more significant to the trucking industry, and its drivers. In truck use, steam would completely eliminate the need for a 10-speed or more transmission or gear box, with resultant savings in maintenance and substantial reduction of driver's fatigue. Steam also can provide a dynamic braking capability of enormous safety and operating advantage in mountainous terrain.

The modern steam engine, in contrast to the old, also scores high on economy grounds. The Williams and Thermo Electron engines are reported to give diesel efficiencies, which means that 30 to 40 miles per gallon of fuel would be expected from full-sized American cars. A steam engine displays maximum torque at the rear wheels at zero and low engine speeds, not only eliminating the need of clutch, change-

speed transmission, and engine idling, but also requiring minimal fuel consumption for stop-and-go driving. All of the possible fuels likely to be used, such as diesel oil, are cheaper than high-test gasoline and should give a higher profit margin to the oil refineries.

The basic simplicity and operating response characteristics of the modern steam vehicle provide very substantial safety advantages both at rest and at speed; for example, a steamcar cannot stall on a hill or in an emergency situation; fire danger is greatly reduced in case of accident because the fuel is far less flammable than gasoline; there is no danger of a steam explosion under any circumstances.

In our opinion, any modern steamcar put into production should not require a major overhaul more frequently than once in 200,000 miles, and the motorist can anticipate better tire mileage as well. In general, the entire steampower system is far less complicated both to manufacture and to maintain than the present day IC powerplant.

The committee members certainly will hear the view that steampower cannot cope with freezing temperatures—they used to use steam locomotives in Alaska. Those of us currently in steam development believe this admitted significant difficulty can be met in several ways: by utilizing special antifreeze additives; by modern adaptation of the standby principle; by utilizing the inherent latest heat of fusion of ice; or by substituting a different fluid for steam—water—as the working medium of the system. Space does not permit elaboration, but we are confident that one or more of these alternatives are viable for mass production.

A number of promising research and development projects in automotive steampower are worthy of support toward being brought to a practical and commercial conclusion. These developments include the Williams Engine Co., Thermo Electron Engineering Corp., Empirical Engineering Co.—Richard Smith—possibly the Keen Manufacturing Co., and others, including our own Gibbs-Hosick Trust and the newly patented Elliptocline steam engine. However, the committee members should be cautioned against considering automotive steampower promotional schemes which are mere rehashes of obsolete systems with no present-day merit. Such people, on the other hand, should be given the opportunity to defend themselves against qualified people in the field, just in case something of merit has been

Although the other steam developments have strong points of merit, we would like to point out certain advantages of our Elliptocline rotary-reciprocating, uniflow steam engine which combines the inherent balance of the rotary engine with the ease of sealing of the reciprocating engine. Although a few of the features are still design goals and do not yet exist in an operating model due to our limited research funds, we are confident that with the proper aid, we can achieve our goals with ease. The Elliptocline features include: (1) basic simplicity, (2) low cost per cylinder permitting use of multitude cylinders, (3) ease of mass production, (4) only one valve to control and time all steam admission and auxiliary exhaust events, giving infinitely variable steam admission cut-off control between the limits of 3 and 80 percent, both in the forward and reverse directions, (5) inherently balanced reciprocating motions for vibration-free operation—one of our engines has turned several thousand revolutions per

minute, while a nickel coin was balanced on edge upon the engine—(6) even torque, (7) is self-starting at short cutoff's for high thermal efficiency under all modes of operation, (8) permits extremely small cylinder clearance volumes for high ratios of steam expansion and resulting high thermal efficiency, (9) will eliminate hydrocarbon oil lubricants by use of self-lubricating and steam lubricated bearing surfaces, thus permitting high steam superheats for high thermal efficiency, and (10) can be modified thermodynamically within the engine for improved thermal efficiency. Although the Elliptocline is a modification of an old engine configuration, any engineer who categorizes the engine as an inefficient, high-friction unit does not understand or appreciate the significance of our design objectives. Although some confusion has been displayed in this regard, the Elliptocline steam engine is not a wobble plate engine and does not have the imbalance that such engines may exhibit.

The committee members should further be cautioned against unwarranted criticism of an irrelevant nature of all automotive steampower developments by those who have an ax to grind, so to speak, or by those who are swayed by mistaken images out of the past. We have witnessed from time to time the irrelevant arguments against steam from the 1910 or 1920 era, from individuals who are very influencial and capable of doing our cause much harm. Furthermore, the interest of management has been squelched by their own research personnel, due to the latter's fear that such outside ideas represent a definite threat to their livelyhood. Gentlemen, the time is near that we can no longer afford the folly of such erroneous evaluation of the only automotive propulsion system, which right now, without any major technological breakthrough, can more than supersede our present basically poor, but wonderfully adapted, IC system without threatening the poisoning of our atmosphere. We ask only that we be permitted to refute any and all basic arguments against the practicality of automotive steampower at this time. In this regard, we are attaching a strong antisteam editorial that appeared in the April 15 issue of the automobile industrial trade journal, Automotive Industries, along with our strong rebuttal to the editor's viewpoints.

In conclusion, we can have in a very short time a completely practical steamcar, virtually free of pollutant emission, and very desirable from a consumer standpoint. All that is needed is the proper support of the development projects that can give us the car. Gentlemen, it is the time for action.

Senator BAKER. Thank you, Mr. Gibbs. The attachments to your statement will be placed in the record at this point.

(The exhibits are as follows:)

COMPARISON OF CHARACTERISTICS OF INTERNAL COMBUSTION ENGINES AND LOW-SMOG ALTERNATE SYSTEMS TO ONE ANOTHER AND TO THOSE DESIRED IN IDEAL AUTOMOTIVE POWER SYSTEM (BY T. A. HOSICK)

	Ideal power system	Modern steam engine	Gasoline engine	Diesel engine	Gas turbine	Battery electric	Stirling hot-air engine
1. Smog emission	None	Very low	Very high	High	Some upon startup	Very low	Very low.
2. Noise level	No noise	do	Quite high	do	Quite high	do	Do.
3. Is torque highest at zero engine speed (very important for simplicity).	Yes	Yes	No	No	Yes	Yes	No.
4. Fuel consumption at maximum torque on rear wheels at zero rear axle r.p.m.	None	None	High to highest	High	Highest	Probably highest	Very little.
5. Is torque smooth for high tire mileage	Yes	Yes	No	No	Yes	Yes	Yes.
6. Is reverse torque capability inherent for simple dynamic braking?	Yes	Yes	No	No	No	Yes	Yes.
7. Is idling required?	No	No	Yes	Yes	Yes	No	No.
8. Is transmission required?	No	No	Yes	Yes	Generally	No	Maybe.
9. Can system produce overloads of power for high-speed acceleration bursts?	Yes	Yes	No	No	Possibly	Yes	(?).
10. Power-to-weight ratio	Excellent	Good	Good	Poor	Very good	Poor	Very poor.
11. Fuel generally used	(?)	Fuel oil	Gasoline	Fuel oil	Kerosene	Electricity	Fuel oil.
12. Fuel economy	Excellent	Good to very good	Good	Very good	Fair to good	Should be very good	Very good.
13. Relative 1st cost	Low	Low	Quite low	High	Very high	Very high	High.
14. Is winter freezeup a problem?	No	Yes	Yes	Yes	No	Should be no	No.
15. Maintenance requirements	Low	Should be low	Appreciable	Quite low	Low	High	Probably low.
16. Throttle response	Excellent	Very good	Very good	Very good	Poor	Excellent	Poor.
17. Is technology breakthrough needed to make practical?	No (?)	No	No	No	Yes	Yes	(?).
Score: fuel type not considered	+16	+15	+5	+4	+6	+11	+9.

[From Automotive Industries, Apr. 15, 1968]

NONSENSE HITS A NEW PEAK

The latest blast against the automotive industry dished up by the small clique of anti autoism experts is the accusation that the industry is at fault in having failed to manufacture a new steam powered car. This is a real dandy. It achieves a new peak for organized nonsense. It is to be hoped that such influential senators as Kennedy, Magnuson, Ribicoff, et al, do not get taken in by this gambit of publicity seeking.

Reliable engineering analysts have studied this problem for engines of 150 hp and above, and have concluded that with a most modern design boiler and steam engine combo, a working pressure of 3000 pounds per square inch could be maintained, using a small amount of superheating. At this pressure an operating temperature of 700 degrees F would be required. The thermal efficiency would be somewhere around 30%. At the present state of the arts of engineering it is possible to design and manufacture such a large steam power plant. However, whether or not it would be a safe design for passenger cars or trucks is another problem.

When legislators, lawyers, prosecuting attorneys, lobbyists and others who lack modern engineering training attempt to legislate engineering matters, they are moving into an area which is loaded with possibly much more hazard, risk and danger for the public than they realize. Even granting that the hypothetical steam engine could be manufactured, how would Senators Kennedy, Ribicoff and Magnuson, et al, like to be driving down the street behind a steam engine which operates at 3000 psi and 700 degrees F total temperature, and have the engine leak or the boiler leak this superheated steam which could cause such complete physical damage to a human body that even instant death would be more likely than effective first aid? The high pressure, furthermore, could result in steam explosions with a tremendous potential for great damage to the car, car occupants or nearby pedestrians. Verification of these facts can be obtained from any chief engineer in any local power plant operating at even 700 psi. The superheated steam power plant would only increase danger rather than decreasing it.

HARTLEY W. BARCLAY,
Editor and Publisher.

GIBBS-HOSICK TRUST STEAM MOTOR SYSTEMS,
Winston-Salem, N.C., May 17, 1968.

HARTLEY W. BARCLAY,
Editor and Publisher, Automotive Industries,
Philadelphia, Pa.

DEAR MR. BARCLAY: Your editorial, "Nonsense Hits New Peak," in the April 15 issue of Automotive Industries has been brought to my attention by a Chrysler engineer. This surprising piece of diatribe so astounds me that I could not possibly write what one could call a "nice letter" in regard thereto and say what needs to be said. Your title for the article certainly is applicable to its editorial content.

Somehow I was under the impression that Automotive Industries was a professional trade journal. However, if this example of editorial balderdash is indicative of your objective and truthful reporting, my respect for your magazine's content must be subject to drastic revision. Such non-factual emotionalism has no place in a professional journal.

Why did not you trouble yourself to learn the facts about the nature of modern automotive steam power plants before blundering into an anti-steam diatribe that may have had some relevance to the 1910 mentality, but certainly has no place in 1968? If you are going to produce a magazine concerning automobiles, please learn your subject.

For example, in your editorial you mention operating parameters for the design of an efficient steam automobile power plant. It is absurd to suggest that a practical, efficient automotive steam engine, presumably operating within the Rankine cycle, could be made to operate on low quality steam of 3000 psia. pressure and a mere 5°F of superheat (700°F total temperature). Such steam contains very little more energy than hot water at the boiling temperature under the same pressure. It has only 10.3 B.T.U. more heat energy per pound than saturated steam at atmospheric pressure and 212°F temperature. For comparison, 1200°F steam at 1000 psia. pressure contains 466.9 B.T.U./lb. more than the 212°F steam at atmospheric pressure. If a steam engine were to use the 3000

psia., 700°F steam at late cut-off (no utilization of expansive energy), about 30% of its power would be wasted just to pump its own feedwater, compared to 2 to 5 per cent requirements for truly efficient steam systems. If we consider the full use of the steam's expansive energy by its isentropic expansion to 14.7 psia., the Rankine cycle does give us a theoretical efficiency of a little over 30 per cent. However, such an expansion will cause a 39 per cent condensation of water within the cylinder, causing such drastic losses that only minimal thermal efficiency would be expected, far too low for practical automotive power.

To paraphrase your quality of reasoning, how would Senators Magnuson, Kennedy, and Ribicoff, et al, like to be driving down the street behind an I.C. explosion engine (conventional gasoline engine) which operates on a highly poisonous mixture of obnoxious, toxic gases under 500 psi. of pressure and 4000°F of searing temperature, while burning a highly volatile and flammable mixture of lead-containing hydrocarbons (gasoline), stored in a tank in twenty gallon quantities having the explosive potential of 600 pounds of pure nitroglycerine, enough to blow up an entire city block? Neither man nor animal would be safe within a quarter-mile of such a machine.

In regard to the nonsense in the preceding paragraph and your "crying wolf" about the modern steam car's explosive potential, the *facts* are that it just doesn't happen that way. The gasoline car is the more dangerous of the two, but not nearly so hazardous as it could be made out to be. You mention that verification of these facts about the hazards of high-pressure, superheated steam can be obtained from any chief engineer in any local power plant. Such "verification," if obtained, would be completely irrelevant to the problem under consideration; the steam power plant engineer is concerned with a system capable of instant release of prodigious quantities of dangerous steam. The steam car power plant is incapable of release of steam in a dangerous manner, except in the most unusual of circumstances. Similarly, the conventional gasoline car can release steam in a dangerous manner under unusual circumstances, but it is not a problem for the careful individual.

In the early White steam cars (circa 1900), the operator and passenger sat right over the monotube "boiler" or steam generator. When the crude safety valve stuck, which it often did, the steam pressure many times would overrun to 1000 psi., but there was no worry of danger. If a tube let go, no steam would get to the occupants of the car or anyone on the street. Even the noise involved was not particularly startling. A typical modern steam car might be designed to operate on high-quality steam at 1000 psia. pressure and 755°F of superheat (1200°F of total temperature). Combustion temperature might be 2500°F at slightly above atmospheric pressure. The monotube steam generator contains so little hot water under pressure and that contained is in such small tubes that a steam explosion, in the dangerous sense of the word, is an absolute impossibility. A tubing rupture is no more startling than merely opening a steam valve to the atmosphere. Although high-pressure 1200°F steam can char wood before it expands, after it expands through an opening, it cools very quickly. I have stood several feet back from a forceful jet emitting high-pressure, 1200°F steam directed upon me, and it feels actually like a cool wind. Such a jet was the entire output of an automotive sized steam generator. However, it would not be safe to stand in front of a jet of relatively low temperature, saturated steam containing slugs of boiling water, as the latter does the scalding and cannot cool off quickly by expansion. The modern gasoline car with low pressure radiator has as much potential for scalding as would the modern steam car. We feel so safe with modern automotive steam equipment that on our experimental cars we do not even bother to install a safety valve. The unit is fail-safe within itself.

Now, those of us who have dedicated our lives to the development and perfection of steam cars are not "anti-autoists" and publicity seekers, but rather are auto-enthusiasts who would like to make possible for our fellow man to be able to drive an automobile powered by an engine which inherently has the type of torque and performance characteristics needed for the application. What we have now is an elaborate make-shift of components that make it possible for an inherently poor automotive power source, the gasoline engine, to propel a car.

Furthermore, recently a much more insidious problem has come to light: the specter of impending mass deaths due to air pollution caused mainly by internal combustion engines. Apparently many in the automotive industry are having trouble recognizing the seriousness of the situation. An associate of the California State Assembly informs me that medical doctors in the state are concerned about the strong possibility that a mass build-up of smog could wipe out the en-

tire population of a sizable community overnight—even involving the deaths of millions of people in a single catastrophe. Contemplate what reaction such a tragedy would direct toward the automotive industry, which is not ready yet to replace the gasoline car with an alternate equal to or better than the present system. The modern steam car has demonstrated that even in relatively crude models it can cut hydrocarbon emissions to four per cent of that produced by a conventional car and reduce other pollutants by similar drastic percentages. It is the only alternate automotive power system that the present state of the arts can give us without major technological breakthroughs. To solve the problem by cleaning up or attempting to clean up the gasoline engine is economic tomfoolery. You are doing a great disservice both to the automotive industry and to your fellow man by publishing in an influencial journal such a thoughtless editorial. At least the Ford Motor Company recognizes the importance of investigating automotive steam power. The industry has got to quit kidding itself in this regard.

As the coinventor and developer of the rotary-reciprocating uniflow steam engine, the Elliptocline, I will review the advantages and design goals for an Elliptocline-equipped, automotive steam power system, still under development:

1. Extremely smooth and quiet operation—car seems to be coasting along.
2. Engine inherently balanced and vibration-free.
3. Engine contains only one valve to control nine cylinders.
4. Torque smooth—nine power impulses per revolution versus only four for V-8 gasoline engine.
5. Maximum torque at zero rpm—superior get-away from stop lights.
6. No clutch—engine stops when car stops.
7. No change speed transmission, either manual or automatic—for reverse, engine reverses by change of position of the valve.
8. Dynamic braking available via engine reversal—boon for truckers descending long grades, thus saving brakes.
9. Operation simple—foot accelerator pedal: push forward on pivot for acceleration, backward for dynamic braking or reverse—controls both throttle and steam admission cut-off variation. Brake pedal for emergency stopping. Steam generation automatic upon the driver's turning on the key switch.
10. Engine capable of producing much higher powers for short bursts than the continuous rating of the system, due to stored power within the steam generator (thermal inertia). Good for high speed acceleration needed for passing. In some systems, short duration overloads may produce power five times the continuous rating. The gasoline engine has no similiar characteristic—consequently cannot perform like steam engine.
11. Low "smog emission" of steam generator—no emission of engine.
12. Exhaust steam available for interior heating and jet-type air conditioning—both systems would start on "live" steam.
13. Since components of steam system readily can be separated, improved weight distribution with fewer design limitations are possible.
14. Fuel economy eventually should be equal to that of diesel engine.
15. Engine to require no hydrocarbon lubrication—to use self-lubricating and steam lubricated bearings.
16. Ability to burn wide range of liquid fuels can be incorporated.
17. Engine compatible with nuclear power as a component thereof.
18. System should be easily adapted to mass production—less expensive than present I.C. system.
19. Maintenance, wear, and lube problems should be lessened.
20. As much as 1000 hp. may be incorporated into truck tractor, permitting 60 mph. on heavy grades and allowing more efficient use of driver time and truck investment.
21. Antifreeze may be incorporated into virtually sealed system.
22. Steam condenser with thermal inertia will be installed to accept brief engine overloads.

If one studies this list, it should become apparent that the steam system potentially is far superior to internal combustion for automotive power.

I hope you will consider retracting your editorial.

Yours very truly,

THOMAS A. HOSICK.

(Subsequently, this following supplemental statement was received from Mr. Gibbs and Mr. Hosick:)

SUPPLEMENTARY STATEMENT OF THOMAS A. HOSICK AND R. A. GIBBS, GIBBS-HOSICK TRUST

Having submitted a statement in support of "smogfree" steam power for automobiles in the form of a memorandum dated May 23, 1968, to go into the record of the joint hearing held on May 27, 1968, and having heard the testimony of other witnesses at that hearing, we would like to submit the following supplementary statement concerning points which we felt were either misleading or subject to further interpretation.

Referring to the presentation of the Ford Motor Company, particularly to their Exhibit I,[1] we would suggest that the prime fundamental advantage of automotive steam power is omitted—steam, unlike I.C., has the proper torque characteristics for powering an automobile. This exhibit lists four advantages of automotive steam power; our initial memorandum for the joint hearing lists twenty-two. Exhibit I lists steam as having a poor high speed economy. The fact is that steam's "poor" high speed economy is relative only to itself. What it means is that, for example, a Williams steam car merely would show less fuel economy *improvement* over an I.C. powered car at speeds over 100 miles per hour than it would at normal driving speeds.

Ford stresses the alleged complexity of the steam car versus the gasoline car. We believe just the opposite. The graph in Exhibit II appears to be quite misleading and subject to variance of interpretation. For example, the steam car burner assembly is listed as almost half as complex as the entire basic gasoline engine! It consists merely of a fuel nozzle and an electric motor with blower mounted on its shaft; it has no more complexity or parts than a gasoline heater for a Volkswagen or a Corvair. The modern carburetor, on the other hand, is a very complex device with several butterfly valves, one to several intake manifold pressure sensor-actuators, temperature sensor-actuators, and is very subject to mal-function with severe service problems. Ford's rating of "4+" for the burner assembly seems too high and below "2" for the carburetor much too low.

The basic "boiler" or steam generator consists only of continuous stacks of spiral coils within an air jacket, and contains connections for two sensing devices and for input and output—no moving parts. To rate it as 65 per cent as complex as the basic I.C. engine, with its multiplicity of various moving parts, would seem open to question.

The comparison of steam car sensors and controls to gasoline car ignition, sensors, and controls appears to be evaluated about opposite from what it should be. The only sensors the steam generator has is for temperature and pressure of the steam. The pressure sensor-actuator controls the burner and the temperature sensor-actuator controls water pumping and overrides the burner control. The burner has an ignition sensor for safety, as does the home oil furnace. The steam car has a very simple ignition system, which may consist of the coil, breaker points operated by a cam on the blower motor shaft (which do not have to be timed), and a single spark plug, requiring little maintenance. The accelerator pedal may operate a simple throttle valve plus adjusting tension on fly-weights which control automatic cut-off for torque and economy variation. The gas car, on the other hand, has a complex distributor requiring much maintenance, besides the coil and six to eight spark plugs. The distributor has both manifold-pressure sensor-actuator and one or two fly-weight actuators to vary timing. It also must be driven by gears from the engine cam shaft. The gasoline car has several temperature sensor-actuators in addition to the numerous pressure devices and rpm. sensor-actuators already mentioned.

The Ford graph indicates the basic steam engine to be 75 per cent as complex as the basic gasoline engine, which may be valid for a steam engine of the Williams type. However, if a perfected version of our Elliptocline engine were used, the basic steam engine complexity line should be reduced to about half of its present length. If an accessory steam engine must be used (and I am not sure that it must), then a self-lubricated rotary vane type of engine with high expansion ratio should be both efficient and simple—less complex than the usual air conditioner compressor. Since both the Thermo Electron engine and the perfected Elliptocline engine will use no oil lubricant within the cylinders, the oil separator can be omitted. A clutch on the condenser fan is needed no more than on a conventional car's radiator fan. In slow city driving, condenser heat dissipation for an efficient steam car will be no greater than I.C. radiator heat

[1] Refer to attachments.

FORD ← hdn

ADVANTAGES - DISADVANTAGES OF A STEAM POWER PLANT

	ADVANTAGES	DISADVANTAGES
MAJOR & FUNDAMENTAL	• ULTRA-LOW EMISSIONS • ULTRA-QUIET OPERATION	* COMPLEXITY • HIGH TEMPERATURE MATERIALS
SECONDARY	• MULTIFUEL CAPABILITY • QUICK PASSENGER COMPARTMENT HEAT	• START-UP TIME • POOR HIGH SPEED FUEL ECONOMY

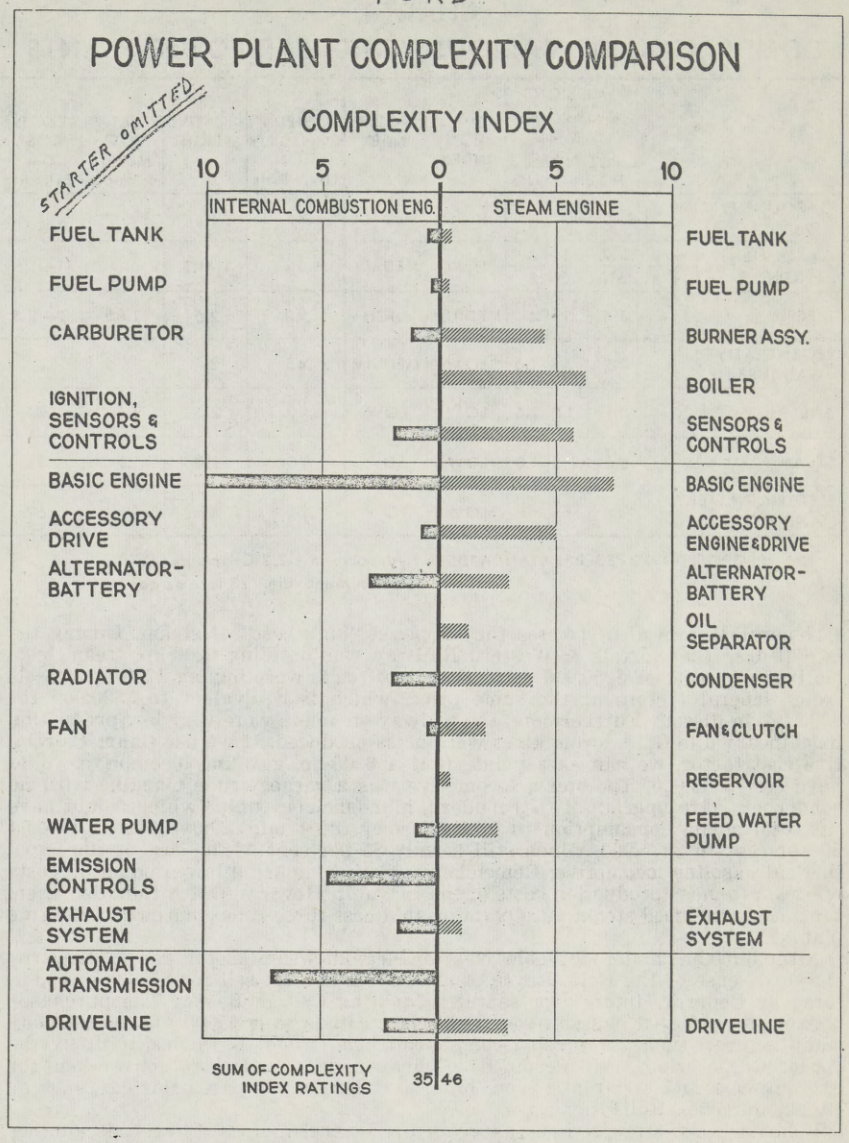
ENGINEERING PROBLEMS - ASSUMED SOLVABLE

- LUBRICATION AT HIGH TEMPERATURES
- MAINTAINING PURITY OF WORKING FLUID
- BOILER DESIGN FOR SAFE OPERATION
- ISOLATION OF POWER IMPULSES
- FREEZING OF THE WORKING FLUID
- ACHIEVE ADEQUATE RELIABILITY & SERVICEABILITY

Ford Exhibit I

dissipation—probably less. At higher road speeds, sufficient air can be rammed through the condensor for effective cooling; the fan load will be no greater than on an I.C. car. The water reservoir, as separate from the condenser hot well, may or may not be needed. The difference shown for water pumping may or may not be valid, depending upon how it is handled. If any difference would be observed in the drive train, it would appear that steam would be simplier; it does not have to stand the shock of "popped" clutches. In any case, the line for the automatic transmission should be longer than the line for the basic steam engine—especially so for our Elliptocline engine. Today's automatic transmission is a highly complex device with many and various sensor-actuators.

FORD <— [illegible]



Ford Exhibit II

In our newspapers lately we have read much about the alleged "credibility gap" that exists in certain news releases by some of those in our government. Certainly General Motors cannot be far behind with their own "credibility gap," as is exemplified by their Chart I. This chart gives the emissions of the projected 1970 gasoline car in comparison to those of an unoptimized steam car, the latter having emissions close to an order of magnitude lower (more specifically, 0.6 to 0.8 orders of magnitude). To classify both vehicles, then, to have emission indices that are "low" must surely be some sort of "breakthrough" in semantics.

General Motors Corporation

CHART I
COMPARISON OF VARIOUS VEHICULAR POWER PLANTS

		EMISSIONS Grams/Mile California Driving Cycle			EMISSION INDEX	NOISE INDEX	FUEL CONSUMPTION Lbs/HP-Hr	RELATIVE WEIGHT	RELATIVE COST Morse Estimate	RELATIVE COST GM Estimate
		HC	CO	NO						
GASOLINE ENGINE 1960		11.0	80	4	HIGH	MEDIUM	.45	1	1	1
GASOLINE ENGINE	1970	2.2	23	4?	LOW	MEDIUM	.50	1—1.5	---	1—1.5
	197X	STILL LOWER								
DIESEL		3.5	5	4	MEDIUM	HIGH	.40	2.5	1.85	2—2.5
REGENERATIVE GAS TURBINE		0.22	2.4	1.0	LOW	MEDIUM	.45	2	3.75	3
STIRLING		0.1	1.0	2.6	LOW	LOW	.40	2.5	2.5	3
STEAM		0.62	2.8	1.0	LOW	LOW	.70+	3.0	1.5	3
ELECTRIC BATTERY AND MOTOR		---	---	---	LOW	LOW	?	4?	---	6?

PROPOSED 1970 FEDERAL STANDARDS: Hydrocarbons: 2.2 Grams per Mile
Carbon Monoxide: 23 Grams per Mile

General Motors also stresses the supposed "high cost" of steam. During the late 1940's,[1] the Norfolk & Western Railway was building 6200-hp. steam locomotives at a cost of $250,000 each. Other railroads were buying 1750-hp. diesels from General Motors at the same price, which is equivalent to $890,000 for 6200 hp. in diesels. Furthermore, the railway steamers were very low production machines, while GM's locomotives were mass produced. If we use Chart I's relative cost factor, we can extrapolate that a 6200-hp. gasoline locomotive would have cost $445,000. The steam locomotive was a rather crude machine with no condenser, so to upgrade it to a modern, high-efficiency unit (which would have cut total steam consumption to ¼ its former rate) might have raised its cost 50 per cent to $375,000, which still is only 85 per cent of the cost of the hypothetical gasoline locomotive. Remember, we are comparing low production costs of steam to mass production costs of the I.C. unit. How can GM rationalize, then, that mass produced steam auto plants would cost three times *more* than gasoline plants?

Although the Model E Doble was an elegant steam motor car in the true classical sense of the Rolls Royce of the day, it did not sell for $75,000, as indicated by General Motors representative quoting George Besler. The purchaser bought the powered chassis from Doble for a little over $5000 and had a body manufacturer, such as Murphy, complete it. The Model F Dobles, built by the Besler Corporation, were designed as cheaper units that were conversions for existing cars and apparently were built to order for the particular car, such as Buick, Mercedes, Rolls Royce, etc.

Relative weight projections, as given by General Motors' Chart I is another absurdity. The diesel is given as 2½ times as heavy as gasoline, and steam, three times as heavy—in other words, steam is heavier than diesel! What possible rationalization can GM give for that kind of nonsense? In 1936 the New Haven roalroad began testing two modern-for-the-day, self-propelled passenger trains, one diesel and the other steam. The steam train, built by the Besler Corporation, was the most modern automatic oil-fired unit consistant with the technology of the time. Variable steam pressure was up to 1750 psig., steam temperature was 760° F, and vacuum condensation was utilized, giving a specific fuel consumption of 0.835 lb./hp.-hr. measured at the rail. The 550-hp. steam unit weighed

[1] And early 1950's.

only 55 per cent as much as the 600-hp. diesel unit, *on a weight-per-horsepower basis.* This weight advantage was one of Besler's main selling points! The modern steam unit, being almost twice as efficient as the Besler or Doble unit, should weigh much less, because of reduced size of the steam generator and condenser required.

Next brings us to brake specific fuel consumption (BSFC), which is measured in pounds of fuel burned per horsepower-hour as measured on the brake (now usually measured by dynamometer). BSFC is related both to overall thermal efficiency and to the heat content per pound of fuel burned. Right away, the oil-burning steam car is put at a disadvantage because gasoline contains more Btu. per pound than does diesel fuel. However, we do not buy fuel by the pound—we buy it by the gallon. Diesel fuel has *more* Btu. per gallon than does gasoline because of its greater density, and it costs appreciably less per gallon.

When one wishes to slant efficiency figures in favor of the gasoline engine over the steam engine in the automotive application, he talks about full throttle BSFC or full throttle overall thermal efficiency—but please consider, just what percentage of the time do we drive our cars at full throttle? Although the gasoline engine peaks its efficiency at about the point of maximum torque, giving a value of around 30 per cent, under partial loads its efficiency suffers a rather extensive decrease—to the extent that at a steady 25 miles per hour, it may have been *halved* in value. (Another gimmick for slanting efficiency figures upward is to base the value upon the *low* heat value of the fuel rather than upon the *high* heat value, the latter being customarily used in this country.) Furthermore, in the gasoline car, extensive transmission losses are observed. Published figures indicate that at a steady 60 miles an hour on the level with no wind (which requires approximately 30 horsepower for the average full-sized American car), the overall thermal efficiency of most American cars will lie between 16 and 19 per cent, *measured at the road,* where it counts.

When we start with a 29 per cent overall thermal efficiency at the shaft for the Williams steam engine and consider that (1) transmission losses are lessened and (2) steam engine efficiency changes very little during non-extreme variation of the partial load to which the engine is subjected during most normal driving conditions, then it is easy to anticipate a much better *usable* efficiency for the steam car—possibly 25 per cent at the road at a steady 60 miles an hour. The Williams car's reported 30 miles per gallon economy for highway driving, plus the fact that they use a radiator for a condenser very little larger than found on I.C. cars, bears out this reasoning. The BSFC of the Williams engine is 0.461 based upon diesel oil, or 0.423 based upon gasoline as the steam car fuel. Where General Motors got their figure for the BSFC of steam cars of 0.70+ is beyond our comprehension.

On page 7 of their statement before the joint hearing, as an example of their periodic re-evaluation of alternate forms of automotive power, General Motors proudly mentions their investigation of vapor-powered, steam-type engines, reported in SAE Paper No. 931B, entitled "Fluorocarbon Vapor Machine," published in 1963. We would suggest that it might be quite revealing for any of the technically minded Senators, such as Senator Baker, to obtain a copy of this paper and observe the quality and lack of comprehensive nature of this very preliminary study to gain some insight into General Motor's lack of tenacity in their approach to a radical power system, which could *beneficially power an automobile.* The project was "dumped" in favor of studying the Stirling engine, which shows little true encouragement for powering automobiles in a practical manner at this time. General Motors, of course, has the resources to have managed both investigations simultaneously, but one might theorize that the "fluorochemical machine," if perfected, would represent a definite threat to the "eternal" internal combustion engine. It would appear that GM would rather spend its time working on "glamorous" power systems with little near-term potential as an I.C. engine threat—such systems as gas turbines, battery electrics, fuel cell electrics, and Stirling electric hybrids, all of which are good for public relations and giving the image of a progressive, science-oriented company, but do very little towards solving the country's grave problem of air pollution.

Next, we would like to dwell briefly on the subject of turbines, whether propelled by gas, steam, or heavy organic vapors, and indicate why we are partial to reciprocating or rotary, displacement-type engines. Both the turbine and the steam (or vapor) engine have maximum torque at zero rpm., although the turbine's torque at low rpm. does not increase proportionately to the engine's capability. One glaring difference is manifested, however: At zero rpm. under

maximum torque conditions, the fuel consumption of the turbine is maximal, while the fuel consumption of the engine is, for practical purposes, virtually zero. Such is an important consideration for an engine that must be able to run under partial load conditions most of the time and with greatly varying engine speeds.

In consideration of hybrids, such as steam-electric, why should we go to such a system, when the properly designed steam *engine* has all of the torque characteristics needed for automotive propulsion without the complication of electric transmission? Furthermore, the steam electric system with maximum torque at zero rpm. also exhibits maximum fuel consumption under those conditions.

In the hearings, the point was made that steam engine dynamic braking would be of no use because it is two-wheel braking and, besides, the engine could not develop the reverse horsepower equal to that of conventional brakes. These facts are immaterial to the proper use of dynamic braking. In the first place, dynamic braking would not be used for "panic" stopping. The only emergency use for this system would be in event of failure of the primary brakes—a very important safety feature. The main use would be for anticipated relatively low rates of deceleration, as for approaching a stop light or sign, or for descending long grades as in mountainous territory.

Another statement was made implying that little likelihood exists that, if the steam car were introduced as an alternative to the I.C. car, their evolution would result in any particularly significant increase in efficiency—which, to us, appears to be an incredible position for a technical individual to take. All steam (or vapor) systems mentioned at the hearing have been those operating within the Rankine cycle, except for the Williams system. The "Detroit" point is that any abandonment of the very inefficient Rankine cycle would cause too much complexity to be of consideration. To the contrary, the Williams modification is very simple, and we would project that it would be only the beginning of a vast transformation of steam engine thermodynamics that would evolve if a little engineering "horses" were put behind the task. The large central steam-electric power generating stations long ago abandoned the Rankine cycle and now are running on the reheat-regeneration cycle. Their method of regenerative feedwater preheating is quite complex, but they are not bothered by weight and space limitations. However, a very simple method exists for doing the same thing in a car with minor modification of the present Rankine equipment. One stage reheating is a little more involved, but can add very significantly to actual efficiency and easily could be incorporated into steam plants for large trucks. Very little has been done with efficient isothermal or Carnot-type expansions, which can give theoretical water rates below 3 lb. per ihp.-hr. within temperature limits presently in use, compared to 5 lb. per ihp.-hr. for the Williams engine (a low water rate for a steam engine operating within a thermodynamic cycle utilizing Rankine-type compression indicates a high thermal efficiency for the engine). Modern technology continually brings up new possibilities of thermodynamic improvement as each new applicable development comes to light. No end is in sight.

During the hearing it was pointed out that the parts-per-million pollutant figures should be adjusted to take into account the rich mixture of the gasoline engine fuel mixture versus the lean mixture of the steam car's fuel, to the advantage of the relative position of the gasoline car in pollutant emission. The figures *also* should be adjusted to the actual thermal efficiency of the power plant under operating conditions, which would favor the efficient steam car. A more relevant comparison would be the average mass of pollutants released per unit of work done by the power system in question.

Apparently, in consideration of pollutant emission, we are concentrating primarily on unburned hydrocarbons and carbon monoxide. Current investigations at the Bowman Gray School of Medicine show rabbit lungs to be severely damaged by breathing 5 ppm. of nitric oxide for three hours. In addition, we hear nothing particularly about partially burned hydrocarbons. We wonder about the release of the highly toxic tear gas, acrolein, and similar vicious organic aldehydes, which would be expected among the partially burned hydrocarbons. Very little is said about the release of carcinogens, in spite of the prevalence of lung cancer. Although much has been said during the hearings about the efficiency of heat use and the economics involved in various automotive power systems, the one overriding consideration is the efficiency of *not* poisoning our atmosphere—of not *killing* people and our food supplies. We

strongly believe that the optimized steam car represents by far the most efficient practical automotive power plant in this regard.

We are attaching a reprint of an article by James MacNees of The Baltimore Sun. It suggests what the United States Government might do to advance the cause for steam power. Certainly, few items of national concern should have a higher priority.

Thank you, gentlemen, for the opportunity of this testimony.

[Reprint appearing in the Twin City Sentinel, June 4, 1968, Winston-Salem, N.C.]

AMERICA '75—THE STEAM-ENGINED AUTO OF THE FUTURE

(By James MacNees, the Baltimore Sun)

WASHINGTON.—The year is 1975, you've just purchased your first steam-engined automobile and you're about to take the family for its first ride.

You pile in the kids, turn the key and there's a low vroom as the oil burner ignites.

You wait fifteen seconds—about the time it used to take to start your old gas buggy—ease the cut-off level into forward drive position and press down the accelerator.

It's a quiet ride, almost ghostly. There is no shifting to be done, no jerks as an automatic transmission goes through its gears. There's no transmission: the accelerator governs your steam supply through any number of higher speed positions.

You come to your first stop sign, slide the lever into reverse drive position, and something like today's turbo prop or jet airplane "reverse thrust" provides dynamic braking. As you near the stop you move the lever to a neutral position and come completely to a halt with your foot brake.

While you are stopped your engine is stopped also—a steam engine need not "idle." As you drove virtually all the sound you heard, except for the kids fighting in the back seat, was your fuel burner cutting "in and out" as it kept up steam pressure—burning about 5 seconds out of every 25 seconds.

What's under the hood up front? Four cylinders putting out 150 horsepower continuously and 250 horsepower intermittently when you demanded more "oomph" in passing or climbing a hill.

Your fuel supply is kerosene, No. 1 fuel oil or diesel oil—you are saving about 10 cents a gallon on fuel and, in addition, getting between 20 and 30 miles to the gallon. Oh, you also need water, but only about 12 gallons for every 500 miles and that ratio is coming down.

Surely you noticed the smooth feel of your new "steamer"—something like the steady pull of a high speed elevator, or the take-off in a high efficiency turbine jet plane?

Old Timers used to speculate on what would happen if the boiler exploded in a 1904 Stanley-steamer—Detroit is still indulging itself in that kind of speculation, at least in front of congressional committees.

The answer is that they seldom, if ever, "blew up" and the modern version of the Stanley has discarded the boiler altogether for a "monotube generator" assembly which, if it ever ruptured, would spew out a "hiss" of steam and that would be the end of that. About a pint of water is in the combuster at any one time.

So you end your ride, pull into the garage, turn off your oil burner and give it a friendly pat as you alight. But wait, you have contributed something to mankind which might not occur to you immediately—you have reduced the pollutants you would have spewed into your neighborhood's atmosphere, had you been driving a conventional internal combustion engine automobile, almost to nullity.

The so-called "Modern" gasoline engine, experts say, was responsible for 85 per cent of the lung-searing, vegetation-killing pollution in yesterday's ambient air.

And your state, if you lived in California, reached what medical and technical experts called the "pollution peril point" seven years ago, in 1968.

In that year your state undertook an experimental steam car program, purchasing six steam-powered vehicles for its highway patrol, based on evidence, Assemblyman John Francis Foran asserted, that the pollution charac-

teristics of modern steam cars "surpass any expected improvement in the internal combusion engine for years to come."

A little later your government recognized the truth of what a secretary of transportation had said a number of times earlier, that "just the growth in population of the internal combustion engine powered cars" would defeat the best air quality standards the federal government could enforce.

And when the government finally decided that clean air was a desirable social goal, it awarded research and development grants to steam-engine producers and a new industry was on its way.

At first the new steamers were much more expensive than the old gas-engined vehicles, but their growth in numbers steadily lowered the price. In addition to mass production the new steamers do without a lot of the vital components heretofore needed. There is no clutch, no transmission (remember what it cost to overhaul one of those), no carburetor, your steamer goes anywhere from 200,000 to 500,000 miles before it needs an overhaul and its thermal efficiency on the road is about 28 per cent. Your old gas buggy was about 15 per cent, remember?

Fantasy, you say? Not at all. Congressional testimony this week was to the effect that the state of the art of vehicle steam propulsion is such that a steam car can be put into mass production from scratch in two or three years.

Senator BAKER. The record will be held open for a period of about 2 weeks to enable interested parties to submit statements.

The committee is adjourned.

(Whereupon at 4:50 p.m. the hearing was adjourned.)

APPENDIX

(Written Statements, Articles, and Letters)

95-905 O—68——12

Statement by California Assemblyman John Francis Foran

Senator Magnuson, Senator Muskie, committee members, on behalf of the California Assembly and the Members of the Assembly Committee on Transportation and Commerce, of which I am Chairman, I am very pleased to have this opportunity to submit our views on steam power for automotive use as a means of combating air pollution. I commend you for offering such a prestigious forum for this inquiry.

Vehicle smog confronts California with a public health crisis. It is a formidable problem elsewhere in the nation. Our interest in steam power as a practical alternative to the conventional internal combustion engine originated in the conviction that no possible solution to the vehicle smog problem should be left unexplored. To that end, the Assembly Transportation and Commerce Committee has introduced two bills, AB 357 and AB 356, and a resolution, ACR 111. AB 357 is designed to curb emissions from conventional internal combustion engines, and I shall not discuss it further. AB 356 encourages the rapid development of low emission engines of any kind by requiring minimum state purchases (approximately 750 vehicles yearly) of low emission vehicles for state use if, when and as they become available. Under AB 356, the state could purchase improved internal combustion, turbine, electric or steam cars or any other low emission vehicle that met state needs. ACR 111 deals directly with steam cars and the bulk of my testimony today will be directed to that resolution.

Your hearing and invitation to testify on steam power systems for automotive use could not have come at a more propitious moment. Last Monday, May 20, General Motors Corporation informed us that they will fund the steam car test program proposed in our Assembly Concurrent Resolution 111. This resolution has passed the Assembly and is currently moving through the California Senate.

ACR 111 requests the California Highway Patrol to conduct a carefully designed test in which six of its cruisers will be fitted with steam engines. These cruisers will be operated in the same manner as any other patrol car in each of the California Highway Patrol's six geographic-administrative zones. Since a variety of legal and political obstacles made it unlikely that we could fund this test program through conventional channels, we are very grateful to General Motors for its decision to underwrite the program's cost. Their offer is a unique and public-spirited commitment to the solution of the smog problem.

In contrast to the present encouraging events, our previous investigation of the prospects for steam vehicles had been frequently disappointing.

Our Committee and staff had conducted extensive investigations throughout the country, meeting both with steam power enthusiasts and the Big Three's representatives in Detroit. Additional contacts were made at the Department of Health, Education and Welfare, the Department of Transportation and the Department of Housing and Urban Development. In early March, on the basis of preliminary findings, our Committee held hearings similar to yours. On the basis of the testimony received then, we were persuaded that steam had to be taken seriously, *despite the lack of enthusiasm of both Detroit and federal officials at that time.*

Detroit's position was understandable; the federal government's was less so.

Based on our contacts, present federal research and development effort in this area can only be classified as leisurely. The federal interest in steam, compared to federal interest in internal combustion engines or electric power, is low-pressure, to say the least. California's approach under ACR 111 may seem unsophisticated to some federal investigators; but, because we are very interested in *results*, we will chance that.

We are enthusiastic about steam primarily because it appears to us to be the most readily manufacturable and salable low emission power source. Based on evidence presented to our Committee, it appears that emission characteristics of modern steam cars far surpass any expected improvement in the internal combustion engines for years to come. In the Morse Committee report to the U.S. Department of Commerce, *The Automobile and Air Pollution: A Program for Progress*, it was noted that:

"The heat engines being discussed in this section (the gas turbine, reciprocating and *rotating steam engines*, and Stirling cycle engines) can all use a continuous combustion device to convert the chemical energy of the fuel into thermal energy of a working fluid. This is in contrast with internal combustion engines (Otto cycle and Diesel cycle) which use intermittent combustion, or a controlled explosion. While there is not an extensive body of data on the subject, it can be reasonably assumed that continuous combustion burners can be designed with a cleaner exhaust 254,273 than the intermittent combustion devices. *Continuous combustion can take place with unleaded fuels under more steady and controlled conditions at lower peak temperatures and pressures. This should result in low concentrations of unburned hydrocarbons, carbon monoxide, and oxides of nitrogen.*" [Emphasis added.] Part II, page 55.

The steam engine was clearly favored by the Committee, however; for, after noting problems with both the electric and turbine cars, it stated among its major findings that:

"Vehicles using external combustion engines for propulsion, such as the piston-type steam engine of advanced design, potentially offer a satisfactory alternative to the present automobile and should have very low pollution and noise characteristics." Part I, page 2.

In other words, steam reduces harmful emissions to negligible levels, and it does it *now*—not in 1975 or 1980.

Secondly, our studies indicate that steam couples low emissions with *immediate applicability* in a wide variety of automotive propulsion requirements. Although we are aware of current developments in electric and gas turbine power systems, we see no indication of their early availability. Thus, if it becomes apparent that a changeover from the internal combustion system is feasible, steam would offer the possibility of this changeover most rapidly. This is crucially important in California where we have 12 million registered vehicles now and will have 20 million by 1980.

We are very aware of the skepticism regarding steam's reliability and performance. That is why we deliberately chose to have the California Highway Patrol conduct the test program. We know that when it comes to cars, the American public in influenced by results. We know of no better way to get reliable data rapidly than to have a prestigious vehicle user test steam cars under the toughest possible operating conditions.

Witnesses here today can discuss the comparative costs of steam versus the conventional system. We have been told that, assuming reasonable levels of mass production, there should be little or no cost penalty in switching to steam power. I assure you that we in California cannot afford to pay the human price that failure to develop and adopt a low emission power system will entail.

We face a grave environmental health problem in California. For fifteen years, we have been applying increasingly stringent curbs on the sources of air pollution—with only temporary successes. During the past year, our medical and technical experts have repeatedly testified that, despite past efforts, we are at the "peril point". We are forced to seek much more adequate countermeasures.

Since the conventional IC-powered motor vehicle is the principal remaining source of air pollution, and since the car, bus and truck will be with us for a long time, we see little profit in tinkering, or in ignoring promising alternatives, particularly when such a policy may have widespread and even fatal consequences. Our response has been to search for better systems. We believe that steam may provide that system. We intend to get the answer from our test program.

Our need cannot await federal action, although we will certainly welcome any help that the federal program can provide. We are ready and willing to collaborate in any way that can be useful.

Let me again express our appreciation at being asked to participate in your inquiry.

COMSTOCK & WESCOTT, INC.,
Cambridge, Mass., June 4, 1968.

Hon. WARREN G. MAGNUSON,
Chairman, Senate Commerce Committee,
U.S. Senate, Washington, D.C.

MY DEAR SENATOR MAGNUSON: In connection with their hearings on steam propulsion systems for vehicles, the Committee on Commerce and the Subcommittee on Air and Water Pollution may be interested not only in the present state-of-the-art, but also in new and emergent technologies which can be brought to bear on the problems. I would like to describe one such technology which we believe can be applied to the steam generator, which is of course an essential element of the propulsion system.

For the past several years we have conducted a research and engineering program to develop practical methods and materials for the storage and subsequent delivery of large amounts of heat. Current developments in this field are sponsored by the Hooker Chemical Corporation, and have lead to the production of a new type of equipment for heating water to satisfy the hot water needs in commercial buildings such as apartments and motels. This development has reached the stage of field testing, with several units now operating.

We have recognized that with suitable modifications, the heat-storage and steam-generating principle used in the new water heater can be applied to the generation of steam, or other vapor, to operate an engine for vehicle propulsion. We believe a boiler utilizing this principle would have worthwhile advantages over conventional boilers, especially with respect to its control devices.

I'm enclosing herewith a memorandum which describes in more detail the operation of the water-heating system, how it could be applied to steam boiler design, and the advantages which are anticipated.

Sincerely yours,

RICHARD E. RICE, *Vice President.*

MEMORANDUM ON THE "THERMALLY-BUFFERED" STEAM GENERATOR

INTRODUCTION

A novel alternative to the conventional steam generator has been suggested by work carried out over several years in the field of heat storage by Comstock & Westcott, Inc. of Cambridge, Mass. The novelty resides in the use of a "Thermal Buffer" which completely surrounds the steam generating tubes and prevents hot gases from impinging directly on them. The thermal buffer is a heat storing material which should have a high heat capacity, a large latent heat-of-fusion, and a melting point close to the temperature at which the steam is to be delivered. A steam generator employing this thermal buffer concept can produce steam in a state suitable for use in a steam propulsion system with much simpler controls than the boilers which are conventionally used.

BACKGROUND

The concept of the thermally buffered steam generator stems from approximately ten years of research and development work on energy storage systems. This work was initiated by the electric utility industries through the Edison Electric Institute, in their search for energy storage systems for electrically heated houses. These systems were to be charged with off-peak power and were to deliver energy as heat from storage during peak periods. From among the many materials studied as heat storage media, sodium hydroxide was found to be outstanding.

Subsequently, in cooperation with the Hooker Chemical Corporation, systems based upon chemically modified sodium hydroxide were developed which have proven entirely practical. The Hooker Chemical Corporation now makes such heat storage media under the tradename Thermkeep.[1] These modified sodium hydroxide compositions have high heat capacities, high latent heats-of-fusion and comparatively low costs. In addition, they can be contained in ordinary steel, and can be cycled through wide temperature ranges without decomposition.

[1] Registered Trademark Hooker Chemical Corporation.

Currently this principle of heat storage is being applied to water heaters which bear the tradename Therm-Bank [2] for supplying hot water to commercial buildings such as motels and apartment buildings. This development, underwritten by the Hooker Chemical Corporation, has advanced to the field testing stage.

The water heating equipment consists of three basic elements: a heat storing unit, a water heating tank, and a heat-transfer system. The heat storage unit consists of a steel tank containing the Thermkeep, heat storage medium, electric resistance heaters protected by steel sheaths immersed in the medium, and a steel steam generating coil, also immersed in the medium. The water heating tank is a conventional hot water tank having a capacity of 50 gallons. The heat-transfer system includes, in addition to the steam generating coil, a condenser in the water tank, a condensate receiver, a pump for injecting water into the coil, and an expansible element which maintains near-atmospheric pressure within the heat-transfer system regardless of changes in vapor volume.

The medium is heated to a maximum temperature of 850–900 F. At these temperatures the 1400 lbs. of medium used store approximately 600,000 Btu of recoverable heat of which over 200,000 Btu come from latent heats at approximately 600 F. The transfer of heat from storage to the water tank is controlled by the pump which delivers the heat-transfer water to the steam generating coil.

An important part of the work on heat storage systems has been to develop methods to hermetically seal Thermkeep systems. Practical answers to the problems have been found, and heat storing cells constructed of ordinary steel, completely sealed by welding, have been operated successfully in the laboratory for 2½ years. For use in vehicles the hermetically sealed system is considered mandatory.

CONCEPT FOR A THERMALLY BUFFERED STEAM GENERATOR

The transition from water heater practice to the design of a steam generator suitable for use with a steam engine is regarded as a relatively straightforward development. By modifications in design, it will be feasible to deliver steam at high pressures, up to 3000 psi or more, from such a system. Through suitable internal heat transfer designs, the temperature of the steam can be controlled. The electric heaters can be replaced by a fuel oil burner.

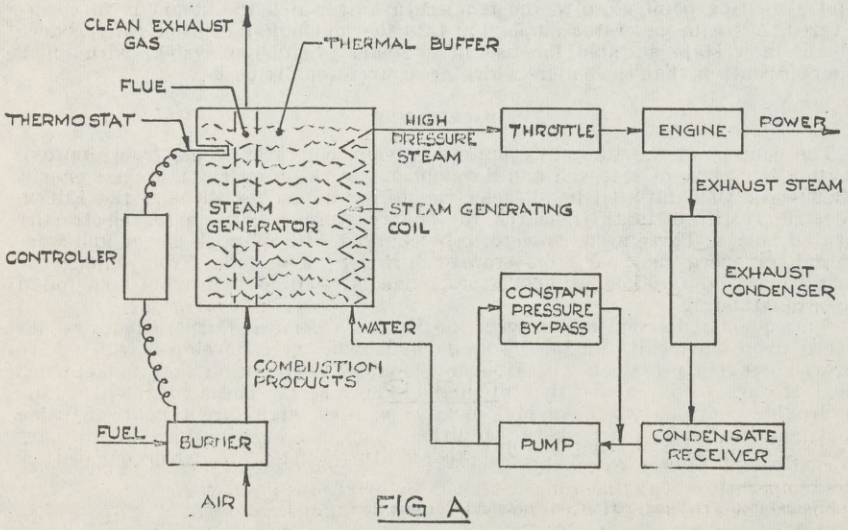


FIG A

[2] Registered Trademark Comstock & Wescott, Inc.

Figure A is a schematic representation of a power generating system using the thermally buffered steam generator. The principal elements are: the steam generator, a throttle, a steam engine, an exhaust condenser, a condensate receiver, a pump with a constant pressure by-pass, and a fuel burner. The steam generator consists of a welded, hermetically sealed steel tank containing the heat storing medium, through which pass the steam generating coil and the flues for the hot combustion product of the burner. The medium completely surrounds the coil. Its temperature is sensed by a thermostat which actuates the burner to maintain the desired temperature. The pump delivers water to the coil at the pressure desired in the steam. A constant pressure by-pass is provided around the pump allowing the pump to run continuously. The presence of the buffer protects the coil from direct exposure to the burner gases, and it is unnecessary to maintain liquid in the coil to prevent overheating. Thus water enters the coil only at such times and rates as are required to satisfy the varying steam demands of the engine. If the engine requires no steam, the entire output of the pump circulates through the by-pass, but full pressure is maintained in the steam coil. The exhaust steam from the engine is condensed and flows into the condensate receiver. The system is closed to insure efficient operation of the condenser and to protect the hot parts of the system from oxidation.

To further describe the anticipated operating characteristics of the thermally buffered generator, a more detailed explanation is given with reference to Figure B.

One possible configuration comprises a casing having a boiler chamber defined by a top, bottom, and a combustion chamber, all of which are surrounded by a thermal insulation (not shown). Extending through the boiler chamber from a manifold at the bottom to an exhaust manifold at the top are lateral gas ducts and a central duct opening into the combustion chamber. The combustion gases flow downwardly through the central duct and upwardly through the lateral ducts. The steam generating coil has its inlet near the top and its outlet near the bottom of the boiler chamber. The space between coil and flues is filled with modified sodium hydroxide heat storing medium except for a small clearance space at the top. Extending around the injection pump is a by-pass containing a valve responsive to the pressure between the inlet and the pump to by-pass liquid around the pump when the pressure reaches a predetermined

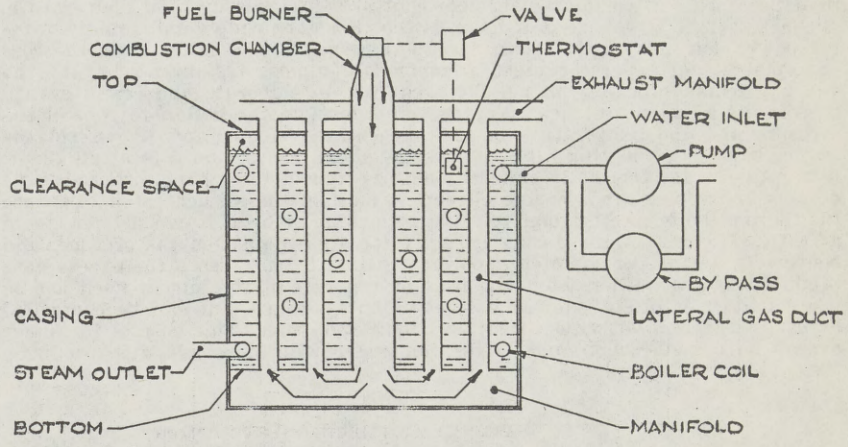


FIG B

maximum. The fuel burner is controlled by a valve responsive to a thermostat buried in the sodium hydroxide near the top which closes the fuel valve when the temperature of the medium reaches a predetermined maximum of 650 F, and opens it when the temperature reaches a predetermined minimum of 625 F, which is above the melting point (605 F).

The pump delivers water at a substantially constant rate somewhat in excess of the maximum required by the boiler, the excess circulating through the by-pass. The characteristics of the by-pass valve are such that the pressure drop across it changes only slightly as the flow rate through it varies from maximum to minimum, and it maintains a substantially constant pressure in the liquid delivered to the inlet to the boiler. Thus the desired pressure can be maintained within sufficiently narrow limits regardless of whether the engine is demanding steam at maximum rate or almost no steam when delivering little or no power. The coil is designed with a length and cross-section such that the pressure drop between entrance and exit at maximum through-put is small; consequently, control of the pressure at the entrance provides adequate control over the pressure of the steam delivered at the exit. Since the coil is completely surrounded by the medium which is limited to a maximum temperature of 650 F, the coil cannot be overheated even if no water enters. The coil is designed with enough surface to permit evaporation of all the liquid in its upper section, the vapor being superheated in the lower part.

Other temperatures in the superheated steam can be produced by the use of other heat-storage materials; for example, modified lithium hydroxide having a melting point above 800 F and a latent heat of fusion of 375 Btu/lb is expected to be useful for producing steam at temperatures near its melting point. Intermediate temperatures can be obtained through the use of mixtures of modified alkali metal hydroxides, with the eutectic mixtures being especially useful.

The benefits of the system can be realized with a relatively small amount of the heat storing medium; for example, in a vehicle weighing 4000 lbs. powered with an engine designed to produce 60 hp efficiently, and with a burner operating at a heating rate equivalent to 18 hp delivered by the engine, less than 50 lbs of the heat storage medium is sufficient to cope with a normal duty pattern providing for such peak-loads as travel at high speed up grades, acceleration, etc.

SUMMARY OF SYSTEM CHARACTERISTICS

The advantages of the thermally buffered boiler over conventional boilers lie in simplification of the control system and in improvement of overall burner efficiency. For efficient engine operation, the generator must deliver steam at a predetermined state, achieved through control of its pressure and temperature. A characteristic of vehicle propulsion is that it makes widely and rapidly varying power demands on the engine. In the absence of thermal storage, the conventional steam generator must accommodate almost instantaneously to the varying demands of the engine. This requires an elaborate and costly system of controls to maintain the necessary water level in the boiler, to control the pressure and the temperature of the superheated steam, and to control the burner so that its heating rate matches the steam generation rate at all times.

In contrast, the thermally buffered boiler is controlled by simple thermostatic devices and requires no sensing elements at all in the steam system. Because the thermal buffer stores relatively large amounts of heat, it can deliver steam at rates in excess of the burner capacity for appreciable lengths of time, and conversely during periods of low power demand, it can absorb the excess heat produced by the burner. Thus the heat output rate of the burner need not be modulated as is often required in conventional designs, but can be controlled by cycling on and off with a relatively long cycle time. This results in higher overall burner efficiency, and a reduction in air-polluting combustion products.

SARASOTA RESEARCH & DEVELOPMENT CORP.,
Sarasota, Fla., May 21, 1968.

HON. WARREN G. MAGNUSON,
Chairman, Senate Commerce Committee,
Washington, D.C.

DEAR SENATOR MAGNUSON: This letter and the pertinent enclosures are being sent to you at the request of our Washington associate and attorney, Mr. James J. Shepard, Jr., following his recent conference with Mr. W. G. Meserve. Mr. Dan O'Neil of your office has also been informed of the work here.

We feel that the subject matter is closely related to the scheduled hearings. Therefore, we respectfully request and urge that the information provided be inserted into the formal report of the hearings.

A U.S. Patent Application, entitled *Low Entropy Engine*, was filed on 6 July 1967 and was assigned Serial Number 651,580 by the patent office. The patent attorneys of record are Wolder & Gross, 521 Fifth Ave., New York, N.Y. 10017.

After the first public demonstration of our prototype vehicle here, we would consider bringing the vehicle to Washington for a public demonstration if such would be of value to the efforts of your committee. We, of course, share the committee's concern with the pressing need to begin significant reduction and ultimate elimination of vehicular air pollution that threatens human health in many parts of the nation today.

Sincerely yours,

WALLACE L. MINTO, *President.*

ANTIPOLLUTION ENGINE

An internal combustion engine has inherent limitations concerning the fuel-air ratios that may be burned within the confining cylinders. Combustion at high pressures results in such thermodynamic equilibria that carbon monoxide necessarily constitutes a significant proportion of the exhaust gases. The high pressures involved require the presence of anti-knock additives, usually lead compounds. Thus, an internal combustion engine necessarily emits substances which are serious air pollutants, particularly under varying load conditions. The most serious air pollutants emitted are carbon monoxide, lead compounds and unburned hydrocarbons.

On the other hand, if hydrocarbons are burned at atmospheric pressure in a flame with excess air, virtually no carbon monoxide results and there are no detectable unburned hydrocarbons. No lead compounds are required in the fuel. The carbon dioxide resulting from such free flame combustion is not a serious pollution hazard.

It is proposed that virtually all of the toxic air pollutants generated by automotive traffic would be eliminated if an efficient and convenient engine were developed which was powered by the heat energy of free flame combustion. This we believe to be fully feasible and to present many engineering advantages in addition to drastic reduction in air pollution.

We propose that a prime mover engine, suitable for trucks, busses and automobiles, be constructed which employs hydrocarbon fuel burned in a variable free flame, the flame and resultant hot gases are used to heat a flash boiler, which preferably contains a low-boiling liquid such as freon 11, trichlorofluoromethane. The vapors thereof are used to drive one or more turbines or piston engines, the mechanical output of which is used to drive the vehicle. A closed cycle is employed for the power fluid, whereby the turbine exhaust is liquified and pumped back into the boiler.

This system has the following advantages over an internal combustion engine:

1. *Virtual absence of air pollutants in exhaust.*
2. Much lower fuel consumption during idling periods, as in city traffic.
3. Lower overall fuel consumption and lesser per gallon fuel cost.
4. *Less heat pollution of ambient air.*
5. Few moving parts and less wear.
6. Since torque-RPM ratio is opposite to internal combustion engine, transmission ratio gearing requirements are reduced.
7. No fluid drive coupling required.
8. Virtually noiseless operation.
9. Smoother power flow over greater speed range.
10. Multi-wheel drive without complex differential gearing is feasible, better traction and acceleration.
11. *Non-fading dynamic power braking* to improve high speed safety.
12. Greater latitude in engine placement and more variable chassis and body design, more latitude to engineer and stylist, hence more model changes possible.

The use of a low boiling liquid has several advantages over the traditional water-steam cycle:

1. *Very short start-up time* because of the low boiling point, low specific heat and low latent heat of vaporization.
2. *No danger of freezing in cold weather.*
3. *Smaller size* of piping, valves and engine because vapor has ten times the density of steam.
4. *Lighter weight* of components because smaller size requires less wall thickness to achieve required hoop strength.

5. *Less expensive* materials of construction of boiler and engine because same pressure is achieved at lower temperature.
6. *Higher overall engine efficiency* because less latent heat of vaporization is lost in liquification stage.
7. *Smaller condenser* because less latent heat of vaporization is to be discarded; greater vapor density requires smaller diameter condenser tubes which are substantially more efficient for heat transfer.
8. *Greater boiler efficiency* because lower temperature required to reach same pressure results in lower stack exhaust temperature, more efficient recovery of fuel heat content.

RELATIVE OPERATIONAL AND COST CHARACTERISTICS OF ENGINE SYSTEMS

	Internal combustion	Gas turbine	Electric	Sarasota engine
Operational characteristics:				
Range per refuel	300 miles	150 miles	50 miles	400 miles.
Refuel time	Minutes	Minutes	4 hrs	Minutes.
Refuel availability	Everywhere	Restricted	None	Everywhere.
Acceleration ability	Moderate	High	Low	High.
Dynamic braking	----do	None	High	Do.
Lubrication requirements	----do	Severe	Small	Small.
Complexity	High	Moderate	Low	Moderate.
Curb weight	----do	----do	Very high	Do.
Monetary considerations:				
Purchase cost	Moderate	High	----do	Low.
Maintenence cost	----do	----do	----do	Do.
Powerplant life	----do	Short	Very short	Long.
Depreciation	----do	Fast	Very fast	Slow.

COMPARATIVE POLLUTION CHARACTERISTICS OF ENGINE SYSTEMS

Urban driving:				
Chemical pollution	Very high	Moderate	None	None.
Thermal pollution	Moderate	High	Very low	Low.
Noise pollution	Variable	----do	None	None.
Fuel consumption at idle	Moderate	----do	----do	Very low.
Throughway driving:				
Chemical pollution	High	Moderate	Not usable	None.
Thermal pollution	Moderate	High	----do	Moderate.
Noise pollution	Variable	----do	----do	None.
Fuel consumption	Moderate	----do	----do	Moderate.

[Excerpt from St. Petersburg Times, May 12, 1968]

WALLACE L. MINTO—PATERNAL RIGHTS ON THE ATOMIC AGE

Several years ago, a Bergen, N.J., newspaper reporter wrote, "It is not enough to say that Wallace L. Minto is a respected scientist with an international reputation and many honors. He is more than that—he's one of the truly prominent members of the brain world. He could be called the father of the Atomic Age. That's saying a lot!"

Perhaps it wasn't saying enough. For Minto, who lives in Sarasota and calls himself an "interdisciplinary scientist and engineer," has accomplished so many noteworthy scientific breakthroughs he forgets to mention some himself when pressed for details by an interviewer.

Here is the man—he's 46 now—who was dabbling with the test tubes and chemical apparatus at the age of 10 and who, at 12, surprised his engineer-father by reading the 1,000 pages of Ostwald's "Chemistry," a textbook for university graduate students, and who then began a series of hours-long debates with his dad on atomic theory.

At the age of 16, he had discovered so many previously unknown secrets about atomic power that some say he was the first to realize its tremendous potential. Minto now admits he could have caused an atomic explosion in his New Jersey basement workshop seven years before the A-bomb devastated Hiroshima!

Because of his youth, Minto hardly got a tumble from prominent scientists of the day. When he announced in 1938 that he had discovered four new elements, including plutonium, which later became the prime explosive used in the atomic bomb, Dr. Harold C. Urey, a Nobel Prize winner, scoffed, "I suspect it's the result of a lively imagination, a young boy's foolish dream."

Years later, between 1940 and 1944, elements Nos. 93 to 96, which Minto says are identical to those he announced earlier, were "re-discovered" by others and added to the official list. He received no public credit for them. A yellowed newspaper clipping of May, 1938, however, reports his findings and on May 7, 1938, he published a full description of the elements which was copyrighted and remains a matter of record.

Months before World War II, Minto and his father had stockpiled the then virtually worthless uranium in the backyard, had built an Atomic Pile in an old steel drum, and had caused the first known uranium atom chain reaction (fission)—the same reaction which is indispensable in the atomic bomb.

He applied for a patent for the pile but the U.S. Patent Office did not take him seriously until years later—after the explosion of the first A-bomb in 1945—when it admitted that perhaps he had had something all along.

His methods of splitting the atom—developed between 1938 and 1940—were the same as those used today in nuclear research laboratories.

While a student at Columbia College in New York City, 1938–42, Minto badgered his professors and Columbia physicists to launch major atomic power research without success. His youth—he was then 19—was against him. As one reporter noted, "Wallace Minto was just too brilliant too soon."

Then in 1942 came the startling intelligence that German scientists were on the verge of perfecting an atomic weapon of devastating power which could quickly decide World War II. The scientists at Columbia suddenly became interested. They urged President Roosevelt to initiate a crash program to develop an A-bomb. FDR did. The program was called the Manhattan Project.

The big need of the project at the beginning was uranium. Who had some? Wallace Minto had 75 tons in his backyard, almost the entire U.S. supply at the time. The Manhattan Project bought it all, shipped it to Stagg Field in Chicago, to launch experiments, and named Minto, then 23, laboratory chief of the project's Special Problems Division.

Recognition, of a sort, had come at last. A citation now hangs on his office wall expressing the "appreciation" of the government for his "participation in work essential to the production of the Atomic Bomb, thereby contributing to the successful conclusion of World War II." It is signed by Henry M. Stimson, Secretary of War.

After the war, he busied himself with research and development—"inventing" things in the fields of chemistry, physics, electrical and mechanical engineering—which won him a place in such professional listings as "Leaders in American Science," "American Men of Science" and "Chemical Who's Who."

In 1950, he developed the Geigerscope, "a poor man's Geigercounter," of which more than half a million have been sold at from $1 to $5 each.

The violet ray flashlight, an infra-massage machine marketed by department stores, an air-ionizer which purifies the air in a room, and a compression closer for plastic packages and brief cases, are only a few of his patented inventions.

The light-reflecting material used on the large, green directional signs on interstate highways, and in highway and airport runway dividers, was created by Minto while still a student at Columbia. He sold it to the U.S. Rubber Corp., for $200 and two suits of clothes "because I needed the suits and some spending money." Today, known as Scotchlite, it is used around the world.

Last year, Minto and his associates announced an important breakthrough in the development of a process for isolating fissionable uranium (used in reactor fuel cores). They say that eventually it may cut the cost of nuclear fuel used by U.S. utilities at least in half.

Minto is a big fellow—6 ft., 3 in., 210 pounds—with neatly combed black, graying hair, hazel eyes and a closely clipped moustache. Dressed in crisp khaki and carrying a swagger stick, he'd be the typical movie version of a British Colonial officer.

He is, in fact, the scion of a distinguished Scottish family—a direct descendant of the first Earl of Minto and of Sir Walter Scott. Two of his great-grandfathers were viceroys of India and governors-general of Canada. William Minto, the renowned 19th Century Scottish mathematician, was a grand-uncle.

When he's not dreaming up some new mechanical contraption or chemical formula, writing scientific articles or researching a problem with the help of one of the hundreds of volumes with unpronounceable titles which line his office walls, he has a number of hobbies. He owns an 18-foot outboard motorboat, and a favorite weekend pastime of the Mintos—Wallace, his fashion-model wife, Marilyn, their three daughters and a son—is island-hopping in the waters off Sarasota and picnicking on the beach of some remote key.

He likes to fish and has a 185-pound tarpon and a 30-foot Mako shark among his angling credits. He's a former New Jersey state rifle shooting champion and he still enjoys target shooting. "I'm not a hunter because I'm opposed to killing animals, but I like to shoot."

He's interested in treasure hunting—the sunken Spanish galleon kind—because it is related to a hobby, collecting Spanish Colonial coins, of which he has a substantial collection. He's a recognized authority on these coins and is often consulted by dealers wishing to establish the authenticity of gold or silver pieces and artifacts offered them.

He's a student of ancient American civilizations and has explored many a Suncoast Indian mound seeking bits of pottery, utensils and weapons.

Today, he has two consuming interests: the development of a soundless, anti-pollution engine for automobiles powered by pressurized vapors from liquid Freon, and research in hydronic radiations.

[Excerpt From the Floridian, May 12, 1968]

Now, a Freon Auto Engine

Wallace Minto started out to design an anti-pollution engine and may have hit on a formula that will revolutionize the automobile industry.

Early in June, he and his associates at Sarasota Research and Development Corp. plan to road test their product—an engine whose double-acting pistons are driven by pressurized vapors created by heating Freon—a liquid with a low boiling point widely used as a cooling agent in refrigerators.

The most exciting aspect of this engine, though not necessarily its greatest potential value, is that its exhaust fumes are harmless carbon dioxide, rather than the poisonous carbon monoxide, nitrogen oxides, lead compounds and unburned hydrocarbons which pour out of the conventional gasoline engine.

It also is virtually soundless. Thus, it offers an answer to another critical problem of today's cities—traffic noise.

Minto is confident it will prove a top competitor with conventional engines in many other categories, too.

It will cost 25 to 50 per cent less to produce than the gasoline engine.

Maintenance expense will be minimal because the engine requires no complex gear trains, no transmission, no fluid drive couplings.

There will be little wear and tear on parts, none of which comes in contact with the open flame (external combustion) which heats the Freon in a flash boiler.

Says Minto: "It should run for 500,000 miles."

This prediction may explain why Detroit's auto makers are not waiting in line to produce it. Understandably, they have little enthusiasm for an engine that may last a lifetime.

Ford Motor Co. engineers, who have evaluated the Minto engine theory, agree it is feasible, operable and non-polluting. They also agree it would cost Ford—or any major manufactlurer, a fortune to switch to mass-producing it while they have billions invested in equipment to manufacture the gasoline engine.

Minto calls it the "Sarasota engine" and it can best be described as a grandson of the famous Stanley Steamer of the early 1900s, with the "bugs" removed.

He explains: "The Stanley Steamer worked, but it had fatal shortcomings. It took 20 minutes to get it heated up enough to run and it wouldn't run at all in cold weather. It was so complicated, the average motorist couldn't cope with it.

"We have overcome these deficits by using modern engineering materials, automated electronic controls and a source of power compatible with weather at any temperature."

It is small (100 pounds) compared to the bulky gasoline engine (600 pounds), but is so potentially powerful, says Minto, that only the structural frailty of body, chassis and tires will limit its speed.

"Its acceleration capacity and maneuverability will make monkeys out of everything at Indianapolis within a few years," predicts Jack Faber, an electrical engineer and Minto associate.

As for versatility, Minto believes it will prove superior for trucks, buses, draglines, cranes, hoists, bulldozers, boats and trains, and for such stationary uses as power plants and pumping stations.

They now are installing the Sarasota engine in a Volkswagen bus, preparatory to testing it. Within a month, with Minto at the wheel and the bearded Faber beside him, it will be driven down North Palm Avenue and over the

Ringling Causeway to Sarasota's beaches. Then the automotive world and that ever-increasing army of air pollution fighters may sit up and take notice. At least that's the hope of the engine's inventors.

Anti-pollution engines are not new. Their development for this purpose, however, is new, and Minto is not the only engineer working on the problem. Steam-powered engines, which are non-polluting, have been built since 1770 when a steam carriage made its appearance in Paris, France. The Austin Steam Car was built in England in 1863. The Stanley brothers created the Stanley Steamer at the turn of the century and it inspired the use of steam power in cars for nearly 30 years. But steam engines for autos never have proved compatible with economy, simplicity of operation or versatility.

Recently, attention has been focused on electric cars but these have so many defects that engineers do not see them in mass-production for many years, if ever.

Meanwhile, all major car makers are trying to meet the challenge of pollution by modifying gasoline engines, attaching gadgets to carbuetors or "treating" exhaust fumes. Thus far, they have managed to reduce pollution only a trifle by such methods, and this small reduction, compared to the need, will be quickly offset by an increase in the number of cars creating the pollution.

The challenge, then, is to eliminate the problem at its source. This Minto hopes to do. Experts say that if this is not done soon, gasoline engines may have to be outlawed.

Frank M. Stead, California's chief of environmental santitation, already is urging that pollution-plagued state to start a campaign immediately to ban all gasoline-powered vehicles by 1980.

A mayor's committee in New York City has urged a program of "mammoth dimensions" to develop a clean, efficient alternative to the internal combustion engine. Otherwise, predicts the committee, the New York City area will become uninhabitable within a decade because of polluted air.

The magazine Environmental Science and Technology reports, "Each year motor vehicles spew into the air 86-million tons of pollutants in the United States. As population grows and more cars are made and sold, the situation is certain to get worse.

Does Wallace Louis Minto have an answer? He believes he has.

So does a group of scientists and engineers who met recently at Florida State University to study the Freon engine. They agreed that potentially it is all that Minto claims.

Meanwhile, a large European auto maker is dickering with Minto to mass-produce it overseas.

ROAD TEST,
THE FACTUAL AUTOMOTIVE GUIDE,
West Los Angeles, Calif., May 26, 1968.

Senator WARREN G. MAGNUSON,
Chairman, Senate Committee on Commerce,
Senator JENNINGS RANDOLPH,
Chairman, Senate Committee on Public Works,
U.S. Senate, Washington, D.C.

DEAR SENATORS: The Senate Committees on Commerce and Public Works have been probing into the array of remedies for alleviating the national dilemma of air pollution . . . including how to cope with a major source of such pollution: the internal combustion engine as used in motor vehicles.

Your present *Joint Hearings on Steam Engine Vehicles* should help enlighten the government, industry, and the consumer public that such "steam cars" are both technologically feasible and practical. Indeed, modern steam cars are inherently superior to present-day internal combustion engine vehicles . . . in terms of their overall simplicity, lack of chemical emissions, economy of operation and maintenance, silence, and total performance capabilities. And many of these same virtues could also be said for some advanced versions of electric vehicles.

In terms of coping with automotive sources of air pollution, one major thrust has been to somehow "clean up" the internal combustion engine as a principal source of toxic hydrocarbons, carbon monoxide, oxides of nitrogen, lead particulates, and other chemicals that are conclusively injurious to human health and environment. It is my professional judgment, as Research Editor of Road Test Magazine and as a human factors engineer and industrial designer, that the extraordinarily complex nature and mechanics of the internal

combustion engine vehicle are antagonistic toward its being "cleaned up" in an efficient, economical, easily-maintainable, and prompt manner.

My recommended approach to your Committees and the Senate is to encourage the further development, mass-production, and marketing of both advanced-design "steam cars" and "electric cars" as viable and rational solutions toward alleviating air pollution as caused by the internal combustion engine.

In support of my contentions, I herewith submit this letter and the accompanying two documents for inclusion in the published record of the Joint Hearings on Steam Engine Vehicles. The two documents are:

—"*Steam—The Answer to Smog?* Written by the Staff of Road Test. Special Steam Car Issue, Road Test Magazine, December 1967

—"*The Truth About the G.E. Electric Car.*" Written by Byron Bloch. Road Test Magazine, February 1968.

Both articles will point out the background, merits, and potential of steam and electric vehicles as viable propulsion systems for motor vehicles. The development of advanced-design versions of these two generic propulsion systems is progressing rapidly . . . and in many innovative versions. Supportive legislation by the Federal Government, acting in the best interests of a suffering public that is beleagured by the health menace of air pollution, is highly encouraged. Such legislation might also serve as a necessary competitive prod to our lethargic and oligopolistic auto industry . . . whose major investment in the internal combustion engine precludes the rapid demise of such a polluting, complex, and quite anti-economical apparatus.

I hope that this letter and accompanying documents, coming from myself as the Research Editor of Road Test, a national monthly automotive magazine of rationality in the consumers' interests, will help point out that (1) there is nothing eternal about the cumbersome internal combustion engine, and (2) that both steam engine vehicles and electric vehicles are viable and emergent systems offering minimal pollution and economy of operation.

Sincerely,

BYRON BLOCH,
Research Editor.

[From Road Test Magazine, December 1967]

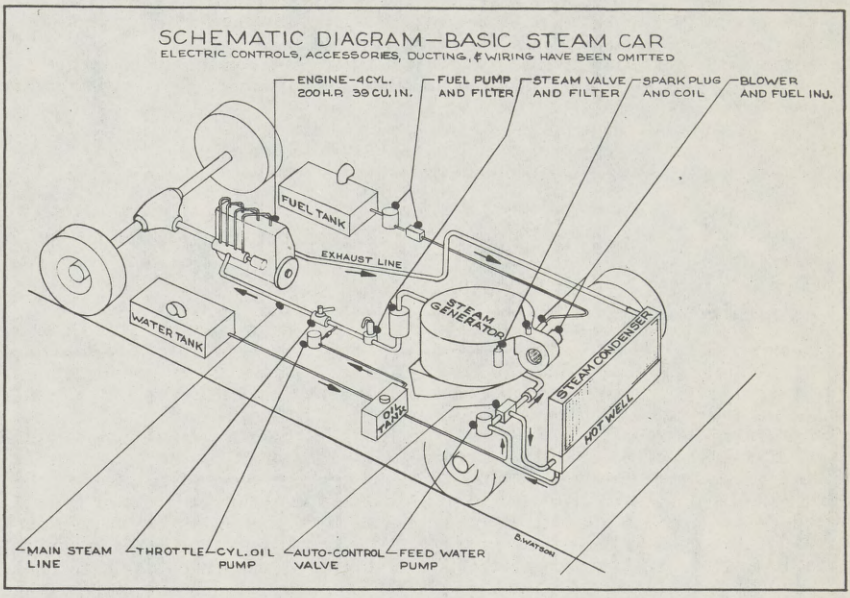
STEAM—THE ANSWER TO SMOG?

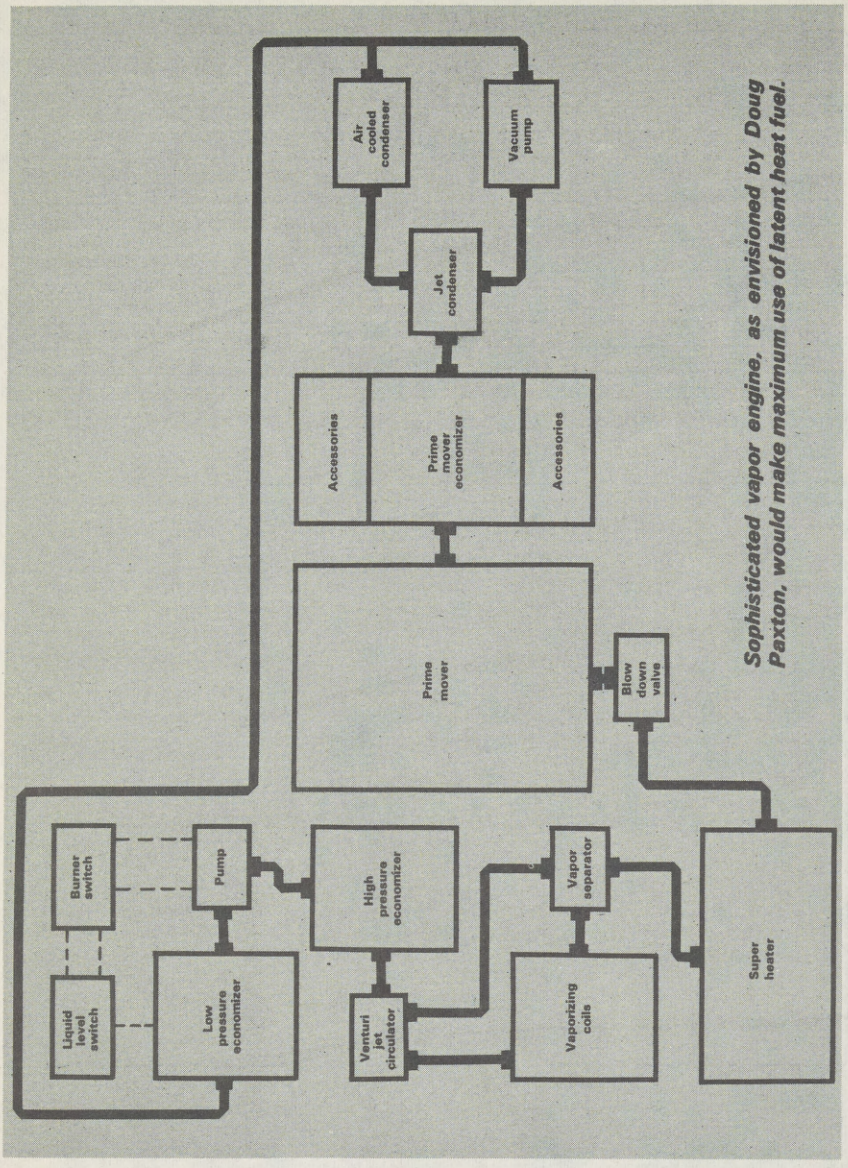
First, check the water and fuel level, if they're not up enough, give them a few pumps. Then open the throttle and drain cock. Next, be sure pilot tank is about one-half full of naphtha, and pump up air pressure to 25–30 pounds. Pump fuel pressure to 125 pounds and check lubricating oil. Push the car outside and leave the emergency brake off. Block the left rear wheel and jack up the right rear wheel. Use a torch to heat up the pilot burner and then open the naphtha valve. After the pilot is burning, play the torch on the main burner jets for about three minutes and then crack open the main fuel valve. If the burner lights, jump into the seat and quickly pump kerosene to maintain 80–125 pounds pressure. Soon you will hear steam and water being blown through the engine drain cock and the right rear wheel will begin to turn. Discontinue pumping (the engine will not take over this function) and when the steam reaches 425 pounds close the throttle and drain cock. Apply the hand brake, remove the blocks and let the right rear wheel down. If you had luck in getting the burner hot the first time and didn't experience a flame-out, it should have taken you about 25–30 minutes to get ready to go.

By now, you have probably surmised that this is the description of the starting of a steam-powered car. Actually, these are just the basic steps. There are many more details of opening and closing valves, checking gauges, setting levers and eye-balling the color of the flame. They were no novelty back in the early 1900's in the heyday of the Stanley and White when steam power was considered superior to the internal combustion engine. The last commercially produced steam car was built in 1930.

	I. C. ENGINE	STEAM ENGINE
Cylinders	8	4
Brake H. P.	200 @ 4400 Max. R. P. M.	200 @ 4400 R. P. M.
Bore & Stroke	4" × 2-7/8"	2-7/16" × 2.3"
Cubic Inches	289	39
Horsepower	282 @ 2400 R. P. M.	437 @ 2400 R. P. M.
Pounds per H. P.	5-3/4 Lbs. with Trans.	1-1/2 Lbs. with Steam Generator
Fuel	Regular Gas	Fuel Oil (Distillate #2)
Weight of Engine	560 Lbs. with Trans.	65 Lbs Engine, 300 Lbs. Generator
Curb Weight	2560 Lbs.	1825 Lbs.
1/4-Mile Speed	87 M. P. H.	98 M. P. H.
Top Speed	122 M. P. H. in 4th	150+ Direct Drive
Water Consumption	None	100 M. P. G.
Fuel Consumption	18 M. P. G.	21 M. P. G.

Hypothetical comparison of steam versus Ford V-8.





Sophisticated vapor engine, as envisioned by Doug Paxton, would make maximum use of latent heat fuel.

Now, nearly 40 years later, the steam automobile is gaining renewed attention because of the specter of air pollution.

Concern over the quality of air we breathe has become a public issue of the first magnitude. But like many important issues facing our society "smog" is widely misunderstood, susceptible to distortion and ignorance. Actually smog in one form or another was a public complaint long before the auto or industrialism. In ancient Rome residents complained that air-borne soot soiled their wool garments. In 1660, London was described as being engulfed in clouds of smoke and sulphur. In the intervening 300 years, air pollution problems have grown considerably more complex. Having smog is like putting money in a savings account. It keeps building up by drawing interest. Nature's means of cleansing the air cannot keep pace with the rate contaminants are dumped into the atmosphere and a backlog is building up fast. The industrial revolution, increasing population and the car explosion has accelerated the contamination problem. Some scientists predict we will be destroyed by our own environment unless immediate action is taken on all levels to fight air pollution.

The auto is being singled out by many critics as the "main" cause of our problems. Auto manufacturers know of no way to "completely" eliminate the air-polluting emissions of the I.C. (internal combustion) engine. Moreover, any reduction of harmful hydrocarbons achieved by 1968 Federal smog controls are likely to be offset by the rising auto population: nearly 70 million in use today, 200 million are seen by the year 2000.

To solve our pollution problems, say leading authorities, a revolutionary and sweeping change must be made in automobile propulsion. We need a power plant that is made to run completely clean and not work at the problem backwards in trying to clean up an inherently polluting device.

A steam powerplant can qualify. Last January, a Williams steam car was tested at Mobil's smog lab in New Jersey. This experiment confirmed the findings of Los Angeles' APCD which checked Edgar Bergen's White a few years ago and called it "lily white." The unburned hydrocarbons, carbon monoxide and nitrous oxide emitted by the steamer were minute fractions of the quantity produced by even the best "smog-device" equipped car.

Fine. But isn't steam a dead issue? Didn't it really pass from the scene in 1915?

"No!", say its proponents who will tell you that there are many individuals who have kept alive a love of their youth, or who have been intrigued by the benefits of steam power for cars (silence, smooth acceleration, long life of components, lack of vibration, simplified drive mechanism) and who have piled up notable developments in spite of working with small amounts of money and no recognition. The advancements made by these mavericks, they say, make steam a real, live possibility here and now.

Before we examine the current state of the steamer's art, let's turn back the clock to the heyday of steam and see what caused it demise.

Historians give many reasons for the failure of the steam powered automobile to gain permanent public acceptance. There were 137 different steam makes at various times and each company probably failed for a different reason. But, a quick examination of the fates of the Stanley and the Doble, the first-largest and last-best should provide sufficient indication of the problems and causes.

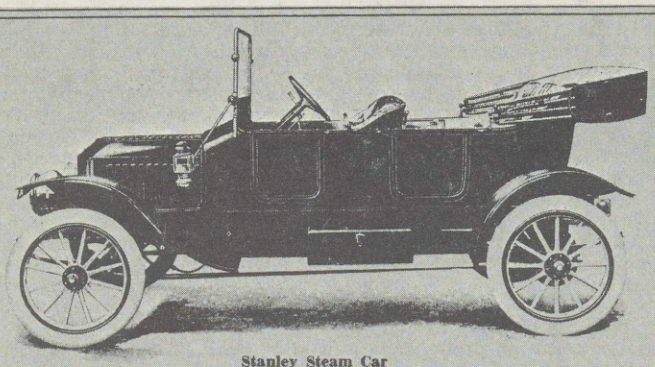
THE STANLEY

The Stanley twins, Freelan O. and Francis E., founded the Stanley Steam Carriage Company and entered the horseless carriage business in the late 1890's. Both Stanleys were ingenious and technically knowledgeable men. They owned several patents in the X-ray and photographic fields and on a gas generator, and were first to apply manufacturing principles to making violins. Their first car was built as an experiment to see how it would perform against gasoline powered cars.

They designed an entirely new boiler and engine that was radically divergent from conventional equipment of the day. The fire tube boiler weighed only 90 pounds and could hold 600 pounds of steam pressure, while the two cylinder, double-acting engine weighed only 60 pounds. In 1897, the little steam buggy outclassed all its competitors, gas or steam in races and hill climbs. Because of their racing success, they soon had many orders for the car.

In a very short time, the Stanleys were producing over 600 cars per year and they had all the business they could handle. It might be well to note at this

point, that the Stanleys were already into their early 50's and they had no thoughts of building an automotive empire. Henry Ford once visited the Stanley factory and inquired as to how many cars they built per year. The answer was 650. The astonished Mr. Ford remarked, "We build that many in one day at my factory."



Stanley Steam Car

MODEL 65, TEN HORSE POWER, FOUR PASSENGERS

Price, $1,300 F.O.B. Factory. Equipment includes top; windshield; speedometer; headlights and Prest-O-Lite tank; electric attachment for lighting gas headlights; electric gauge light; combination oil and electric side and tail lights; storage battery; "Long" horn; black-and-nickel finish. Wheel base, 112 inches; tires 32 x 4; quick detachable rims.

Price of Model 65 chassis including everything on the Model 65 except the body, top, windshield, robe rail, foot rest and the electric parts of the lighting outfit; $1,025 F. O. B. Factory.

It is interesting to speculate on what would have been the outcome had Mr. Ford applied his mass production techniques, business genius and marketing to this type of vehicle. Regardless, historians believe, had positions been reversed, the Stanleys would have lost out again. The Stanley brothers never really had an assembly line; they relied on 300 skilled craftsmen located in separate departments. No attempt was made to cut costs or to apply labor saving methods. They made comfortable profits and saw no reason to disturb the status-quo by trying to improve production, financing or sales.

In January 1906, a coffin shaped red Stanley Rocket driven by Fred Marriott set five world speed records at Ormond Beach, Florida. Top speed was an astounding 127.66 mph. It was over daring feats such as this that writers built up many myths about the performance of the Stanley. One occurred the following year when the Stanley racer was again brought to the beach with improvements made to the boiler and engine. This year, the car crashed due to poor beach conditions but F. E. Stanley estimated that Marriott was doing 150 mph at the time of the crash. Writers later built this to 197 mph. Another myth was that the Stanleys offered $1,000 cash to anyone who would hold the throttle wide open for three minutes.

Although improvements and simplifications were made on the Stanley, the brothers were stubborn men and fought many time-saving accessories. One such device was an automatic water tank filler which was developed by the Mason Regulator Company. To fill the tank you just uncoiled a hose at the side of the car and put the free end into any convenient horse-watering trough, turned a valve and in a few minutes the tank was full. It was only at the insistence of F. O.'s wife that the filler became standard equipment.

A major fault with the early Stanley was its short range. It had to be filled with water every 40 miles because there was no condensing system. And for many years the Stanleys stubbornly refused to install a steam condenser until the cities of Boston and Chicago informed them that they would not be allowed within the city limits. During damp or cold weather the steamers billowed clouds of exhaust steam and seriously hampered visibility of vehicles behind them. Also most public troughs were removed in the early 1900's due to an epidemic of hoof and mouth disease. Production was cut back to only 126 cars per year while experiments were made to perfect a condensing system.

By 1915 the Stanley twins were nearly 70 years old and we must excuse them for not wanting to compete with the now-mushrooming industry greats. This, plus a series of other events greatly hurt the Stanley Company. They had no reserve capital to see them through lean years and were reluctant to borrow money. War-time restrictions further limited production. In 1918, F. E. Stanley was killed in an auto accident. The remaining twin was forced to give up active management due to failing health. The company tried to recoup losses after the war, but sales for high priced cars were dwindling and the recession put the Stanley Company into the hands of a receiver in 1923.

STANLEY RACE CAR



On January 26, 1906, Fred Marriott drove this Stanley "Rocket" to a new world's speed record of 127.66 at Ormond Beach, Florida. Seated at the controls is F. E. Stanley. The wire wheels are 34 inches in diameter and are equipped with three-inch G. & J tires.

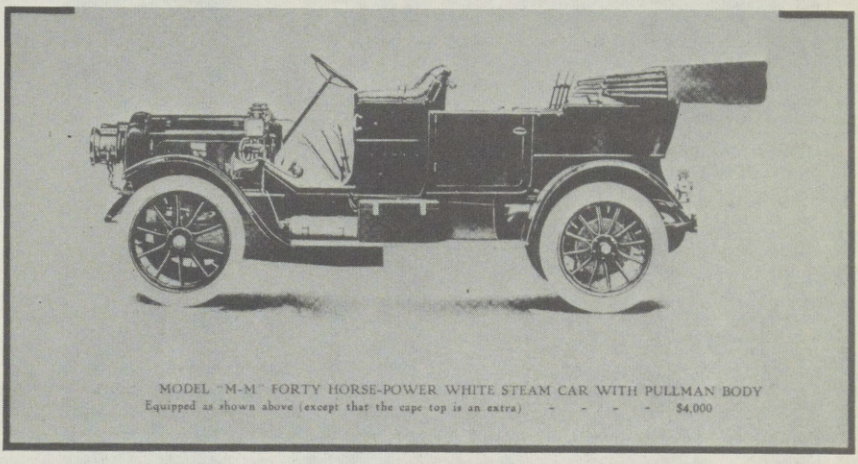
1903


The Incomparable WHITE
The Car renowned the world over, for reliability and for flexibility of control. Steam the motive-power, but not a steamer in the ordinary sense.
An entirely unique system of steam generation with automatic water feed and automatic fuel regulation. High economy compound engine, with condenser; there is therefore no exhaust and the water is used over and over again.
100 miles on one filling of water
WHITE SEWING MACHINE COMPANY
CLEVELAND, O., 300 ROSE BLDG.
NEW YORK, 215 W. 40 St. SAN FRANCISCO, 300 Post St.
BOSTON, 509 Tremont St. DETROIT, 212 Woodward Ave
LONDON, ENGLAND, 35-36-37 King St., Regent St.

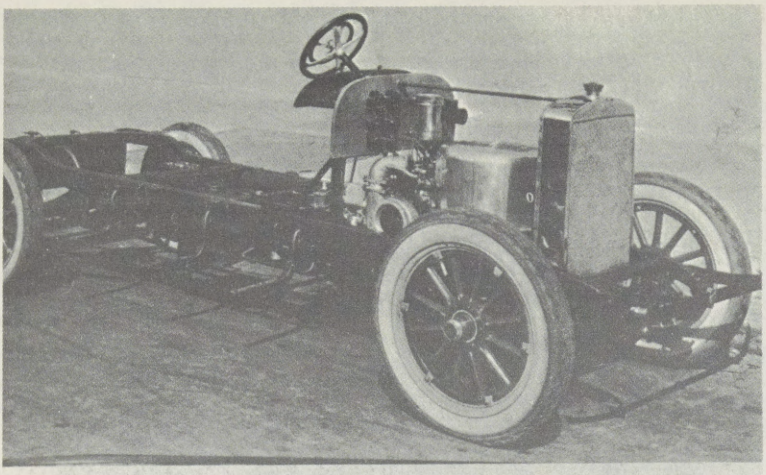
WHITE

The White, with its compound engine, was also a finely built car and used a condensing system from the beginning.

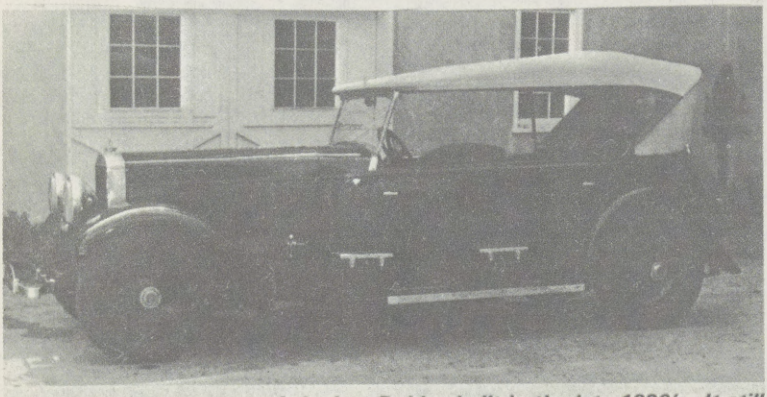
Driving range for the White was considerably longer than the Stanley. The White was built by the White Sewing Machine Company, an old established plant which had a high reputation to maintain. And during the years the White Steamer was produced they continued to make significant improvements. However, the White people were good business men and must have seen the writing on the wall, that the gas engine was gaining preference, and in 1910 they built their first gasoline powered I.C. car. Moreover, like all great companies they looked for a new niche in the market to fill and they soon became specialists in trucks and buses and left the production of passenger cars to other industry giants. As we now know, this was a sound decision.



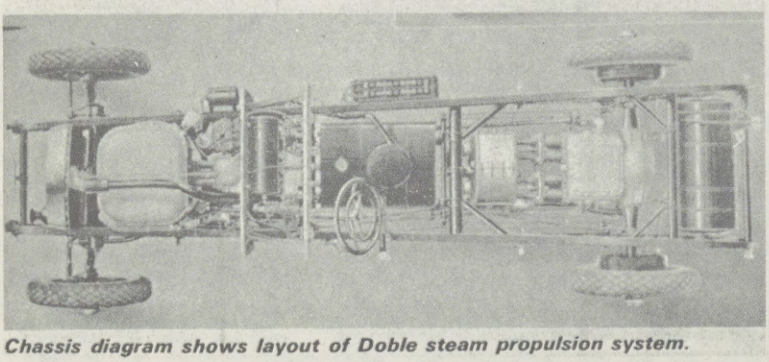
MODEL "M-M" FORTY HORSE-POWER WHITE STEAM CAR WITH PULLMAN BODY
Equipped as shown above (except that the cape top is an extra) - - - - $4,000



This is one of the very early Doble chassis which had not yet reached the state of refinement as shown by car number 24



Car number 19 was one of the last Dobles built in the late 1920's. It still runs today and in perfect condition. Quality in materials and construction is evident throughout. E-19 is now on display in the Marshall Auto Museum, Yorklyn, Delaware.



Chassis diagram shows layout of Doble steam propulsion system.

DOBLE

One more prominent figure was to write another chapter in the history of the steam automobile. In 1917 Abner Doble wrote "The internal combustion engine—the type used in cars consuming gasoline for fuel—has about reached the limits of its possibilities. On the other hand, the day of the steam propelled vehicle—the ultimate car—is just dawning."

Doble was able to look at the shortcomings of the early steam car objectively and not from sentiment. The objections he listed were: "Low water mileage, formation of scale in boiler with resultant drop in efficiency, time and toil in firing up, expensive to run, too complicated to operate requiring intelligent and unfailing attention."

The last was probably the biggest drawback to the steamers. A driver had to pay constant attention to two pressure gauges; boiler water indicator, water and fuel tank gauges (service stations were few and far between) and if any one of these were neglected he was in big trouble. For today's steam enthusiast, who fires up his antique car several times a year for a short ride, this is fun. But for people who had to use their car for every day necessities it was too much.

The 1917 Doble steam car did overcome these objections. When the Doble was introduced at the New York Auto Show, it caused a sensation. Letters passed the 50,000 mark and 700 telegrams arrived from dealers who wanted to handle the car or buy stock. In 90 days, 11,320 orders were received but few cars were built. The War Emergency Board clamped a lid on manufacturing during the war, operations were discontinued and vital materials were turned over to the Government. However in the short time that the Doble Detroit Steam Motors Inc., was in business it booked orders amounting to over $27,000,000.

Production resumed in 1921 with an even more improved and luxurious car. Every option including choice of upholstery and paint was offered the customer and a 100,000 mile guarantee was made on the steam generator unit including the tubing and fire box. The rest of the chassis had a three year warranty.

The Doble was as easy to drive as any car made and it was ready to go in 45 seconds from stone cold after turning on the ignition switch and only a few seconds if the car had been used in the past 10 hours. There were only 22 moving parts, of which 11 were in the engine. It could travel 1,000–1,200 miles on 25 gallons of water, 15 mpg on kerosene fuel and had a lubricating system which used only one pint of oil every 500 miles (oil served not only to lubricate the engine but to prevent the formation of scale in the boiler). Steam, water, fuel pressure and temperature were all maintained automatically. The cars were simple, reliable and smooth.

In all, 24 Dobles were produced, the last in 1930. This brought to a close the last major steam car attempt for many years to come. After 1930 there were only a few lonely steam car experimenters. Those who continued to make a living working with steam applied it to trains, boats, electric generating systems and various other stationary applications.

M'CULLOCH

It wasn't until 20 years later that the next major steam automobile project was started when Robert Paxton McCulloch, President of McCulloch Motors, established the Paxton Division to handle design and manufacture of a prototype car. His company, founded in 1946, was highly successful in marketing two-cycle engines and gas powered chain saws. McCulloch himself, was an engineer and wanted to fulfill a life-long ambition to build a superior car for the discriminating motorist: A car in the $10,000 bracket.

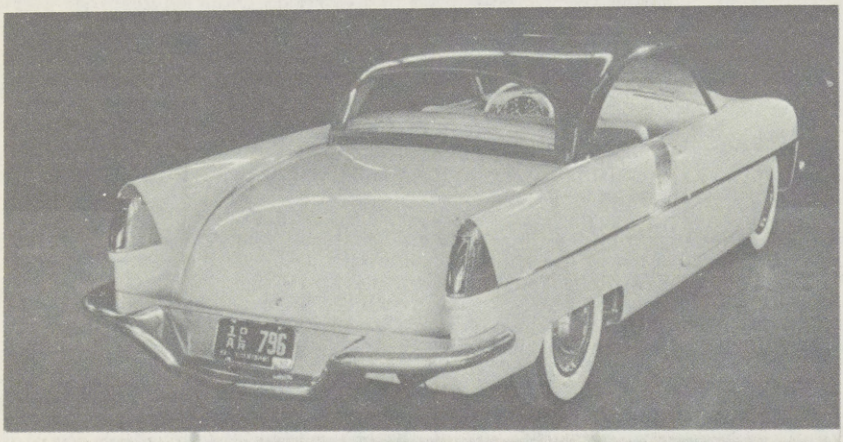
In the beginning, no expense was spared. The body design was given over to Brooks Stevens, well-known automotive stylist and other experts were retained to do chassis engineering. The project progressed well until the one, and only, Paxton was assembled early in 1953. It was to have a radical, new (for that time) internal combustion power plant but research hasn't disclosed if one was ever built and tested. A Porsche engine provided power for initial testing.

It was at this point that Abner Doble was engaged as a consultant to work on an even more advanced steam power plant than the one he perfected in the 1920's. It was a four cylinder, eight-piston compound engine with steam generator capable of providing steam in 20 seconds from dead cold. The engine was dynamometer tested but never installed in the chassis. In 1954 the project

was discontinued. McCulloch termed the Paxton project too costly and felt more money could be made for the company in other fields with less risk.

And so another dream of steam power enthusiasts died, not because of a lack of technology, but because at that time McCulloch estimated it would take 50 million dollars to start up production . . . a sum not too many companies are willing to risk in view of the past business mortality rate among automobile manufacturers.

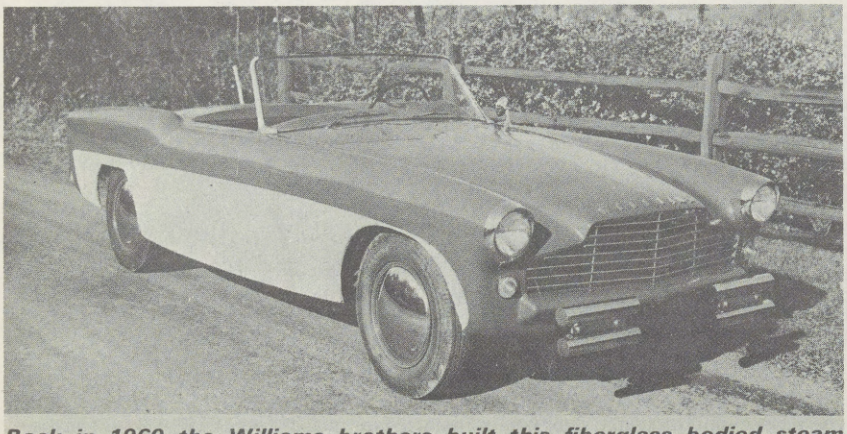
Today, 13 years after the Paxton project there are a number of experimenters hard at work on even more advanced designs. These men believe more than ever that steam will one day displace the I.C. engine in the automobile. In the months to come you'll hear more of these men: Calvin C. and Charles J. Williams, R. A. Gibbs, Thomas Hosick, Richard Smith, Don Johnson, Roy Ferrier and others.



The one and only Paxton used a Porsche 1500 engine for testing purposes and although work was well along on the steam power plant, it was never installed. Lack of money was the demise of this project.

WILLIAMS

The Williams Engine Company, Inc., is located in the small town of Ambler, Pennsylvania. It has been a family-operated steam engine business for 80 years, being founded by the grandfather of the present proprietors Calvin E. and Charles Williams. Calvin C., has spent his entire life on research and development of steam power culminating in the patented "Williams Steam Cycle," an impressive



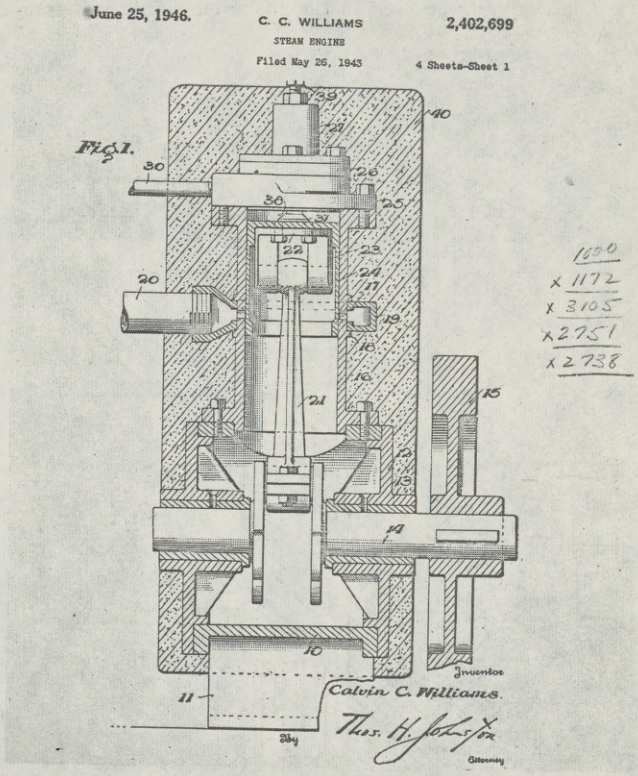
Back in 1960 the Williams brothers built this fiberglass bodied steam roadster. The car now has over 25,000 miles of testing on the odometer and is the same one which participated in the Mobil Oil Company smog test in Paulsboro, N.J. in January of this year.

new development in steam thermodynamics. The twins have been working with their father since 1936 and have designed, built and tested many steam power plants from fractional horse power to over 500 hp.

They say they have spent over one million dollars on these projects to date.

To prove a few points, the Williams brothers cite tests made at the University of Pennsylvania and other facilities. These tests showed a reduction of over 50% in the use of available steam (pounds per hour) because of the Williams Cycle. The Williams Cycle which has a thermal efficiency of 27–30% on the road is not a rejuvenation of the old Stanley, White or Doble that operated on the Rankin Cycle and showed thermal efficiencies of only 6–12%. The improvement is gained by building 'compression' in the cylinder on the exhaust stroke to equal the pressure of incoming steam, rather than creating low pressure. Then, in January 1967, at the request of Ford Motor Company, a seven year old steam roadster which the Williams built as a test car was driven to the Mobile Oil Company lab in Paulsboro, N.J. for a smog emission test.

STEAM ENGINE PATENT (WILLIAMS)



This is a vertical cross-section of the Williams engine. The Williams Steam Cycle uses superheated steam to increase the efficiency of the engine which results in less feed steam for given work and corresponding economy of water and fuel.

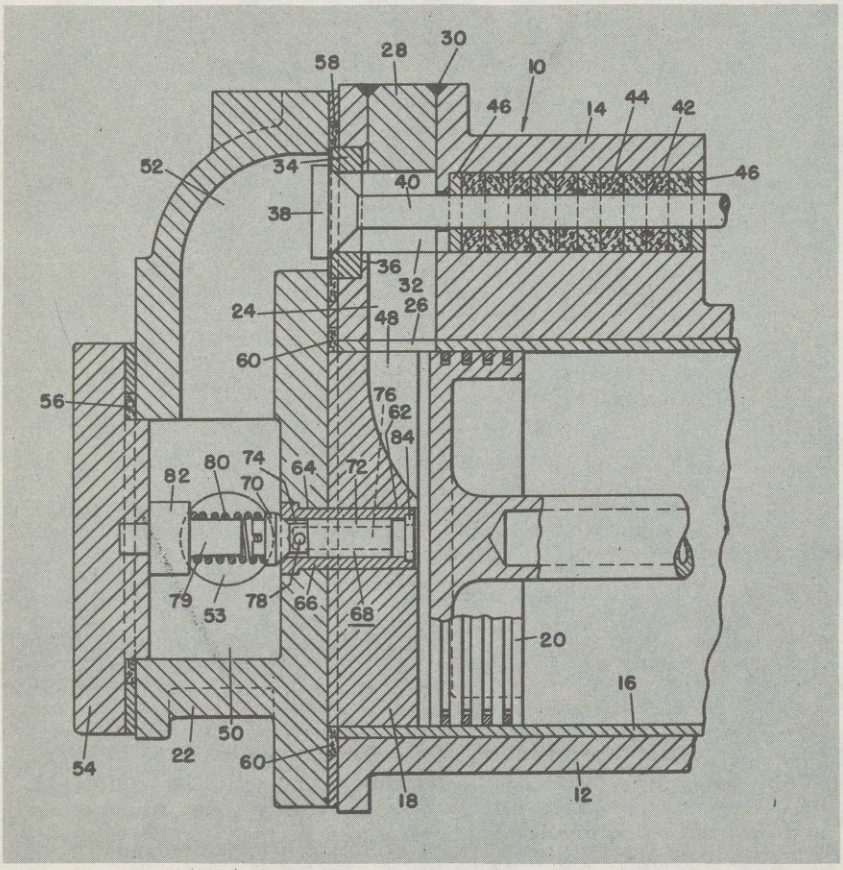
The car has over 25,000 miles on it and on the way ran 80 mph down the N.J. Turnpike. Results of the test showed only 20 ppm of hydrocarbons as compared to 275 ppm on '68 vehicles by Federal standards. Cars without anti-smog controls emit between 800 and 1,000 ppm. Carbon monoxide level is only .05% compared to 1.5% permitted. At the time of the test no attempt was made to reduce harmful

emissions, however the Williams feel they can reduce this to 2–3 ppm, practically smog free. The big difference in hydrocarbon emissions is because in a steam generator the flame burns 'all' the fuel (there's no time limit) and has an unlimited supply of oxygen. In an I.C. engine, a spark ignites the fuel/air mixture and it only has a fraction of a second to burn, hence there is a thin layer of fuel that is not consumed. This thin layer is the origin of the partially reacted hydrocarbons that pass into the atmosphere through the exhaust pipe.

At the present time, the Williams brothers are installing their steam power plant in 10, 1967 Chevrolet Chevelle cars and in one Fairlane (for Ford Motor Company).

The Chevelles will sell for $10,250. But Charles Williams says the high cost is due to the low quantity and that each car is practically hand built. "In mass production our steam automobile could be built at less cost than the I.C. automobile. We have fewer parts (no expensive automatic transmission, drive shaft, U-joints, etc.) and only four cylinders which give the same power impulses per revolution as a V–8 I.C. engine. We have always felt there was a market for a steam car even if just for those people that liked something better and different. Now, of course, there's the smog factor to consider, too."

The Williams brothers are probably further along than any other current experimenters. The engine to be used in their Chevelles will be a four cylinder



Shown is a sectional view of the Williams balanced steam feed valve and regulating valve for maintaining the compression pressure of the engine equal to the steam operating pressure. It maintains this balance even if the operating pressure is varied.

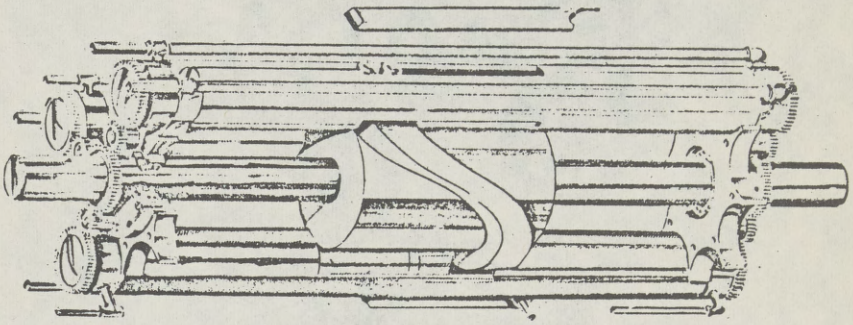
in-line, single acting type of 105 cubic inches displacement. With 1,000 psi steam pressure it puts out 150 hp continuous and up to 250 hp intermittent (passing, steep hills, etc.) At 2400 rpm the Chevelle will cruise at 60 mph. It will have a top speed of 120 mph plus.

All is not running smoothly though. The Williams Engine Company is small and is having government priority problems with suppliers of critical castings and other components. There is an unwritten law of bumping rights to firms with larger orders, but it seems as though the Williams are conditioned to this and are determined to produce steam automobiles. Who knows. The Hamlet of Ambler may become famous as the birthplace of a revolution.

CONTROLLED STEAM DYNAMICS

Out West, there is a research and development firm called Controlled Steam Dynamics, Inc., of Mesa, Arizona. Don Johnson, President of C.S.D. has also come up with a new patentable steam engine design.

According to Johnson, the practical solution in the steam engine field as applied to automobiles, is a compact, lightweight energy source. Right now, as in the past, the biggest single piece of equipment is the steam generator or boiler. Johnson's device is not a conventional boiler such as might be envisioned but a complex of high-strength tubing super heated by a direct flame in the combustion chamber. Start-up time has been reduced. "You can get a car moving from a cold start in four or five seconds and develop full power in ten. And that's faster than most I.C. engines," says Johnson.



At the other end, Johnson's engine has eight pistons arranged parallel with the main power shaft. A helix on a rotating drum operates as a camshaft for the pistons and takes energy on the power stroke. The eight cylinder engine is said to produce about 600 hp and weighs much less than an average I.C. engine.

Johnson says that C.S.D. is basically a research and development company and he doesn't intend to get into manufacturing, leaving that to someone else. However, there is an Indy racing car on C.S.D.'s drawing boards which will use Johnson's new engine, hopefully in 1968.

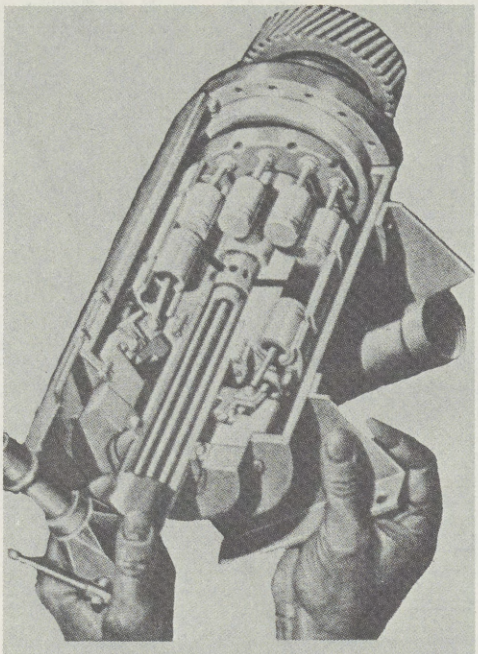
STEAM MOTOR SYSTEMS

About 425 miles south of Ambler is Winston-Salem, North Carolina where another small firm, Steam Motor Systems is also experimenting with a revolutionary new type of steam engine said to be capable of producing over 1000 hp., it is of nine cylinder, 18 piston configuration.

R. A. Gibbs and Thomas A. Hosick got the idea for this engine from a 1964 Popular Science Magazine cover illustration. It was an I.C. engine but they thought it would work better on steam. The finished engine differs from the original concept, but the general idea remains the same. The team of Gibbs and Hosick call their new baby an "Elliptocline," derived from the motion of its pistons which travel in an inclined elliptical path.

The Elliptocline can best be described as a rotary-reciprocating uniflow steam engine of the opposed-piston, parallel orbiting cylinder type. Open-end cylinders orbit around a central chamber containing a single stationary steam distribution valve which properly times all steam movement events that must be valved in the engine. Each cylinder carries two opposed-motion, single-acting pistons work-

ing against inclined bearings at each end of the rotary block. Initial tests of this engine showed it to be so vibration free that a nickel could be balanced on edge at several hundred rpm.



The model XG-2000 Elliptocline has nine cylinders and 18 pistons. Bore and stroke is 2 3/8 x 2 1/2 inches. Gibbs and Hosick estimate that at 2000 psi steam pressure nominal horsepower is 1000 at 2900 rpm.

The latest experimental Elliptocline displaces 200 cubic inches and weighs under 300 pounds. According to the investors it develops 1000 hp at 2900 rpm at 2000 psi steam pressure. It is not a big engine. Cylindrically shaped, 28 inches long and less than a foot in diameter, it will easily fit into any car or truck. Clearly, it is best suited to furnish the power required by today's big tandem-rig trucks.

Gibbs and Hosick are also quick to point out that the steam engine has remarkable overload capabilities for acceleration and passing. "These momentary outputs may be as high as five times the nominal power plant rating." They say, however, this is only true if there is a big reserve of steam and the ability to replace the steam quickly for continued operation. So far, no one has such a generator system suitable for automotive use.

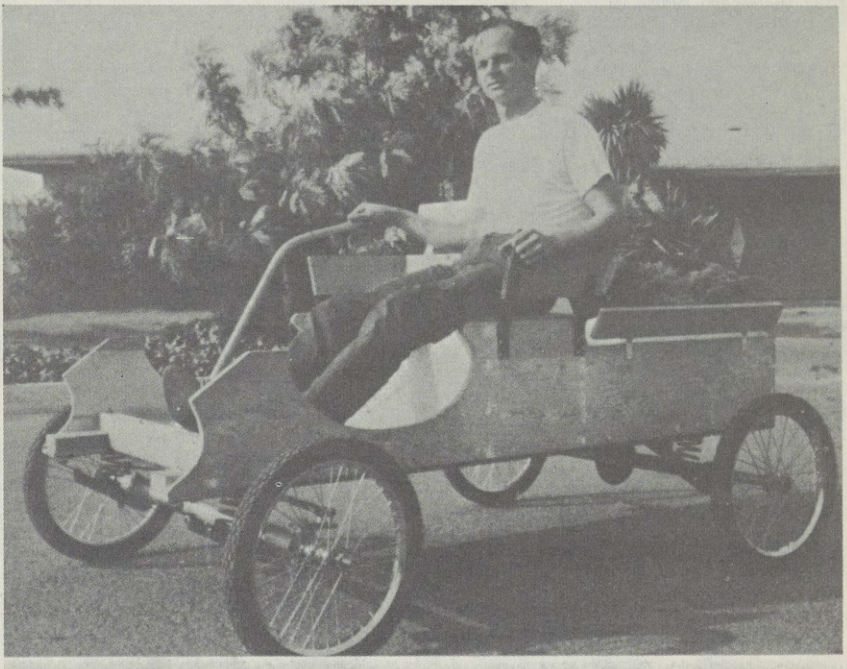
RICHARD SMITH

In Midway City, California, consulting engineer, Richard Smith has been working on steam research and development for the past seven years and has applied for a patent on a novel steam distributor. To date, he has built a steam Go-Kart, a steam buggy and a steam surfboard.

In his latest experiments, Smith has converted a 40 hp Mercury outboard motor to run on steam. To do this, he has closed off the exhaust ports and uses the intake for exhausting. Steam is admitted via a special fitting in the spark plug

holes. On steam, the 42 cubic inch engine is said to develop 400 foot pounds of torque at stall and 250 hp at 6,000 rpm with 1000 psi. Smith has also worked out a lightweight, compact steam generator. It uses thin-wall copper tubing enclosed in a stainless steel shell and operating temperatures can be attained and held in from five to 14 seconds. At first, steam buffs were skeptical at Smith's choice of copper tubing but they now admit it works and works well.

The combustion chamber is also jacketed in lightweight stainless steel (the type used for pots and pans) and is fired with a standard spark plug. Steam is exhausted through a combined spray condenser and feed water heater. According to Smith, "water loss is virtually nil," and he estimates that the generator is 90% effective.



Consulting Engineer, Richard Smith with his experimental steam powered buggy. Projects such as this are lots of fun to build as any steam buff will attest.

His new rotary steam distributor valve works much like a fuel injector system, releasing high pressure steam at timed intervals to deliver the power to the pistons. A stock Mercury timing belt drives the distributor valve through the old magneto drive.

Just this year Dick stuffed everything into a '58 Volkswagen (actually it fits with room to spare) and is using the set-up as a test vehicle.

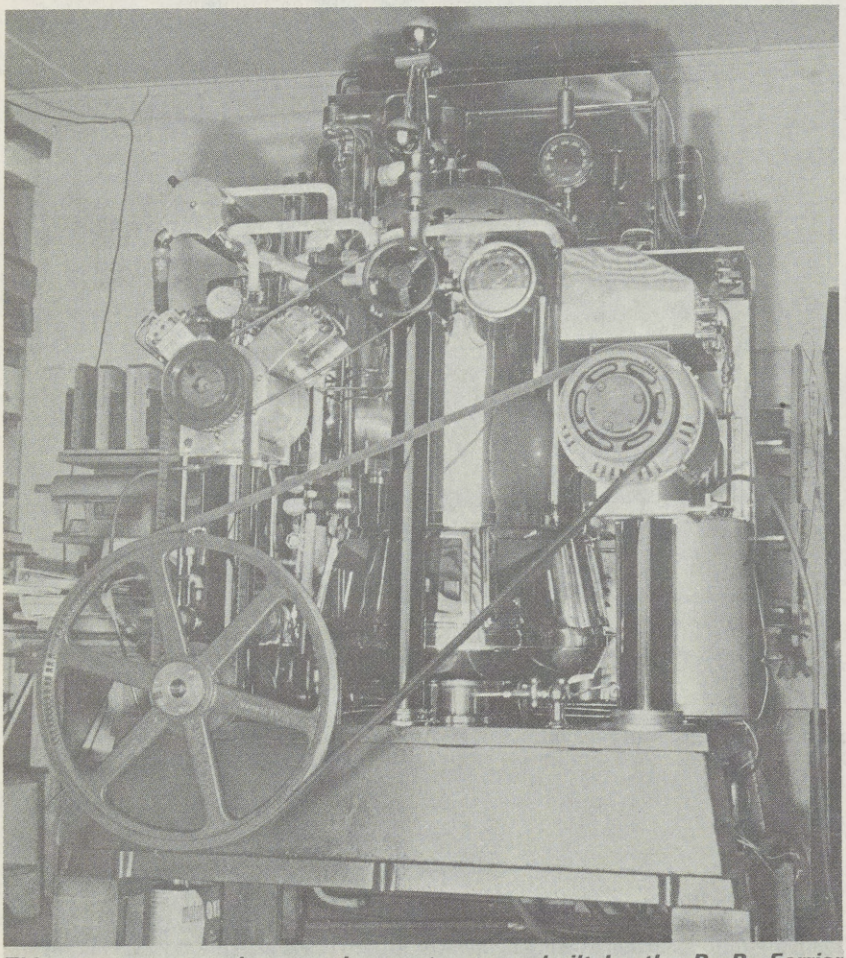
R. R. FERRIER CO.

Another Californian, Roy Ferrier has been in the engine business for over 40 years, with the last 10 devoted to steam. The Los Angeles-based R. R. Ferrier Company builds custom steam engines for all purposes as well as carrying on its own research and development work. In addition, Ferrier is a consultant to the Marquardt Corporation, whose prime interest at this time is in small electric generating systems.

Roy Ferrier has developed what he calls "a modern steam engine." It's a V–4 in configuration and so uncomplicated that it uses no castings. The complete engine is built from standard stock aluminum except for the cylinder sleeves which are steel tubing and the center core of the crankshaft which is steel rod. Ball bearings support the crankshaft as well as the rod ends and the wrist pins operate in needle bearings. A complete 17 cubic inch engine weighs less than 40 pounds.

Ferrier hasn't tried to apply his steam engine to an automobile yet because he believes no one really has the answers to building a good steam generator that can keep up with the demand called for by a modern day car.

Several of Detroit's auto makers have been out to look over Ferrier's operation and see what he's working on, but have never made any comment. Roy believes they just want to see the size of the company and reassure themselves that no one is about to threaten their empire with a significant breakthrough.



This steam powered generating system was built by the R. R. Ferrier Company and is completely automatic. It can provide electricity, heat and air conditioning for a seven room house. Unit is to go on display at the Los Angeles Museum and will operate during regular hours.

WHERE DO WE STAND?

There are many experimenters around today who have perpetuated the automotive steam engine idea. Over the years their tireless efforts have resulted in significant discoveries in all areas. It's also interesting to note that each one is working on his own pet project and no two are alike. Consequently each one is having technical problems with one or more important parts of the total system. Moreover, the companies are small and grossly under-financed to carry on energetic research with modern-day test facilities. Much less the ability to build a giant manufacturing facility for the production of a steam automobile. Some cars, like the Williams project, will be built but because of the price, and some technical problems, they will only be bought by enthusiasts.

However, there is no doubt that the technology is here today to build a steam powered car equal to or better than the I.C. engine car. And most important, it is a rapid, practical solution to our serious air pollution problems.

Dr. John T. Middleton, head of air pollution control of the United States Public Health Service wrote: "We can no longer tolerate the destruction of our air resources by the gasoline-powered motor vehicle. The importance of the motor vehicle and petroleum industries to the economy and wealth of America requires that their manufacturing and production ingenuity be exploited for the development of propulsion systems which do not pollute the air. The issue is not so much removing the motor vehicle but rather having a power plant which produces no pollutants."

It might be added air pollution damage costs our nation 12 billion dollars annually.

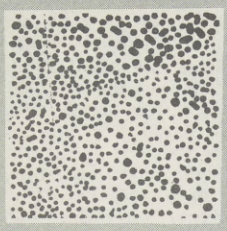
Why aren't we using steam propulsion now?

The crux of the matter is money or, rather a lack of it. Unfortunately, as long as the steam-powered automobile remains in the hands of small manufacturers or unsubsidized inventors it can never be made available for general use.

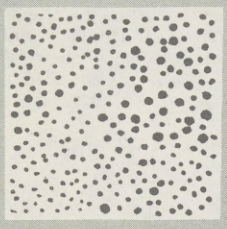
The I.C. automobile has been lavished with fifty years of improvements and tailored to the buyer. It will be hard to replace it because of mass production, mass marketing, advertising and planned obsolescence. Oil companies and auto manufacturers are reluctant to make changes, preferring to protect the multi-billion dollar status-quo, but the American people deserve clean air. A change-over to steam could insure cleaner air.

To those who say we can't afford to change, Road Test says we can't afford not to change.

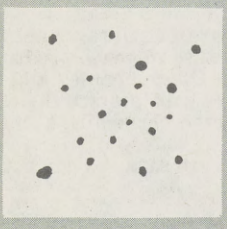
POLLUTION COMPARISON



1963 Jaguar XK-E
No smog device
Tested April 1967
following tune-up.
Hydrocarbons 596 ppm



1967 Plymouth Barracuda
California smog device
Tested April 1967
following tune-up.
Hydrocarbons 267 ppm



1960 Williams steamer
No smog device.
Tested January 1967
no tune-up.
Hydrocarbons 20 ppm

PAXTON VAPOR ENGINE

One inventor who has been well outside the main stream of steam progress and who has been "sitting on" a radical vapor engine for the past ten years because he was "doing something nobody thought we needed" is Douglas R. Paxton.

Not related to Robert Paxton McCulloch, who gave his middle name to a steam car project, Doug Paxton almost brought his idealistic dream to fruition in 1957 after more than two years of designing and building. Yellowed newspaper clippings from the Ventura County Star-Free Press in Paxton's home town of Ventura, California, tell how the largely self-educated engineer and his two partners spent thousands of hours laboring over the revolutionary "Paxton Vapor Engine" and of their plans for applying it to stationary power uses as well as a racing car.

Even after discounting the usual newspaper over-statements, Paxton's story has a lot of fascination. Three models of the engine-system were built and reliable accounts state that a fantastic amount of power was developed from an installation of small size and weight.

The hardware does not exist today but Paxton's notes definitely show that he has a unique, fully-developed and highly sophisticated thermodynamic unit.

NOT STEAM

The term "Vapor Engine" is insisted on by Paxton because the working medium used is not watersteam but a common chemical which is cheap, readily available and nontoxic. Its advantages according to Paxton, are several including the property of being a lubricant for metals (thus requiring no oil dilution) 500-to-1 ex-

pansion on vaporization and requiring less heat to remain in a super-heated state than water.

Aside from this aspect, the engine-generator system is notable in that the principles of heat-exchanging are carried to great lengths, thus delivering maximum economy.

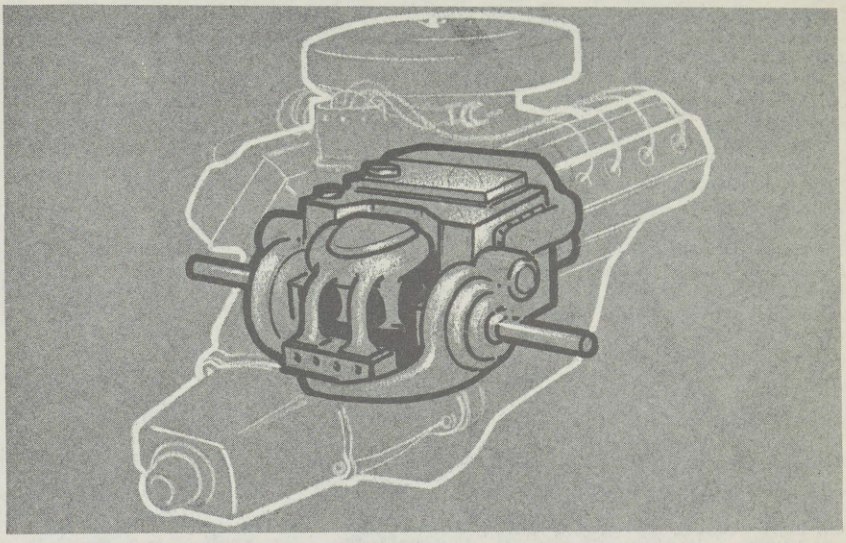


Illustration shows the comparative size of the Paxton design as to a Chrysler V-8. Also note figures below.

	PAXTON	CHRYSLER
Weight	200 Lbs.	850 Lbs.
H. P.	800	425
Lb./Ft. Torque	16,000	350
M. P. G., Full Power	15	12-14
M. P. G., Normal	30-50	14-18
Fuel	Kerosene	Gasoline
Cubic Inches	50	426

The Paxton vapor engine consists of six sections. They are: (1) the burner, (2) the generator (often called a boiler), (3) the prime mover, (4) the prime mover economizer, (5) the condenser and (6) the auxiliary equipment section. Each of these embodies certain features of unique design or usage of new materials. The burner uses multiple carburetors working progressively according to the thermostatically-transmitted demands of the working medium. For example if the demand placed upon the working medium by a heavily loaded prime mover requires a fast circulation of that medium, the heat in it would be used up. In this case, several burners would go into action, providing the heat required to maintain the working medium at the level which will produce the most power.

On the other hand, when the engine is at rest one carburetor can provide enough heat to maintain the working medium in a ready state and take care of losses experienced from radiation.

The multiple carburetor system insures continual supply of heat at an economical rate. These burners obtain air through a heat exchanger system that preheats the intake air utilizing exhaust heat which would otherwise have been lost and reducing the span of temperature required to be raised.

The second section of the Paxton engine includes several subsections, within itself. Physically, this section is made up of hundreds of feet of coiled special alloy thin wall tubing. The working medium is carried through the tubes and

subjected to heat from the flame and exhaust gases. Prior to exposure to the direct flame, the medium moves through a series of coils called the low pressure economizer. This brings the temperature of the medium up to a point that requires less heat to vaporize. After the medium flows through the direct flame area, it goes into the vapor-separator section to remove any non-vaporized medium. The vapor goes on to another set of coils exposed to the very high temprature exhaust gases for super heating, while any non vaporized medium is recycled through the burner section. The vapor is heated to such an extent here that it arrives at a near perfect state.

The third section, the prime mover, appears much like a four clyinder, flat opposed reciprocating engine. It is much smaller than a Volkswagen unit having a displacement of only 50 cu. in. It has a very beefy block enclosing a crank shaft which is operated by a Scotch yoke at each piston set. The working medium is brought from the generator section through tubing and placed at the intake valves. There are no restrictions between the generator and the valves whatever, so that the medium is at full pressure right at the valve itself.

Conventional steam engines use a combination of two valve systems. The first is a throttle valve which limits the flow and pressure of the vapor. The second is a valve which opens and shuts during a specified portion of the piston stroke. The Paxton engine does not use the first valve at all. On most steam engines the cut-off valves are not infinitely variable, creating certain problems at varying load conditions. The valving on the Paxton engine is, however, infinitely variable and is in fact, the control for the engine.

To illustrate this all important feature, suppose the driver of a Paxton powered car wished to proceed at a slow speed. Here is what happens: His throttle setting would, through an ingenious camming device, open the intake valve all of the way for a short duration of time, which is in turn directly timed to a portion of the piston stroke. This action allows fully super-heated vapor to enter the cylinder under full pressure in measured amount. Expansion of the vapor pushes the piston and turns the crank, not the flow. This takes the full advantage of the medium's expansion qualities. To sum up the Paxton engine, one could accurately say that this feature produces the greatest results. The total of the other features together go to make this one work.

To complete the cycle of action in the prime mover section the medium must, of course, follow a path out of the cylinder by way of an exhaust valve. It is important to point out here that the full potential of the medium is never completely used up and a portion of its expansion qualities are exited from the cylinder. The amount is determined by what has been taken from it in the form of work.

At this point we go to the prime mover economizer section. This section has two reasons for being. One is to turn the remaining potential of the working medium into work. The other reason is to smooth out the pulsations of the pistons. This section is made up of turbines propelled by exhausted "steam" and coupled to a drive shaft through a torque converter.

In addition, auxiliary equipment drives are located here. After the working medium exits this section, still more energy can be recovered. The very first steam machines utilized the principle of creating a vacuum by suddenly cooling the working medium. The Paxton engine also uses this method of extracting power in the first action of the condensing unit. As the working medium exits the turbine, a nozzle sprays ambient medium to cause immediate partial condensation which in turn creates a partial vacuum at this point and increases its efficiency.

At this point the working medium splits its path. That portion of the medium which has condensed, still retains considerable heat. It moves to the liquid storage area. The uncondensed vapor moves into another heat exchanger which acts to finish the condensing cycle. After condensing, it too, courses on to the storage area. The heat removed during this last effort is piped back and used again.

The final section involves such items as pumps and electrical generators that provide flow and pressure for the engine. These are much the same as is seen on any automotive engine and are driven from the turbines.

A verbal description of the Paxton vapor engine could lead one to conclude that this is a complicated device. It is not. What has been described here has mostly involved the phenomenon of fluids and gases. The mechanism itself is simple with few moving parts. This engine could be produced for automotive use at a cost competitive with our present engine/transmission units. Combine this

economy with the following authenticated test results and you will ask why this design lies dormant and is not in use. The Paxton engine produces 882.1 hp at 600 rpm (more at higher rpms). It weighs 212 pounds (the entire engine including all equipment). The unit produces 16,723 lb. ft. of torque at one rpm and 12,586 lb. ft. of torque at 1,000 rpm.

Why hasn't this engine and its inventor been successful? There are two answers. One, the time for a change have not been right until now. Paxton, like many inventors, was ahead of his time ten years ago. Two, he expended his funds and needs an investor . . . not just anyone with the money but someone who is interested in and understands the project and its idealistic goals. Road Test will put qualified people in touch with Mr. Paxton.

[From Road Test Magazine, February 1968]

The Truth About the G.E. Electric Car

(By Byron Bloch)

Does General Electric have an electric car? Yes, indeed, though there's still a bit of mystery about what G.E.'s released publicly versus what the substantial rumors claim they've really got under wraps. If the General Electric developments are as far along as now appears feasible, they could well serve as the necessary catalyst that might *revolutionize*, rather than evolutionize, the entire automobile industry. The avant-garde electric car would not only bring an end to the near-catastrophic problem of air pollution, but would also offer major benefits in economy of operation, ease of maintenance, high reliability, silent running, versatility of vehicle design, and could lead to a decentralization of automobile manufacturing away from the present-day 'Big Three and a Half.'

To fully understand and appreciate the General Electric electric car saga, it is enlightening to trace certain developments over, especially, the past two to three years . . . including technical reports, Senate Hearings, Ralph Nader, and other sources.

COMES THE REVOLUTION

How did GE get so involved with electric cars in the first place? As the pieces of the GE puzzle now seem to fit together, the story began over four years ago, though intensifying in early 1964. GE management was logically prompted to 'keep in touch' with electric car developments . . . just in case a potential market might develop for GE's electric traction motors, electronic control systems, fuel cells, and metal-air batteries. Thus, they decided to assign their researchers to probe what might lie ahead.

Some of these creative scientists, especially a few at GE's 'think factory' in Santa Barbara, California, began to realize that the advanced technological capabilities at GE (and elsewhere) could quickly lead to a truly modern electric automobile with a total performance that would rival that of a typical internal combustion engine automobile . . .

(*Coincidentally, General Motors Corporation also has research laboratories in Santa Barbara, where creative scientists have been working on a 'secret' GM electric car that unites a small internal combustion engine (ICE) with a generator, rechargeable batteries, and electric traction motors. The engine speed is regulated at a low, fairly constant rate which, in conjunction with the small engine size, minimizes the emission of pollutants. Thus, GM has a 'hybrid' ICE-battery electric car under development . . . versus the equally-secretive GE 'hybrid' fuel cell-battery electric car.*)

The GE staff recommended the building of a prototype modern electric car as the next logical step. The optimum design appeared to be a blend, or 'hybrid' of refuellable fuel cells—for normal motive power, and to maintain a continuous full-charge on the batteries—plus powerful, quick-recharge metal-air batteries—for abundant reserve power in peakload conditions, as in climbing hills and passing situations.

In the meantime, GE had also funded a small-scale electric car project at the Illinois Institute of Technology, under the guidance of IIT's Professor Jay Doblin. GE next parlayed all of its electric car energies back east to a combination of its motor-generator and transportation research facilities in Erie, Pennsylvania; to its electrochemical research and development facilities in Schenectady, New York, and to its aircraft accessory turbine department in Lynn,



Massachusetts. At least two basic electric vehicle designs were to be developed: a rather conventional battery-powered vehicle to approximate the non-GE state-of-the-art; and a much bolder look ahead . . . the "hybrid" fuel cell/quick-recharge metal-air battery version that would compete with, and even transcend, tomorrow's Mustang. (*For the sake of convenience, the latter GE vehicle will hereafter be referred to as their "ElectroCar".*)

True to GE's corporate slogan that "*Progress is our most important product*", the exciting progress embodied in their evolving ElectroCar project exceeded the expectations . . . or probably even the wildest dreams . . . of GE's top management. The ElectroCar was shaping up as an excitingly-styled, ultra-modern four-passenger hardtop sedan . . . with cruising speeds in the 60 mph category, and a range exceeding 200 miles . . . easily refueled-and-recharged in a matter of minutes. Performance, size, durability, economy, style . . . it was all there!

What do you do with a revolutionary electric automobile that could cause havoc to the existing auto and petroleum industries . . . two of GE's best customers. The answer could not be arrived at too hastily, for even our national economists and politicians . . . not to mention the highly vocal auto-oil industry spokesmen . . . frequently proclaim loudly that cars and petroleum are, after all, the very "foundation" of the American economy.

While management hesitated, the creative GE researchers were innocently expounding their capabilities and achievements. And just in case GE might decide to become the fifth major automaker in the U.S., and thereby perhaps need a partner, GE management reportedly held some preliminary on-again, off-again chats with such fellow industrial giants as Alcoa and Chrysler. The words began to leak out here and there, and the pieces started to fall into place.

There was little doubt as to what a highly motivated GE could really do. General Electric Corporation has the innovative brains, the progressive (though inhibited) management abilities, the necessary technological base (fuel cells, metal-air batteries, electronic control systems, electric motors) . . . and the abundant capital. (GE is the fourth largest U.S. industrial corporation . . . conspicuously right behind GM, Ford, and Standard Oil, and right in front of Chrysler, Mobil Oil, and Texaco.) The dilemma and intrigue focused upon what GE might actually do with the remarkable ElectroCar project. Go for a touchdown? Punt? Quit the game? And while GE management delayed their next course of action, a wealth of evidence bubbled up from out of the recent past.

A PRELUDE OF PROGRESS

In September, 1965, a prominent GE electrochemist wrote in a technical article that a special three-electrode cell had been developed at the GE labs in Schenectady, New York. Among its features to greatly increase the rate of recom-

bining the oxygen at the negative electrode, and thereby facilitate a faster rate of recharging, was a third (auxiliary) "catalyst" electrode to encourage the combination of hydrogen with the evolved oxygen.

The result: "Cells can be charged safely in less than an hour."

In June, 1966, another technical article appeared, discussing the "revolution" being caused by newly designed primary batteries that used easily-replaceable plates of zinc or magnesium for the metal electrode, and plain air for the positive electrodes. These metal-air batteries are actually half battery (the metal anode) and half fuel cell (the air cathode) . . . and can pack more energy per pound than any standard dry cell battery. Among the principal examples was the new GE magnesium-air battery, which employed a salt water electrolyte, magnesium plate anodes, and air cathodes. Only the magnesium anode is consumed, and is readily deposited in a nylon mesh bag at the bottom of the battery case . . . as a magnesium hydroxide flock (milk of magnesia). As the article states:

"The mesh bag is easily lifted out, emptied, and returned for re-use with a fresh plate of magnesium and a fresh charge of salt water. A whole battery can be 'recharged' this way in ten minutes."

Note what this does to our conventional thinking about recharging a battery: Normally, we assume that a battery must be connected to another source of electrical energy—and then wait perhaps a few hours for a full recharge to take place.

When the present auto industry spokesman from "The Big Three and a Half" and oil companies discuss the possibilities of electric cars, they are always quick to point out the time-consuming chores of recharging the batteries. Yet, by the method of quickly and easily removing and replacing—or replenishing—the magnesium anode and salt water electrolyte at your nearest "Electrocar Service Station," you'd be back on the road again in eight minutes maximum. Compared to the similar time that it now takes to refuel a car's gasoline tank, the electric car suddenly looks a lot more appealing. Straight electrical recharging—rather than the replenishment method just cited—could also be used to fully recharge the system in less than an hour or so.

CELLS TO SELL

General Electric Company has also published a lucid book entitled "*Some Plain Talk About Fuel Cells*", in which they proclaim the many attributes of modern fuel cells and, in particular, their own ion-exchange membrane fuel cell. GE offers the following basic description:

"*A fuel cell is a continuous-feed electrochemical device in which the chemical energy of the reaction of a conventional fuel and air (oxygen) is converted directly into useful electricity. It can operate continuously as long as fuel and air are available.*"

Noting that their ion-exchange membrane fuel cells are suitable for a wide variety of ground, space, and undersea applications, GE goes on to list their many extraordinary advantages:

"No noxious exhaust."
"Silent operation."
"Nothing to wear out."
"Operates at room temperature and normal pressure."
"Self-regulating. Fuel is consumed only on demand."
"No caustic liquid electrolyte."
"High power-to-weight and power-to-volume ratios."
"High fuel efficiency."
"Regenerative operation."

A fuel cell will produce electricity continuously, as long as fuel is fed to the system. Thus, the range of a fuel cell powered automobile would only be limited by the amount of fuel stored in containers aboard the vehicle—in precisely the same manner that the range of an internal combustion engine vehicle depends on the amount of gasoline in the tank. Thus, a fuel cell powered electric auto could travel 200 to 400 miles on a tankful of hydrazine, hydrogen, ammonia, or some other fuel and you'd merely stop at a local 'electromobile service station', take a few minutes to fill up, and be back on your way again. (Oh, the attendant would also probably have to drain some excess water from an auxiliary storage tank . . . since a fuel cell produces water in addition to useful electricity.)

While a fuel cell produces continuous electrical energy . . . most useful when a vehicle is cruising . . . it must also be coupled to an auxiliary fast-discharge

electrical battery system, for abundant power in peakload situations, such as when a burst of acceleration is needed. The most likely partner for the fuel cell? The prime candidates include GE's own special three-electrode battery cell (rechargeable in less than an hour), and GE's own ion-exchange membrane magnesium-air battery (which could be fully replenished in a few quick minutes).

A SENATE PROBE

Seeking methods to alleviate the problems of air pollution in our cities, Joint Hearings were held before the Committee on Commerce and the Subcommittee on Air and Water Pollution of the Committee on Public Works, of the U.S. Senate. These Hearings, held in March and April, 1967, were officially entitled: 'Electric Vehicles and Other Alternatives to the Internal Combustion Engine.' The published record encompasses 550 pages of the most extensive technical discourse on electric cars ever published.

General Electric is mentioned in the published record, but, strangely, not in their own words—for, although GE is listed on page 126 as being among those companies believed to be conducting electric vehicle and component research. GE is nonetheless conspicuous by its total absence from the Hearings and the published record. GE is also listed on pages 129, 130, 131, 422, 423, and 425 as having a total of eleven contracts from various governmental, military, and aerospace organizations . . . all on behalf of fuel cell and battery development. The point here, simply stated, is that General Electric has been using governmental contracts—(taxpayers' money)—to build a firm base of advanced technology in fuel cells, batteries, and related components, all of which are highly relevant to the solving of a pressing national problem called air pollution.

Apparently either some Senator 'forgot' to request GE's appearance at the Hearings, or perhaps GE judiciously decided to stay safely at home.

Finally, on page 509 of the same document, there's an intriguing statement by Robert Ayres, of the Hudson Institute, Inc., of New York: "In fact, GE is building a prototype refuellable magnesium-air battery for an electric truck under a contract from the U.S. Marine Corps."

Thus, even in the face of major Senate probings and formal hearings into electric vehicles and related components, such as batteries, fuel cells, controls, motor—areas in which GE excels—GE nonetheless stood strangely silent. The Hearings were supposed to determine whether or not the Federal Government should significantly aid the development of electric cars. (Refer to Senate Bills 451 and 453, of the 90th Congress, 1st Session, 1967.)

The result of those Hearings? An impotent shadow-boxing . . . and no conclusions or actions of merit.

A SECRET

On July 17, 1967, The Wall Street Journal published a front page article of high impact . . . "Detroit Rife With Talk That GE is Readying an Electric Automobile" . . . subtitled "Rumors of Mustang-Like Car Abound, But So Do Denials: The Big Three Act Worried." The article went on to describe what was known, and what was rumored—plus quite a few rebuttal statements from members of the internal combustion engined automobile industry. The article stated that GE actually had a prototype car built by the Modern Engineering Service Company, of Detroit. (The car was later spotted on the roads around Troy, Michigan, prior to its being shipped to the GE plant at Schenectady, New York.) In trying to verify the rumors, Tim Metz, the Wall Street Journal reporter, contacted GE top management and technical personnel. While the brass denied that GE was working on an electric car, either by itself or with a partner. Metz was able to glean some information from technical personnel. What he uncovered was essentially a confirmation of earlier rumors: Yes, it was a 'Mustang-type' car, it could travel at more than 80 miles per hour, and it could cruise more than 200 miles before its power source had to be replenished.

The next day, GE top management publicly discounted the Wall Street Journal article. In his statement, Gerald Phillippe, chairman of the board, did admit that GE was then building a small battery powered car, but that it was "strictly a research vehicle." (The full statement appeared in Road Test, November, 1967.) No mention was made of fuel cells which, because of GE's extraordinary avant-garde efforts for aerospace programs, has become a substantial technological base for GE. The Gemini space missions, for example, successfully utilized compact, efficient, powerful fuel cells made by GE.

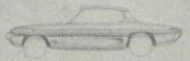
Chairman Phillippe also neglected to mention that GE had already teamed with Monsanto Chemical Company to convert a U.S. Army truck into a workable fuel cell electric vehicle . . . the M–37, earmarked for silent and efficient service in Vietnam. The compact, quiet, and powerful under-the-hood Monsanto fuel cells use hydrazine fuel and, of note, the efficient and smooth solid-state electronic control system was built by . . . General Electric! (Now you'd think that GE's electronic control system could also be teamed with GE's own advanced fuel cell technology and quick-recharge/replenish metal-air battery technology . . . and, quite reasonably, they'd have their "electric Mustang" or ElectroCar, even if GE management would prefer to call it "strictly a research vehicle".)

TECHNICAL DATA
COMPARISON CHART

	G.E. MINI-CAR	G.E. "MUSTANG"	FORD MUSTANG
Purpose:	To test battery systems, electronic controls, motors, and other components.	To test and develop "hybrid" fuel cell and battery systems, quick-recharging systems, electronic controls, motors, and other components . . . suitable for development of feasible/practical electric automobiles.	To provide practical, dependable, economical, reliable, comfortable, and safe transportation on streets and highways.
Dimensions:	130 inches long, 56 inches wide, 59 inches high.	184 inches long, 68 inches wide, 54 inches high.	184 inches long, 71 inches wide, 52 inches high.
Weight:	Approximately 2,300 pounds, depending on experimental equipment aboard.	Approximately 2,400 pounds, fully fueled.	2,600 to 3,200 pounds, depending on engine, transmission, and other options.
Seating capacity:	Two adults (front seats) plus two children (rear seats).	Four adults.	Four-to-five adults.
Major materials:	Magnesium frame, fiberglass-polyester body, specially molded windows.	Aluminum framing and structural panels, with honeycomb inner sections; ABS thermoplastic and reinforced polyester thermoset plastic.	All-steel frame, box sections, and fender panels.
Motive source:	DC electrical motor; special design; experimental battery system employing a combination of special lead-acid batteries and nickel-cadmium batteries.	Front-wheel drive, twin electrical motor; hybrid blend of fuel cells and batteries; special ion-membrane, hydrogen-air fuel cell; porous electrode (lithium-magnesium-zinc/air batteries, with anode-electrolyte replenishment and/or electrical recharge in less than eight minutes (as a quick stop at a service station).	Internal combustion engine, four cycle (intake, compression, power, exhaust), six or eight cylinders, reciprocating motion (linear to rotary) pistons; gasoline fueled.
Controls:	A variety of special solid-state control systems have been tested.	A-C, special design, solid-state control system	Mechanical and mechanical-hydraulic.
Drive:	Transaxle to front wheels.	Front-wheel drive, twin electrical motors.	Mechanical-hydraulic geared transmission; drive shaft, rear-mounted differential, rear-wheel drive.
Tires:	Radial-ply.	Radial-ply.	Cross-ply or radial-ply (optional).
Maximum speed:	55 miles per hour.	80-plus miles per hour.	100-plus miles per hour.
Range at constant cruising speed:	100-120 miles. (at 30-35 mph over level terrain); 40-50 miles (based on average of four stops per mile, acceleration at approximately 3.75 mph per second, and maximum speeds of 30-35 mph).	200-300 miles (at 50 miles per hour cruising speed).	256 miles (16 gallons times 16 miles per gallon).
Refuel or Re-charge time:	8-10 hours (on-board charger, using ordinary house current).	Less than eight minutes; combination of refueling the fuel cell tank with "conventional" hydrogen-type fuel (and deletion of excess water), plus replenishment of L-M-Z anode and "salt water"-type electrolyte, or electrical recharge.	Less than eight minutes, primarily to re-fill the fuel tank with 16 gallons (maximum) of gasoline; national network of approximately 216,000 service stations.



G.E. MINI-CAR



G.E. "MUSTANG"



MUSTANG



THE ROWAN ELECTRIC CAR . . . . AND G. E.

Furthering its involvement in electric automobile technology, General Electric has also designed powerful and compact electric motors especially for the new Rowan twin-motor rear-drive electric car. First displayed at the Turin (Italy) Automobile Show in November, 1967, this advanced-concept and practical 4-passenger vehicle is fully described in the following ROAD TEST article, beginning on Page 25.

NADER ELECTRIFIES

Ralph Nader was next to plunge into the GE electric car probe. Spurred on by what he termed the auto industry's lethargic and arrogant attitude regarding air pollution, and their feeble attempts to develop adequate controls for their internal combustion engined vehicles. Nader took a deep look at the feasibility of practical electric cars—and GE appeared much too wise to not be working on electric cars. Finally, on September 14th, 1967, Nader publicly spoke on his findings. He stated that it appeared that GE had developed an electric car good for 80 miles an hour over ranges up to 200 miles, using a "hybrid fuel cell" system whose battery could be recharged in eight minutes. Nader further claimed that the car was being kept "top secret" because of GE's desires not to disturb the auto and petroleum industries.

Nader's charges were responded to by a GE company research official, who added that company policy precluded use of his name. The GE official alleged that Nader's claim of "recharging batteries in less than eight minutes . . . if off by a factor of 20. You'd have to shoot 2,000 amperes into the car to recharge batteries that fast—and you'd melt the whole system down trying to do it."

The GE official's statement is astonishingly remote from GE's own previously-proclaimed capability. As we cited earlier, GE personnel stated, in September of 1965, that they had developed a three-electrode cell that can be "charged safely in less than an hour." Furthermore, in June of 1966, GE personnel stated that their new magnesium-air battery could be easily "recharged this way in ten minutes." Finally, in August, 1967, scientists at the Argonne National Laboratory stated that they had developed light-weight battery packs that "can be recharged in 15 minutes with special equipment. If used in a subcompact electric car, the battery could have power for a range of 200 miles at a top speed of 60 miles an hour."

These statements about battery recharging performance cast substantial doubt on that unnamed GE employee's claim that 160 minutes (8 minutes times a factor of 20) are necessary for recharging!

The GE official had also remarked that "Nader's claim for 80 miles an hour speed is off by almost 2 to 1. So is the claim for a 200-mile range." Yet, even electric vehicles that are inferior to GE's own rumored vehicle serve to contradict this statement. In testimony before the Senate Commerce Committee, Mr. Robert A. Charpie, President of the Electronics Division of Union Carbide, described an *existing* fuel cell vehicle with a "70 mph top speed and a range of about 150 miles." He also noted that "by doubling the size of the fuel tank, the vehicle range could be increased up to 300 miles."

Others have testified in the same Hearings that existing technology can permit speeds easily exceeding 60 miles per hour.

The General Electric official also mentioned that GE's family of fuel cells "would cost $5,000–$10,000 even in production." However, Dr. Clare P. Stanford of Allis-Chalmers Company stated, at those Senate Hearings in 1967, that "there is nothing inherently expensive in the fuel cell. We don't need research breakthrough. We need engineering, production, development." And again, Mr. Charpie of Union Carbide simply noted that "the average cost of (an internal combustion) power plant in a present vehicle is, give or take, a dollar per pound; and the cost of materials which go into fuel cell and battery systems is substantially lower than a dollar a pound. It is the handcrafting assembly which is required at low production rates which makes them expensive at present." And, of course, overall efficiency and operating costs are significantly lower for electric vehicles than those obtainable for internal combustion engined vehicles.

Thus, in summation, it appears that the rumored performance of General Electric's 'Mustang-type' electric car is feasible and could well be accurate . . . despite initial denials in September, 1967, by an unnamed GE spokesman.

On October 9th, 1967, Nader sent a detailed letter to Phillippe of GE, urging him to utilize his company's vast technological resources to help remedy the "worsening air pollution epidemic" and, specifically, to reconsider his company's apparent policy of secrecy regarding its electric car research and development. Nader made copies of his letter public at a press conference in Los Angeles . . . which was, at that very moment, in the throes of many consecutive days of 'smog alerts', those dangerously-toxic air pollution conditions of which 80 to 90 percent was and is caused by automobiles.

A BOX OF BATTERIES

On October 19th, 1967, GE finally broke the silence. At a stockholder information meeting in Cincinnati, Arthur Gueche, GE vice president of research and development, revealed that his company had built a "strictly experimental" electric car that could reach speeds up to 55 miles per hour, and has a range of around 100 miles between battery chargings. (*Technical data on the GE vehicle appears in the accompanying comparison chart.*)

As each smog-infested day drifts by, it becomes disturbingly apparent that revolutionary innovations will be needed to avoid a "doomsday" in Los Angeles, New York City, Washington, D.C., or in the entire nation for that matter. Air pollution can no longer be slowly and haphazardly battled by the apathetic efforts of the monolithic automobile and petroleum industries, whose multi-billion dollar investment in the status quo . . . or in 'a slow and controlled progress' . . . precludes the rapid attainment of substantial remedies. And one very feasible remedy is the modern electric automobile.

Is there truly a General Electric 'electric' Mustang' . . . the elusive ElectroCar? While specific affirmative news from GE would indeed be welcome this in-depth probe strongly indicates that such an ElectroCar is highly feasible in light of today's emerging avant-garde technology. Thus, GE or no GE, the ElectroCar might well be 'hidden' in the smog, and merely just around the corner. Perchance it'll even be named the "Progress"!

[Society of Automotive Engineers, January 22, 1962]

DESCRIPTION OF A MODERN AUTOMOTIVE STEAM POWERPLANT

(By James L. Dooley and Allan F. Bell, McCulloch Corp.)

To tell you a little of the technical aspects of the McCulloch Corp. steam car development, we go into the steam cycle, very briefly, primarily to show what we were trying to accomplish, to show some pictures of the previous, better efforts in this field for comparison, and then to give some details of the Paxton Car development. We believe the McCulloch work in this field is the latest, concerted effort of applying modern engineering and the latest methods and materials to the modern, automatic, lightweight, high-performance, automotive steam powerplant. However, this development was discontinued in 1954 and the entire project is now in dead storage. Reasons for this will be given later.

In 1951, McCulloch Corp., looking for a superior automotive propulsion system, designed for today's driver under today's traffic requirements, decided to look into the "steamer." We were engaged in the development of the Paxton automobile at that time with another unusual powerplant, and the steam powerplant was intended as an alternate to power this same, luxury sports-type car. This automobile was styled by Brooks Stevens, and has since been shown to the Detroit stylists. Perhaps some of you have seen it in some of the automotive literature. It is shown in Fig. 28.[1]

To facilitate this development, the late Abner Doble was engaged as a consultant, not only to make use of his lifetime of experience in the steam field, but also to avail ourselves of his creative mind. We also licensed all Doble patents, which gave us a good business position.

As many of you will remember, the Doble Steam Car was built in San Francisco up until about 1930. The latest models, known as the "Series E" were truly superlative vehicles. I believe this car was the last production effort in the steam automotive field in this country and possibly in the world.

Our specifications were merely that the powerplant would have to give the Paxton performance superior to any similar vehicle. That's a big order, but our preliminary studies indicated we could do just that; so, we launched into the development of steam generators, feedwater pumps, engines with variable cutoff, condensers, and all sorts of new and intriguing problems. I might add here that what was considered phenominal acceleration in 1951 is no longer unusual. You'll see this in some of the data presented. However, our latest testing indicated that even today's performance can be met or bettered.

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[1] The figures referred to are not reproducible and appear in the committee files.

Most very early steam automobiles had, literally, a boiler with a large quantity of water to be heated, and a noncondensing, single-expansion, steam engine, permanently geared to the drive wheels, with reversing accomplished in the valving. The vehicles had a large, thermal storage capacity which was fine in operation to minimize the boiler control problems, but it did take a long time to heat up—sometimes as long as half an hour! Later versions used a monotube boiler or steam generator with very little water in actual cycle operation. For example, the last Stanley Steamer built carried 6½ gal of water in the boiler alone—more than in the complete Paxton system.

The later models such as the Doble "E" series used almost complete condensing. These early machines all had quite low steam pressures and temperatures (about 750 psig and 600 F) and were not too efficient. Worst of all, they consumed lots of water. Some of them even had built-in pumps for sucking water from the local creek or nearby horsewatering trough! Obviously, this would not be acceptable in a modern automobile because one can hardly find horsewatering troughs these days; so, our requirements included complete condensing of the exhaust steam under all conditions—the system had to be almost sealed, and should use no more water than the current automobile requires in radiator refilling. Now, since we had to condense all exhaust steam, we have a double premium on efficiency or a low specific steam rate. A low specific steam rate not only saves fuel and reduces the steam generator size, but, more important, it reduces the condenser and cooling-fan size. As you will be able to see in the photographs, the condenser and cooling air system are the apparent limiting factors in the powerplant size in a given vehicle.

To get low specific steam rates, one must consider high pressures, high temperatures, and high expansion efficiencies. To get high efficiency, the Phoenix development (as the project came to be called) was designed for 2000 psig nominal maximum steam presure at the throttle valve, 1200 F nominal maximum steam temperature from the steam generator, and the engine was double-acting, double-expansion, with variable cutoff of the high pressure steam entering the cylinder to provide outstanding maximum low-speed torque (long cutoff) combined with very efficient high-speed operation (short cutoff).

The steam automobile is not new. Fig. 1 shows the Gurney Coach of 1827, and Fig. 2, a Clarkson bus of 1904. The early 1900's produced a host of various steam automobiles—the more famous of which were the Stanleys and Whites. The last Stanley of about 1925 was a good looking, good performing, 80-hp (bursts), 20-hp (continuous) car.

Because the system we were considering was, in many respects, quite similar to the latest Doble cars, their designs should be studied. Fig. 3 is a photograph of one of the latest Doble Steam Cars. This unit was built around 1930. It had a 142-in. wheel base, and was powered by a 4-cyl, cross-compound, double-acting engine, using Stephenson valve gear with manual cutoff variation and reverse. It carried 17 gal of water and had a gross weight of some 5500 lb. The chassis arrangement is shown in Figs. 4 and 5.

In pursuing the McCulloch development, we searched the world-over for some of these cars, or parts thereof, to facilitate our development, and finally did purchase Abner Doble's personal car, Serial No. 24, in England, and returned it to Los Angeles. Several Doble steam generators and auxiliary sets were also found and restored to use. We found it quite a problem obtaining 2000 psig, 1200 F, small-capacity laboratory steam supply for our testing of engines, valve gear, insulation, condensers, exhaust turbines, and the like.

The Doble engine, together with reduction gear, locking-type differential, and brake shoes, is shown in Fig. 6, all the steam generator, together with its motor-driven combustion air blower and carburetor, in Fig. 7. The auxiliary unit, which includes the 4-cyl feedwater pump, lubricators, and electric generator, is shown in Fig. 8. This automobile was, clearly, one of the better pieces of automotive engineering of its day. We can say, first-hand, that Serial No. 24, after having been around the world in 25 years of use (and disuse) and, after having gone several hundred-thousand miles, still was an acceptable vehicle (Fig. 9).

In the early study phases of the development, many vapor cycles were considered, and fluids other than water were given serious study. A fairly standard water-vapor cycle, with stress on high pressure to reduce size, high temperature to improve efficiency, and good mechanical design, appeared the best. Many exotic fluids show a high theoretical efficiency, but they also present some very difficult problems. When one considers that this equipment is to go into the hands

of the inexperienced—and even incompetent—such things as mercury vapor lose their appeal.

TABLE 1.—COMPARISON OF VARIOUS STEAM SYSTEMS

System	Stanley steam car	White steam car	Doble steam car ("E" series)	McCulloch steam car	Modern steam electric generating plant
Type of steam generating unit.	Fire tube	Monotube	Monotube	Monotube	Complete power plant type.
Type of engine	Single expansion.	Double expansion.	Double expansion.	Double expansion.	Turbine with reheat.
Condenser	None	Partial air cooled.	Partial air cooled.	Complete air cooled.	Complete large natural body of water.
Pressure, p.s.i	600	600	1500	2000	2400.
Temperature at superheater outlet, F.	800	800	800	1200 design	1050.
Exhaust pressure (40 m.p.h. cruise for steam cars).	20 p.s.i.a	Atmospheric	5 p.s.i.a	1 p.s.i.a. design	0.75 p.s.i.a.
Specific steam rate pounds stem per b. hp.-hr.	Over 20 (estimated).	17 (estimated)	12 claimed	6.5 dyno test of engine.	5.6.

By far, the most soul-searching occurred when we had to commit ourselves to the maximum operating temperature. Many limiting factors must be considered here, but lubrication of the high-pressure cylinder is certainly among the more pressing issues. At these temperatures, there is enough oxygen in the steam from disassociation and other sources to oxidize partially the conventional lubricant. Can the cylinders be lubricated at all at these temperatures? Is it possible to run the piston and rings and shaft seals of materials that require no lubrication? Unfortunately, when lubricant is used in the engine, it will find its way into the steam system where it breaks down, the hydrogen grabs the available oxygen first, leaving the carbon as deposits in the steam generator tubing. This worried us until we learned of operating experience on the Dobles where it appeared to be no major service problem. Although they did operate at lower temperatures, finally 1200 F was selected as our design objective, and, I am pleased to report, we did run our dynamometer test engines under this condition of 2000 psig and 1200 F. Initially, we backed down a little for use in the automobile because we had enough development problems without including over-temperature complexities.

The schematic steam cycle (Fig. 10) shows the complete fluid path.

I am sure you are acquainted with vapor-cycle theory, but, for completeness, we have the Mollier chart (Fig. 11). This chart illustrates vividly what the high-pressure ratio and superheat do for you in cycle efficiency. Table 1 also illustrates how this powerplant compares with the earlier steam cars and with a modern generating plant. Although these objectives were not easily attainable, our calculations indicated that this powerplant should give us a luxury sports-type car with high mileage and excellent acceleration, as well as the other inherent advantages of a vehicular vapor-cycle powerplant. These advantages are:

1. Separation of the chemical heat release process from the conversion of this energy to mechanical power. This permits a "readiness" of power unattainable in most other prime movers.

2. Separation of the compression and expansion functions of the vapor-cycle. This permits stopping the expansion process whenever no power is needed. Literally, the expansion engine can be coupled irrevocably to the vehicle's driving wheels and not related to the compression functions—the boiler feedwater pump and steam generator—whatsoever.

3. Close control of the combustion process. Combustion is performed in a most leisurely manner, compared to the high-speed internal-combustion type engine. No tetraethyl lead is required in the fuel. Excess oxygen is always present, so high-combustion efficiency is attainable, and no smog or noxious fumes are produced (no carbon monoxide is produced). The furnace can be operated indoors without danger to personnel.

4. Closely related to the control of combustion and the long burning time in the steam generator is the ability to burn almost any fuel. While our experimental work was all done on the liquid hydrocarbons, solid or pulverized fuel can readily be used with a little burner variation. Of course, there is always the hope that, eventually, a fission or fusion source of nuclear heat would become available.

5. Because the combustion process is separated from the operating fluid, no contamination occurs from sulfurous or obnoxious combustion products.

6. The reciprocating-engine type expander has a wide permissible variation in mean effective operating pressure (including negative values for braking), giving excellent torque and speed characteristics for an automobile with no transmission complications.

7. A wide range of expansion ratios are attainable because the compression and expansion portions of the cycle are not interconnected. This can improve the efficiency under some operating conditions.

8. High operating pressures and two-stroke cycle, double-acting engine functions result in high specific outputs—that is, high bhp per cubic inch of engine piston displacement. As you may have noted in the Doble chassis (Fig. 4), the engine is small enough to lie beneath the floor panels. In the 1953 Ford coupe in which we installed the first Paxton steam plant, the engine and differential mounted beneath the trunk floor without change from standard. This characteristic also results in low specific engine weight.

9. Although the steady-state, high-output efficiency offers no advantage over current gasoline and diesel powerplants, the actual variable-duty, low-average power operation demanded by modern, metropolitan traffic does give the steam plant a favorable position. The best way to explain this is to note that the steam generator burner brings the unit to full temperature a few seconds after the throttle valve admitting steam to the engine is closed, so during all coast-down and during all time at a stop-light, or during all time in a traffic jam, no fuel is being consumed. The well insulated generator only restarts the burner a few seconds every several minutes to maintain temperature. These characteristics result in the high mileages shown in subsequent figures.

10. We would be remiss if we did not list some of the secondary features of steam that were true advantages in the days of the Stanleys and Dobles, but can no longer be better than the highly-developed gasoline automobile:

a. Virtually silent operation.

b. Instantaneous high-capacity cabin heat available—or continously available when standing, if desired.

c. Minimal vibration.

d. Smooth acceleration throughout range, from standing to full speed.

e. Infallible cold-weather starting (no high-output battery required).

f. No freezing problems.

I'm sure you can see why we believed steam could make a superlative automotive powerplant.

Needless to say, the steam-cycle powerplant also has some disadvantages that must be noted and carefully studied to be minimized:

1. The cycle efficiency is not as high as high-compression gasoline and diesel engines at high power.

2. The system must be designed to minimize the loss of fluid and it must be replaced easily.

3. Overall powerplant weight will be higher than competitive systems, unless careful design and light alloys are used. The reduced size of the high-pressure system minimizes this disadvantage. (It should be noted here that our steam system is actually lighter when the transmission and drive lines are considered.)

4. Long, cold-starting time can be serious, and this was a serious problem on old steam cars, but modern monotube steam generators with greatly reduced thermal capacity have brought the cold-starting time to under 30 sec. I might add here that, with modern, automatic, well-insulated steam generators, it might easily be left on "under steam" continuously if rapid starting is desirable. Our Paxton generators were still hot after a cold, overnight shutdown. In fact, a butterfly-type damper was installed downstream of the carburetor to preclude thermal air convection and thereby minimize thermal losses.

5. Since the automobile may draw electric power for the burner air-blower, as well as the other usual electric uses, for some periods (perhaps extended) when the generator is not in operation (the vehicle is stationary), a large capacity battery is desirable, although we did use the standard automotive unit in our test car. It should be noted that the present automotive battery, designed for the high current drains of cranking, is not the optimum type.

6. Last, we should mention that there are some legal problems about licensing in states that still have laws requiring a steam engineer's license to drive a steam-powered car. These would certainly not stand up under challenge, and were not always enforced in the last years of the older steamers.

Figs. 12–14 show the predicted performance of the Phoenix engine in the Paxton automobile. Although this particular combination was never road-tested, the powerplant was operated in a converted 1953 Ford coupe chassis, and the performance data taken there proved these curves could be equaled or bettered.

Fig. 12 shows the "flash" or short-term horsepower output, as well as the continuous output of the Paxton engine. The short-term power is limited by the steaming capacity. An approximate road load curve is also shown. The difference between the two curves is the power available for acceleration and for hill-climbing at any speed.

Fig. 13 shows the torque available at the crankshaft over the speed range. The ratio between the engine and rear-axle is 1.6 : 1. The torque available at the poorest crank-angle in the engine is adequate to pull a 30% grade. Also shown is the water or steam rate in pounds per shaft horsepower hour as a compound engine. At the very left of the curve, the very high water rate at very low speed indicates the starting operation as a "simple" engine. The application of full steam pressure to the large piston area of the low pressure cylinder produces the very high initial torques and, under these circumstances, has a very high water rate. The water rate expected is also shown and, as expected, it is not as good as we would like at the low speeds and light loads.

Fig. 14 illustrates the calculated specific fuel consumption for the car and, I might add here, again, that the actual test data from the converted Ford bears out the validity of these forecasts.

The steam generator is shown in cross-section in Fig. 15. This unit illustrates vividly that, within limits, the higher the pressure and temperature for a given power, the smaller the boiler will be. This unit is only 18 in. in diameter. It comprises a preheat or economizer section where transfer is largely by convection and high, internal water velocities and large external surfaces are used. Aluminum-copper bimetal tubing was used. In the next warmer section, a greater portion of the heat is transferred by radiation and less by convection, so all-steel tubing is used, with no extended external surface. In the evaporation and superheater sections of the boiler, the tubing is exposed to full radiation from the furnace and, with low-alloy tubing, we did experience some mechanical damage to the tubing from "heat cracking" on the surface where the temperatures can rise to very high values when the throttle is closed suddenly after a heavy load. Inconel or stainless tubing with heavy walls is essential in these areas.

The gas passages are designed to narrow-down in flow area to allow for shrinkage of the hot gases passing through the boiler to maintain high velocities and good heat transfer.

The fire-box not only guides the burning air-fuel mixture to insure a very turbulent vortex, but protects the tubing in the upper part of the unit from direct flame impingement. The fire-box is hot enough to be virtually transparent to radiation. Stainless or equivalent must be used, and 310 Series was found to be satisfactory during the extent of our testing. In later steam generators, a crown coil was added to the top for more surface and lower heat losses.

Initially, "Santocel" insulation was tried, but the finely-divided powder leaked out everywhere, so subsequent steam generating units were insulated with "Fibrefrax"—a fibrous material. Its insulating characterisics are not quite so good, but it does stay in place.

I might squelch some old stories here about "the boiler blowing up." There is so little actual steam volume in our unit that we customarily ran without safety valves. We did have several tubing failures, but none were caused by excessive pressure alone. Both Mr. Bell and I, as well as others on the development, have been around these operating units when a tube has ruptured for some reason, and we consider it no hazard whatsoever in the automobile.

Figs. 16 and 17 present a cross-section of the boiler control. Needless to say, the boiler output must closely follow the operator's accelerator pedal or demands. By the same token, it cannot exceed prescribed pressure or temperature limits. In this unit, temperature is detected by the differential expansion between the steel tubing and a quartz rod that extends across the boiler, as shown in Fig. 16. Pressure is determined by the spring-loaded diaphragm shown in Fig. 17. Either of these controls can cut off the fire and the pressure unit controls feedwater also.

The feedwater admitted to the boiler is directly related to engine speed, since the engine drives the 3-cyl, positive-displacement, plunger-type feedwater pump. It is beyond the scope of this paper to go into detail regarding boiler control, but I should say that when extra feedwater (over normal) is admitted, it enters

what we call the Normalizer which bypasses much of the first part of the boiler to provide a prompt temperature response. Foodwater added to the Normalizer circuit, together with normal boiler-feed coming through the economizer, exceeds the evaporative capacity of the unit, so the temperature falls.

Fig. 18 presents a cross-section of the boiler feed and vacuum pumps. The feedpumps' cylinders can be cut out (made inoperative, but still reciprocating) individually with the solenoids, which merely hold the inlet-valve open. Noncondensibles, such as air-leaks and burned lubricants, together with some water vapor, are handled by the three vacuum pump cylinders. These noncondensibles are removed to maintain good condenser heat transfer on the vapor side.

An operational schematic of the Wolfe compound Paxton engine is shown in Fig. 19, which should make the engine cross-sections clearer. The steeple-mount high-pressure and low-pressure pistons are both approaching top dead-center—cutoff has been completed so both the high-pressure inlet and low-pressure exhaust valves on the left are closed. As the crank proceeds, the transfer-valve on the right will open, permitting gas from the high-pressure cylinder (now expanded) to continue its expansion in the low-pressure cylinder. Near bottom-center, the exhaust port opens, allowing the major blow-down to flow from the cylinder to the turbine; at that time, the transfer closes. As the pistons again start upward, the high-pressure valve and small exhaust valve on the left are opened, as permitted by the amount of cutoff used. At 20% cutoff, these valves close very early. The small exhaust valve prevents excessive precompression in the low-pressure cylinder.

Fig. 20 is the same, basic engine in actual cross-section. The transfer valve is shown; the high-pressure inlet and low-pressure exhaust valves lie behind it. The ported exhaust is shown at the top of the engine. The cams are three-dimensional, and the camshaft is shifted lengthwise to alter the cutoff of the admission of high-pressure steam. This is done automatically, based on engine speed and steam chest pressure. Fig. 21 is a lengthwise section of the engine.

The automobile had a De Dion type rear-axle with the gear reduction of 1.6:1 and differential, as shown in Fig. 22. This equipment, as well as the engine, is shock-mounted to the automobile frame, and universals connect the differential to the rear wheels. This installation is better illustrated in Figs. 23 and 24 where the Paxton equipment is mounted under the floor of the trunk in a standard 1953 Ford coupe.

The Paxton steam generator is also mounted under the standard hood of this car, and the floor-board tunnel was completely removed (Fig. 25).

Table 2 is the automobile specifications; Table 3, the steam generator specifications; and Table 4, the engine specifications. Table 5 shows the weight of such an installation.

What do you put in? and where does it all go? The chart in Fig. 26 illustrates this. I might add that this is based on full-loaded circumstances. The 23% efficiency shown would not be seen on the road very frequently.

TABLE 2.—*General specifications—Paxton steam car*

Chassis:	
Wheel base	118 in.
Tread	59 in.
Overall length	200 in.
Overall width	76 in.
Overall height	56 in.
Curb weight, unloaded	3,050 lb.
Weight distribution:	
Front	55%.
Rear	45%.
Powerplant:	
Engine horsepower	150 bhp (not sustained because of insufficient steam).
Engine torque	900+ft-lb.
Maximum continuous steaming rate	900 lb/hr.
Expected actual average water rate	9.0 lb per bhp-hr.
Steam pressure	2,000 psi at boiler.
Steam temperature	900 F max at engine.
Fuel	Any gasoline, kerosene, or diesel fuel—Will burn in any ratio, without adjustment.

TABLE 3.—*Detail boiler specifications, Paxton steam car*

Case diameter (inches)	18
Case height (inches)	27
Tubing length (approximate feet):	
Helical coil	92
Crown coil	17
Super-heater	24
Thermostat	3.5
Boiler coil	21
Water-heater coil	41
Economizer coil	19
Total	215
External area of coil	57 sq ft.
Combustion chamber volume	1.1 cu ft.
Fire-box volume	0.51 cu ft.
Fuel consumption at full load	72 lb/hr (approximately).
Weight of boiler with thermostat, control, carburetor, but no blower or water	188 lb.
Heat release as steam	1,200,000 Btu/hr.
Steam generator efficiency	90% (approximately).

TABLE 4.—*Detail engine specifications, Paxton steam car*

Type	3-cyl, double-acting Wolfe compound.
Bore	HP–1¾ in. LP–3¾ in.
Stroke	3½ in.
Displacement (total)	23 and 116 cu. in.
Output	120 bhp.
Speed range	0–2,000 rpm (full power from 1,200 rpm).
Steam conditions at engine:	
Pressure	1560 psig.
Temperature	1200 F max.
Quantity	750 lb/hr.
Torque at worst crank angle	900 ft-lb.
Max expansion (at 10% cutoff)	24:1.
Clearance volume HP cylinder	15.5%.
Terminal ports on LB cylinders	145 deg atc. 0.8 sq in. area.

TABLE.—*Weight breakdown, Paxton powerplant*

	Pounds
Steam generating unit:	
Boiler tubing	119
Casing with insulation and controls	69
Fan and motor	25
Carburetor	10
Total	223
Engine	285
Transfer case and differential	65
Condenser with fans and housings	140
Exhaust turbine	15
Feed pumps, vacuum pumps, and drive	35
Steam piping and wiring	35
Valves and controls	30
Generator and control	20
Flues	25
Hotwell	20
Water and oil	60
Total powerplant weight	953
Total vehicle weight (2 passengers)	3,335

The instrument panel of the test car had the usual speedometer, gas gage, and the like on the left, and the special instruments, as shown in Fig. 27, on the right. These were not required for normal driving and could be covered with a snap-in panel so the casual driver would not be confused. The only instrument he saw pertaining to the steam system was the pressure gage in the center—which indicated the availability of power. All other controls are standard.

Fig. 28 shows the Paxton automobile, built to accommodate this unusual powerplant. Styling is an ephemeral thing, but performance-wise, even by today's standards, it should be very interesting.

Now—when one gets through with all the technical description, you must project yourself into the position of a potential customer from Waukegan or Boise or Miami who asks, "But what does it do better for me?" Unless this question is answered in a positive, forthright manner, all is for naught—for no one will want a steam automobile, just because it's "different." In fact—many will not want it because it's different.

Briefly, here's what it can do better:

1. It gives very high performance—effortlessly.
2. Fuel economy will be markedly better in some driving patterns—but always better.
3. It will accept a wide range of fuels—burn the cheapest available.
4. There are no critical tuning adjustments, whatsoever.
5. There is no urgent sensation of engine speed when accelerating, as there is with the present engine and automatic transmission, or in the proposed new gas turbines.
6. The noise level is generally below the best automobile built today.
7. There is instantaneous and continuous passenger-compartment heating or cooling available (by steam jets).

With all these virtues, you have every right to wonder why this development was not continued. To this, I can only say that it was not stopped because of technical difficulties, although it is obvious that the current state of the art in internal combustion engines and automatic transmissions is so advanced and has had so many millions of man-hours and dollars spent on its perfection that steam, or any other newcomer, will require a tremendous development effort to better it—and any new system must be better from the beginning, or fail. Also, many business and tax factors vitally influence the course of a large, long-range development program such as this. Primarily because of these factors, the McCulloch Corp. decided to hold the development in abeyance in 1954, and no work has been done on it since.

WASHINGTON, D.C., *March 9, 1968.*

Senator WARREN G. MAGNUSON,
Senator EDMUND S. MUSKIE,
U.S. Senate,
Washington, D.C.

DEAR SENATORS MAGNUSON AND MUSKIE: Yesterday the President submitted to Congress his message on environmental pollutants and conservation. Once again he warned the nation that "Of all the problems of conservation, none is more urgent than the polluted air which endangers the American people." By far the major source of air pollution are motor vehicles and their internal combustion engines.

You have been in the vanguard of public inquiry into what this country's policy should be concerning automotive air pollution with its serious health hazards and property damage. In addition to the pioneering hearings by Senator Muskie and his Subcommittee on Air and Water Pollution, your joint hearings last March–April on electric vehicles and other alternatives to the internal combustion engine raised critical questions which were not answered by government and industry witnesses and which need constructive reply now more than ever. Senator Muskie's comment: "I am not sure that the (automotive) industry is moving with that sense of urgency," remains as properly a skeptical statement now as then.

Consider, for a moment, the salient developments in the past year revolving around the theme of your March–April 1967 hearings on bills to get the federal government moving toward development of demonstration vehicles that do not pollute.

On January 30, 1967, President Johnson told Congress: "The sheer number of motor vehicles may, within a decade or two, defy the best pollution control methods we can develop. If this proves true, surely we cannot continue to use the type of internal combustion engine now in service. New types of internal combustion engines—or indeed, new propulsion systems—may be required."

Less than two months later, the Administration's spokesmen—representing three Departments (DOT, HEW & Commerce) appeared at your joint hearings with negative responses to your bills. Secretary of Transportation Alan Boyd, presented his case in this manner:

"There are times when the Federal Government should participate with industry in the development of new transportation systems. Such governmental-industry partnership is usually necessary when the development risk is high, capital requirements are very large, and the public welfare is involved. Presently, there is considerable incentive for various elements of industry to pursue development of an electric car. Private industry stands to reap substantial rewards of sucessful development of such a vehicle. And private industry has the necessary technical capability and risk capital."

Mr. Boyd rejected adoption of the bills in favor of a wait and see attitude. The issue is not whether the industry has the capital and human resources to do the job, but whether it in fact has an economic incentive and the will or desire to innovate new propulsion systems for the public health and safety. That it has not had the will or incentive has been demonstrated by the agonizing experience of California, during the past 17 years, in trying to persuade the auto industry to do something about vehicular pollution. The conflict between State and the industry has attracted the interest of the Antitrust Division of the Justice Department which claims collusive practices by the domestic industry in restraining the development and marketing of exhaust control systems. The sincerity of the industry can be measured also by the trivial resources allocated to research and development for pollution control, by the pervasive secrecy of the companies and their failure to produce California bound vehicles that maintain the State standards on emissions.

Like Secretary Boyd, the HEW spokesman, Dean Coston urged your Committee to defer consideration of the bills until issuance of the report by the Commerce Department's Technical Advisory Panel on Electrically Powered Vehicles. The Panel reported in October 1967. It contradicted Secretary Boyd's statement that an incentive exists to develop electric cars. But, pitifully, it recommended only that the federal government initiate a five year program, in total amount of approximately 60 million dollars to support innovative developments in controlling motor vehicle pollution, without specifying prototype vehicle development.

I believe it is time to recognize that the government's response to the automotive pollution problem is both trivial in resource and misdirected in priority. On the one hand, we hear government pronouncements of the serious health effects of such pollution—particularly in contributing to chronic respiratory diseases. We hear government warning of the billions of dollars in property damage each year, the devastating effect on farm crops and vegetation, and the reduction of visibility and increase in carbon monoxide exposure leading to motor vehicle and even air accidents. On the other hand, to cope with this environmental assault, the government last year spent for research, abatement and enforcement for air pollution control substantially less than the cost of a single atomic submarine. Between 1955 and March 1967, HEW spent only $28 million for research on all air pollution sources and effects. Rarely has the gap between caveat and commitment been greater. A national menace afflicting almost all Americans and corroding property from metals to fabrics simply cannot be driven back with mini-level money and manpower.

A key to understanding why our auto pollution efforts resemble more pantomime than substance can be found in President Johnson's message of Jan. 30, 1967 on "Protecting Our National Heritage:"

"We must recognize that in dealing with fuels for industry and motor vehicles we are dealing with matters of enormous importance to every section of the Nation and to many economic interests. . . . Great investments have been made on given assumptions about those fuels and uses. These considerations require that we approach the pollution problem with respect for its complexity and its economic implications."

This is the reality of the hapless struggle for a pollution-free automobile. A massive industrial establishment, centering around the auto and petroleum industries, has a vested interest in preserving the internal combustion engine.

Investment in innovation is almost always undertaken only if it either reduces costs or increases sales for a company *in an industry with a common product policy.* A less polluting engine, in the present market and government climate, does not meet these criteria; consequently health and safety considerations do not receive the capital investment required for alternative propulsion systems.

The automobile manufacturing industry alone, with a capital investment exceeding $40 billion and roughly that amount in annual sales, is spending far less than one day's gross revenue of General Motors (GM grosses $55 million on the average every day of the year) on research and development for non-polluting vehicles (generously estimated at $20 million). The historical and contemporary attitude of the industry is that there is something external about the internal combustion engine.)

In this context, it is pertinent to cite a comment by Professor Richard S. Morse of MIT (Chairman of the Commerce Department's Technical Advisory Panel on Electrically Powered Vehicles) before an industry engineering audience on January 8, 1968:

"I leave you to conclude what would now be the dominant system if the same high level of development work had been put into steam cycle or electric autos as has been devoted to the gasoline internal combustion in the past fifty years." . . . [U]nfortunately history suggests that without California and Federal action, the auto industry would voluntarily not have even made the limited progress presently achieved in reducing harmful emissions."

The foregoing material brings me to the principal point. The federal agencies responsible for curtailing automotive pollution are foundering. Quite apart from other problems besetting the agencies, the absence of demonstration or prototype pollution-free vehicle program cuts the ground from under the adoption of strong standards. To await the revealed innovations of industry is to be dragged into the 21st century on a heap of clever delaying tactics, endemic secrecy over information and anemic research budgets from Detroit. Because there are no sanctions for such tactics and delays the industry can delay with impunity as long as it largely controls the "state of the art" in emission technology. Control of the innovative process and barriers to new technological entries is at the root of the cooperative research programs between the auto and petroleum industries and their insupportable assurance that the internal combustion engine can be cleaned up to acceptable levels without incurring prohibitive costs and maintenance problems relative to far superior alternatives. It is noteworthy that by far the largest portion of this research money is being applied to working within the existing engine design and not outside of it. Such an assumption is the predictable prisoner of its common industry bias.

There are at least three reasons for new hearings by your joint committee:

1. To publicly hear testimony about the modern steam engine which some specialists believe (without being contradicted) to be the most immediate, practical alternative to the internal combustion engine. Remarkably little has been heard about the steam engine's capability under postwar design advances. The auto industry is especially silent here and for understandable reasons. The technology applicable to highly effective steam engines is at hand and can begin to displace the internal combustion engine within three years.

The Commerce Department's Technical Advisory Panel discussed briefly the prospect as follows: "Vehicles using external combustion engines for propulsion, such as the piston-type steam engine of advanced design, potentially offer a satisfactory alternative to the present automobile and should have very low pollution and noise characteristics." Reliable estimates put the pollution flowing out of fuel burning steam engines at less than five percent that of the internal combustion engine. The Panel's Report was very positive about the reliability, performance, convenience, economy and maintenance of this kind of steam engine as well.

In an authoritative study soon to be published under the auspices of Resources for the Future, Inc., Dr. Robert Ayres concludes that the objective of reducing air pollution and noise without sacrificing other desirable performance characteristics of internal combustion engines can be met almost immediately by means of a modern closed-cycle version of the steam engine. His analysis points up that steam engines are capable of offering better and more economical service than is presently available to motorists as well as eliminating the noise, smoke and products of inefficient and incomplete combustion that make up the automotive pollution problem. Apart from operating at low fuel consumption even under repetitive start-stop conditions, states Dr. Ayres, a steam engine eliminates transmission, clutch, starter motor, distributors, sparkplugs and carburetor. Recent innovation

and advances in new materials have solved many of the nagging problems which affected steam engines in the early part of the century—including slow start-up and weight.

Up to now, no auto company has revealed any serious work on steam engines. It is known, however, that Ford Motor Co. has an in-house program underway which has examined some of the more advanced steam engine cars built and operated by lone inventors. The company has also contracted out to smaller companies for different steam engine types. As occurred in the electric area, it will take public testimony and dialogue about steam engines to flush out what the auto companies have and have not done in this regard. Available indications are that stagnation has been the norm for most of the industry in steam car development, largely because of its imminent potential for displacing existing engines and the sub-industry that has grown up around it.

2. To inquire further into new developments and unveil older, hitherto undisclosed achievements in electric propulsion systems for motor vehicles, General Electric's fuel cell research and development project is a case in point. That company did not choose to testify last year although it probably has the most encouraging news to tell the joint Committee.

3. To examine the non-technical obstacles to pollution-free engine innovation. This inquiry would place on the public record for the first time details about conversion costs and benefits from existing engines to alternative systems and a host of other little-mentioned factors which present the real roadblocks to cleaner propulsion systems. This area of inquiry is probably the most fundamental and one considered increasingly more important by some members of the Commerce Department's Technical Advisory Panel as they grappled with an industry posture that, in the words of one member, "is not really moving with the mainstream of many other technically-based progressive industrial groups."

It would be a major step forward were Congress to enact legislation making it perfectly clear to the Executive Branch that these two objectives are pursued with dispatch:

A. A prototype, pollution-free vehicle design and development program utilizing the most efficient and immediate alternatives to the internal combustion engine. Such a program will eliminate once and for all the industry defense that such solutions are not technologically or economically possible or that they would have to take until the year 2000 for adoption. A demonstration program will also free the engineering imagination to achieve what apparently is only achievable outside the corporate structure—basic innovation.

B. A focused government policy to use its procurement leverage in the direction of the least polluting vehicles, thus creating an initial market for innovative firms. A past parallel for this purchasing policy for government vehicles lies in the auto safety area and the GSA standards.

I urge you to give serious consideration to further hearings on pollution-free automotive technology. Congress remains the chief, perhaps the only, forum for the candid presentation of varied testimony on a subject bound by corporate secrecy and intransigence and depressed by the severe constraints of a highly concentrated and united industry. Once again, the nation's hope for cleaner air awaits your leadership.

Thank you for your kind consideration of the above remarks.

Sincerely yours,

RALPH NADER.

U.S. SENATE,
Washington, D.C., May 2, 1968.

Mr. RALPH NADER,
Washington, D.C.

DEAR MR. NADER: Thank you very much for your excellent letter suggesting that the Federal Government should move more vigorously in dealing with the problems of air pollution and the automobile.

As you know, we have long been troubled with the growing menace which air pollution poses for our society. We are painfully aware of its steadily increasing impact in impairing the health and shortening the lives of our citizens, in begriming our buildings, and in limiting our visibility. We are concerned that in our major cities today, on a clear day you cannot see forever. And we realize that approximately 60 percent of the pollutants in the air we breathe are contributed by the automobile. Faced with these disturbing facts, it would be foolhardy to contend that "there is something eternal about the internal combustion engine."

The 1965 Clean Air Act amendments provided a mechanism to control emissions from automobiles and other motor vehicles. The first Federal standards are in effect on new 1968 model cars and light trucks, and the Department of Health, Education, and Welfare has recently announced that even more stringent standards will be applied to 1970 model automobiles and light trucks. It has also extended the application of the standards to buses and larger trucks.

But control of emissions from internal combustion engines may not be sufficient to protect the health and welfare of people living in our major metropolitan areas. Therefore, last year, in joint hearings before the Commerce Committee and the Subcommittee on Air and Water Pollution of the Committee on Public Works, we began to explore alternatives to the internal combustion engine, devoting five days to discussion of the electric car. This year we shall turn to steam. Like you, we were intrigued by suggestions in the report of the Commerce Department's Advisory Panel on Electrically Powered Vehicles that the steam engine might be a reasonable alternative to the internal combustion engine "in terms of performance and emission requirements." As a result, we have scheduled new hearings on the 27th and 28th of May, to explore in greater detail the technical feasibility and performance characteristics of steam-powered vehicles.

Because of the limited amount of time available, however, we do not plan to reopen discussion of the electric car at this time, and we believe that Senator Hart's hearings before the Antitrust and Monopolies Subcommittee of the Judiciary Committee, entitled "New Technologies," have elicited a great deal of useful information about the "non-technical obstacles" to adoption of low pollution automobiles. Nevertheless, we would like to assure you that our interest will not flag in pursuing any reasonable suggestion which will help check the frightening increase in pollution of our environment.

Sincerely,

WARREN G. MAGNUSON,
Chairman, Commerce Committee.
EDMUND S. MUSKIE,
Chairman, Subcommittee on Air and Water Pollution.

[From the New Republic, Apr. 27, 1968]

THE INFERNAL, ETERNAL, INTERNAL COMBUSTION ENGINE

(By Ralph Nader)

Since 1951, when Professor Haagen-Smit discovered the bond between smog and autos, the car manufacturers, by act and inaction, have been telling Southern Californians that there is something eternal about the internal combustion engine (ICE). For years, the industry's assertion was that only the ICE could give Americans what they were deemed to want in vehicle performance. Californians and the rest of the nation believed it and began to strain over how fast to clean up the ICE, rather than how fast to displace it entirely with far superior systems.

Now the advanced, virtually pollution-free steam engine—a far cry from the Stanley Steamer of yore—is about to make an enduring debut. Unlike electric vehicle proposals, the auto industry will have a far more difficult time obfuscating the issues, suppressing innovation and dismissing steam's advocates as atavistic eccentrics.

In an authoritative analysis, soon to be released by Resources for the Future, Inc., physicist Robert Ayres concludes that recent innovation and advances in new materials have solved many of the nagging problems that plagued steam engines early in the century. These solved problems included slow start-up, weight and exorbitant water consumption. The modern reciprocating steam engine belches less than one percent of the various kinds of pollution given off by the ICE; it performs with very little noise and can be fully competitive in price and performance.

One such steam-engine car has been designed and built by the Williams Brothers—inventors in Ambler, Pa. Using kerosene as its fuel, the Williams car has attracted serious attention among specialists and visits from domestic auto companies. The interest is obvious: here is a steam engine that provides extremely high torque, low maintenance, very high combustion efficiency and low

fuel consumption even under repetitive start-stop conditions. Such a steam engine eliminates the transmission, clutch, starter motor, distributors, spark plugs (except one), muffler and carburetor. The engine would be cheaper to build and easier to maintain.

Ford Motor Co. has shown the most overt interest in steam engines. It has done unrevealed work at its own facilities and recently moved to establish a strong relationship with Thermo Electron Inc., a small science-based plant in Waltham, Mass. A two-year joint development venture was launched ostensibly to develop low-power steam engines for use as outboard boat motors or golf-cart power plants. An application to motor vehicles was not officially contemplated in the agreement. Ford was also given the right to buy 100,000 shares of Thermo Electron at a stated price (20 percent of their shares outstanding). What made Thermo Electron a natural candidate for such an acquisition move issued from work that company did for the Pentagon on steam generators that could not be easily heard by the Viet Cong. When the company began looking for opportunities to use this know-how for civilian application, Ford decided that a footloose innovator could cause trouble or, alternatively, could bring the Ford stable a bit of self-insurance for a rainy day should steam become a focal point for anti-pollutionists in and out of government.

Ford's concern is not misplaced; though one would have liked to sense something more positive in attitude. Clear signs in recent months point to a serious revival of the steam principle for vehicle propulsion. The Commerce Department's Technical Advisory Panel on auto pollution reported in February that the reciprocating steam engine power plant is a reasonable alternative to the ICE "in terms of performance and emission requirements." The chairman of the panel, Professor Richard Morse of the Massachusetts Institute of Technology, has become such a believer in steam engines licking pollution that his company, Energy Systems, is seeking to interest government departments in funding the development of demonstration vehicles.

Steam engines have other advantages over competing displacements such as electric vehicles—even assuming the latter's range, speed, and recharging problems are overcome. Steam engines burn fuel which would keep the petroleum industry busy, though eliminating the need for tetraethyl lead (itself a major pollutor) would upset Ethyl Corp., jointly owned by General Motors and Standard Oil of New Jersey, and DuPont. Service stations and repair and maintenance industries would not suffer as much disruption as would be the case with electric vehicles. And because steam is less economically disruptive to existing capital commitments, the level of non-technical obstacles to such an innovation is lower.

The next step is to awaken the federal government to steam's potential for drastically curbing pollution. In a carefully conceived government strategy lies the main hope for a breakthrough. Certainly, the industry cannot be relied upon to lead the way. No domestic auto maker has published any research findings on the steam engine. All are mum; but behind the corporate curtain engineers are plainly following managerial directives to prepare the case against. However, they'll soon have a chance to fail at this unprofessional mission, set for them by corporate parochialism not by their own professional instincts. Senators Warren Magnuson and Edmund Muskie will probably hold joint hearings next month on steam engine developments.

There is some stirring in the executive branch. HEW is trying to obtain more funds for demonstration vehicle-propulsion contracts; HUD is interested in applying steam propulsion to city buses. Government weakness in standards-setting emphasizes the need for more fundamental solutions. Many exhaust devices on California cars are failing to meet the state standard after an average 8,000 miles. It's too easy for drivers to disconnect the anti-smog devices (in contrast to systems inherent in the car, like steam engines).

So it's time for the federal government to invoke its procurement power to encourage steam engine producers. The government created the private nuclear power industry, spending enormous sums aimed at cheaper power. Now it is human health that's at stake. The coming hearing will permit HUD, HEW and the Department of Transportation to reconsider their coolness to Senators Magnuson's and Muskie's 1967 proposal to launch a research and development program for alternative vehicle-propulsion systems.

The auto industry has been unprogressive about propulsion systems because of its capital investment in building and servicing the gas-gluttonous ICE. Professor Morse excoriated the industry at the annual meeting of the Society of Automotive Engineers as "not really moving with the mainstream of many other technically-

based progressive industrial groups." He added that "the time is ripe for automotive innovation in *other* industries" (his emphasis). As auto pollution problems worsen in our cities, the trail to alternative power sources for motor vehicles can be blazed by new pioneers. Antirust enforcement, government procurement and government-sponsored demonstration projects can give critical help.

STATEMENT OF SAMUEL MINER AT HEARINGS ON THE STEAM AUTOMOBILE, BEFORE THE CALIFORNIA ASSEMBLY COMMITTEE ON TRANSPORTATION AND COMMERCE, MARCH 5, 1968

Mr. Chairman and members of the committee, my name is Samuel Miner; I reside in Niles, Michigan and by profession am a consultant in the field of machinery design and construction, and of manufacturing methods for the footwear industry. Several years ago, I became interested in the possibility of modernizing steam power, and as an avocation have been studying steam automobile development. I am also editor of THE STEAM AUTOMOBILE, the quarterly publication of the Steam Automobile Club of America, Inc.

In my view, your two bills, AB 356 and 357, are progressive, necessary steps in the direction that all governments must take, sooner or later, toward curbing pollution of our environment. In this field, as in others, California appears to be leading the way.

The necessity for curbing atmospheric pollution has become urgent in your State, and it is clear that the principal corrective measure, today, must be taken with respect to vehicle emissions, the chief cause of smog.

Highly developed though it is, the internal combustion engine cannot completely burn the fuel it uses, and anticipated improvements or modifications will still find the IC engine falling far short of desired emission levels. On the other hand, the inherent combustion characteristics of a steam engine reduce these harmful emissions to an insignificant level, as Mr. Williams will indicate in a few moments when he refers to the Mobil Oil Company/California Cycle test results.

To advocate steam automobiles as an alternative to conventional vehicles in this State may seem anachronistic and impractical. We are aware of the widely accepted fallacies and misinformation that surround the steam car. Let me say right here that we are not advocating the return of the Stanley or anything that resembles a locomotive. My purpose is to explain briefly and nontechnically what a modern steam car would be like, and why it would help you to greatly reduce vehicle smog in California.

There is a vast technology that has evolved over the past 40 years, in many fields, including the automotive, and steam has participated, and can share, in that evolution. Much of this work has been done by our SACA members; an advanced prototype, that you will see in action on film, will be described by its co-inventor, Mr. Calvin Williams in a moment.

A modern steam car would not be inferior to a conventional car, despite many recent statements, before Congress and elsewhere, to the contrary, and with respect the steam car will be overwhelmingly superior. Specifically, it has been said by some Detroit representatives that a steam car is impractical because of excessive size and weight, long start-up time, condensing problems and freezing in winter weather. Let me address these in order:

(1) A modern steam engine, operating on high pressure steam, would be smaller and lighter than an IC engine of comparable power (because steam puts out more HP/cubic inch). Other system components would not bring the gross weight or size beyond that of present cars.

(2) Start-up time would be about 20 *seconds* in cold weather; less in warm weather.

(3) A modern steam car condenses its exhaust steam, and feeds the condensate back to the boiler. Tests have shown that a driving range of about 1,000 miles can be expected under favorable driving conditions: in very warm weather, the range would be shortened but probably would remain within the limit of usual fuel and convenience stops.

(4) Freezing, in a steam car, is about the same problem as it is for home plumbing—that is, the car would keep itself warm automatically and the necessary heating cycles would be infrequent. In conditions where this would not be desirable (for instance, leaving one's car at the airport for several days) automatic draining into a non-bursting sump can be provided.

Other objections have been voiced, particularly about performance. Frankly, the old steam cars outperformed their contemporaries and the same would be true of a modern steam vehicle, if the designer or consumer tastes dictated it. The steam engine is inherently peppier than the IC engine and notably more powerful in the low-speed range. It has immense starting torque at zero RPM, requiring no transmission to get a load moving; its lugging ability and acceleration would be very high, while there is no danger of stalling under any operating conditions.

As for complexity, present day technology allows all the work of regulating the boiler feed water, fuel pumping, and the like to be performed by automatic controls—very similar to those employed in a household refrigerator. The driver of a steam car would find a starting switch, a foot throttle, a brake, and a three-position (Forward-Stop-Reverse) as the only needed controls.

Again, let me remind you that all of these advantages are combined with extremely low emissions—*both when the car is manufactured and throughout its life.* A backyard mechanic cannot tinker with a steam engine in such a way as to nullify its low emission performance, while a minute with a 39¢ screwdriver can undo a $25 million investment in 100% control of carburetor calibration on the production line. Contrast the millions that are currently going into these efforts to reduce IC emission to a barely acceptable level with the work done by a few individuals with their own money, which has resulted in the immediate possibility of a smog-free vehicle.

Gentlemen, this concludes my presentation. Thank you for inviting me to testify.

[Society of Automotive Engineers]

A Suggested Program for Government and Industry in Solving the Automotive Emissions Problem

(By Richard S. Morse, Sloan School of Management, M.I.T.)

In January 1967, Secretary of Commerce John T. Connor appointed a "Panel on Electrically Powered Vehicles." The establishment of this study group followed a pattern of activity initiated by the Technical Advisory Board of the U.S. Dept. of Commerce, then under the chairmanship of Dr. J. Herbert Hollomon, Assistant Secretary for Science and Technology.

Stimulation for this undertaking and the ability to enlist the services of many individuals and organizations on a volunteer basis was clearly promoted by many previous professional conferences dealing with the air pollution problem and more particularly the very competent and continued work of Senators Edmund Muskie and Warren Magnuson. Hearings on bills presented by these senators served to focus national attention on the prospects and need for action on automotive emissions, and recent enactment of the Air Quality Act is a tribute to their concern for the public welfare.

The 16 members of this Panel were drawn from the industrial and academic communities, and a joint support agreement was entered into with the Departments of Defense; Health, Education, and Welfare; Housing and Urban Development; Interior; Post Office; and Transportation, as well as the Atomic Energy Commission and the Federal Power Commission. Appropriate government liaison people were appointed from these departments and agencies to assist in the Panel's activities as well as a representative from the Office of Science and Technology. Subsequent detailed subpanel studies were undertaken with the valuable assistance of over 50 individual specialists, government agencies, the principal automobile manufacturers and their suppliers, producers of fuels, lubricants and additives, small and large companies and individuals with detailed knowledge and information relating to the automobile industry, the air pollution problem, and novel propulsion technology.

This concept of initiating ad hoc study programs and the involvement of individuals with pertinent skills and objective analytical abilities drawn from industry, our universities, and government, represents a uniquely American approach to a growing number of national problems.

This procedure, initiated by the executive branch of the federal government, could well serve as a model for Congress, and our cities, states, and regions. Major concerns of our people, in such areas as air and water pollution, transportation, communication, housing, and urban renewal, can no longer be effec-

tively handled by legislation and funding alone. The combined efforts and expertise of the industrial-academic community must be more fully utilized by government at all levels to make certain that the best management talents, economic and systems analysis, and advanced technology are applied in new and innovative ways.

A summary of the findings and recommendations of this study group. "The Automobile and Air Pollution: A Program for Progress. Part I," was made available to the public by the U.S. Government Printing Office in October 1967. Part II of this study is also now available and includes specific subpanel reports dealing with: air pollution, current automotive systems, energy storage and conversion systems, the automobile and the economy, automotive energy sources, and transportation system requirements, together with extensive reference material.

RESULTS OF STUDY

The results of this study, and the findings and recommendations of the main panel, have been presented in detail to appropriate departments of the government, the President's Science Advisory Committee, and wide distribution has been made to Congress, state governors, and foreign countries. In an effort to promptly implement such recommendations as appear appropriate, responsibility for coordination and review has now been established at a high level in the executive branch of the federal government.

The more important findings and recommendations can be summarized as follows:

1. Air pollution presents a serious threat of increasing significance to the health and welfare of this country. Automotive vehicle emissions, mainly carbon monoxide, hydrocarbon, oxides of nitrogen, and lead compounds, are a principal contributor to this problem.

2. There is a major need for more extensive information regarding the significance of specific and combined air pollutants on public health as well as the cost factors associated with air pollution.

3. Population increase and current urbanization trends emphasize the need for early and effective implementation of emission standards and air quality goals. Local, state and federal agencies have in general given inadequate consideration to implications of pollution in the development of transportation systems.

4. On the basis of current technology, it will be feasible to reduce exhaust emissions from gasoline engines to values at least as low as: hydrocarbons, 50 ppm; carbon monoxide; 0.5%; and oxides of nitrogen, 250 ppm.

5. Because of the large population of automotive vehicles currently in use, that is, 90 million, no significant reduction in total air pollution will be achieved throughout the country through the use of unconventional low polluting energy conversion devices during the next decade.

6. The current state of technology does not now permit the development of an economically feasible all electric car using fuel cells or batteries except for special purpose limited range use. Hybrid electric systems may prove useful for limited area application, but no currently contemplated electric system will have a substantial effect on the total pollution problem in the next decade.

7. External combustion engines, such as a piston type steam engine of advanced design, potentially offers a satisfactory alternative to the present automobile, and low pollution and noise characteristics could be achieved by such a mechanism. Although the technical feasibility of the steam cycle may be now established, and its compatibility with existing fuel production and distribution is attractive, prospects for its rapid introduction into the marketplace by industry is not a promising solution to pollution in the near future.

8. No currently proposed new propulsion system, including those of advanced design, would be restricted because of supply of materials or energy sources—with the possible execption of devices which require large amounts of cadmium, platinum group metals, or silver.

9. Because of the characteristics of the business, no one individual automobile manufacturer, or fuel producer, has historically found an adequate incentive to apply pollution control technology in advance of competition.

10. The automotive and petroleum industries now clearly recognize that government has the primary responsibility to determine the effects of pollution and to establish realistic nationwide standards for automotive emissions.

11. Vehicles meeting federal standards for 1968 and California standards for 1970 will represent substantial progress for automobile generated pollution, but

more severe standards, with respect to currently controlled emissions and the control of addition exhaust products, including smoke and odor from diesels, gasoline additives including lead from autos, buses, and trucks, will be required in the future.

To date emission standards have been based on a percentage of the pollutant present in the exhaust. Future controls should be based upon "mass emissions" and viewed in terms of "grams per mile" of a specific pollutant in order to place more equitable restrictions upon largest horsepower vehicles.

12. Authority and responsibility for pollution research and control activities have not been established at an organizational level within the government consistent with the magnitude and importance of this problem.

13. The federal government should support innovative developments useful in the establishment of future emission standards in total amount of about $60 million over a 5-year period. This expenditure amounts to some $0.13 per year per auto now in use and hopefully will stimulate novel innovative development that otherwise might not be available, or would be unduly delayed, in their ultimate technical evolution or commercial adoption. Industry has the primary responsibility for research in this field and the commercial development of improved low emission vehicles.

The urgent requirement for rapid introduction of improved control devices and investigation of new energy systems dictates a requirement for a modest federal support of new concepts that might otherwise be delayed or remain unproven. There is certainly evidence to suggest that the auto industry has moved forward with somewhat greater speed after new emission control devices have been demonstrated by others outside the industry.

This expenditure of federal funds, in an area that should be the sole responsibility of industry, can best be justified as insurance against delays in the development of the best technically and economically feasible automotive vehicles with lowest pollution characteristics, at the earliest possible date.

CONCLUSIONS

It is common for Detroit to remark that "the gasoline engine has been around for a long time and nothing has come to take its place." This statement is good reason why change is long overdue in the light of today's rapidly changing technology and the availability of new advanced materials, techniques, and devices. Changes in such a mammoth industry will be evolutionary rather than revolutionary, but changes will come if "innovation" becomes more a way of life than has been apparent in recent years.

What would now be the dominant system if the same high level of development work had been put into steam cycle or electric autos as has been devoted to the gasoline internal combusion in the past 50 years?

The entire textile industry knew that cotton and wool were unquestionably the "ultimate," the only thing, and it took the chemical industry to prove otherwise.

Almost all innovative developments in color photography have come from outside that industry, and Polaroid found little enthusiasm for its early Land Camera idea within Eastman Kodak. The NIH factor—"Not Invented Here"—is high in all of us and unusually so in most large organizations.

Xerography was not developed by the business machine people. Even IBM finds competition from young entrepreneurs who are clever enough to find new and unique commercial applications for advanced technology in the computer field.

The time is ripe for innovation in the auto industry—or, in view of the above examples, perhaps we should say the time is ripe for automotive innovation in other industries.

It is no secret that the image of the auto industry has been periodically tarnished in the eyes of the federal government, the public, and the nation's scientists and engineers. This dilemma, with its resulting mutual lack of confidence, serves no useful purpose. The problem of auto emissions is now being viewed far more constructively by both government and industry than the earlier case of auto safety with its many resulting overtones.

Engineering and production procedures of auto manufacturers are now better understood by government; within the industry one can find a firm desire on the part of management to recognize its obligations to meet the auto pollution problem with more corrected action. Joint research programs are now underway between automobile companies and their fuel suppliers, an obvious and significant step in expediting solutions to an engine-fuel system problem.

The control of emissions presents a great opportunity for the automotive industry, or one or more of its progressive segments, to take the initiative and to lead the federal government rather than maintain its past defensive position.

The graduates of our best universities today are looking for action, and we have never had a better educated and motivated group. The best of them recognize the massive and intriguing problems of our country and the world, both in the private and public sector, and wish to participate in their solutions. Employment with many of the largest companies has rarely represented a great challenging environment for the really outstanding graduate, and he has looked to corporate life with a more innovative image, government, or a new enterprise for stimulation. The most important component to a successful business enterprise is the caliber of its people, and good people want to work in an innovative environment.

In today's changing technological society, a large corporation must also understand the process of innovation and join hands with the industrial-government-university team in order to seek solutions to many problems with which we are faced, even though these may fall outside the company's field of endeavor.

During the war, technically oriented businesses such as General Electric, duPont, Monsanto, Union Carbide, and Western Electric, all became engaged in research, development and management of massive complex programs relating to the production of nuclear weapons. These companies, and many others concerned with advanced technology and public service—hopefully with direct or indirect corporate profitability—continue to engage in new business activities within both the public and private sectors.

The image of a large corporation in today's technical world is, in many instances, dependent upon its interest in the innovative process and adaptability to change. Current advertising and public relations methods presumably are effective in increasing automobile sales to the consumer, but they make it equally difficult to attract the top 5% of the graduating class. In these days of opportunity, salaries alone do not attract top quality people, particularly scientists and engineers. Rather it is the environment in which they work and the technical and commercial challenges presented by management. If top executives, including directors, cannot understand the total process of innovation, and the application of advanced technology and the need for entrepreneurial skills, even the best corporate research laboratory will go unused. Historically, the top management of the auto companies, as in the case with "big steel," has come from "within the industry." Among the four auto manufacturers, it is hard to find a single director, for example, who has even been directly engaged in research and development work.

Management methods are rapidly being developed to cope with technological changes, and new techniques for exploiting the innovation process are underway in most technically based industries. It is extremely important that this essential segment of our free enterprise private sector be properly recognized and it experience, technology, and management fully contribute to our economic growth. Aerospace companies have, in many cases, too large an influence on the federal budget and Congress. On the other hand, such organizations are attempting to apply their advanced techniques and technology to problems of public concern. The automotive industry, with its great experience and background in the private sector, might more appropriately find solutions to many of these challenges. An articulate and respected voice from this industry should be heard as a prime representative of a large section of the private economy, particularly in connection with the effective allocation of our national resources in areas of science and technology. In the final analysis it will be this allocation, rather than the impact of defense and space expenditures, that determines our standard of living and progress in terms of health and welfare of the public consumer.

One notorious problem, the "smog" photosynthesis reaction, was postulated as early as 1951. Unfortunately, history suggests that without California and federal action, the auto industry would voluntarily not have even made the limited progress presently achieved in reducing harmful emissions. It should be pointed out that we have yet to see the public announcement from the auto industry of pollution control concepts more effective than those required to meet the current standards. The ideas which give us hope have come from elsewhere. To be blunt, this ostrich posture makes an interesting target.

As a mechanism for future cooperation, the industry might well consider initiating voluntary standards. The chemical industry took this road with its nondegradable detergent problem—why not the automotive industry? Procedures could be developed through the SAE or other appropriate organizations to ensure

the more rapid adoption of timely standards consistent with technological advances. This mechanism, which should enlist the cooperation of other industry groups, particularly fuel and additive producers, would certainly be viewed as constructive action by the public and all responsible sections of government including that relentless scourge, the Anti-Trust Division of the Department of Justice.

Now is also the time for industry to anticipate future public safeguards in other areas of control. No one likes to see either the stimulation of innovation, or the enforcement of industry standards, by federal action, if the same results can be achieved for the public on a voluntary industry-initiated basis. "Noise" pollution, for example, is certainly becoming a national problem, and, even before the landing of our first SST, it is easy to predict that this will become another area of both increased public concern and future government action. American industry should not wait again, as it has with the air pollution problem, but proceed now in the development of noiseless consumer and industrial products of all types.

This country needs greater involvement from the great industrial complex known as "Detroit" in many segments of society. A key technical executive from the industry is now a member of the President's Scientific Advisory Committee, and another is an active participant on the Commerce Technical Advisory Board. Such involvement with activities "outside the establishment" should be encouraged by the auto industry as a whole and every effort should be made to illuminate the corporate image of a "club" that is not really moving with the mainstream of many other technically based progressive industrial groups.

The real or assumed threat of antitrust action has certainly not made life simple for the auto executive, and government should recognize both the pros and cons of such activity in terms of total impact upon the consumer and the innovative environment.

Progressive American companies concerned with the problem of new product development now recognize the need for new mechanisms to promote both internal and external entrepreneurship. Organizations must be developed to create an entrepreneurial environment within the corporation and let those few gifted individuals bring new ideas, products and processes into the marketplace on an expedited scale.

Several large corporations are so concerned with the current high cost and complexity of their R & D activities that they are experimenting with new concepts of "external entrepreneurships." There is evidence to suggest that entrepreneurial talents and special advanced technology are more readily available in new technical enterprises. Techniques are now being developed, some with great success, whereby large companies have developed relations with more innovative small companies in order to expedite the commercial development of new processes and products on a mutually attractive financial basis.

The auto industry has historically been cut off from many external sources of new technical ideas because of a reluctance—justified or not—on the part of small and large companies, engineers and entrepreneurs, to deal with the industry. While the role of the inventor is a hard one, it is important for any company in today's changing technical environment to create a receptive and objective climate to attract profitable ideas from within or without the corporate structure.

The challenge—the development of effective means to continually infuse the new, the creative, the innovative, idea in to this great industry—is going to be a never-ending task, but its success will be essential to the health and progress of your companies—and your country.

CITY OF LIVERMORE,
Livermore, Calif., May 29, 1968.

Hon. WARREN G. MAGNUSON,
Committee on Commerce,
Senate Office Building, Washington, D.C.

SIR: It has come to my attention that your Senate Committee on Commerce is to hold hearings in the near future on air pollution and the automobiles. Specifically, I understand you plan to explore alternatives to the internal combustion engine.

I wish to stress the importance of alternatives to the internal combustion engine for the fast growing interior valley areas of California. The cities of Pleasanton and Livermore, California, which are located in the Livermore-Amador Valley about 40 miles east of San Francicso, have become very concerned about smog.

A citizens committee, of which I am chairman, was appointed by the City Councils to study the Valley's current and potential smog problems. A copy of our report is enclosed. The big conclusion is that the Valley has a smog problem now and that about 90 percent of the pollutants comes from the automobiles. With a population growth rate of 10 percent per year and the completion of two interstate freeways through the Valley, our future looks rather unpleasant.

Since our report was prepared, I have examined further the role of the automobile in our future. Attached is a table which lists the pollutant output per mile of the automobile according to the degree of control on automobile emissions. The 1970's entries are those specified in State of California Assembly Bills 356 and 357 which are currently being considered in the State Legislature. AB–356 is a "Clean Car" bill and, as has been pointed out in the report of the Panel on Electrically Powered Vehicles, U.S. Dept. of Commerce, October, 1967, "The Automobile and Air Pollution," it is not technologically possible in the foreseeable future for an internal combustion engine to emit much less than 1 gram/mile of hydrocarbons and 1 gram/mile of nitrogen oxides. The last row of the table, and the most interesting, is the Mobil Oil Company test of a modern steam car. It was the Williams Brothers' car with some 35,000 miles on it and with not attempt at optimization for low emissions.

As pointed out by the report of the Panel on Electrically Powered Vehicles and L. D. Hadson Institute Report, "Technology and Urban Transportation; Environmental Quality Considerations," HI–948/I & II–RR, Jan., 1968, the internal combustion engine is not amenable to really being cleaned up; the chemistry is such that it is extremely difficult to eliminate the nitrogen oxides while reducing the hydrocarbons. Significant reductions in all of the pollutants are necessary or growth in our Valley will outstrip the attempts at control. Thus, I strongly recommend that you seriously consider steam cars or an alternative to the internal combustion engine.

To illustrate the position of the small rapidly growing area of interior California, I have used the data in the automobile emission table, Livermore-Amador Valley population predictions through the year 2000 (to predict miles driven per day based on current miles/person), and the California car population distribution for the years 1932–67 to predict the tons/day of pollutant emission under different control options. Obviously, it takes a while from implementation of a control system until most of the cars on the road are of the model year, or newer, in which the control system was introduced. The steam car curve assumes all new cars in 1975 and thereafter, are steam cars. If AB–357 is passed, then the Valley's growth will just about be offset by the rate of car clean up provided that *all of the cars conform to the standards in AB–357 throughout the lifetime of the automobile.* This is very optimistic because (1) experience so far has indicated significant deterioration of the effectiveness of today's control devices with mileage and, (2) there is not any, nor proposed, effective inspection system. Therefore, I think it is imperative that we seriously consider the steam car as a replacement for the internal combustion engine. The steam car technology is here, whereas we will probably have to wait a while for the electric car technology. We cannot afford to wait.

Sincerely yours,

Dr. Todd V. Crawford,
Chairman, Air Pollution Control Study Committee.

GASOLINE POWERED MOTOR VEHICLE POLLUTANTS

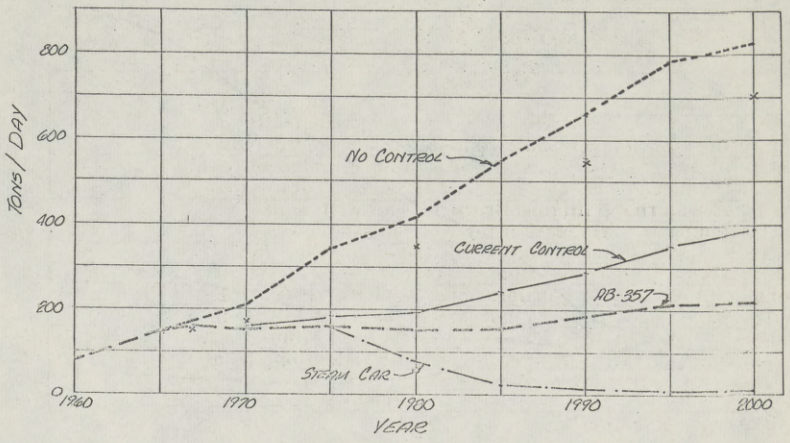
[grams/mile]

Pollutants	No controls [1]	1961–65 [1]	1966–69 [1]	1970 AB–357	1971 AB–357	1972 AB–357	1974 AB–357	AB–356 low emission motor vehicle	Steam car
Hydrocarbons:									
Exhaust	12	12	4	2.2	2.2	1.5	1.5	0.5	0.2
Evaporation	3	3	3	[2] 0.3	[2] 0.3	[2] 0.3	[2] 0.3	----	----
Crankcase	4	0	0	0	0	0	0	----	----
Carbon monoxide:									
Exhaust	83	83	37	23.0	23.0	23.0	23.0	11.0	1.0
Crankcase	1	0	0	0	0	0	0	----	----
Nitrogen oxides	4	4	6	5.5	4.0	3.0	1.3	0.75	0.4

[1] Assume 15 miles/gallon and Ventura Co. report conversions.
[2] Assume 30 miles/day.

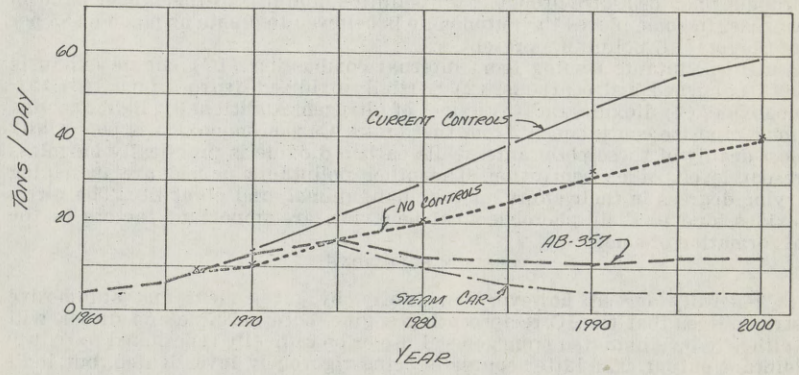
AUTOMOTIVE EMISSIONS OF CARBON MONOXIDE
LIVERMORE-AMADOR VALLEY
CALIFORNIA

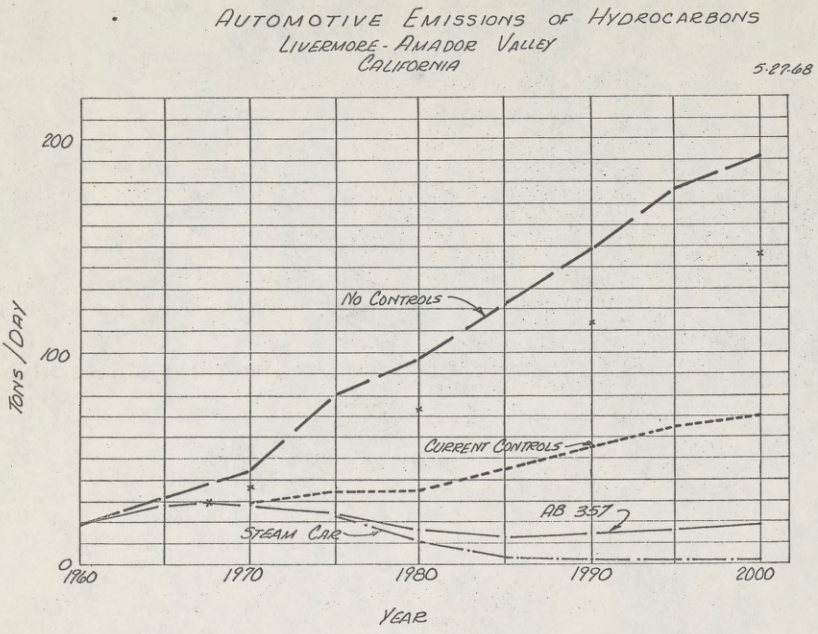
5-27-68



AUTOMOTIVE EMISSION OF NITROGEN OXIDES
LIVERMORE-AMADOR VALLEY
CALIFORNIA

5-27-68





[Excerpts from the Steam Automobile, vol. 9, No. 3, 1967]

MODERN STEAM AUTOMOTIVE POWER AND AIR POLLUTION

(By Thomas A. Hosick, Steam Motor Systems)

AIR POLLUTION

The mushrooming growth of automotive transportation in the United States has brought upon us a dire problem: air pollution, and it is at the danger point in many areas. In some places the automobile is believed to create as much as 85 per cent of the total air pollutants present.

The main pollutants issuing from internal combustion (IC) engine exhausts are: (1) unburned hydrocarbons, (2) partially oxidized hydrocarbons, (3) carbon monoxide, (4) dioxide, and (5) oxides of nitrogen. Additionally, light gasoline fractions vaporize continuously from fuel tanks. Carbon monoxide is potentially the most deadly of these pollutants, while carbon dioxide is practically harmless at present levels of concentration. The other pollutants named are damaging in varying degrees in their effort upon human, animal, and plant life. The nitrogen oxides, due to their photochemical behavior, are important factors in the actual formation of smog.

POSSIBLE SOLUTIONS

It is generally agreed, however reluctantly, by government and automotive industry sources that the IC reciprocating engine, both gasoline and diesel, will have either to be eliminated from general use or be radically redesigned to reduce its pollutant output. The latter course is being rigorously investigated, but indications are that the needed changes will be very expensive if they are to be effective. The present state of the art is that hydrocarbon emissions of gasoline engines can be reduced to 25 per cent of their usual output with rather costly added equipment.

Other possible automotive power plants under study are gas turbines, battery-electrics, fuel-cell electrics, Stirling-cycle hot-gas engines, and steam (or vapor) engines. It is not anticipated that battery development will permit the electric automobiles to become capable of supplanting modern gasoline car needs for many years. Technical problems in making the fuel cell practical for automotive

use are staggering. The highly publicized gas turbine still causes emission of smog-forming agents during the warm-up period and is beset by other technical and economic problems contra-indicating its general use for automotive power. The Stirling air engine appears too heavy in relation to its power output for automotive use.

The steam engine power system appears to offer by far the best early solution to the smog problem, and as a bonus has for automotive propulsion many features that make it far superior to the present gasoline or diesel engine. The steam engine also fits right in as a component of nuclear power systems. On the other hand, the steam turbine has many of the technical drawbacks of the gas turbine.

THE FORD TESTS

The Ford Motor Company recently sponsored comparative air pollutant emission tests of modern steam and IC automobiles. Hydrocarbon emission was found to be only four per cent as great in the steam car as in a conventional Ford, while carbon monoxide and oxides of nitrogen were not detectable in the steam car exhaust at all! The manufacturer of the steam car stated that no precautions had been taken in the design to eliminate emission of smog-producing substances, and had this been done, the emission probably could have been reduced even further.

THE STEAM AUTOMOBILE HISTORICALLY

The steam car was ushered in commercially with the introduction of the Stanley Steamer in 1896, the Locomobile in 1898, and the White in 1900. Of the 126 different makes of steam cars produced, the Stanley was the most popular, hitting a peak about 1910 and going out of business in 1926. The company did not believe in advertising and did not change the basic design of the power system during the entire history of the company, except to offer the system in a larger size and to introduce condensers reluctantly in 1915. Approximately a half-hour was required to light the Stanley vaporizing kerosene burner and to get steam up in the vertical firetube boiler from a cold start. The introduction of the electric starter on gasoline cars virtually spelled the end to the Stanley enterprise which failed to modernize into a competitive position.

Even while considering the many drawbacks of the old Stanley steamers, one may still marvel at their remarkable characteristics. They were very quiet in operation, appearing to be coasting when running, and the light weight sports roadsters of the 1906 to 1908 period were capable of surprising performance even by today's standards. The 30 hp Gentleman's Speedy Roadster could accelerate from 0 to 60 miles per hour in five seconds and could cross the finish line of an eight-mile drag at 78 miles per hour! Although the continuous power capability of this roadster limited its top continuous speed to about 60 miles per hour, its power storage capacity was so great that one would not dare to leave it wide open from a standing start, so we do not know what it would do in a quarter-mile drag. A streamlined Stanley with the 30 hp engine and larger capacity boilers took off from the ground and then crashed at Ormond Beach, Florida, at a speed that was estimated to be as high as 197 miles per hour way back in 1907.[1] However, most of the larger Stanleys built during the later years and rated at 20 hp could not maintain continuous speeds over about 45 miles per hour, due to the relatively low continuous steaming capacities of their boilers.

During the twenties, the magnificent Doble was developed and built in California. With its sophisticated electrically controlled control system, it could get up steam pressure from cold in 30 seconds merely by the turn of the electrical switch key. Its 150 hp rated power plant was as efficient as many of today's gasoline cars, and it probably could spurt to 500 hp. The huge Doble cars were true classics in design and were very advanced for their time. Unfortunately, poor management of the company resulted in its quick demise and only a few over forty Dobles were built. Many of these cars are still running today, and one in California has around 800,000 miles on it. The owner states that it will do 130 miles per hour.

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[1] What actual top speed was reached in these speed trials of 60 years ago has been the subject of speculation and controversy ever since. Fred Marriott (the driver) in his last years gave support to the 197 mph figure, but many students of the matter have doubted this, and believe the true figure may be nearer to 130 or 140 mph. An article touching on this subject is in preparation, and will appear in an early issue of the Steam Automobile.—Editor.

THE ULTIMATE POWER SYSTEM

Due to a combination of business and technical reasons, the internal combustion engine achieved a virtual monopoly in the automotive power field by the early thirties. To this day, however, many automotive engineering journals still use the smooth and powerful performance of the steam automobile as a standard of comparison for evaluating new propulsive or transmission systems under consideration. Steam performance is thus made a sort of ultimate goal. But why not have the ultimate now, instead of trying to continue putting up with a poor substitute?

THE MODERN STEAM AUTOMOBILE

One might ask, then, "What is the nature of this ultimate system—the automotive steam power plant?" Like the gasoline IC power plant, the steam plant consists of three main components. In the IC plant, the three are: (1) the complex engine (with carburetor), (2) the complex automatic speed-change transmission, and (3) the relatively simple radiator. The three main steam plant components are: (1) relatively simple steam generator (with burner), (2) the simple, self-starting, reversible steam engine, and (3) the condenser, which resembles the IC radiator. In the modern steam car, the steam generator is completely automatic with electrical start-up. Operating pressure should be obtainable from cold start-up within 10 to 30 seconds. The burner is similar to a home oil furnace burner and is arranged to heat a coil of tubing. Water is pumped into one end of the tube and steam comes out the other. It cannot explode—insufficient water is under pressure at any one time.

Advantage of the properly designed steam system over conventional IC systems in automobiles and trucks are:

1. Extremely smooth and quiet operation—appears to be gliding along.
2. Engine virtually vibration free.
3. Operation very easy for driver. No speed-change transmission or clutch required, either automatic or manual, as engine develops maximum torque while stopped and the vehicle is reversed by reversing the engine itself.
4. Much greater performance is possible because of superb high-torque characteristics of the steam engine at slow engine speeds and due to the steam generator's capability to act as a power storage unit. For spurt demands, such as in passing, the steam generator can deliver power to the engine for a short period of time at a much greater rate than the continuous ability of the steam generator. In some steam systems, this overload capacity is as much as five times the continuous power capability. Such performance characteristics are unknown in IC power systems.
5. Low smog emission of burner exhaust.
6. Simple dynamic braking available merely by using engine in reverse with slight steam pressure to create the desired amount of backward torque. This capability should be a great boon to truck operators in saving brakes.
7. Exhaust steam available for quick space heating and steam-jet air conditioning. Also could be used for other auxiliary power.
8. Since components of steam system can be easily separated, better weight distribution with fewer design limitations are possible.
9. Fuel economy should range from that of the gasoline engine to that of the diesel engine, depending upon the sophistication of the system.
10. Ability to burn a wide variety of liquid fuels can be incorporated, if desired.
11. As much as 1000 hp continuous rating could be given to truck-tractor, allowing more efficient use of driver time and truck investment.
12. Maintenance, wear, and lubrication problems should be lessened in steam system.

PAST WEAKNESSES OF STEAM SYSTEMS

In the past, the steam engine has been the weak point in automotive steam power systems, mainly from the standpoint of low thermal efficiency, i.e.: the engines just used too much steam per hour for each horsepower developed (pounds of steam per horsepower-hour is called the water rate of the engine and is the amount of water which must be evaporated for each horsepower to be developed by an hour). For example, the smooth, high-torque Stanley engine, which gave their light-weight cars such outstanding performance, hoggishly consumed steam at the rate of 25 lb./hp-hr. The modern steam engine should have a water rate in the five to ten pound per hp/hr. range. Obviously, an efficient

engine would require a much smaller steam generator and condenser for a particular continuous power rating than would a Stanley engine.

Uninformed developers of so-called "modern" steam car prototypes often make the mistake of using high-water-rate engines in their design. Immediately they get into what they think are boiler and condenser problems when they try to produce continuous powers required for modern expressway speeds, when they are only encountering the uncomprehended manifestations of their engine problems. The extent of this problem is illustrated by the following: One could pull out the engine of an old 30 hp Stanley Steamer, which had most of its available power space occupied with its archaic boiler and condenser, and replace the engine with one giving a 5 lb. hp/hr. water rate. Minor boiler modifications would be required to accommodate the new engine, such as the addition of a few more feet of superheater tubing. This archaic steam generation and condensing system in combination with the new engine, however, could produce 150 hp available at the rear wheels; for a conventional gasoline car to develop as much available power at the rear wheels, it would require about a 300 hp rating.

NATURE OF THE STEAM-ENGINE-THERMODYNAMIC REQUIREMENTS FOR HIGH EFFICIENCY

The steam engine develops from high-pressure, high temperature steam by a two-step process. The initial or dynamic step consists of the admission of steam through a valve into a cylinder, where it pushes down on a piston which then starts its stroke. Generally, the piston is connected to a crank by means of a connecting rod in order to convert the reciprocating motion of the piston to the rotary motion of the crank shaft. At some percentage (called the "per cent cutoff") of the power stroke, the admission valve closes and the steam then trapped within the cylinder continues to expand and produce power as the stroke of the piston proceeds. This is the second step in the process. At the end of the stroke, the exhaust valve opens (in a "uniflow" engine the piston uncovers an exhaust port at the end of the stroke), and the cylinder is allowed to exhaust during the return or exhaust stroke. If steam acts on one side of the piston only, the engine is said to be single-acting; if it acts on both sides alternately, the engine is double-acting. The use of short (early) cutoff, resulting in a high ratio of expansion of the steam, is required to get high thermal efficiency in a steam engine. (Thermal efficiency of a steam engine is the per cent of the heat contained within the feed steam which is converted into work by the engine.) For example, an engine operating at 50 per cent cutoff will develop 83 per cent as much power as it would operating at 100 per cent cutoff, yet will use only half as much steam. Variations of cutoffs is the most efficient way to control steam engine torque. Torque also can be varied by means of a throttle valve which reduces the pressure of the live steam fed to the engine.

The use of high temperature in the admission steam is also very important to obtaining a low water rate in a steam engine. Let us consider two steam engines of equal piston displacement running at the same rpm and expanding the same percentage of their displacements each revolution. If steam of the same pressure is used by each engine, almost identical amounts of power will be produced. Considering steam at 500 psi heated to 1100° F, we will need only half as much steam to fill the volumes under consideration as we would need were we to heat it only to 4700° F. Heating this steam to 1100° F requires a relatively small amount of additional heat over that required to heat it to 470° F. Furthermore, 500-psi steam at 470° F can be expanded very little before cylinder condensation begins, and the resulting water cannot expand and give additional power. Steam at 1100° F, however, can be expanded to a high degree before condensation will begin. Steam at the higher temperature is therefore much more favorable to the use of the desired early cutoffs.

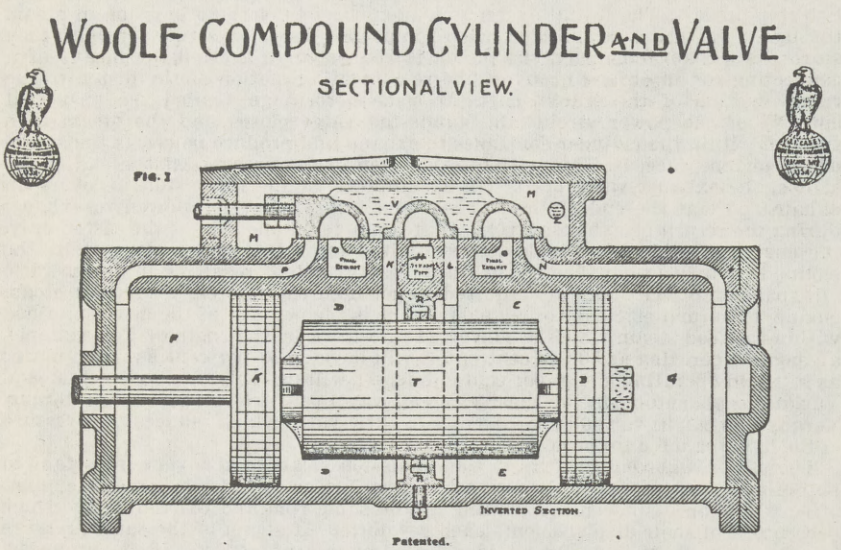
Steam engines of the past generally were limited to a temperature of about 750° F by hydrocarbon cylinder lubricants pumped in with the steam. The two-cylinder double-acting Stanley engine, besides had two further drawbacks: for the engine to be self-starting in all positions of the engine crank, a cutoff of at least 65 per cent was required, and the shortest cutoff possible was 35 per cent. Any attempt at using cutoff would result in such early closing of the exhaust valves that the unrelieved high compression would make the engine jerk due to uneven torque.

The Stanley engine also had considerable nonthermodynamic problems, such as the imbalance of its two cranks set 90° apart and the problems of unbalanced reciprocating motion. The latter problem, of course, is shared by most reciprocating engines, whether steam or internal combustion.

THE ELLIPTOCLINE STEAM ENGINE DEVELOPMENT

Gibbs and Hosick's steam power systems has set out to design a steam engine which will solve the many problems just described. Their Elliptocline rotary-reciprocating, uniflow steam engine combines the ease-of-sealing characteristics of the reciprocating engine with the inherent balance of rotary engines. Development is aimed towards the elimination of hydrocarbon lubrication by means of self-lubricated or steam-lubricated bearing surfaces, thereby permitting much higher steam temperatures with the resulting increase of thermal efficiency. Further, it is planned to attempt some modifications of the thermodynamics of the engine and/or the entire system toward a higher efficiency than that possible from the use of the usual Rankine cycle by which most light steam systems operate. The elimination of hydrocarbon lubricants also would permit the engine's use in high neutron flux density environments such as are found in the vicinity of nuclear reactors.

In the Elliptocline engine, which has been thoroughly described in previous issues of The Steam Automobile cutoff is infinitely variable all the way from 80 per cent down to 4 percent, both in forward and reverse, by means of a slight adjustment of the position of the central steam valve. This valve also controls auxiliary exhaust for compression relief. The generally undersiable clearance



The ring is fitted in the cylinder, encircling the trunk "T," and forms a division or partition in the cylinder. The spaces "D" and "E," which are angular or ring-like in shape, are the two ends of the small or high pressure cylinder, and spaces "F" and "G" are the corresponding ends of the larger or low pressure cylinder. The piston and valve are shown in their central position. The steam from the boiler enters at "H," and if the valve, "V," is moved to the left it will pass through the port "K" into "D," one end of the high pressure cylinder. At the same moment the steam already in "E," the other end of the high pressure cylinder, would be passing through the port "L" into the valve chest "M," and thence through the port "N" into "G," one end of the low pressure cylinder, and from "F," the other end of the low pressure cylinder, steam already used there would be passing through port "P" into the final exhaust port "O," into the heater. When the valve is returned to the extreme of its throw to the right, the same series of events would take place simultaneously in the reverse order.

DIMENSIONS.

8 H. P., Compound, High Pressure Cylinder, 5 inch bore; low pressure, 7 inch bore, 8 inch stroke.
12 H. P., Compound, High Pressure Cylinder, 5¾ inch bore; low pressure, 8¼ inch bore, 10 inch stroke.
15 H. P., Compound, High Pressure Cylinder, 6 inch bore; low pressure, 8½ inch bore, 10 inch stroke.
20 H. P., Compound, High Pressure Cylinder, 6¾ inch bore; low pressure, 9¼ inch bore, 10 inch stroke.

This cut of a once-used type of steam engine came from an old J. I. Case circular, and was submitted by Earle Eckel. It shows an interesting and compact method of achieving compound action within a single cylinder. Incidentally, the engine designed in the 1950's by Abner Doble for the Paxton car was also a Woolf compound, but of the so-called "steeple" type.

volume (volume remaining between piston and valve at the start of the power stroke), which must be filled with steam before each stroke begins, is held to 1¾ per cent of the piston displacement volume, compared to 5 per cent or more for most steam engines. This value is equivalent to a 60:1 compression ratio. A nine-cylinder Elliptocline is self-starting in any position with only a 22 per cent cutoff, compared to the 65 per cent required by the Stanley.

The first Elliptocline engine was a seven cylinder model with fourteen free pistons and only fifteen moving parts, excluding the anti-friction bearings. Displacement was 3.1 cu. in. and design power was 30 hp @ 10,000 rpm and 2000 psi pressure. It weighed 29 pounds. Speeds as high as 15,000 rpm were measured. It was so vibration free that a nickel coin could bebalanced on edge upon the engine while the engine was turning several thousand revolutions per minute. At present, two Elliptocline engines of 200 cu. in. displacement are undergoing preliminary tests. The engines, weighing 250 to 300 pounds, have a normal rating of 1000 hp @ 2900 rpm and 200 psi steam pressure. Starting torque of the nine-cylinder engines is 4200 lb. ft. They are cylindrically shaped, 28 inches (excluding shaft) long and less than a foot in diameter. Such a size will fit easily where the present truck-tractor transmission is located. Powers of this magnitude would be required for the large highway rigs to maintain general interstate traffic speeds in mountainous areas.

THE TOTAL SYSTEM

It would require a minimal amount of development to perfect the Elliptocline steam engine. When coupled with a good steam generator and condensing system (several such systems are quite well developed by other sources in this country), a superior power system with the proper characteristics for propelling automobiles should once again be available to the American public—the ultimate in performance, quietness, economy, simplicity of operation and freedom from the dire pollution of our atmosphere—all available with a minimal technological advance. Can we settle for anything less?

[From the Boston Herald-Traveler, Jan. 14, 1968]

THE STEAM ENGINE IS COMING BACK

(By John Lannan)

Strange as it may seem in this age of space flight, atomic energy and medical miracles, the ancient reciprocating steam engine may be heading for a comeback.

Far from being outdated by the advance of modern technology, the steam engine may make its renaissance because of it.

Atomic energy, as the power companies have shown, is the ideal source of heat.

Materials developed for aerospace applications make possible reciprocating engines which perform beyond the wildest dreams of the engineers of Grandpa's day.

Such developments point to potential for motive uses because of the non-polluting qualities of modern steam boilers and engine efficiencies approaching those of gasoline power plants.

This means a possibility of the return to the steam-powered car.

Further, their complete lack of noise and low exhaust temperatures make them ideal candidates for small stationary applications, things like power plants and pumps.

This is why the military is paying for the rebirth of the steam engine.

Perhaps the most exciting promise of all, however, lies in their potential as the power plant for an artifical heart.

Using an atom-powered heat source and a hermetically-sealed reciprocating engine for a pump, doctors and engineers are already studying such possibilities under a grant from the Atomic Energy Commission.

Much of the modern redevelopment of the reciprocating steam engine is being done at Thermo-Electron Engineering Corp. in Waltham, according to Sotiris S. Kitrilakis, manager of the Dynamic Systems Div. there.

"We grew up in an aerospace climate," he said in an interview last week. "The people who developed our engine had no preconceived notion of how a steam engine should work. We tried some new things.

"Furthermore," he added, "we were able to make use of materials and heat transfer techniques that were unknown 10 to 15 years ago."

There are several fundamental differences between Thermo-Electron's steam engine and older designs.

"The basic one is that the steam side of the engine is hermetically-sealed off from the driving side. None of the steam can get to the oil-lubricated side and none of the oil gets into the steam side."

The second major difference is that the steam end of the engine is water lubricated.

"The steam is actually lubricating the piston and the rings . . . due to the availability of new materials such as special graphites," Kitrilakis said.

The third major difference is that the positive sealing valves which control the flow of steam in an out of the cylinders are actuated by the piston itself.

"There is no need for an external valve system and no internal connections between the steam and oil sides of the engine to compromise the hermetic seal."

Beyond these three basic differences there are a lot of less outstanding changes, most of them having to do with new ways to do old chores; handling heat, friction and torque.

Thermo-Electron's engine was developed for the military to power a field generator. A number of them are now being delivered for testing purposes.

The generator itself is a modern alternator ordinarily coupled to a gasoline engine.

There the resemblance to existing systems—except for size, weight and efficiency—stops.

The steam is produced by a boiler, a super-efficient burner rated at 100,000 BTUs, about the same capacity as the furnace of a modern house. It burns any kind of fuel up to diesel oil.

The boilers, too, were pioneered by Thermo-Electron and though about the size of a gallon jug, pour out enough steam to keep the T–E three-cylinder engine grinding out a steady three-horsepower.

Like the engine, the steam circuit itself is hermetically-sealed—a closed system.

It requires very little stored water, is therefore freeze-proof and, theoretically, will run forever on its initial charge of fluid.

A hand-cranking system turns a fan providing force-fed air into the boiler. A new piezo-electric crystal igniter provides spark to the combustion chamber at every turn of the crank.

The same crank turns a high pressure fuel pump.

Almost as soon as the boiler fires, after a minute or so of easy cranking, high pressure steam begins to fill the cylinders and the engine takes over the firing load.

Almost as quickly as it is produced and used the steam is condensed in a system of fan blown radiators originally designed for aerospace use.

In a very few seconds, the engine is up to speed and ready to deliver 1½ kilowatts of electric power.

The beauty of the system, from the point of view of the military, is that—

It burns almost any available fuel;

Turns out very few BTUs from the stack, thus making it difficult to detect even with infra-red sensors;

Operates almost noiselessly;

And, in theory at least is relatively simple to operate and long-lived.

One of the units has been delivered. Several more are in the shipping process.

Next, says Kitrilakis, is a long-sought order for a number of units for field testing, "at least that's what we're hoping."

T-E has a good deal of faith in its steam engines. Because of the availability of atomic power, steam engines are a natural for low power—up to 30 HP—applications where turbines begin to lose their efficiency.

Using conventional fuels, steam engines could be used for everything from cars and portable generators to outboard motors and heart pumps.

"As far as motive power is concerned, we're looking at special applications where non-polluting capability and low noise are prime requirements. This means something like a fork lift or industrial truck. We're already talking to some people about this," Kitrilakis said.

"We were excited about the steam automobile for awhile, but we've cooled off a little. It means a lot of development that someone has to be willing to pay for and we're not sure anyone is willing . . . yet."

However, he admitted the firm has plans to scale up its three-horse, three-cylinder units to 100 HP auto size, an area in which such a power plant offers

the distinct advantage of not needing expensive power transmission equipment, gear shift capability or a reverse system.

"When you talk about one of these as a propulsion unit, there are some immediate cost savings which help offset the apparent high costs of a super-efficient boiler and a well-machined steam engine—though we think that with the application of automotive mass production techniques these costs won't be very high anyway.

"Steam powered reciprocating engines," Kitrilakis pointed out, "provide a constant torque, so there's no need to shift. And to reverse, all you do is stop the engine and run it in the opposite direction.

"We think this offers major potential for the sportsmen's market. If you've ever stayed awake all night listening to a portable generator roaring, you know what I mean.

"And we also think there is quite an opportunity in the outboard motor market. Here the costs could really come down—you use the surrounding water as the condenser."

[From the Steam Automobile, vol. 9, No. 2, 1967]

Can the Steam Automobile Come Back?

(By Richard M. Wyman)

This, of course, is possible, but none too probable, for there are many stumbling blocks in the path. There are perhaps two chief categories of obstacles—technical and financial.

In the first category, I think the toughest problem is that of freezing; a subject that Prof. McLaughlin [1] completely ignores. In the old days, we steamer owners got around that problem by keeping a horse the year around. Come freezing weather, we jacked up our steamer in the garage, drained the water and reverted to horse and buggy for four months or so. Those who did not care for horses walked; at least to the trolley car stop or to the railroad station.

So far as I am aware, the problem of freezing has not been licked and until it is licked it is absurd even to dream that the steam passenger car will be acceptable for popular use.

There may be new anti-freeze chemicals of which I am unaware that could solve that problem; chemicals that would neither harm the power plant, nor break down chemically under high heat and pressure, nor detrimentally affect the thermodynamic properties of steam. Barring such chemicals whose likelihood, present or future, seems very doubtful, I believe the best answer lies in proper design; a design providing maximum compactness of power plant with the shortest possible water lines between all elements—tank, pump, boiler, engine, condenser, etc., all enclosed within a shroud, having high qualities of insulation against heat loss.

Such a design precludes a "Stanleyish" arrangement of units and accessories. Incidentally, I see little or nothing of Stanley design meriting adoption, or even adaptation. In general, I think a truly compact design might dictate a choice between rear wheel drive with entire power plant at rear, or, on the other hand, front wheel drive with entire power plant at front. With an engine sufficiently compact, a third arrangement could be practical—the engine placed at the flywheel/transmission hump under the front toe-board (boiler and other units under the hood) and utilizing the conventional drive shaft of gasoline cars. Of course, this would cheat a little on the foot room of the middle passenger on the front seat, but perhaps not seriously.

Another reason why super-compact design of the total power plant will be necessary is that buyers of future steam automobiles will not take kindly to ark-styled cars such as were the rule back in steamer days; nor to giving up trunk space to accommodate bulky power plant units.

With highly efficient oil burners and automatic controls readily available, a well-shrouded super-compact steam plant could be kept from freezing just so long as the fuel held out and the burner remains in working condition. With extremely compact design, many small water-conducting parts made with extra

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[1] Assistant Professor of American Civilization, American University, Washington, D.C., whose article "The Fall (and Possible Rise) of the Steam Car" appeared in the fall and winter, 1965, issue of the Steam Automobile.

heavy walls might provide unburstability without adding too much weight. To accomplish this would require considerable highly-imaginative designing and engineering.

The present trend toward high pressures, high temperatures, and engine speeds approaching, but not necessarily equaling, those of the gasoline engine, is to my mind a move in the right direction. Double-acting engines, either compound or simple, hold no place in my vision. At today's driving speeds, high-speed, high-pressure single-acting engines will run most of the time from expansion rather than direct pressure, thus gaining all the benefits of the compound engine with none of its drawbacks.

Barring a steam-electric combination, I believe turbines are forever out of the picture. Some slower-speed types of rotary engines are possible, although they present a lot of unsolved problems.

Personally, I like the present attention to the V–4 steam engine, but be they V–4 or in-line or pancake in form, single-acting steam engines made similar in conformation of four-cycle gasoline engines offer definite advantages. An important one—they permit adoption of modern systems of lubrication, which, in turn, will reduce to a minimum the amount of cylinder oil carried to the condenser.

The development of any of the three compact arrangements of power plants I mentioned above, presents interesting opportunities for unconventional but eminently practical engines.

Other technical problems include controls. Not only must the burner and boiler controls be automatic and instantly responsive, but the visible controls operated by the driver must be as simple as those of a modern gasoline engine with automatic transmission. Not only as simple, but as similar in outward appearance and in operational attention required. Turn a key to make steam; move a short lever (Johnson bar) to select direction as well as to lock the car in parking; a foot throttle and a foot brake.

Things to watch? As a present—fuel and oil pressure gauges, ammeter, thermometer—and two new ones, steam pressure and water tank gauges.

Besides the neutral position on the Johnson bar, there should be a neutral spot in the shaft behind the engine by means of a simple synchromesh dog clutch, for use in testing, in warming the engine, in charging the battery, or while being towed.

The financial hurdle is an all but insurmountable obstacle. To sell any consequential number of steam automobiles would require a network of dealers with competent service departments. To interest an adequate number of dealers would, in turn, necessitate an annual output of close to 500,000 cars. At today's costs, this would require an investment of one, or even two billion dollars.

Strictly for the steam-fan trade, a power plant could be devised for installation in one or more models of present stock cars. However, that is a difficult job when one considers the sardine-can aspects of the modern car.

The maker of such a power plant would have to build it to fit into one specific make of car, and furnish all the hardware needed to install the plant in that car. Two cars presently on the market appear to have distinct adaptabilities for steam power plants. For those who may favor front wheel drive, I think Oldsmobile's new Toronado models is a natural. For front power plant with conventional drive shaft to the rear axle, Rambler's monocoque construction provides the maximum unobstructed space.

If the steam automobile is to return in any great numbers, it will be done by one or more of the present Big Three car manufacturers. Only they have capacity, physical, financial and organizational to undertake such a task. What might induce the present makers of internal combustion cars to shift to steam? Mostly, considerations of health.

The gasoline engine, unable to run with a ratio of air-to-fuel sufficient to provide full combustion, gives off large quantities of carbon monoxide, so poisonous to all animal life. The diesel engine can operate successfully with a much higher air ratio, but under the conditions of extreme heat, pressure and speed at which it burns its low-volatility fuel, it becomes a retort which produces exhaust fumes high in many undesirable partly burned hydrocarbons, some of which are believed to promote cancer.

Makers of internal combustion engines are busy developing after-burners and other gadgets to prevent or convert those poisons before they are exhausted into the atmosphere, but with none too notable success. One of these days, they may wake up to the fact that those problems can be eliminated with far greater simplicity by substituting steam power plants. It would not be surprising if the Big

Three have been carrying on research in steam, and stand ready to unwrap a steamer when the time seems propitious.

Several years ago, I was entrusted with custody of the notebook of the late Thomas S. Derr, in which he recorded, more than a generation ago, his experiments in trying to build a modern steam car. He ducted the flue gases from his experimental car into an apparatus for detecting and measuring carbon monoxide. Using gasoline as a fuel he achieved zero CO. With kerosene he got fair to good results, but far from complete elimination of CO.

I think that failure was due to the crudeness of his burner. His nozzles did not atomize the fuel sufficiently, and I think they were over-size compared with the capacity of his blower. On the few occasions when I dropped in on Mr. Derr, during the three year period before his death, I did not see any of his burners in operation, but around the tail flue of his experimental car, there was always a heavy deposit of thick oily soot, indicating very incomplete combustion.

Modern oil burners can burn kerosene and diesel fuel very successfully in a great excess of air, thereby approaching, and probably achieving zero output of carbon monoxide. At most, such an excess of air causes a small loss in thermal efficiency—no great penalty to pay for the safety gained.

A source of exhaust poison about which we hear little is the tetra-ethyl lead present in most gasolines used by modern high-compression engines. While the degree of toxicity of leaded fumes is highly controversial within the medical profession, it would seem to a layman that air devoid of such chemicals must be highly preferable to leaded breathing air.

To me, the most obvious field in which to start introducing steam is with big trucks, tractors and buses, thereby eliminating the worst offenders, volume-wise. Great numbers of them are owned in fleets which have their own service and maintenance facilities—thereby removing one obstacle.

The next step would be local delivery trucks and taxi cabs, operating mostly in cities and compact suburbs; then, pleasure cars in general.

A possible field for steam is now pre-empted by many millions of small air-cooled engines ranging from 2 to 10 horsepower. Having very low torque, they deliver most of their power at speeds from 2,800 to 3,600 RPM. They seldom idle under 1,100 RPM and develop little usable power below 2,000 revs. These single-cylinder engines are poorly balanced, and, at their high operating speeds, their excessive vibration greatly shortens their useful life.

Steam power plants of similar power range would indeed cost more to build than the gasoline units, but they should have enough longer useful life to make their purchase a profitable investment. Here is a field the small manufacturer might well be able to enter.

[From Public Utilities Fortnightly, Jan. 4, 1968]

The Automobile and Air Pollution

(By Edward Falck[1] and John Hoke[2])

Are the all-electric or "hybrid" propulsion systems technically impractical and therefore no serious answer to the air pollution problem from motor vehicular traffic? A special panel appointed to study the problem for the Department of Commerce appears to believe that this is so—that the emphasis should be on cleaning up the conventional internal combustion engine. These authors have different ideas on the subject.

In October, the Commerce Department released a long-awaited report prepared by a special panel on electric vehicles. This panel's original charge was to determine the feasibility of using electrically powered vehicles as a means of reducing air pollution. The panel, however, decided to broaden its inquiry so as to include many other ways of attacking the automotive air pollution problem. The principal "new" recommendation was the idea of establishing governmental standards

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[1] Edward Falck, a frequent contributor to the pages of the Fortnightly, is an industrial engineer with his own consulting organization in Washington, D.C. A graduate of Columbia University (AB, 1930), (BS, 1931), (MS, 1932). Mr. Falck is widely known for his activities in connection with natural gas regulation. During World War II he served as director of the Office of War Utilities and as director of rates and research for the Tennessee Valley Authority.

[2] John Hoke is a Washington, D.C., development engineer who is the author of numerous books for young people on biological and technical subjects, such as solar energy, wildlife, and photography. He is a graduate of Antioch College, Yellow Springs, Ohio, where he received his BA in 1950. Mr. Hoke has built a simple electric car of readily available materials and equipment. The performance of this vehicle was described in 79 Public Utilities Fortnightly 35, May 25, 1967.

to reduce the lead content of gasoline used in cars and trucks. It is generally believed that reducing the lead content would result in a substantial increase in the cost of gasoline having equal performance characteristics. However, even today one major company, American Oil Company, markets a lead-free gasoline. The panel report included a host of recommendations calling for increased research programs to be carried on by various federal government agencies such as the Environmental Science Services Administration of the Department of Commerce, the Department of Health, Education, and Welfare, etc. The panel was composed of numerous experts drawn from universities, government, and industry.

The panel chairman was Richard S. Morse of the Massachusetts Institute of Technology.

It appears that the panel gave greatest emphasis to the possibilities of cleaning up the internal combustion engine. It played down, as not being practical, both the battery-powered electric vehicle and the various hybrid system vehicles. For example, here is an excerpt from the panel's report: ". . . hybrid systems can be expected to be relatively expensive and will have difficulty in competing economically with simpler propulsion approaches. Integration of components in similar systems, such as fuel cells and batteries, may affect this problem but the feasibility of this approach has not been established."

Among the many recommendations of the panel was its observation that steam engines "potentially offer a satisfactory alternative to the present automobile and should have very few pollution and noise characteristics." We feel that if the panel had gone further with this and shown its direct application to the hybrid drive concept, it would not have been so prone to question the feasibility of the hybrid drive approach, and it would have provided a positive direction for future steam research. In this respect, the panel failed to point up the real potential for further research and development in this field.

It was in this brief fashion that the panel brought up the concept of hybrid fossil-fueled electric drive and then summarily dismissed it.

THE "HYBRID" POWER SYSTEM

The panel's conclusion seems ill-advised to us because hybrid drive systems are basically quite simple and practical. The bits and pieces of the technology involved have long been with us. Complete packages involving hybrid solar-battery power systems are even now circling in orbit and taking pictures on the moon. In arriving at its negative judgment the panel erred in tying the hybrid drive concept to the fuel cell rather than to other power sources. Since the fuel cell has yet to be reduced to economic practicality, it was unfortunate that the other aspects of a hybrid system were in the same breath somewhat cavalierly discarded.

It is true that no mass market hybrid electric vehicles are now being produced. But the panel's judgment deals with a set of patently marriageable technologies whose components have long since been reduced to common use—electric motors, gas engine or steam-driven generators, storage batteries, etc. The mere hooking together of these components makes possible a workable and immediately available capability for manufacturing because the parts are shelf items requiring virtually no engineering shakedown. It is particularly in this light that the panel's judgment seems so hasty. Since no description of the hybrid vehicle appears in the panel report, we shall undertake to describe it here, dealing with the vehicle itself first.

An electric automobile employs one or more electric motors to propel it, and its energy source is a bank of batteries carried in the vehicle. The range of the vehicle is limited by the capacity of the batteries. Since battery capacity is fixed and does not allow for the long-distance capability of gas engine-powered vehicles, there has been considerable argument over whether there is any value to electric operation of automobiles. (In the May 25, 1967, issue of Public Utilities Fortnightly, this question was dealt with in detail. It was concluded that a low performance electric vehicle has much to offer in the urban environment.)

The hybrid vehicle is just such an electric vehicle but one which also carries a small generator that can operate continuously to keep the vehicle batteries charged while the vehicle is running.

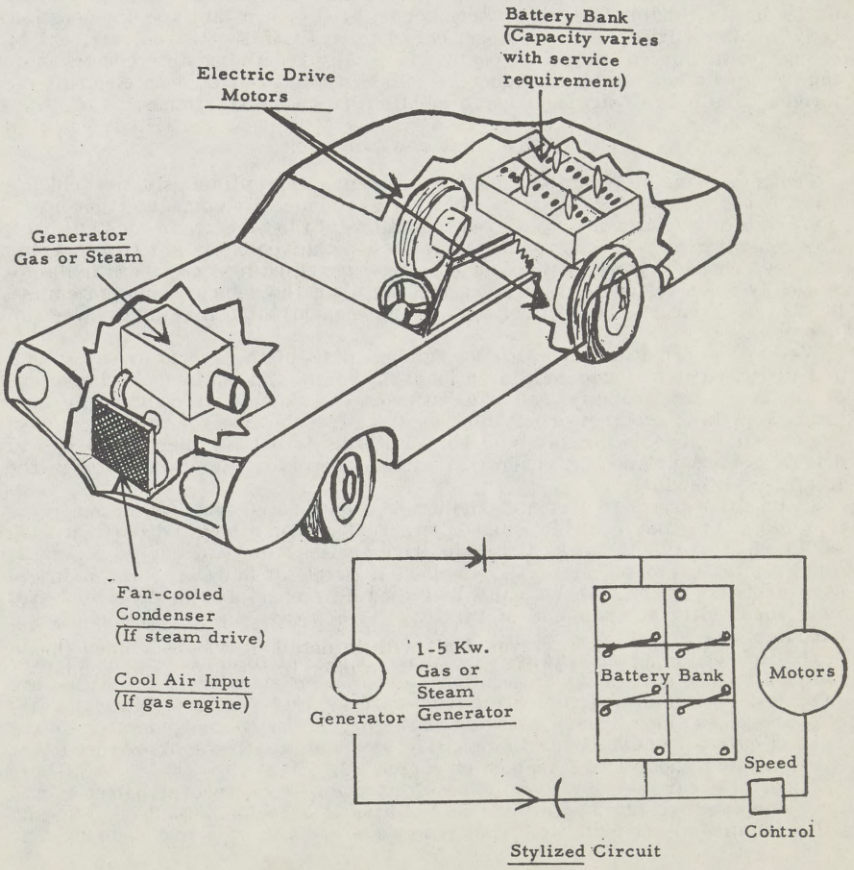
To better understand the benefits of the hybrid electric drive concept, compare it with the small community water system. In order to provide continued around-the-clock service, a large water tank is often located on a hill or tower high enough to gravity-feed water to all in the service area. A small pump de-

livers a continual flow of water up into the standing tank. The outflow of the reservoir is adequate to handle any immediate need, even though several fires would have to be quenched, and the tank's size is based on how long peak service demands last. The net effect is an adequate water supply to meet all demand situations, even though the basic water input is small.

The analogy to the hybrid electric vehicle shapes up like this: The community water tank is the vehicle's battery bank. The water bump equates with the small generator (gas engine-powered or steam driven) that feeds energy into the vehicle battery. The water service itself, with variations in demand, equates to the varied operating service required of the electric vehicle: It must climb steep hills, drawing its excess power needs from the battery bank, or stand idle at traffic lights or in parking lots, while the generator continually charges the batteries.

EFFICIENCY OF HYBRIDS

The hybrid electric vehicle embodies all the conventional components of an ordinary electric vehicle. The size of the battery bank, however, is geared to the particular work requirements of the vehicle. If it is to be used only infrequently during a given day—for shopping, getting to and from work, and similar short-distance trips—the battery can be smaller than for heavy-duty requirements. What makes it a hybrid is, of course, the battery-cum-generator. And it is here that the engine involved markedly differs in its own service requirements from the engine in the ordinary motor vehicle. In a conventional automobile, the engine must be big enough to handle the occasional *maximum speed and power* requirements the vehicle may encounter. At all other times, it puts out but a fraction of this maximum power to service the vehicle's less strenuous needs.



Quite aside from carrying all this dead weight, the slow-running large engine also operates at but a fraction of its optimum efficiency, and therefore its combustion rate is relatively poor: Engine fuel is seldom burned properly or completely—and this is the point at which the vehicle creates the air pollution problem. The cynosure of the whole pollution problem with respect to the automobile is its inability adequately to burn its fuel at all speeds. The gas engine in a conventional automobile must be able to operate over a wide speed range under varying conditions, and so it is equipped with carburation controls to make this possible. Unfortunately, these fuel controls do not enable the engine to operate efficiently at all the various speeds, and so poor combustion is tolerated as a necessary nuisance in order to enable the engine to operate at all the speeds demanded of it.

In the hybrid electric vehicle, where a gasoline engine may be used to generate power, it is not operated with this inherent liability of varying speeds. The engine itself can be very much smaller, for it is called upon only to produce the *mean* power needs for the vehicle over a given service period. It is the battery bank that is called upon to handle peak power needs, such as climbing hills or pulling ahead in tight traffic situations. This small engine will generate power continually—always operating at its most efficient speed. Under this condition, the small gas engine's combustion is virtually complete, and its lesser amount of exhaust is also substantially free of air contaminants.

Even though this method of power generation is not as efficient as that of a central station power plant, which makes utility-supplied power so relatively cheap, it is still more efficient as an energy source than the larger gasoline-driven automobile engines, which spill so much of their energy conversion potential by having to run so often at low efficiency. In short, even though the hybrid system involves an additional energy conversion step—with its losses—it is largely made up for by the reliable long-range efficiency enjoyed by constant speed generation. Only smaller engine "economy" gas cars can upset this equation, and not by enough to amount to anything, penny-wise. (Any remaining difference is more than compensated for by the inherent reliability and convenience elements enjoyed by the hybrid car user, not to mention its smog-free virtues.)

STEAM AS A POWER SOURCE

Though the engine generator runs at a constant rate, continuously, the vehicle's speed is controlled by a foot pedal that varies the motor voltage, and so conventional vehicle performance is enjoyed, regardless of the generator's constant pace. The generator may be kept running even when the vehicle is left in a parking lot—the generator perhaps timed or otherwise governed to cease operation automatically when the batteries are charged. At night the vehicle would, of course, be charged from the house line, so that the economy of utility line power can be enjoyed.

We have so far dealt only with the fundamentals of the hybrid drive concept, and discussed it in terms of conventional materials and equipment, simple gas engine generator, ordinary lead-acid batteries, etc. Completely confined to these terms, forsaking progress or anything new, we feel the case for the hybrid electric-driven vehicle is already sufficient. But this is not all there is to hybrid drive's potential. Another generation method deserves attention, notably the Rankin cycle engine.

Steam drive is an ancient and fine art. A small closed-cycle steam generator that burns propane, coal oil, number two fuel oil, or other hydrocarbon fuel, would yield excellent, low-cost hybrid-drive service. Such an engine generator could easily be (1) noiseless, (2) small as a couple of batteries (and nowhere *near* as heavy), and (3) virtually maintenance free. Start up problems? Not more than thirty seconds, and of little matter anyway, since the vehicle is immediately mobile using the battery tank.

The Defense Department is now re-evaluating the potential of steam as a power source for just such small generation chores. Even substitutes for water are being tested, so that lower operating temperatures can be utilized. When the first of these comes along, it may well unseat the hybrid gas-engine generator that is the best current candidate for the task. The steam approach would produce fewer emissions than the internal combustion engine.

The hybrid car does away with the oft-expressed concern over batteries and their supposed weight-per-watt ratio liabilities. The lead-acid cell was, is, and will remain an excellent, well-tried power *reservoir* for electric vehicles. The

much voiced criticism of the electric car is based on an erroneous attempt to match the electric battery with the much more powerful engine used to drive a long-range, high-speed motorcar. The critics of the electric car seldom mention its advantages for "low performance" urban driving. The hybrid electric approach in its crudest current state, deflates the low-range argument so often pinned to the electric battery car, inasmuch as the hybrid electric's range would exceed any and all urban distance requirements.

NEW DEVELOPMENTS

In light of the recent announcement (by the Department of Housing and Urban Development) of the research under government sponsorship for a gasoline-electric drive vehicle, it is important that the proposed method of drive not be confused with the hybrid concept being discussed. The proposed vehicle differs in that it is a dual-system vehicle: It may be operated either by its electric motors—after the fashion of a conventional electric vehicle—or by its gasoline engine, complete with automatic transmission. Though the engine also serves to charge the electric drive batteries, it is otherwise required to provide the same varying-speed service required of the engines in conventional motor vehicles. It is, therefore, just as subject to combustion and resulting pollution shortcomings associated with conventional vehicles.

Although the announcement indicated that the proposed vehicle would yield only a tenth the pollutants emitted by conventional vehicles, this is due largely to the choice of a low horsepower engine which could provide acceleration equaling only that of "at least a Volkswagen." And they propose the use of a two-cycle engine which, compared with equal horsepower four-cycle engines, is not noted for clean emission. From a cost point of view, the added requirement of a transmission—and the added horsepower sufficient to handle the vehicle's maximum power requirements—makes the proposed vehicle patently more costly than the hybrid vehicle, which, of course, does not require either of these features.

INHERENT VALUES

The electric car itself is here today. It is not "ten years down the road," as some of its critics have stated. Its use is for a different set of conditions and functions. The injection of the hybrid concept will give the electric car even greater promise. In our treatment of the electric car in the May 25, 1967, issue of the FORTNIGHTLY, the case was made for the usefulness of a "low performance" electric runabout for urban uses, that would enjoy the virtues of extremely low operation and maintenance costs, reliability, excellent performance characteristics, all resulting from the use of today's materials, particularly today's conventional batteries. In our judgment, nothing said earlier or since has altered the excellence of these qualifications that offer such ideal solutions to both urban transit requirements and the air pollution problem.

The addition of the hybrid concept is but a step upward from this already established set of values inherent in an electric automobile. It is its own rebuttal to the many concerns that have halted our progress, batteries too heavy, not enough power, not advanced enough, fuel cell better—but too far off, etc. Even without the hybrid concept, and before the advent of those esoteric technologies that will come another day, the electric automobile will benefit our society's present urban needs. With the *addition of hybrid* operation, it will do it all the better.

The panel did recommend a $60 million, five-year program to support "innovative developments" in the following general areas: (1) energy sources for vehicles; (2) vehicular propulsion systems; (3) emission control devices; (4) special purpose urban cars; and (5) general purpose vehicles. However, the panel did not specifically recommend the development of a hybrid electric vehicle.

Congress has just passed a new air pollution bill providing more than $400 million for the federal government to establish and enforce standards for industry and auto exhausts. Included in this authorization is more than $100 million earmarked for research to determine which fuels are responsible for unclean air threatening the health of citizens in urban communities. It may be hoped that an adequate part of these research funds will be made available specifically for research and development of a practical hybrid auto vehicle.

Of course, we must first get on with the electric car itself. The activities of the British and Japanese indicate that other countries already recognize the importance of the electric car. Their progress suggests that we may have been asleep at the *electric* switch.

TESTIMONY OF ROY A. RENNER, ON AIR POLLUTION AND THE STEAM AUTOMOBILE, SUPPLEMENTARY TO JOINT HEARINGS HELD IN THE U.S. SENATE, MAY 27–28, 1968

Commerce Committee, Senator Warren G. Magnuson, chairman

Public Works, Subcommittee on Air and Water Pollution, Senator Edmund S. Muskie, chairman

Introduction

My name is Roy A. Renner, Consulting Engineer. My testimony will be on the low-emission characteristics of the modern steam powered automobile, and the prospects for the introduction of such vehicles as a partial solution to air pollution problems. Professional qualifications include twenty years as a serious student of the steam car. During the late 1940's, I drove a Stanley steam car as an everyday automobile. At the present time, I am experimenting with a steam car of my own construction. My experience also includes research and development in the fields of atomic energy, space auxiliary power units, and work in the trucking industry. Since I am not now affiliated with either the automobile industry or with firms intending to market steam vehicles, perhaps I can speak with a degree of freedom useful to your Committees.

Emission characteristics of steam vehicles

Ideally, combustion of a pure hydrocarbon fuel produces only non-poisonous carbon dioxide and water vapor. A properly designed steam vehicle approaches this ideal in its emissions; that is, it is about as free from *obnoxious* emissions as a fuel-burning motor vehicle can possibly be.

Tests have already shown that experimental models of steam car, constructed with technology available *today*, can meet the most rigorous of emission standards visualized for *tomorrow*. Figure 1 is used to illustrate this point.

The illustration shows how the steamer compares with the contemporary and possible future standards. The first example is the gasoline-fueled car of today, if its smog control devices meet present Federal standards. The second standard is that proposed by the California Legislature, in Assembly Bill 356 introduced this year. This Bill defines a true "Low Emission Motor Vehicle" (LEMV) in terms of the extremely low *absolute values* of certain emissions (in grams per mile). The third example is that of the modern steam car. The estimates for a modern steam car have been authenticated by laboratory tests on the Williams Steamer, developed by the Williams Engine Company, Ambler, Pennsylvania. Confirmation has also been provided by tests on a steam-converted Volkswagen built by Richard J. Smith of Midway City, California.

The chart shows that emissions of carbon monoxide, unburned hydrocarbons, and the oxides of nitrogen are well below the limits of even the most visionary and strict standards of the future. In addition, the emission of poisonous lead compounds can be zero, since the use of high-octane leaded fuels is not required.

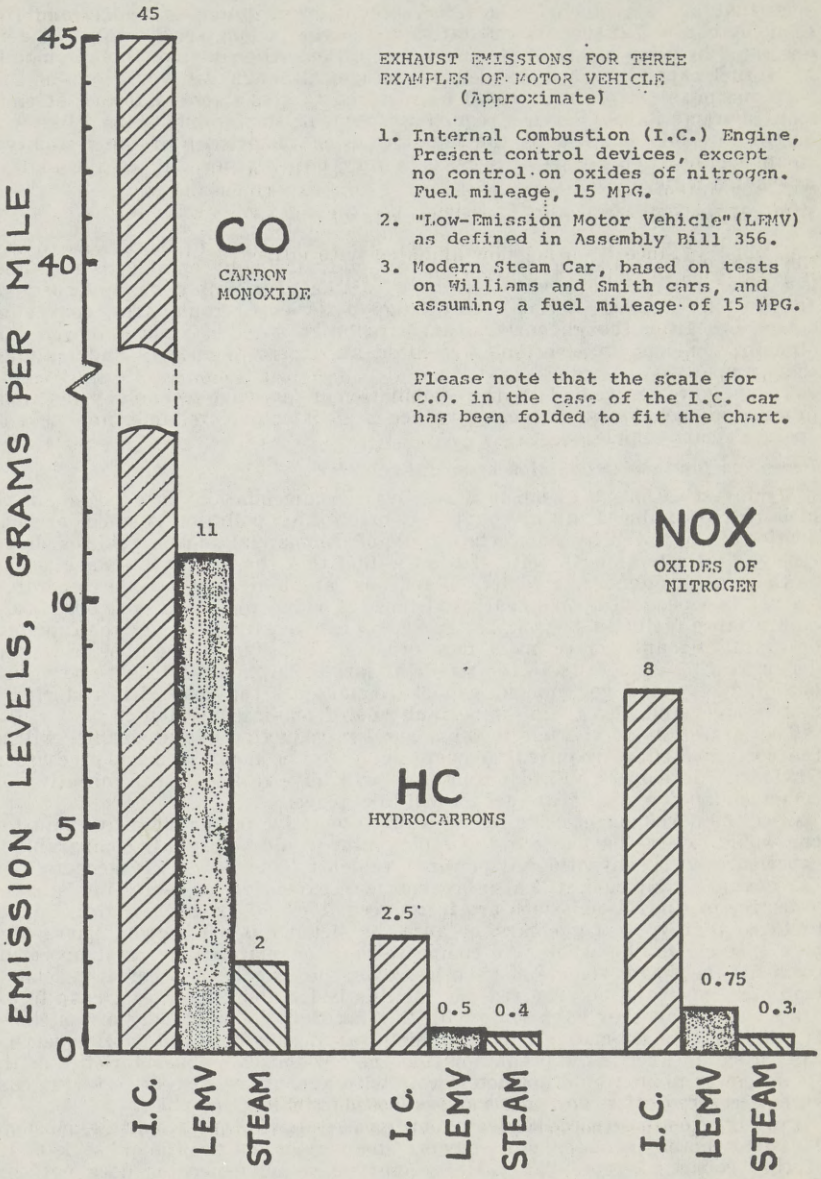
The steam car is a low-emission vehicle because:

1. The burner of a steam generator can burn the fuel cleanly and completely to harmless carbon dioxide and water vapor.
2. Reactions with the nitrogen atoms of the combustion air occur to a greatly reduced extent, when compared with an I.C. engine, This is because the burning takes place at only moderate temperatures and pressures, in the steamer.
3. Leaded fuels are not required.
4. Sudden demands for power can be met without disturbing the combustion process or the fuel mixture.
5. The steam car consumes relatively little fuel under conditions of stop-and-go driving.

Prospects for control with internal combustion engines

Many authorities[1] believe that it will be extremely difficult to provide good simultaneous control on all harmful emissions by modifications of the I.C. engine. Present modifications to control *underburned* products (carbon monoxide, hydrocarbons) can actually lead to an increase in the quantities of *overburned* products (oxides of nitrogen) emitted.

[1] "Report to the (California) Assembly Committee on Transportation and Commerce," Technical Advisory Panel, A. C. Ingersoll, chairman. Apr. 14, 1968; "The Automobile and Air Pollution: A Program for Progress." U.S. Department of Commerce, October 1967.



EXHAUST EMISSIONS FOR THREE EXAMPLES OF MOTOR VEHICLE (Approximate)

1. Internal Combustion (I.C.) Engine, Present control devices, except no control on oxides of nitrogen. Fuel mileage, 15 MPG.
2. "Low-Emission Motor Vehicle" (LEMV) as defined in Assembly Bill 356.
3. Modern Steam Car, based on tests on Williams and Smith cars, and assuming a fuel mileage of 15 MPG.

Please note that the scale for C.O. in the case of the I.C. car has been folded to fit the chart.

It is the writer's opinion that even if a balanced emission control could be achieved with the I.C. engine, the low emission levels already demonstrated by even today's imperfect steamers could not be approached.

Other plus values for the steam car

The performance and operating qualities of the modern steam car can be such that our accustomed tastes for speed, power, quietness, range, and fuel economy can be satisfied. A reputation for having a long service life was demonstrated by some makes of steamer even in the earlier days of the automobile. Multi-fuel capability is a decided advantage, although we would expect that some optimization of fuels would be required to give the very lowest of emission characteristics. Service requiring frequent starts and stops (like city buses) is easily handled by the high-torque characteristics of the piston-type steam engine. (This type of service is very hard on the I.C. engine and its associated transmission.)

Why did the steamer go out of existence before?

With all the advantages claimed, one has every right to inquire as to why the steamer lost favor in an earlier free market. In my opinion, the steamer lost favor because the level of technology of that day simply was not adequate (or was not applied in time), to produce a low-cost, trouble-free, convenient steam car. Even though early steam cars broke speed records and won hill-climbing contests, it nevertheles required an expert to operate and maintain them properly.

Today, however, we do have the combination of space-age technology and mass-production techniques that can produce a satisfactory, reliable, and easy-to-operate steam vehicle.

Prospects for the introduction of steam vehicles

My investigations lead me to a positive recommendation that the steam vehicle be re-introduced in this country. Control of air pollution is sufficient justification. It may well be that certain types of commercial or fleet vehicles should receive first attention, in spite of the the fact that the private automobile may be the greater offender. A variety of reasons can be given. First, fleet operators are not as dependent upon an early existence of widely dispersed sales outlets and maintenance facilities. Second, better control can be exercised over the functions of evaluating and correcting a new product.[2] Finally, it would be a way of demonstrating good faith to the public at large. Through pilot fleet operations, both industry and government can share not only the cost of introducing a new product, but also the all-important role of public education.

The largest single obstacle to the general introduction of the steamer will be the cost and effort required to engineer it for economical mass production. Obviously, developers and manufacturers will have to find either incentives or compulsion before significant action will take place.

Once the development costs for a steam automotive power plant are paid for, one would expect that costs to the vehicle user would be roughly comparable to experience with conventionally-powered vehicles. This takes into account that I.C. engined equipment will also become more expensive, as more sophisticated measures to control emissions are introduced. I would expect a slightly higher first-cost than *present* gas cars, because the steamer is a somewhat more complex system, on the whole. As compensation, the maintenance and operating costs for the steam vehicle may be less over the long term, when it reaches a high state of evolution. The reasons for this last statement are not easy to express briefly, but they have to do with the fact that the machinery of a steamer is inherently better matched to the widely-varying loads of automotive service. Also of significance is the prediction that the low-emission characteristics of the steam power plant would not deteriorate with age, as we suspect to be the case with accessory devices now in use and proposed for the I.C. engine.

Fear is often expressed, regarding a supposed danger from boiler explosions. This fear can be dismissed, since modern steamers do not use the old style boiler of the "capacity" type. The modern coil-type steam generator does not contain large quantities of pressurized water and steam at any one time, and

[2] Disappointment that may be avoided if everyone realizes from the outset, that early prototypes are not likely to be perfect vehicles. Properly viewed and evaluated, correctable defects can be some of the stepping-stones of technical education, hastening the day when a much improved product will become available.

its geometric form precludes a sudden, explosive release of energy even if its tubing is accidentally ruptured.

Possible avenues of Congressional action may be somewhat beyond the scope of this piece of testimony. It may be suggested, however, that the government could set an example in procuring low-emission vehicles for its own fleets; it can broaden the charter of its fine national laboratories to make available the necessary technology to industry at little or no cost; it can set emission standards with the *demonstrated* low-emission characteristics of the steamer as a point of departure. Finally, since clean air—by whatever means this state is achieved—will be at some cost to the public, a public education program will be imperative.

Respectfully submitted.

ROY A. RENNER,
Mechanical Engineer.

FOOTE MINERAL CO.,
OFFICE OF THE PRESIDENT,
Exton, Pa., May 21, 1968.

Hon. WARREN G. MAGNUSON,
Chairman, Senate Commerce Committee.
Hon. JENNINGS RANDOLPH,
Chairman, Senate Public Works Committee.

GENTLEMEN: Foote Mineral Company shares the concern of Congress and the Government for the elimination or substantial reduction of air and water pollution. Tangible evidence of this concern is the company's investment in five years of research to develop electrical propulsion of a vehicle in the belief that, by so doing, air pollution from internal combustion engines would be substantially reduced.

The Foote Mineral Company is recognized as the largest free world miner of lithium ores and brines. It is publicly owned and its sales exceed $85,000,000 per year.

In 1967, Secretary Udall, of the Interior Department, acknowledged the possibility of utilizing a lithium battery to power vehicles but questioned that the reserves of lithium ores were adequate to support the large scale manufacture of batteries made from lithium and its compounds.

Inasmuch as our investment is in the production of lithium batteries, we deemed it advisable to violate our normal policy by releasing prematurely an estimate of reserves of lithium available to us. We record, in substance, the information furnished to the Department of Interior at that time.

1. According to U.S. Geological Survey, indicated reserves of 200,000,000 tons of lithium ore in the State of North Carolina are reported to contain 1,500,000,000 pounds of lithium metal equivalent. The world's largest lithium mine, located at Kings Mountain, N.C. and operated by the Foote Mineral Company, contains proven and indicated ore in excess of 500,000,000 pounds of lithium as metal equivalent.

2. In addition, Foote is commercially producing lithium carbonate from brines rich in lithium chloride at Silver Peak, Nevada. Foote believes that carbonate so produced will ultimately become one of, if not the most economic source of raw material for production of all lithium compounds, including lithium metal.

We recognize that several more years of skillful geological effort will be required to validate estimate reserves of from 5 to 10 billion pounds of lithium in terms of metal at Silver Peak. Nevertheless, we conclude that virtually any reasonable production rate for lithium can be achieved, providing the demand is made known two years in advance of the requirement.

Of course, it is too early in the development of a lithium battery to state the precise number of pounds of lithium that will be required to propel a vehicle. Yet, there is sufficient data to bracket the requirement between 7 and 15 pounds of metal per car, resulting in a lithium requirement of from 60,000,000 to 120,000,000 pounds annually. By referring to estimated reserves, previously cited, you can clearly determine that lithium is available in adequate supply to power 8,000,000 cars per year for many decades.

Foote Mineral Company is convinced that if lithium battery powered vehicles are developed, it can materially contribute as an important miner of lithium ores and manufacturer of lithium metal. Many large companies appear to believe in the electric car by investing suostantial sums to develop an economic battery employing lithium.

We are grateful for this opportunity to record our views on this phase of the anti-pollution deliberations and trust that this statement and the attachments hereto may be of help.

Sincerely,

L. G. BLISS, *President.*

LITHIUM REVIEW

(By W. F. Luckenback, Vice President, Marketing, Foote Mineral Company)

Intense interest in lithium during 1967–68 was generated by electric car competition. The growing threat of air pollution gave impetus to battery research by such companies as Union Carbide, Gulton Industries and the Allison Division of General Motors. Since lithium is the lightest solid element and has a very high electro-chemical potential, it ranks as a leading contender for battery anode material.

Evidence of a potential demand for lithium batteries caused U.S. Secretary of the Interior Stewart L. Udall to register doubt on the matter of adequate reserves. In response, Foote president L. G. Bliss publicly revealed the extent of Foote's reserves in Nevada and Kings Mountain, N.C. The estimate ranged from 5 to 10 billion pounds of recoverable lithium at Silver Peak, Nevada plus 500,000,000 pounds from the North Carolina reserves. Such a reserve should support lithium requirements for batteries to power 8,000,000 new electric cars a year for many decades, according to Bliss.

1968 marks Foote's third year of successful operation at Silver Peak, Nevada where lithium is recovered by solar evaporation of brine. Lithium Corporation of America has built evaporating ponds and is continuing to study recovery of lithium, potash and salt cake chemicals from Great Salt Lake brines.

American Potash & Chemical Corporation is producing lithium as a by-product at Searles Lake, Calif. Interest in lithium recovery from thermal wells in the west was also announced by Morton Salt Company. For the first time small quantities of selected lithium salts of Russian origin have entered the European market and production in Brazil has been reported although no finished product has appeared in world markets.

During the year Vanadium Corporation of America merged with Foote Mineral Company with Foote as the surviving entity. Lithium Corporation of America merged with Gulf Sulfur and became The Lithium Corporation Division of Gulf Resources and Chemicals.

Imports of Rhodesian petalite, a lithium ore used in glassmaking, increased during the year, probably due to stockpile buying as a hedge against the possibility of an embargo.

Foote's process for low iron spodumene (a domestic lithium ore) moved to the pilot plant stage and it is expected that product will reach markets late in 1968. Low iron spodumene will compete directly with petalite for glass applications.

Lithium prices which for a number of years have been depressed increased from 5 to 10 percent in the domestic market and over 10 percent in offshore areas.

World-wide lithium consumption is expected to grow at rates similar to past years. Growth rates in Europe and Japan should exceed those in the U.S.

Domestic production of lithium increased approximately 13 percent over 1966, sustaining the 10 to 15 percent growth rate recorded during the last five years. World-wide consumption was estimated at about 22 to 25 million pounds of lithium carbonate equivalents. Major applications were:

Lithium Carbonate	Ceramics & Aluminum
Lithium Hydroxide	Grease
Lithium Bromide & Chloride	Air Conditioning
Alkyllithium	Polymers
Lithium Hypochlorite	Sanitizers & Bleaches
Lithium Metal	Alloying & Organic Synthesis

Research on lithium products in many diverse fields has been sustained and although no startling new uses developed in 1967 there is the promise of important discoveries ahead. In any event the acceptance and use of lithium on a broad industrial base assures stable and continued future growth.

REPORT TO STOCKHOLDERS, FOOTE MINERAL COMPANY, BY L. G. BLISS, PRESIDENT, APRIL 25, 1968

Mr. Weissenburger has spoken about the significant events occurring during the year 1967, a truly eventful year for the Foote Mineral Company. Since the consummation of the merger of Vanadium Corporation and the Foote Mineral Company on September 1, 1967, the company has been completely reorganized. Many individuals now have assignments of greater responsibilities and, in some instances, in functions of a different nature. A merger, in many respects, is like a marriage. Once it is technically achieved, it requires time to make the adjustments necessary for a happy and prosperous future.

We recognized that important savings could be achieved by the consolidation of several functions. Included in this assessment were Finance, Research, Engineering, Purchasing, Traffic and Sales Coordination. Consequently, we elected to close our New York offices and eventually terminate, through consolidation, the research and engineering functions at Cambridge, Ohio. To accommodate the relocated personnel and attendant facilities, we are building a new wing to our corporate headquarters at Exton, Pennsylvania which will be ready for occupancy September 1, 1968.

Equally importantly, we observed that we had attained a size whereby more intimate attention to dissimilar but related segments of the business would increase growth opportunities for personnel and products. Thus our products were grouped into three divisions, each headed by a general manager and backed up by marketing and productions managers with experience in their specialties. By so doing, more individuals will gain managerial experience essential to the development of our future leaders. In all cases the responsibilities of our corporate officers were increased. Thus as age catches up with the older members of our management team, our younger men will be groomed to replace them.

The relocation of people and the creation of facilities to accommodate them results in temporary increased costs. Such costs should be behind us by the year 1969. To offset these expenditures, we believe we will achieve a less costly and more efficient work force.

As stated, the new Foote Mineral Company consists of three principal operating and selling divisions.

Metallurgical, essentially guiding our destinies in the ferroalloy and electrolytic manganese industries.

Kemco, primarily engaged in the production and sale of various grades of silicon products.

Chemical & Minerals, essentially devoted to lithium chemicals, ores, lime and magnafloat activities.

Our current business is approximately 60% in the Metallurgical Division and 20% each in the Kemco and Chemical and Minerals Divisions. In all three areas we intend to further strengthen our production and marketing expertise and intensify a program of modernization of our facilities.

As a consequence of the decision to install a 57,000 KVA furnace at Graham, we will be able to substantially improve our position in the production and sale of silicon products. The furnace has been in operation for several months and the usual bugs attendant with the start-up of large equipment have been substantially eliminated.

As we meet today we are pleased to report that our new electrolytic manganese plant located on Kentucky Lake in Tennessee is entering the tune-up stage. This facility includes the most modern technology resulting from 12 years of operating experience at Knoxville and many innovations developed in our laboratories. The combination of our new and older plants will provide a total capability of close to 50,000,000 pounds of electrolytic manganese per year. Significantly, we believe we can expand our new plant on Kentucky Lake with a minimal additional capital investment should the marketplace provide the justification.

Several years ago steel producers increased their interests in using vanadium products in higher strength steels. A study of market potentials disclosed a dramatic increase in demand in the years ahead. As a consequence we entered into a long term agreement with Highveld Steel & Vanadium Corporation, located in South Africa, for the supply of an enriched vanadium bearing slag to augment established sources of supply. We anticipate producing several different products from the vanadium bearing slag to bracket industry's techni-

cal and economic requirements. One of these products can be made in existing equipment and marketing is already testing it in industry. However, other products in the research and pilot plant stages require a relatively pure vanadium pentoxide concentrate as a starting raw material. Thus we have committed to a plant designed to extract high purity V_2O_5 from vanadium bearing slags. It should be in operation toward the end of 1969. The first shipments of slags from Highveld are expected to arrive in this country within a few months.

Toward the latter part of 1967, we doubled our capability for the production of lime at Kimballton, Virginia and Asbury, Tennessee. Additional limestone reserves were acquired and we began the development of the ore bodies. Toward the middle of the year, we believe these actions will materially improve our position in the lime industry and enhance our lime profitability.

As previously reported, we still believe one of our most exciting new ventures is located at Silver Peak, Nevada. It is there that we pump brines containing potassium and lithium chlorides into solar evaporating ponds. The concentrate from the ponds is converted into lithium carbonate providing your company with the opportunity of materially improving the economics of lithium products.

During the first few years of the development of the vast brine reserves, we identified unexpected problems in the mining and solar evaporation. The principal problem, dike leakage, has been identified and we consider we have devised the means to resolve it. As a result, production of lithium carbonate should increase several fold in 1968 at a cost substantially below the first two years experience. Currently we have over 18,000,000 lbs. of lithium carbonate equivalents impounded awaiting evaporation. The retention time of each atom of lithium above ground is approximately one year until it is finally converted into lithium carbonate. Thus we now predict that each year beyond 1968 we can anticipate substantially increased production rates, if justified by the market. It is our plan to divert lithium produced at Silver Peak to the production of other lithium chemicals. This, in turn, will release increasing quantities of spodumene concentrates to the ceramic and related industries.

In this connection, we are pleased to report that we continue to make progress in our quest to make spodumene concentrates substantially free of iron, a necessary requisite for the utilization of spodumene in a myriad of ceramic products. semi-commercial plant at Kings Mountain should provide our ceramic customers with this material during the second half of the year.

We expect sales of lithium in its many forms to increase approximately 20% in 1968 over 1967. There are many contributors to the overall increase. Among them are butyllithium, used in the production of polymers, lithium bromide in air conditioning units and lithium carbonate in aluminum pot lines. Beyond these better known applications of lithium products, there are several others showing increasing promise in the laboratories. One has received considerable publicity during the past year. That is the use of lithium electrodes and electrolytes in several types of lithium batteries. We continue to work closely with several large companies evidencing confidence that the commercial utilization of portable electricity can be achieved. It is exciting to note that ultimate sales of lithium for such batteries can be measured in millions of pounds. We grant there are many who consider the lithium battery to be an academic dream despite the millions of research dollars being invested to change the dream into a reality.

We face 1968 with sobriety. We have identified some of our problems and have made plans to cope with them. There are others that we can influence but can't overcome without help. For an example, sales of metallurgical products produced at our Kemco operations are programmed to increase in the neighborhood of 25% in 1968. Yet we note that the imports of low cost competing products continue to make measurable inroads into our domestic markets as government studies the posture it should take in international trade. Needless to say, your company has been and does intend to continue to take an aggressive and active part in influencing government to formulate policies and regulations enhancing domestic industry's profitability and the number of jobs these industries can provide.

Chrome ore, a part of our country's mobilization base, is used in the production of ferrochrome, an essential component of stainless steel. High grade chrome ore is mined principally in Rhodesia and Russia. Our government elected to support United Nations sanctions and England's efforts to economically strangle Rhodesia thus preventing us from using our own Rhodesian ore in our United States based furnaces. As a result the Rhodesian government mandated the two principal

chrome producing companies in Rhodesia. One of these, the Rhodesian Vanadium Corporation, is our wholly owned subsidiary.

Beginning in the fall of 1967, chrome ore required to feed our furnaces at Steubenville and Graham was purchased primarily from Russia at prices considerably in excess of the cost of mining our own ore in Rhodesia. This we must face up to until the Executive Order and the United Nations sanctions are rescinded. We believe our government's Rhodesian policy weakens its mobilization base and our national security. We have made reasonable recommendations to the government which, if accepted, would be beneficial to our country's balance of payments and the economic health of our ferrochrome business. To date we have not received any governmental encouragement. However, we note that there is a rising crescendo emanating from an articulate group of Senators and Congressmen pressing government to initiate a sensible and early resolution of the problem. In the meantime, our inventories of chrome ore, augmented by purchases from Russia and elsewhere, should support our market needs well beyond 1968.

The composite of these comments provides some understanding of the opportunities and the problems we face as we plan for our future. We expect to sell in excess of $90,000,000 worth of goods and services in 1968 at an improved profitability. Forecasting is a risky business in a world so troubled by political, economic and military difficulties; yet we believe that the resources of the Foote Mineral Company, its structure and people are equal to the task ahead. We look forward to continuing growth and improving profits with confidence.

ALEXANDRIA, VA., *May 24, 1968.*

Hon. WARREN G. MAGNUSON,
Chairman, Senate Commerce Committee,
Old Senate Office Building,
Washington, D.C.

DEAR SIR: Time is of the essence regarding the crucial necessity to solve our pollution problems readily, therefore, this invention for a Hydrostatic Pressure Prime Mover for automobiles takes on an even greater significance for reasons indicated below. This invention is the subject matter of a U.S. Patent Application filed by Ralph E. La Pointe.

I would like to point out in simple terminology that my husband's invention for powering a non-combustible automobile engine is not only feasible but practical in that the Hydrostatic Power Source can be used on existing engine blocks, thus eliminating many time consuming measures.

The principle time factor involved would be that which would be required to convert existing blocks to accept this power source and test the timing. My husband would like to work out these conversion details himself and could have them completed in eighteen months with adequate financing.

As to the cost for refinement of this invention, Mr. La Pointe thinks this could be accomplished for approximately Seven Hundred Fifty Thousand Dollars.

Once perfected, this invention could be made available to the consumer within a short period of time based on the time allowance given to the automobile manufacturers to convert their products to the use of Hydrostatic Power.

Another significant consideration for the welfare of Americans other than eliminating air pollution is that it would be far more economical to operate and maintain a Hydrostatic Powered automobile since it is basically a closed system which recirculates one of the working fluids.

I sincerely hope that I have presented a clear concept of this invention. Drawings and more detailed written material will be made available on request and my husband could appear before the Senate Hearing Committee if given a twenty four hour notice.

Respectfully submitted,

DALTRICE D. LA POINTE.

SUMMARY OF THE INVENTION

A conventional crank shaft is turned in response to the displacement of pistons in cylinder chambers where the pistons are subjected to the action of two separated pressurizing fluids on their opposite end faces. One fluid is delivered from a pressurized source and the resulting crank shaft rotation operates the pumps to circulate the second pressurizing fluid. Since no combustion is utilized, pollution of the atmosphere is avoided.

A need exists for a prime mover which will operate automotive vehicles at variable speeds without the combustion of fuel and the resulting pollution of the atmosphere. Various attempts have been made in the prior art to achieve this aim but without complete success. This invention will provide a hydrostatic pressure operated motor or prime mover entirely free from the combustion of fuels and therefore eliminating entirely the atmospheric pollution inherently present in conventional combustion engines while at the same time furnishing a practical device.

In the invention, a first pressurized working fluid from a pressure source is delivered to the corresponding ends of pistons in cylinder chambers to cause initial crank shaft rotation. The resulting initial cylinder displacement will vent the first working fluid to the atmosphere and cut off the delivery of such fluid. The initial displacement and crank shaft rotation will also drive pressurizing pumps to supply a second working fluid, also under pressure, and which is now delivered to the opposite ends or working faces of the pistons to displace them in the opposite direction for causing further crank shaft rotation and cyclically the delivery of a further charge of the first working fluid to the cylinder chambers.

I sincerely hope the brief summary I have sent you is defined clearly enough to stimulate your interest. It is good and will work. I will be most willing to discuss this matter further with you at your earliest convenience.

Very truly yours,

RALPH E. LA POINTE

NORTH PLAINFIELD, N.J.,
May 23, 1968.

Senator WARREN G. MAGNUSON,
Chairman, Commerce Committee,
Senate Office Building, Washington, D.C.

DEAR SENATOR MAGNUSON: Your interest in a high performance, economically feasible and low-polluting steam power plant for motor vehicles, as reported in the May 18th issue of Chemical Week, leads me to bring to your attention a modernized steam engine and boiler design developed by the writer and associates here in Plainfield, N.J. over the past five years, and which qualifies under the above description. This new design has the following characteristics:

1. Emission of exhaust pollutants is well below the minimum required by air pollution authorities. Recent tests made by the Mobil Oil Co. on the exhaust of a steam propelled car after 25000 miles operation, show that the steam unit exhaust had 1/9 the hydrocarbon content of a comparable internal combustion unit, 1/5 the monoxide content, and 1/60 the nitrogen oxide content.

2. The modernized steam unit mentioned above is hermetically sealed so that loss of water has been reduced to a negligible amount. One of the biggest reasons for the abandonment of steam powered units during the early years of automotive development, was the need then for large amounts of water. This is no longer the case.

3. The subject unit will operate on cheaper grades of fuel than required by Diesel or gasoline powered units, so that the cost of operation will be less. Modern combustion techniques now make it possible to burn these cheaper fuels smokelessly and with superior exhaust characteristics. A further advantage of these low grade fuels is that they are not as volatile or explosive as orthodox fuels, and there is consequently less fire hazard in case of accident.

4. One of the greatest advantages of steam power is that when the vehicle stops, the combustion of fuel stops. The worst concentration of air pollution occurs in congested city traffic, where scores of busses and trucks, all with engines running, pour into a confined and poorly ventilated area, a large volume of exhaust gases. Under the same conditions, the exhaust from steam units would be nil.

5. The capability of steam power to provide the energy and range required by modern automotive traffic needs no defense. Its suitability for this application has been well established.

I would like an opportunity to discuss this matter in more detail with you and others interested in getting work started along these lines, and will appreciate your advice as to when and where a meeting could be arranged. Our problem is to finance the building of a prototype, which in this case would be a relatively small amount, since we already have private financing pledged for one half the cost of a prototype.

There will be no problem about financing the demonstration and commercialization phases of this project, once the prototype phase has been satisfactorily completed.

The potential business in the bus and truck field alone is tremendous. If only 1/10 of 1% of the 16½ million buses and trucks in this country could be converted to steam within the next ten years, the volume of sales would exceed $90 million, and this in only one of the potential market areas.

Very truly yours,

H. V. STURTEVANT,
New Jersey Licensed Professional Engineer No. 06964.

STEAM BUS, TRUCK, AND AUTOMOBILE POTENTIAL RE AIR POLLUTION

With all the talk about air pollution in relation to the conventional gasoline-driven automobile, it might be of interest to give some thought to the use of steam-driven automobiles, delivery trucks and transit buses to get rid of a considerable amount of air pollution in cities.

Just after World War I there was developed the Doble Steam Car which, due to its compact steam generator or flash-type boiler, had a continuous power rating of about 120 HP. The use of a condenser made water consumption quite nominal. Data relative to various makes of steam automobiles of the early 1920's indicates that the fuel economy of those cars was equal to or better than that of present day gasoline automobiles.

In 1936 the Doble designs were adapted to bus and truck operation on a rather large scale in Germany, in order to save fuel imports. The Doble system requires only about 20 gallons or 160 pounds of water for continuous operation.

As to the air pollution problem, it should be noted that a well designed steam automobile, bus or truck would not exhaust any unburned hydrocarbons, carbon monoxide, or oxides of lead. The only pollutants would be some oxides of sulphur if liquid fuels were to be used. If *propane* were to be used as a fuel there would be practically no pollution.

Since there might be some objection to the Doble underfloor engine it is suggested that the possibility of a uniflow V–4 single acting two-stage engine be considered. Available data indicates that a complete 120 HP steam power plant could be mounted in about the same space as a six cylinder diesel truck engine. A somewhat smaller unit could be used in a compact automobile.

This writer has a specific proposal for a truck-bus unit which has a number of other advantages besides that of clean exhaust—safer loading, for example.

There is good reason to believe that the steam automobile, thanks to the Doble patents, was well on its way to becoming a factor in our transportation system when the depression hit in the early 1930's. It might now offer a simple, low-cost solution to a large percentage of our air pollution problem with a minimum of delay.

R. J. HARROD, B.S. in M.E.,
Chicago, Ill.

APRIL, 1967.

THE UNIVERSITY OF MICHIGAN,
COLLEGE OF ENGINEERING,
Ann Arbor, May 17, 1968.

Senator WARREN MAGNUSON,
Senate Office Building,
Washington, D.C.

DEAR SENATOR MAGNUSON: In the publication "Automotive News" of May 13, 1968, I have read that the Senate Public Works and the Senate Commerce Committees will start hearings on May 28 on the subject, "Alternatives to the internal combustion engine as a way to reduce air pollutants and noise."

For the purpose of this letter I wish to state that I am familiar with this technology. As evidence of this I was a member of the sub-panel on current automotive systems, which contributed to the report of the Commerce Department Panel on Electrically Power Vehicles, during 1967, chaired by Prof. Richard S. Morse of MIT. Further, I presented the invited paper, "Future Automotive Engines and Air Pollution" at the 3rd National Conference on Air Pollution in Washington in December, 1966.

In this letter I will restrict myself to the topic of vehicle noise, mentioned in the above news statement. The statement has an implication that we must change to alternate powerplants to reduce noise. This is not true, and I wish to comment on this point.

All of the United States, especially citizens of congested areas, are being plagued by an unnecessary amount of vehicle noise, especially from motorcycles, trucks, and sports cars. This works special hardship on the underprivileged, because they live in the noisier areas, in housing with less acoustic insulation. The more privileged escape in quiet air-conditioned cars to air-conditioned homes in the suburbs. Noise in the ghetto areas may be a much more disturbing factor to residents than has yet been recognized.

It is very difficult for a single city to enforce regulation of a noise ordinance concerning vehicles, as we have learned from experience in the city of Ann Arbor, Michigan. Nearly all the States have failed completely to do anything about effective laws and enforcement of vehicle noise control, including the State of Michigan. As has been demonstrated in the case of air pollution, I believe Federal leadership and action is necessary to solve this problem. Only at this broad level can action be taken which will effectively eliminate the manufacture and installation of inadequate sound control equipment (principally exhause mufflers), which is the most important single part of the problem. The Federal regulations of Sweden and Switzerland are good and can help provide a pattern for U.S. regulations.

The point of my letter is that we do not need alternate and new tvpes of powerplants to greatly reduce vehicle noise—we must merely install and maintain effective mufflers and regulate the conventional engine and vehicle types we now have. This will also be much more practical and less costly, and could be accomplished in a fraction of the time.

I, and others, would be glad to develop and document these ideas if they are of interest to your committee.

Yours sincerely,

JAY A. BOLT,
Professor-in-Charge, Automotive Engineering Laboratory.

TSCHUDI ENGINE CORP.,
Flushing, N.Y., June 4, 1968.

HON. WARREN G. MAGNUSON,
U.S. Senate,
Washington, D.C.

DEAR SIR: This letter is prompted by news reports on your interest for new devices that will power vehicles and eliminate air pollution. We have developed a valveless four cycle rotary internal combustion engine that represents a breakthrough in mechanical simplicity. A full size prototype has been constructed and operated. As a result of experience gained therefrom, and further study it became evident that this engine can be designed to have a long expansion stroke, elongated about 60 percent beyond the length of the compression stroke. In this manner the engine can operate on what is technically known as the Idealized Complete Expansion Cycle. The hydrocarbons are more completely burned when they reach the exhaust port. Also, additional power is obtained by this cycle. The expansion—or power stroke is on our engine at least twice as long as that of a comparative conventional engine.

The short stroke on automobile engines has this inconvenience: During the power stroke, while combustion is in progress, the exhaust valve opens suddenly and the partially combusted gases, still at high pressure, undergo a violent blowdown with a consequent waste of energy and emission of unburned hydrocarbons into the atmosphere. To rebuild these engines for a long stroke would make them unduly large and heavy. Our rotary engine, with the long stroke, is 50% lighter than its conventional counterpart.

We take the liberty of enclosing a copy of U.S. patent No. 3,381,669, issued May 7, 1968, together with a 7-page brochure and design drawing, giving full particulars on our engine. At the Engineering School of the Cooper Union for the Advancement of Science and Art, New York, a study on our engine was made, under the guidance of Dr. W. Chinitz, an expert on the chemistry of combustion. It confirms our claim that this engine will indeed reduce air pollution. It is hoped that this will be of interest to you and that we will be favored with your reply.

Very truly yours,

TRAUGOTT TSCHUDI, *President.*

THE TSCHUDI ROTARY COMBUSTION ENGINE

I. Introduction.
II. Reciprocating Crank Engine.
1. Mechanics.
2. Thermodynamics.
III. The Tschudi Rotary Combustion Engine.
IV. Mechanical Features of the Rotary Engine.
1. Compact Shape.
2. Low Friction.
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4. Mounting Position.
5. Power Transmission.
6. Construction.
7. Engine Cooling.
V. Thermodynamic Features of the Rotary Engine.
1. Idealized Complete Expansion Cycle.
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3. Scavenging.
4. Cool Inlet Region.
VI. Development to Date.
VII. Future Development.

I. INTRODUCTION

In his message to Congress on the nationwide Problem of Air Pollution, January 30, 1967, President Lyndon B. Johnson stated:

"The sheer number of motor vehicles may, within a decade or two, defy the best pollution control methods we can develop; if this proves to be true, surely we cannot continue the type of internal combustion engines now in service. New types of internal combustion engines, or indeed, new propulsion systems may be required."

New pollution-free propulsion systems which are economical enough for extensive, everyday use in home and in industry may be decades away. But, a new type of internal combustion engine which answers the need is available now.

The Tschudi Rotary Combustion Engine, disclosed in U.S. Patent No. 3,381,669, and shown on the accompanying drawing, represents a new concept in engine design. It is essentially no more than a simplification and rearrangement of the conventional reciprocating engine, using familiar shapes and parts, such as cams, cam followers, round (in cross section) cylinders, and ring-sealed pistons. The sealing rings are the same as are now used throughout the motor industry.

However, in simplifying the engine, it was found that many of the normal engine parts, such as the valves and valve mechanism, counterweights, crankshaft, connecting rods, sleeve bearings and head gasket, could be totally eliminated. If desired, the ignition system can be replaced by a glow plug. Even bolting can be done away with because this engine, being round, can be assembled by means of quick-fastening devices similar to those now being used on large diameter industrial pipeline joints and on autoclave clousres. Engine assembly or dismantling, now taking several hours, can be carried out in as many minutes.

The net result of all this simplification is an engine with fifty percent less weight, occupying sixty-five percent less space, and requiring only three moving parts instead of twenty-six. Yet, studies have shown that this same engine offers greater power with a cleaner and quieter exhaust due to the nearly complete combustion of its gaseous fuel and the efficiency of its drive mechanism.

How is all of this possible? Through a fresh, unbiased approach using basic Mechanics and Thermodynamics.

II. RECIPROCATING CRANK ENGINE

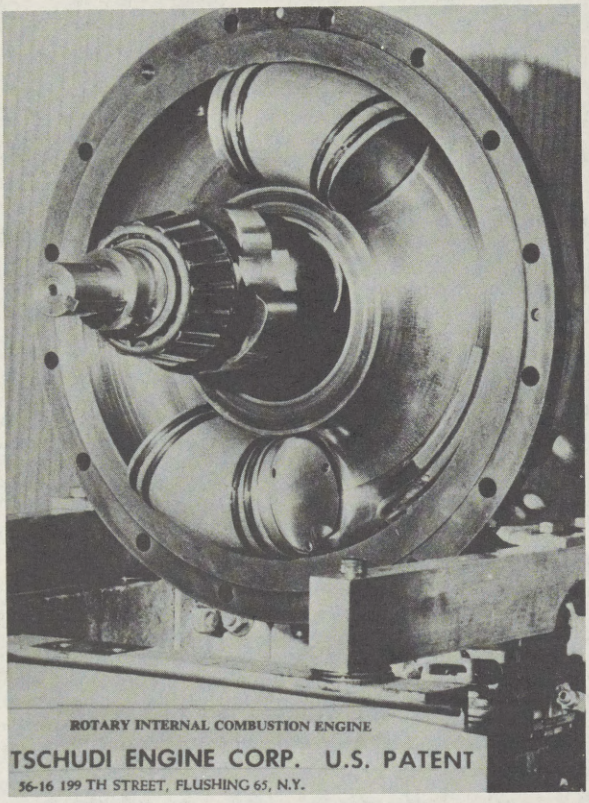
1. *Mechanics.*—Today's conventional reciprocating engine, after almost a century of refinement, is still far from ideal. The very idea of using a linear force perpendicular to a shaft to produce rotary motion in that shaft was a temporary solution at best, and should have been buried along with the steam engine. According to Professor K. Löhner, an authority on internal combustion engines, a rotary engine driven by a force tangential to the shaft will have a power increase of ten to fifteen percent over a comparable reciprocating crank engine.

2. *Thermodynamics.*—Thermodynamically, the reciprocating engine is even less plausible; during the power stroke, while combustion is still in progress, the exhaust valve opens suddenly and the partially combusted gases, at a pressure of 60 to 80 lbs. per square inch. with a temperature of possibly 700 degrees centigrade, undergo a violent blowdown with a consequent waste of energy and emission of unburned hydrocarbons into the atmosphere. It's no wonder that the

thermal efficiency of the reciprocating engine is still only 27%. Of the 73 percent loss, 53% is wasted through exhaust and unburned gases. This is an extravagant use of an irreplaceable raw material and a needless ssault on our environment. But the mechanics of the reciprocating engine restrict further thermodynamic improvement.

III. THE TSCHUDI ROTARY COMBUSTION ENGINE

The development of the Tschudi Rotary Combustion Engine was motivated by the conviction, confirmed by Professor Löhner, that a power stroke having a tangential force in relation to the drive shaft is preferable to the reciprocating crank mechanism. The rotary approach also offered new possibilities for a more flexible, yet simpler design.



IV. MECHANICAL FEATURES OF THE ROTARY ENGINE

1. *Compact Shape.*—Since its inception, it was felt that the only proper way of pressure-sealing a rotary engine would be by using compression rings. This dictated the shape of the combustion chamber, a toroidal space, with four curved pistons operating therein. The pistons form four chambers, each of which, changing in volume during operation, effects, successively, the intake of a mixture, the compression, the expansion, and finally the exhaust and scavenging

of the burned gases, twice per revolution of the drive shaft. This performance by a single toroidal rotary engine equals that of a four cylinder conventional engine, except that the rotary engine is smaller, lighter and more efficient. Two rotary engines, operating on a single drive shaft, can equal the performance of an eight cylinder conventional engine. A two unit engine would provide four evenly spaced power impulses on the drive shaft during one shaft revolution.

2. *Low Friction.*—All bearings have rolling contact. Pistons and rotors are friction free. The sealing rings alone have sliding contact, but the total surface area of the ringfaces is only one-fourth that of a comparable reciprocating engine. This reduced friction contributes to the mechanical efficiency of this engine. Also, battery power is conserved during cold starting.

3. *Lubrication.*—If the interior of this engine is filled to about 25% of the volume with lubricating oil, all bearings will be flooded during operation. The oil will further splash cool the inside of the pistons and the outer wall of the rotors which form part of the toroidal chamber. In absorbing engine heat, it will be circulated through a cooling unit. In order to lubricate the rotor sealing rings, minute holes can be provided. The engine lends itself ideally for pressure lubrication. Lubricants can be pressure injected into any part of the rotors because of the intermittent motion. The inside of the cylinder is not subject to sidewall pressure of the pistons, as is the case in the crank engine. The piston rings alone have sliding contact. Minute quantities of oil can be directed into the chamber from the pistons, or by admixture to the fuel. A porous chrome lining of the toroidal chamber, which retains the lubricant may be the ideal solution for durable operation of the rotary engine. The cost of such a lining is but a fraction as compared with the overall cost reduction in building this simple prime mover.

4. *Mounting Position.*—The mounting position of this rotary engine is not restricted to a horizontal shaft position. The pistons are mounted on rotors and operate friction-free. This, combined with the pressure lubrication of all bearings with rolling contact, and the forced-feed oil cooling of the pistons, make vertical shaft mounting feasible. Besides saving valuable space, vertical mounting of engines, and engine-generator, engine-pump, or engine-compressor units would permit more flexible overall design in any mobile application, such as ships, automobiles, construction equipment, etc. The engine-compressor combination has an additional advantage. With only a slight modification in the design of this engine it becomes a compact rotary air compressor, capable of delivering large volumes of compressed air at high pressure, and with many parts interchangeable, with the rotary engine.

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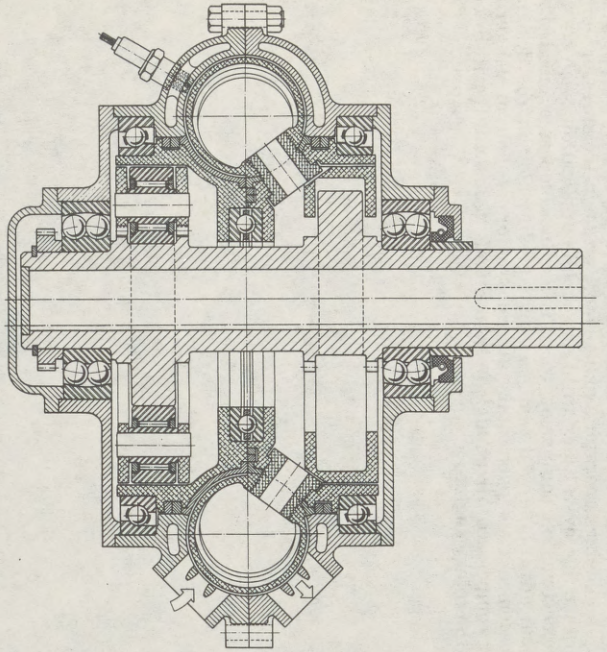

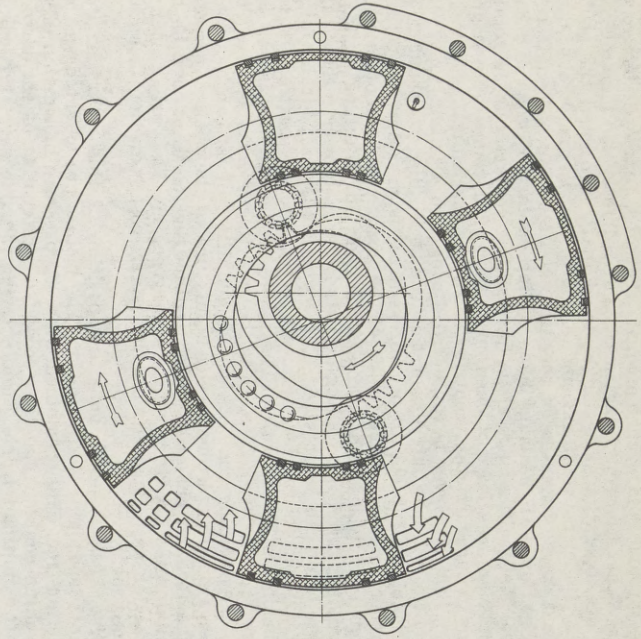

TSCHUDI ROTARY INTERNAL COMBUSTION ENGINE

VALVELESS FOUR CYCLE. TWO POWER STROKES PER SHAFT REVOLUTION. BORE 3,50" STROKE 8,50" 88 H.P. AT 1600 R.P.M. WEIGHT 220 LBS
ENGINE OPERATES ON THE IDEALIZED COMPLETE EXPANSION CYCLE. EXHAUST GASES ARE SCAVENGED BEFORE REACHING INTAKE PORT.

U. S. PATENTS

TSCHUDI ENGINE CORPORATION
56-16 199 TH STREET
FLUSHING, NEW YORK, 11365

5. *Power Transmission.*—The rotor transmits its power to the cams mounted on the drive shaft. However, an alternate method of power transmission is available and is shown on the accompanying drawing. In this arrangement, while the cam and cam followers are in continuous contact, they are relieved from peak pressure during the power stroke by means of a sectional internal gear and pinion drive! The tooth engagement is mechanically controlled by the drive.

6. *Construction.*—In the design of this rotary engine, the overall weight was not a factor since the engine is already fifty percent lighter than its conventional counterpart. The engine block and end plates can be made of ASA alloy cast iron. Rotors and pistons should be of light weight aluminum alloy so as to reduce the inertia forces of the intermittent motion. It will be noted on the drawing that the aluminum rotors are provided with a cast iron cylinder liner, so that wear is uniform with the engine block.

The conjecture has been raised that curved pistons, not presently used in machines, would be difficult to manufacture. Actually, the opposite holds true. The pistons can be manufactured in any machine shop, using a simple procedure. Six pistons are cast together in the shape of a large "doughnut." The casting contains a hollow cavity for each piston. The sand cores which form these cavities are held in casting position by a sand core extension through the large piston opening. The whole "doughnut" is then fastened to a lathe, where first one half of the surface is machined with a concave form-tool. Then the "doughnut" is reversed on the lathe and the form-tool machines the other half. The pistons are then sawed off. Next, each piston is fastened to the lathe with a jig, for facing and cutting grooves for the piston rings. The toroidal chamber can be machined on the lathe in the same manner, using a convex form-tool.

7. *Engine Cooling.*—The engine block can be provided with a series of fins for air cooling instead of the jacked for liquid cooling, shown on the drawing. Pistons and rotors are oil cooled as described above, paragraph 3 of this chapter. Actually, the cooling requirements are moderate: there is less heat loss in the Tschudi Rotary Combustion Engine because of its unique thermodynamic properties.

V. THERMODYNAMIC FEATURES OF THE ROTARY ENGINE

1. *Idealized Complete Expansion Cycle.*—This revolutionary engine is bound to win universal acceptance even if it were judged solely on its mechanical characteristics. But there is a bonus: its unique design permits this engine to be operated close to the idealized *complete expansion cycle* which results in a higher thermal efficiency, more complete combustion of gases, and a cleaner and quieter exhaust.

The Complete Expansion Cycle is a variation of the Otto Cycle, but without the normal waste of energy during the expansion process. By making the expansion stroke much longer than the compression stroke, expansion is permitted to continue to atmospheric pressure, thereby increasing thermal efficiency by producing more work from the same fuel input. While the reciprocating engine could be

adapted to perform as a complete expansion engine, the inordinate size of the resultant engine and the additional friction loss from increased piston travel would more than offset the gain in thermal efficiency. However, with the Rotary Engine, it is simply a matter of locating the intake and exhaust ports somewhat advanced on the toroidal track, in the direction of the piston travel. With its unique and its friction-free pistons, the Tschudi Rotary Combustion Engine is ideally suited to reap all of the benefits of the Complete Expansion Cycle.

2. *Complete Combustion.*—Considering the critical condition of our environment, perhaps the most important advantage of utilizing the Complete Expansion Cycle is that it will reduce air pollution at its source. By permitting nearly complete combustion of the gaseous fuel, the emission of unburned hydrocarbons will be virtually eliminated. Also, engine noise will be abated by avoiding violent blowdown of gases inherent in the reciprocating enigne.

3. *Scavenging.*—Scavenging is not required for the operation of this rotary engine, but its inclusion is quite simple and advantageous. Only a minute quantity of fresh air is needed to expel the remnants, while the combustion chamber, now in its smallest volume, travels from the exhaust port to the intake station.

4. *Cool Inlet Region.*—A large, continuous cool intake port insures an adequate induction of air and a high volumetric efficiency. The weight of the charge is greater, engine knock less.

VI. DEVELOPMENT TO DATE

The Tschudi Rotary Combustion Engine is the result of years of study and research, as documented by several U.S. patents that have been granted on the invention. A full size proto-type engine has been built to check out the mechanical and thermodynamic function. Acknowledgment is due to the Blair Tool and Machine Corp. of College Point, New York: the management who consented to enter this order for a machine with "curved pistons", their skilled machinists who precision built the engine and made it run. The experience gained with this prototype resulted in a new, comprehensive U.S. patent Application which has been granted as U.S. Patent No. 3,381,669, issued May 7, 1968.

Recently, this engine was the subject of a 45 page thermodynamic study by Mr. J. Vargas, an engineer with experience in internal combustion engine design. Mr. Vargas prepared the study as a partial fulfillment of the requirements for obtaining a Master's Degree at The Cooper Union for the Advancement of Science and Art, New York. In the conclusion of his Thesis, Mr. Vargas writes:

"Thermodynamically, then, the Tschudi Engine appears to be an excellent engine, that can yield a large amount of power at speeds and compression ratios that are below those used in modern engines. The operational advantage of this is clear, and graphically illustrates the potential attractiveness of this engine.

"Adding up the excellent thermal and volumetric efficiencies that can be obtained in this engine results in a thermodynamic behavior far superior to any conventional internal combustion engine."

May 7, 1968 T. TSCHUDI 3,381,669

ROTARY INTERNAL COMBUSTION ENGINE

Filed Oct. 31, 1966 4 Sheets-Sheet 1

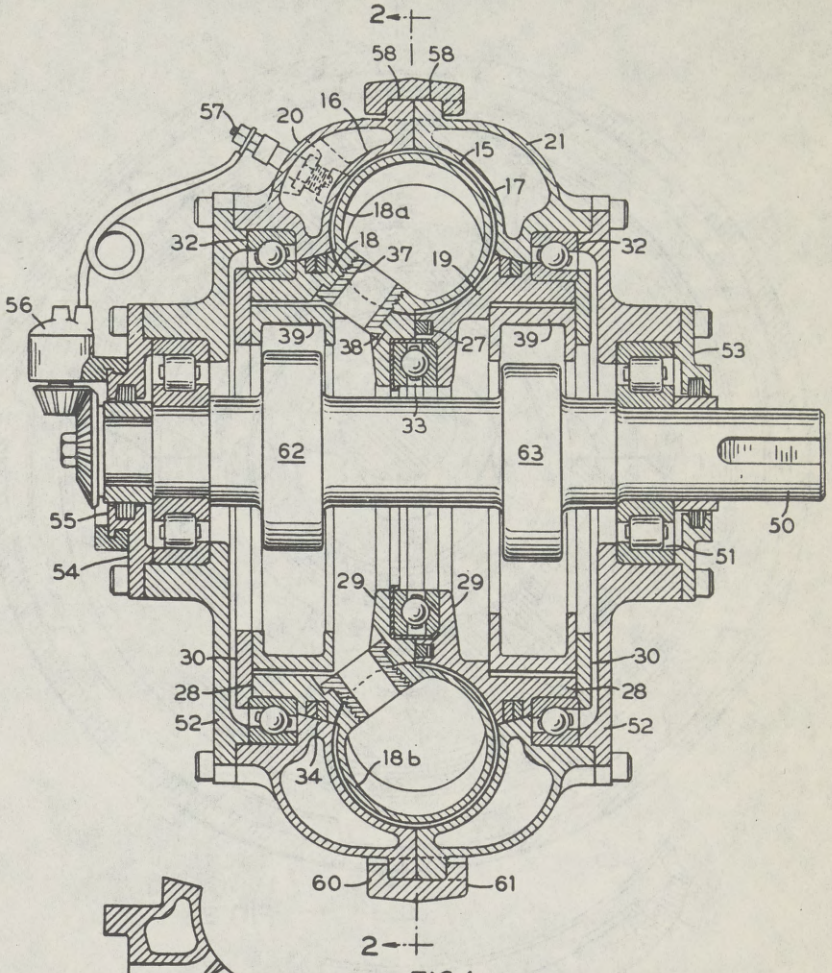

FIG. 1

FIG. 11

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May 7, 1968 T. TSCHUDI 3,381,669

ROTARY INTERNAL COMBUSTION ENGINE

Filed Oct. 31, 1966 4 Sheets-Sheet 2

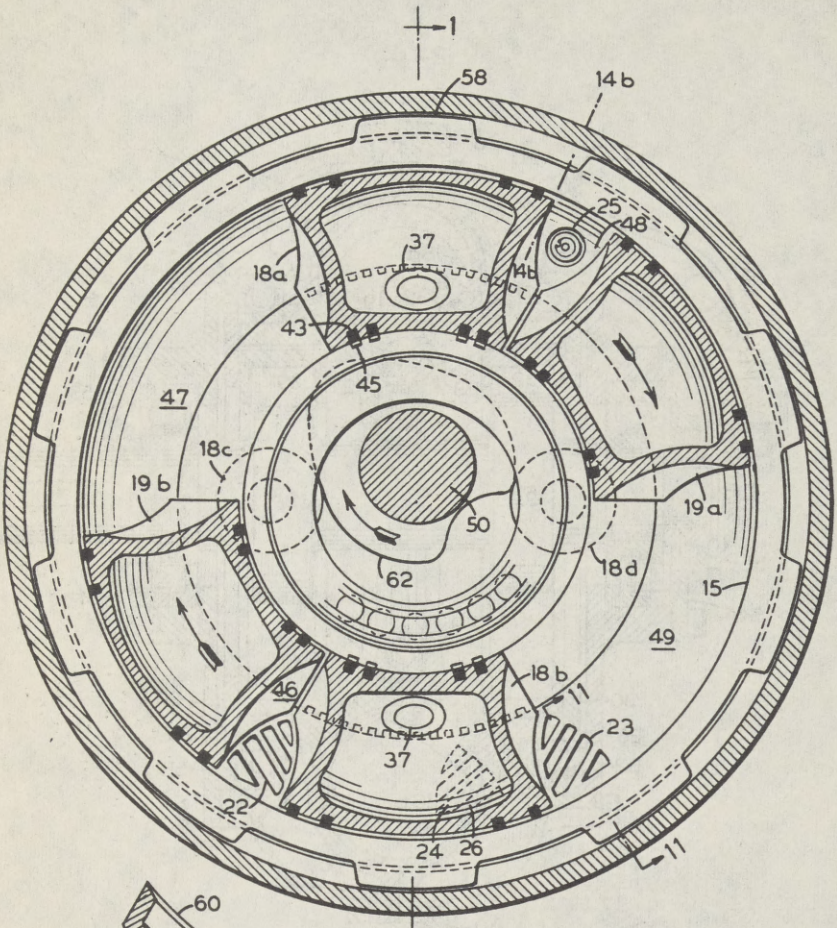

FIG. 2

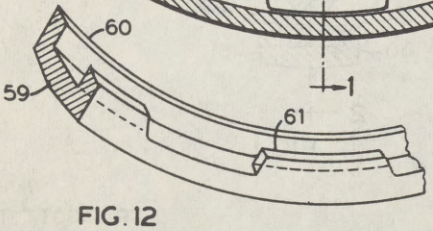

FIG. 12

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May 7, 1968 T. TSCHUDI 3,381,669

ROTARY INTERNAL COMBUSTION ENGINE

Filed Oct. 31, 1966 4 Sheets-Sheet 3

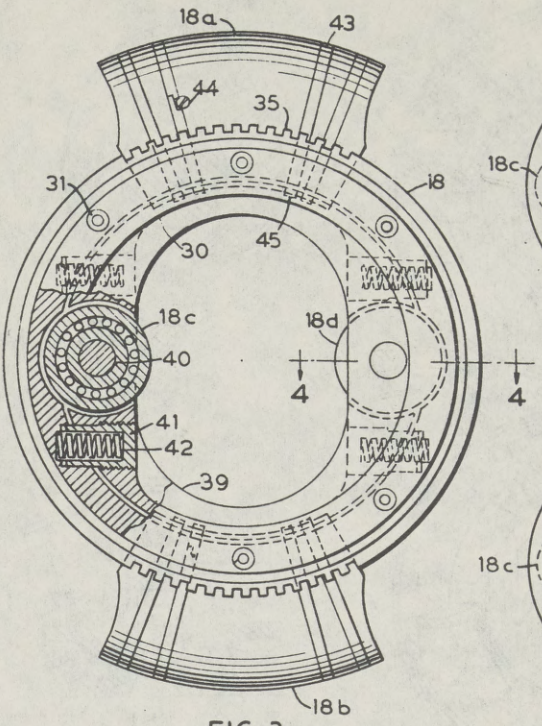

FIG. 3

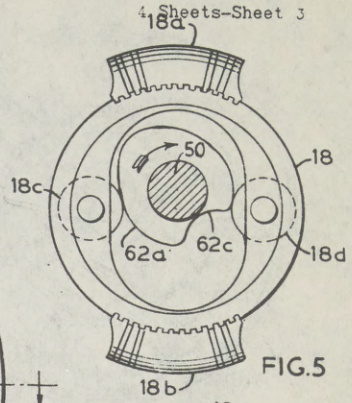

FIG. 5

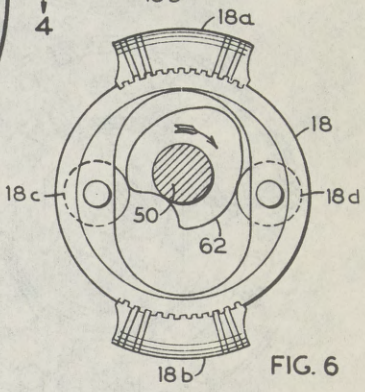

FIG. 6

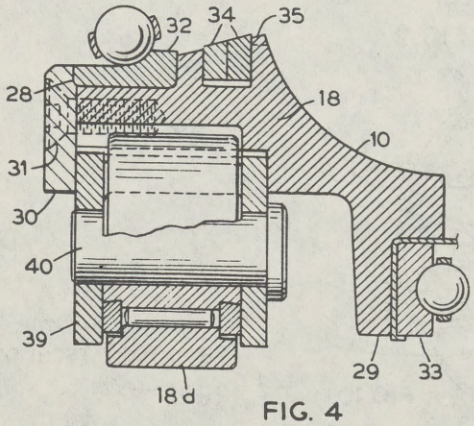

FIG. 4

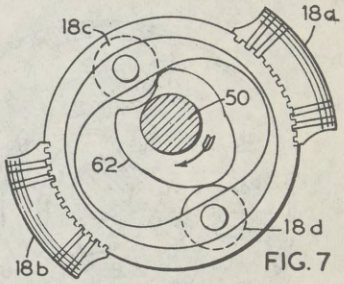

FIG. 7

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ROTARY INTERNAL COMBUSTION ENGINE

Filed Oct. 31, 1966 4 Sheets-Sheet 4

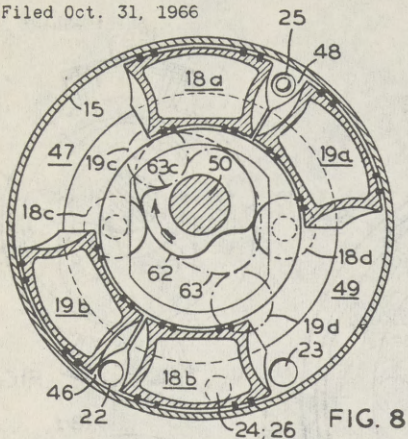

FIG. 8

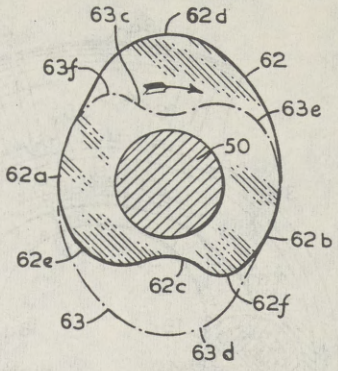

FIG. 13

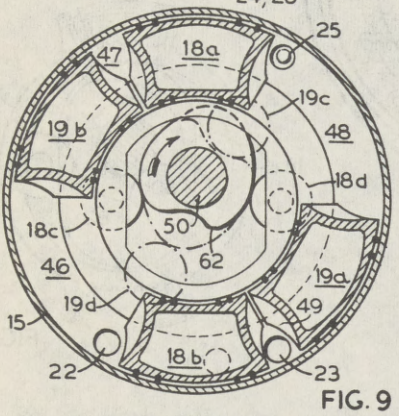

FIG. 9

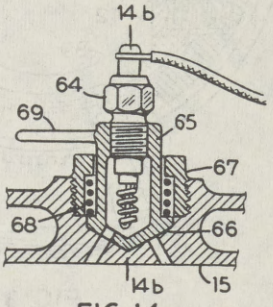

FIG. 14



FIG. 14a

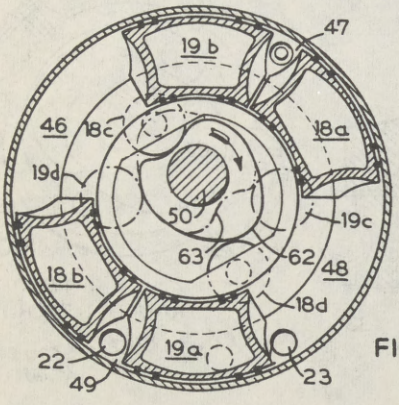

FIG. 10

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United States Patent Office

3,381,669
Patented May 7, 1968

3,381,669

ROTARY INTERNAL COMBUSTION ENGINE

Traugott Tschudi, Flushing, N.Y., assignor to Tschudi Engine Corporation, Flushing, N.Y.

Filed Oct. 31, 1966, Ser. No. 590,918
9 Claims. (Cl. 123—11)

The present invention relates to a valveless four cycle rotary combustion engine, and more particularly to improvements in the type of engine disclosed in my U.S. Patents No. 1,641,911, of Sept. 6, 1927, No. 1,732,995, of Oct. 22, 1929, and No. 2,734,489, of Feb. 14, 1956.

Briefly and generally stated, this type of engine comprises an engine block and a pair of mating rotors coaxially mounted in the stationary engine block for rotation in respect thereto, and the engine block and the rotors together defining a toroidal chamber. A drive shaft extends transversely of the toroidal chamber and has an axis parallel to the axis of the engine block but being eccentric in relation thereto. A pair of diametrically opposite pistons is fixed to each rotor and arranged for revolving movement in the toroidal chamber, the pistons subdividing the chamber into four compartments. A cam drive is provided to move the pistons of each rotor in respect of the drive shaft to vary the size of the compartments, thereby successively and in timed sequence effecting the intake of gaseous fuel, the compression of the fuel, the ignition of the compressed fuel, and the exhaust of the combustion gases, twice per revolution of the drive shaft.

It is one primary object of the present invention to improve the cam drive so that the compression cycle is elongated and the pressure from the fuel intake port to the ignition is gradually increased in the compression chamber. In this manner, the homogenizing of the fuel is improved and, also, the expansion cycle is conversely elongated so that the expansion of the ignited fuel is continued to atmospheric pressure and the thermal efficiency of the engine is increased without adding additional energy in the combustion process. The emission of unburned hydrocarbons is thereby reduced, with a consequent lessening of air pollution now so prevalent in traffic-choked cities.

It is another important object of this invention to provide for yielding engagement between the cam drive and the cam follower means on the rotors to adjust for minor misalignments due to bending of the eccentrically positioned drive shaft which carries cams, thus assuring positive and continuous engagement between the cams and the cam followers, and providing a smooth and noiseless engine operation.

It is also an object of the invention to provide grooves on the annular faces of the rotors to permit full circumferential expansion of piston rings mounted on the pistons.

With these and other objects in view, the invention provides a rotary internal combustion engine which is simple in construction, economical and practical to manufacture with the use of conventional machine tools, low in weight, easy to service, and one that will reduce air pollution by means of an elongated compression and combustion cycle, including scavenging of the combustion gases. The mechanical system is completely self-balanced without the need of counterweights. The pistons and all the moving parts are friction-free.

Merely by way of example and not to delimit the scope of the invention, which is defined by the appended claims, the present invention will be particularly described in connection with one embodiment, taken in conjunction with the accompanying drawing wherein

FIG. 1 is a vertical transverse section of the engine, taken along line **1**—**1** of FIG. 2;

FIG. 2 is a sectional view of the engine, taken along line **2**—**2** of FIG. 1;

FIG. 3 is an elevational front view of a rotor;

FIG. 4 is an enlarged sectional view showing the mounting of the cam followers on the rotor, taken along line **4**—**4** of FIG. 3;

FIGS. 5, 6 and 7 are diagrammatic views showing a rotor and the associated cam drive in successive operating cycles;

FIGS. 8, 9 and 10 are similar diagrammatic views showing the pistons in the toroidal engine chamber in the successive operating cycles;

FIG. 11 is a detailed fragmentary sectional view taken approximately along line **11**—**11** of FIG. 2 and illustrating the construction of the fuel intake, exhaust and scavenging ports;

FIG. 12 is a fragmentary perspective view of a locking ring for fastening engine parts together;

FIG. 13 is a detailed view of the cams;

FIG. 14 shows a preferred ignition device; and

FIG. 14*a* illustrates an arrangement of engine block holes cooperating with the ignition device of FIG. 14.

Referring now to the drawing and more particularly to FIG. 1, the internal combustion engine shown therein by way of example comprises an engine block and a pair of rotors **18**, **19** together defining a toroidal chamber **15**, each rotor carrying a pair of diametrically opposed pistons **18***a*, **18***b* and **19***a*, **19***b*, respectively. The pistons are arcuately shaped in conformity to the toroidal chamber and are mounted for rotation in the chamber, driving the same into four annular engine compartments **46**, **47**, **48** and **49**.

In the illustrated embodiment, the stationary engine block consists of a pair of mating engine block parts **16**, **17** which may be readily assembled and disassembled by means of clamping ring **59** in a manner to be described hereinafter. Respective watercooling jackets **20**, **21** are formed integrally with each engine block part and extend circumferentially thereof.

The engine block has an intake port **22** for gaseous fuel, which is shown to be in engine block part **16** which also has the exhaust port **23**, a scavenging air outlet port **24**, and a tap for ignition device **25** (see FIG. 2). The scavenging air inlet port **26** is located in engine block part **17** opposite to port **24**. FIG. 11 illustrates the cross section of ports **22**, **23**, **24** and **26**.

While the fuel intake and exhaust ports are illustrated in a position adjacent the respective ends of a piston (**18***b* in FIGS. 2 and 8) held momentarily against movement in relation to the drive shaft, this showing merely facilitates a ready understanding of the four-cycle engine operation. If these ports, together with the scavenging air ports, are located in the engine block at respective positions somewhat advanced in a clockwise direction, so that the fuel intake port **22** is somewhat ahead of the momentarily arrested piston during the operation of the engine, the engine will have a higher expansion than compression ratio, whereby the engine will perform as an idealized complete expansion engine.

The two rotors **18**, **19** are identical, except that one rotor, i.e. rotor **19** in the illustrated embodiment, has a groove accommodating sealing ring **27**. Thus, while rotor **18** is specifically described and illustrated in FIGS. 3–7, this description also applies to rotor **19** which, therefore, has been provided with corresponding reference characters to designate like parts.

Each rotor has an annular rim portion **29** and the rotors are so assembled that the rim portions **29** face each other in mating relationship, with thrust bearing **33** interposed between the rim portions of the rotors. While one of the facing surfaces of the rim portions **29** is flat, the other one has a circumferentially extending groove accommodating sealing ring **27**. A suitable spring means, such as a corrugated spring in the groove, forces the

sealing ring **27** against the flat surface of the mating rim portion of the other rotor.

An annular rim **28** extends outwardly from rim portion **29** and carries a ring **30** secured to the rim by flat head machine screws **31**. The rim **28** and rim portion **29** together have an arcuate wall **10** which is complementary to a like wall of the engine block to form toroidal chamber **15**. Self-expanding compression sealing rings **34** are mounted in a circumferential groove in a face of rim **28** which mates with a face of the stationary engine block. Sealing rings **27** and **34** provide a satisfactory seal of the toroidal chamber **15** to prevent escape of fuel therefrom but this seal may be further improved by serrations **35** in the fissures between the sealing rings and the wall **10** along that portion of rotor rim **28** which is contacted by the pistons, the serrations adjacent sealing rings **34** being shown in FIG. 4. The object of these serrations is to provide a friction-free seal against rapid pressure impulses that are generated in the compression and combustion chamber during operation of the engine. Gas escaping across these fissures is subjected at each cavity to sudden expansion and alternatively, while passing from one cavity to the next, to sudden constriction; this results in a series of pressure reductions. Further sealing improvement will be achieved by providing the sealing rings with protrusions engaging the depressions in the serrations to obtain a pressure seal.

Each rotor is mounted in the engine block by means of ball bearings **32** for rotation about the axis of the engine block, the mating rotors being coaxially mounted, with the rim portions **29**, rims **28** and rings **30** being concentrically arranged about the engine block axis, and the mating walls of the stationary engine block and of the rotors defining the sealed toroidal chamber **15**, this engine assembly being most clearly shown in FIG. 1.

Describing the substantially identical rotors with reference to rotor **18**, the rotor carries a pair of diametrically opposed, arcuate, hollow pistons **18***a*, **18***b*. The pistons are rigidly secured to the rotor by means of tubular fastening elements **37**. As shown in FIG. 1, each piston has a thickened wall portion and an inner end of fastening element **37** threadedly engages this wall portion of the piston while an outer end of the fastening element has an annular flange **38** engaging a mating shoulder in rotor parts **28**, **29**. In this manner, the piston fastening element serves also as a conduit for oil to enter the interior of the hollow piston to aid in cooling the same.

As FIG. 1 also shows, while the thickened wall portion of the pistons in contact with the wall **10** of the rotor parts **28**, **29** has a radius equal to the bore radius of toroidal chamber **15**, the radius of the outer piston walls which move in relation to the stationary engine block wall defining the toroidal chamber is slightly reduced to provide a clearance between the moving pistons and the stationary engine block. This clearance eliminates friction and wear of the pistons.

In addition to the pair of diametrically opposed pistons, each rotor also carries a pair of diametrically opposed cam followers, the cam followers being offset by 90° in respect to the pistons. The mounting of the cam followers is best shown in FIGS. 3 and 4. Each cam follower **18***c*, **18***d* is a roller mounted on roller bearings on arbor **40** which is journaled in the side walls of bearing ring **39** of channel shaped cross section. The axis of rotation of the cam follower rollers extends in the same direction as the axis of the engine block.

According to a very important feature of the present invention, the cam followers are yieldingly mounted on the rotor for slight movement in a radial direction in relation to the axis of rotation of the rotor. The illustrated means for yieldingly mounting the cam followers on the rotor includes four hollow screws **41** attaching the bearing ring **39** of each cam follower to the rotor rim **28**. A compression spring **42** is mounted in the bore of each hollow screw **41**, each screw having one threaded

end fixedly engaging the bearing ring **39** while its other end extends into a mating recess in rotor rim **28**. A slight clearance is defined between mating walls of bearing ring **39** and rotor rim **28** so that, under the pressure of spring **42**, the bearing ring and cam follower is floatingly mounted between the rotor rim and the associated cam, permitting minor sliding movements of the cam followers under the pressure of the cam, if needed. This will considerably decrease friction and wear of the rollers and the cam, and also facilitates the smooth movement of the cam in relation to the cam followers without undue torsion being exerted upon the cam drive shaft.

The pistons are preferably made of a light metal, such as an aluminum alloy, to minimize inertia forces, all pistons having the same dimensions and carrying the usual compression rings **43** so as to seal the four engine compartments from each other. The compression rings are mounted in circumferential grooves in each piston and are held therein against rotation by pins **44**. Revolving in toroidal chamber **15**, the movement of the pistons will cause the outer surfaces of the piston rings to take on the minute curvature of the chamber which, in the rings' cross section, will be convex at the outer periphery and minutely concave from the center line of the torus inwardly. As will be noted from FIG. 2, the piston rings will be subject to pressure only over a circumferential arc of about 275° while the dormant circumferential arc of about 85° over the toroidal surface of the rotor will not be subject to wear.

In accordance with another important feature of this invention, the rotor surface beneath each piston ring **43** is undercut to define grooves **45** which permit free circumferential expansion of the piston rings, thus providing an improved seal between the engine compartments **46**, **47**, **48** and **49**. As will be explained hereinafter more fully in connection with the description of the engine operation, each of the engine compartments successively and periodically varies in size as it first operates as the fuel intake chamber, when in communication with gaseous fuel intake port **22**, then as the compression chamber, subsequently as the ignition chamber, when the compressed fuel is ignited and the power stroke of the expanding fuel is effected, and finally as the exhaust chamber of the spent gases, twice for each revolution of drive shaft **50**.

Drive shaft **50** extends through the engine block and through the central clearing of the rotors defined by their annular rim portions **29** parallel to the axis of rotation of the rotors but eccentrically thereof so that the toroidal engine chamber **15** surrounds the drive shaft (see FIG. 1). The illustrated bearing means for drive shaft **50** includes a pair of bearing plates **52**, **52** bolted respectively to the engine block parts **16**, **17** and having secured thereto sealing end plates **53**, **54** through which the shaft projects. Roller bearings **51**, **51** support shaft **50** in the engine block for rotation in respect thereto.

Drive shaft **50** has fixedly secured thereto a pair of identical cams **62**, **63** so spaced along the shaft axis that one cam is in engagement with the pair of cam followers of one rotor while the other cam is in engagement with the pair of cam followers of the other rotor. In the illustrated embodiment, cam **62** cooperates with cam followers **18***c*, **18***d* and cam **63** cooperates with cam followers **19***c*, **19***d*. Thus, shaft **50** and cams **62**, **63** constitute a cam drive for the synchronous revolution of the piston pairs in toroidal chamber **15** to operate the engine in accordance with the invention.

The contour of the cams is critical to the operation of the cam drive according to the present invention, and is best shown in FIG. 13.

Cams **62** and **63** are identical. They are disk cams fixedly secured to shaft **50** and extending radially therefrom into engagement with the pairs of cam followers of the respective rotors. FIG. 13 shows the cams as viewed from the power take-off end of the drive shaft whose

clockwise rotation is indicated by an arrow. Cam **62** is shown in full lines while cam **63** is illustrated in dash-dot lines for a better understanding of the drawing.

Each disk cam has two diametrically extending axes perpendicular to each other and intersecting at the axis of cam shaft **50**, one axis of the cam being longer than the other one. As is conventional in cams of this type used in rotary internal combustion engines, the cam is asymmetrical in respect of its shorter axis but, in accordance with the invention, the cam is also asymmetrical in respect of the longer axis, as the following detailed description of the cam contour will show. To obtain the timed sequence of the drive of the two rotors, the cams are angularly offset by 180° with respect to each other so that like contour portions of the cams are diametrically opposite each other, and by this arrangement, the power shaft is dynamically balanced. Since the cams are identical, the contour thereof will be described in connection with cam **62**, the same reference characters being applied to cam **63** to designate like contour portions.

The contour or cam face includes two diametrically opposed lobes **62***a*, **62***b*. These lobes are convexly contoured so that rotor **18** will be in a stationary position as long as these lobes are in contact with cam followers **18***c*, **18***d*. In other words, the lobes **62***a*, **62***b* will lock them into engagement with the cam drive so as to take the rotor **18** along. The contour also includes two diametrically opposed cam faces **62***c*, **62***d* along the longer axis of the cam. The concave index face **62***c* allows a respective one of cam followers **18***c*, **18***d* to move freely as this cam follower comes closest to the eccentric drive shaft **50** during revolution of the rotor **18** about the shaft, while the irregularly ovate cam face **62***d* contacts the diametrically opposite cam follower, in which position the rotor **18** is free of engagement with the cam drive.

In accordance with the invention, the concave index cam face **62***c*, which frees the rotor from the cam drive, is connected to the faces **62***e*, **62***d* of the cam, which lock the rotor to the cam drive, by convex dwell faces of different lengths. As shown, the dwell face **62***e*, which precedes the index **62***c* in the direction of rotation of the cam, is substantially longer than the dwell face **62***f* which follows the index.

As will be apparent from a consideration of FIGS. 5–7, this contour of the cam elongates the compression and power stroke, as will be more fully explained hereinafter in connection with the description of the engine operation. While the cam lobes **62***c*, **62***d* lock cam follower rollers **18***c*, **18***d* (FIG. 5), as the cam shaft **50** rotates in the direction of the arrow, rotor **18** remains stationary in relation to the shaft. As dwell face **62***e* is rotated into engagement with cam follower **18***c* (FIG. 6), the cam remains locked between the pair of diametrically opposed cam followers **18***c*, **18***d*, and the torsion of the rotating cam drive further moves the rotor, taking it along into the position shown in FIG. 7, at which point the cam follower **18***c* is about to enter into concave index face **62***c* to begin the power stroke.

In the illustrated embodiment of the rotary internal combustion engine, the two mating engine block parts **16**, **17** are assembled by means of a fastening device which makes it very simple and easy rapidly to take the engine apart without tools. As shown, each engine block part has a mutilated flange **58** to enable the parts to be clamped together by a ring **59**, which is more clearly shown in FIG. 12. Clamping ring **59** includes a continuous rim **60** and a mutilated rim **61**. The contacting surfaces of continuous rim **60** and engine block part **16** are flat, whereas the contacting surfaces of mutilated flange **58** on engine block part **17** are radially wedge-shaped. Upon assembly, the ring **59** is turned so as to tighten the wedges, thus providing a bolt-less means of assembling the engine block. Similar assembling means may be used for mounting bearing plates **52** on the engine block parts and end plates **53**, **54** on the bearing plates, instead of the illustrated bolts.

As shown in FIG. 1, end plate **54** has a circular track **55** which carries a rotatable mounting base for an ignition distributor or magneto **56**. This device is provided for adjusting the ignition timing of spark plug **57** extending into tap **25**, in relation to the movement of a compressed fuel charge towards the spark plug while the engine is in operation.

FIGS. 14 and 14*a* show a glow plug **64** to be substituted for the conventional spark plug ignition system. Glow plug **64** is an electrical device with a heating element extending into a housing **65** having a conical base with a shoulder **66**. A threaded bushing **67** fastens the housing **65** to the engine block, an annular cavity being defined between the inner bushing wall, the outer housing wall and the shoulder **66**, and a helical spring **68** in this cavity pressing the glow plug housing tightly against bore means in the engine block. Housing **65** has a single port, whereas the bore means in the engine block includes a series of holes arranged to define a cone.

A handle **69** is attached to the upper end of the glow plug housing and when the housing is turned by the handle, the housing port will be in communication with different ones of the engine block holes so that the glow plug will spark the compressed charge of gaseous fuel at various points within a distance of several degrees of piston travel. With the glow plug assembly having as its center the line **14***b*–**14***b*, as shown in FIG. 2, it is possible to pre-ignite the fuel in the same manner as with the conventional electric distributing system. But with this simplification, the entire unit will be even more economical in manufacturing cost, performance and maintenance.

The operation of the internal combustion engine will be obvious from the above description of its structure and will now be summarized for a fuller understanding:

Assuming the engine has been started electrically so that there is an intake of gaseous fuel through port **22** and the rotors are in the position shown in FIG. 8 (see also FIG. 5), with cam shaft **50** rotating at constant speed in a clockwise direction. As shown, pistons **18***a*, **18***b* are at vertical center and cam followers **18***c*, **18***d* are in contact, respectively, with diametrically opposed cam lobes **62***a*, **62***b* of cam **62** at horizontal center at points 90° removed from the respective pistons of rotor **18**. As long as cam followers **18***c*, **18***d* remain in contact with lobes **62***a*, **62***b*, they lock the rotor **18** into position against rotation in respect of shaft **50**. Thus, the rotor and its pistons **18***a*, **18***b* move with the shaft but not in relation thereto. At the same time, the cam follower **19***c* of rotor **19** rests in concave index face **63***c* of cam **63** while cam follower **19***d* remains unobstructed by diametrically opposed cam face **63***d*. While cam followers **19***c*, **19***d* are in contact with concave index face **63***c* and ovate cam face **63***d*, respectively, the rotor **19** is free to move in relation to the cam shaft **50**, and it is so moved when the compressed charge of fuel in compartment **48** is ignited by device **57** or **64**, thereby imparting a power impulse to piston **19***a*. This power impulse is transmitted to cam shaft **50** through piston **19***a*, fastening element **37**, rotor rim **28**, hollow screws **41**, bearing ring **39**, cam followers **19***c*, **19***d* and cam **63**, in the order named. The ignited compressed fuel charge in compartment **48** pushes pistons **19***a*, **19***b* of rotor **19** through an arcuate path of about 50°, the arcs of cam lobes **62***a*, **62***b* being of corresponding length to remain in locked engagement with cam followers **18***c*, **18***d* to hold rotor **18** stationary in relation to shaft **50** while rotor **19** moves into the position shown in FIG. 9 (see also FIG. 6). During this period and for some distance thereafter, compartment **46** in registry with intake port **22** receives a charge of gaseous fuel, the fuel charge in compartment **47** is simultaneously compressed, and

the spent gases in compartment **49** leave the engine block chamber through exhaust port **23**. The movement of rotor **19** from the position shown in FIG. 8 to that illustrated in FIG. 9 is instantaneous upon ignition of the charge in compartment **48**, the above-described fuel charge, compression and exhaustion taking place simultaneously.

At this stage, cams **62** and **63** have begun to move from the position shown in FIG. 9 to that of FIG. 10, i.e. cam follower **19***c* has moved out of the concave index face **63***c* onto the short cam dwell face **63***f* while cam follower **19***d* is locked to lobe **63***a*, thus moving rotor **19** into the locked position of FIG. 10 while the rotor **18** assumes the freely rotatable position described hereinabove. In other words, the position of FIG. 10 is identical with that of FIG. 8, except that the role of the two rotors is reversed. Now, compartment **49** receives the fresh charge of fuel, the charge in compartment **46** is about to be compressed, the fuel charge in compartment **47** is about to be exploded, and the spent gases in compartment **48** are exhausted and scavenged. The power impulse in this cycle is transmitted to cam shaft **50** through piston **18***a*, fastening element **37**, rotor rim **28**, hollow screws **41**, bearing ring **39**, cam followers **18***c*, **18***d* and cam **62**, in the order named, thus duplicating the action of rotor **19**.

Thus, two power impulses are transmitted to the cam shaft **50** during each revolution, and sequentially by pistons **19***a*, **18***a*, **19***b* and **18***b* during two revolutions, to be repeated every two revolutions.

As indicated, each power stroke involves an arcuate piston movement of about 50° of one rotor while the other rotor remains stationary in relation to the drive shaft **50**, with the pistons of this rotor at the vertical center. As each power stroke is completed, the pistons at vertical center begin to move since a respective one of the elongated cam dwell faces **62***e* or **63***e* gradually releases the contacting cam follower and permits rotary motion of the corresponding rotor. This results in a gradual enlargement of the combustion chamber and, therefore, elongates the expansion stroke to a travel of about 120° of the toroidal chamber, producing a more thorough combustion of the fuel and, consequently, higher engine efficiency.

While the combustion chamber is subjected to a gradual expansion, due to the asymmetrical curvature of the cam faces in respect of the longer axis of the cam, the compression cycle, which is converse to the expnsion cycle, also is elongated to the same arcuate length of about 120°, allowing the gaseous fuel charge to be homogenized more thoroughly than in conventional engines, and thus further improving the engine efficiency.

The exhaust compartment passes through a scavenging zone wherein a compressed charge of fresh air is blown through port **26** to evacuate remaining impurities from the exhaust compartment so that the same is clean when it reaches the charging station in registry with inlet port **22**.

I claim:

1. In a rotary four cycle internal combustion engine comprising a stationary engine block having an axis, a pair of mating rotors coaxially mounted in the engine block for rotation in respect thereto, the engine block and the rotors together defining a toroidal chamber; a drive shaft extending transversely of the toroidal chamber and having an axis parallel to the axis of the engine block but being eccentric in relation thereto; a pair of diametrically opposite pistons fixed to each of said rotors and arranged for revolving movement in the toroidal chamber, the pistons subdividing the chamber into four compartments; a pair of diametrically opposite cam follower rollers fixed to each of said rotors and spaced angularly 90° from the pistons on the respective rotor; and a pair of identical cams fixed on the drive shaft, extending radially therefrom and so spaced along the shaft axis as to be in engagement with a respective one of the pairs of cam follower rollers, each cam having two diametrically extending axes perpendicular to each other and intersecting at the shaft axis, one cam axis being longer than the other cam axis, a concave index cam face and an ovate cam face opposite thereto along the longer cam axis, and the cams being angularly offset by 180° in respect of each other: the improvement of two cam lobes opposite each other along the shorter axis of each cam and asymmetric in respect of the longer axis.

2. The improvement in the engine of claim **1**, wherein each of said cam lobes includes a dwell face merging into the concave index cam face, one of the dwell faces being longer than the other dwell face.

3. The improvement in the engine of claim **2**, wherein the lobe and longer dwell face associated therewith define an arcuate path of about 120° for a respective cam follower roller-engaged therewith.

4. The improvement in the engine of claim **1**, further comprising means for yieldingly mounting the cam follower rollers on the rotors for movement in a radial direction in relation to the axis of rotation of the rotors.

5. The improvement in the engine of claim **4**, wherein each rotor comprises an annular rim extending concentrically about the axis of rotation, and said mounting means comprises a bearing ring arranged concentrically about the axis of rotation and yieldingly secured to the annular rotor rim.

6. The improvement in the engine of claim **1**, further comprising piston rings on each of said pistons to seal the compartments from each other, and the rotor surface beneath each piston ring is undercut to define grooves permitting free circumferential expansion of the piston rings.

7. The improvement in the engine of claim **1**, further comprising a pair of sealing rings on each side of each piston between the rotors and the engine block, and serrations adjacent the sealing rings and facing the toroidal chamber.

8. In a rotary four cycle internal combustion engine comprising a stationary engine block having an axis, a pair of mating rotors coaxially counted in the engine block for rotation in respect thereto, the engine block and the rotors together defining a toroidal chamber; a drive shaft extending transversely of the toroidal chamber and having an axis parallel to the axis of the engine block but being eccentric in relation thereto; a pair of diametrically opposite pistons fixed to each of said rotors and arranged for revolving movement in the toroidal chamber, the pistons subdividing the chamber into four compartments; a pair of diametrically opposite cam follower rollers fixed to each of said rotors and spaced angularly 90° from the pistons on the respective rotor; and a pair of identical cams fixed on the drive shaft, extending radially therefrom and so spaced along the shaft axis as to be in engagement with a respective one of the pairs of cam follower rollers, each cam having two diametrically extending axes perpendicular to each other and intersecting at the shaft axis, one cam axis being longer than the other cam axis, a concave index cam face and an ovate cam face opposite thereto along the longer cam axis, and two cam lobes opposite each other along the shorter cam axis, and the cams being angularly offset by 180° in respect of each other: the improvement of means for yieldingly mounting the cam follower rollers on the rotors for movement in a radial direction in relation to the axis of rotation of the rotors.

9. In a rotary four cycle internal combustion engine comprising a stationary engine block having an axis, a pair of mating rotors coaxially mounted in the engine block for rotation in respect thereto, the engine block and the rotors together defining a toroidal chamber; a drive shaft extending transversely of the toroidal chamber and having an axis parallel to the axis of the engine block but being eccentric in relation thereto; a pair of diametrically opposite pistons fixed to each of said rotors and arranged for revolving movement in the toroidal chamber, the pis-

tons subdividing the chamber into four compartments; a pair of diametrically opposite cam follower rollers fixed to each of said rotors and spaced angularly 90° from the pistons on the respective rotor; and a pair of identical cams fixed on the drive shaft, extending radially therefrom and so spaced along the shaft axis as to be in engagement with a respective one of the pairs of cam follower rollers, each cam having two diametrically extending axes perpendicular to each other and intersecting at the shaft axis, one cam axis being longer than the other cam axis, a concave index cam face and an ovate cam face opposite thereto along the longer cam axis, and two cam lobes opposite each other along the shorter cam axis, and the cams being angularly offset by 180° in respect of each other: the improvement of piston rings on each of said pistons to seal the compartments from each other, and the rotor surface beneath each piston being undercut to define grooves permitting free circumferential expansion of the piston rings.

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VII. FUTURE DEVELOPMENT

The Tschudi Engine Corporation was formed to fund the final development work of this engine which included the construction and testing of a prototype unit. We are now seeking an established manufacturing concern in this field whose technical staff and production facilities are geared to mass-produce this engine. The Rotary Engine depends on such a corporation. As President Johnson said: "It is in private laboratories, and in private boardrooms, that the crucial decisions on new means of developing power and locomotion will be made".

It is essential that the Tschudi Rotary Combustion Engine be reviewed with the same fresh, unbiased approach which led to its creation and development. The need for a new type internal combustion engine which can reduce air pollution is urgent. The fact that this particular engine is also efficient, light, compact and simple should favorably affect any decision on its future.

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