What's Happening to the Automotive Power Plant?

A forecast for the next 25 years

by PETER KYROPOULOS

FOR the next 25 years there seems to be no indication of an early return to horses, nor any probability that steam or electric power will become attractive for use in the automotive powerplant. Too little is known about the miniaturization of nuclear reactors to even take a guess as to whether this might become a practical source of power—and this is also true for the direct utilization of solar energy.

Indications are that a summarization of present ideas on automotive powerplants would give us a better clue to what's in the future. For this forecast we might ask: How many people? How many cars? How much fuel?

	People	Cars	Gasoline
	10^6	10^6	10^9 gallons/year
1940	130	27	21
1950	150	40	35
1960	180	60	55
1970	200	80	75
1980	210	90	85

Since the table brings us to a formidable figure of 90,000,000 powerplants, the next question might be: How are these automobile powerplants going to work? The term automobile powerplant indicates that we are concerned with the whole propulsion system; the engine, transmission, drive line, differential and rear wheels.

As far as the engine is concerned, we have three choices, the piston engine, gas turbine, or the gas turbine with a free piston gas generator.

The forecast also lists gasoline consumption. Whether or not it will be gasoline or another liquid hydrocarbon is an important question. Whatever the type of fuel will be, the quantity should be about 85 billion gallons per year, and this, as the saying goes, "ain't hay."

Before we can discuss types of powerplants, we should establish the desirable and probable output required.

An abstract of a paper presented at the annual meeting of the Western Engine Rebuilder's Association in Palm Springs, California, on November 2, 1956.

Let us consider a typical passenger car traveling on a superhighway at 70 mph. The power required adds up as follows:

Air and rolling resistance		**40 hp**
(No headwind, summer temperature. This figure would be 60 hp with a 13 mph headwind at 30° temperature.)		
Transmission efficiency		**.88**
Rear end efficiency		**.96**
Engine power required	$= \dfrac{40}{.88 \times .96} =$	**47.5 hp**
Accessories	**hp**	
Power steering	1	
Generator, charging	2	
Air conditioner	6	
Fan	3	
Total accessories	**12**	
Total engine power required for cruising:	**47.5 + 12** =	**59.5**

This indicates only the minimum required. Acceptable acceleration can be obtained with an engine of 200 to 250 hp.

Although engines with considerably more power are common today, this trend may be eventually reversed. Acceleration at low speeds can be had from high torque at low speeds, without requiring very high peak power. The very high peak powers which are advertised are, in themselves, not very meaningful. The peak occurs at engine speeds which can be utilized only infrequently, if at all, because they correspond to high road speeds. It is doubtful whether cruising speeds over 75 mph will be practicable. If fully automatic steering and control systems become available, cruising speeds of around 100 mph on superhighways may be feasible. This would require about 160 hp at the rear wheels. This is easily available in many of our present engines.

Commercial vehicles such as trucks and off-the-road equipment are in quite a different situation. Here full load uphill operation is critical. A 65,000 pound truck going up a 6 percent grade at 45 mph requires about 1100 hp. There is at present no powerplant which will deliver this amount of power and which will fit into a truck.

The torque needed for low speed acceleration is not only a characteristic of the engine but depends on the correct *matching of the engine and transmission.* This matching has a twofold objective:

(1) Performance (meaning smooth and rapid acceleration over a wide speed range) and

(2) Economy (meaning an acceptable miles per gallon vs speed relation).

Meeting the requirements

Both these requirements can be met by a transmission with an infinitely variable gear ratio, automatically controlled. Basically the hydrodynamic transmission (commonly called a *torque converter)* is such a transmission. Actually, present torque converters still fall short of our requirements.

The chart, right, shows typical curves for two converters. One is designed for high stall torque ratio (4.3) at low speed, i.e., designed for high acceleration at low speed.

At a speed ratio of about .62 the stator is allowed to free-wheel (intersection of heavy and broken line). This is called the "clutch point." The torque ratio becomes 1 and the converter degenerates into a coupling. Efficiency peak is at a speed ratio of about .4. Between this peak and the clutch point, the converter efficiency is quite low, hence performance is unacceptably low.

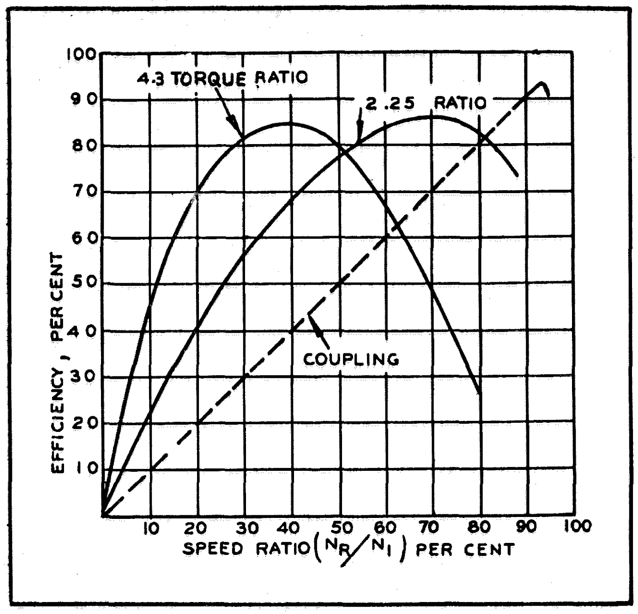
The second converter has a stall torque ratio of only 2.25, an efficiency peak at high speed ratio and atrocious efficiencies at lower speeds, hence no performance.

With fixed blade angles, the torque converter is essentially a single speed machine. We will need torque converters with continuously controllable blade angles. This would give us a transmission with high stall torque and high efficiency over a wide range of speed ratios.

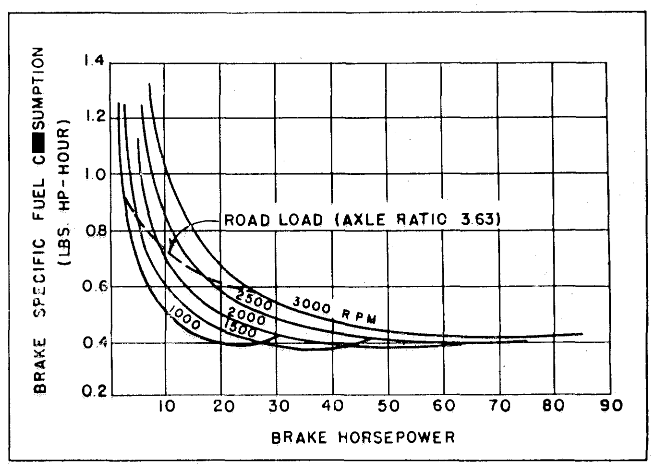
The second requirement—Economy—demands, first of all, high transmission efficiencies over the widest possible range of speed ratios. This is strictly a matter of converter development. Besides, the transmission should automatically seek the most economical operating point of the engine, compatible with speed and load requirements. This is illustrated in the center chart.

This plot shows fuel consumption vs power for a typical piston engine (spark ignition). The broken curve represents operation at road load for a typical passenger car with fixed gear ratio transmission. It is evident that the engine is forced to operate considerably above its optimum fuel consumption. The transmission should permit us to operate on the envelope around the minima of the consumption curves. What this means in terms of miles per gallon is shown in the bottom chart, where we have designated the latter case as "ideal transmission."

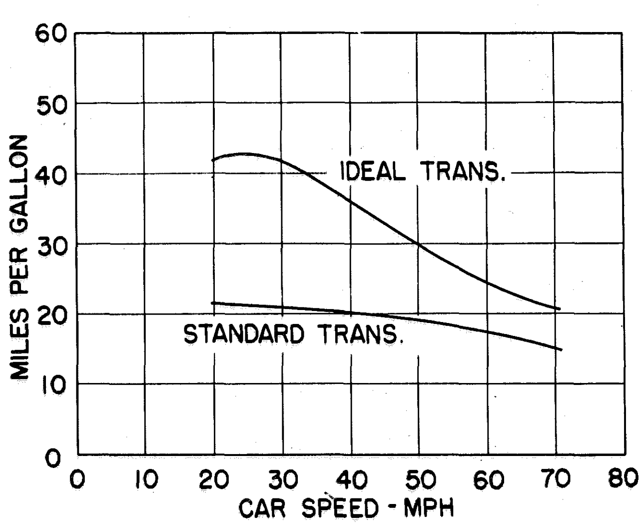
It is within the capability of the variable pitch trans-



Efficiency vs speed for two converters with different design points (Ref. 6). Speed ratio = output speed/input speed.



Typical piston engine curves of fuel consumption vs power (Ref. 5).



Comparison of economy for fixed gear ratio (standard) transmission with optimum within the capability of the engine (Ref. 5).

mission to utilize the large potential gain in economy.

The transmission problem in one form or another is common to all propulsion systems and is not limited to the piston engine. It is, therefore, considered ahead of an evaluation of engine types.

Pistons or pinwheels?

It has been said that, had we been driving around with turbine engines for the last 35 years, and someone had just now invented the piston engine, he would be considered quite a genius.

Just what is the status now and what is the potential? For passenger cars, the maximum practicable power is somewhere between 400 and 500 hp. Considerably less is most likely sufficient, as has been demonstrated earlier in this report. The objective of future development will be to

(1) improve economy without sacrifice in performance;

(2) increase specific output (bhp/cu.in.) while, at the same time, decreasing the weight of the powerplant (lbs/bhp).

Piston Engines: The first objective clearly indicates continuation of the trend towards increased compression ratios. At present it is estimated that we shall use compression ratios of 12:1 and premium fuels of 110 octane number. The potential gains were established as far back as 1949 (Ref. 7). Raising compression ratio from 8:1 to 12:1 decreases the specific fuel consumption from .53 to .44 lbs/bhp-hr. In the meantime fuel technology and research in combustion chambers have progressed to the point where 12:1 compression ratios will be practicable.

The effect of combustion chamber shape on octane requirement (mechanical octanes) is illustrated in the charts below. Each point on the curves is a maximum i.m.e.p. obtained with a fuel as denoted by the octane number above the curve. Design A has the i.m.e.p. of 99 percent maximum of 141 psi and requires a 95 O.N. fuel. Design B has a corresponding i.m.e.p. of 136 psi and requires only a 73 O.N. fuel.

We have witnessed a gradual increase in displacement volumes. There is a definite limit to this, dictated primarily by the amount of space and weight allotted to the powerplant. We will have to make smaller engines do more work per cubic inch and per pound of engine weight. This can be accomplished by the use of (1) *turbo-charging* and (2) *lightweight materials.*

Active research is being carried out in both areas. (1) shows promise for commercial engines, rather than passenger cars. Both types will profit from (2). Aluminum die casting offers not only weight advantages but also appreciable savings in manufacturing cost. A die casting machine exists which produces a complete crankcase-block combination requiring a minimum of machining. The crankcase of the Volkswagen engine is a magnesium casting. The variable blade angle transmission which we need is heavy and offers only limited opportunity for weight saving. The engine crankcase and block offers the biggest single component which can reduce powerplant weight effectively. A better appreciation of weight will become more and more necessary.

Heavy equipment

Turbo-charging of spark-ignition engines has a considerable potential for trucks and earthmoving equipment and will be fully investigated and utilized before very long. It will be used with fuel injection.

Fuel injection *(into the cylinder rather than the manifold)*, will be closely investigated, especially in conjunction with turbo-charging. There are some fundamental difficulties in applying cylinder injection to engines of small displacement (compared with aircraft engines) and operating over a wide range of speed and loads (compared with constant speed in aircraft). This has all been

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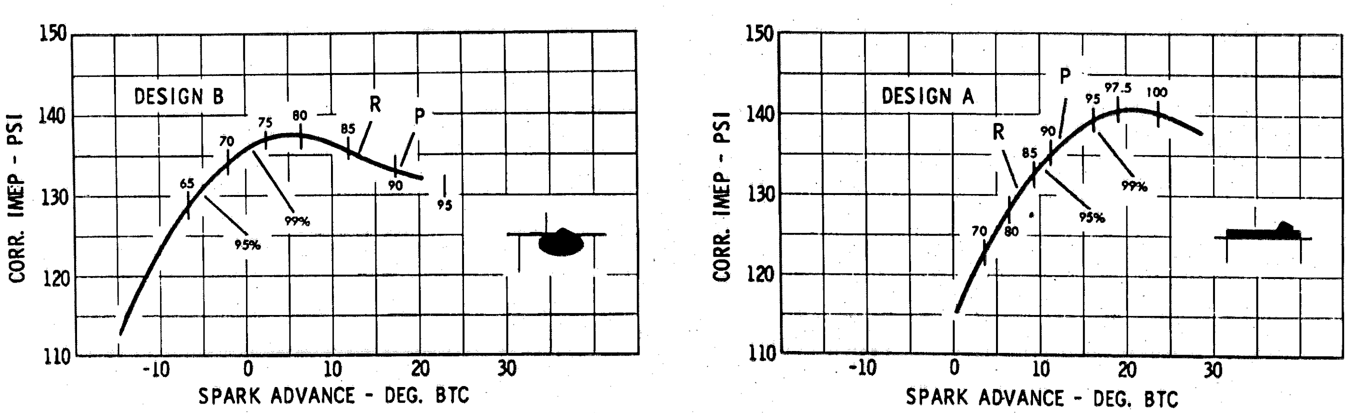
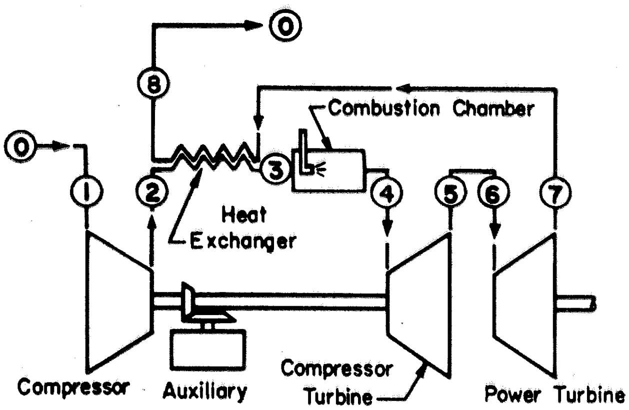
The effect of combustion chamber shape on octane requirement (mechanical octanes)

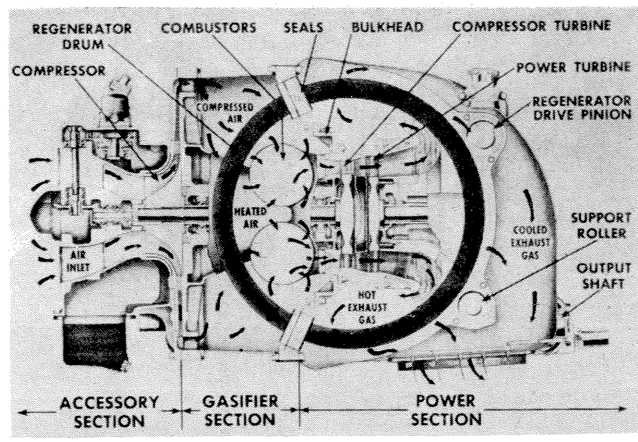


Comparison of flat (Design A) and compact (Design B) combustion chamber .9:1 compression ratio; 1,000 rpm. R = Regular, P = Premium (1954 level) 99 percent = 99 percent of maximum i.m.e.p. (indicated mean effective pressure) (Ref. 9)

ENGINE SCHEMATIC



Schematic diagram of a regenerative turbine (Ref. 12) (Ford)



Section through a Whirlfire regenerative gas turbine (Ref. 13) (G.M.)

spelled out (Ref. 18) but is not clearly understood by everybody who is talking about the subject.

So far, nothing has been said about the diesel engine. Since diesel and spark ignition engine compression ratios have approached each other, the thermodynamic advantages of the diesel have gradually diminished. High speed diesels require carefully controlled fuels, which decreases the cost advantage of diesel fuel over gasoline.

First cost of diesels is higher than that of gasoline engines. In the passenger car field there is no real incentive for the use of diesels. In the truck and heavy off-the-road field the diesel predominates today, but seems to offer little capability for future growth. Its weight and size are unfavorable as compared with the gasoline engine. Increase in displacement and hence engine size is limited as much as in the gasoline engine. It therefore cannot offer the trucker the 1000 hp engine for which he is hoping.

Turbines: The *automotive gas turbine* has progressed faster than was expected. At the left, above, is a schematic of a regenerative turbine. At the right is a section through the actual engine—which in this case, is a Whirlfire regenerative gas turbine.

The regenerator is of the rotating matrix type. Regenerator efficiencies are of the order of .80 at low loads, dropping to .60 at high loads.

Typical performance curves are shown below for a truck turbine.

Since vehicle turbines operate predominantly at variable load and speed, the part load performance is particularly interesting and significant.

Cruising power fuel consumption is far from good. Best miles per gallon for the engine in the charts below is 3.7 mpg as compared with 7.0 for comparable piston engine. The turbine utilizes a cheaper fuel and hence

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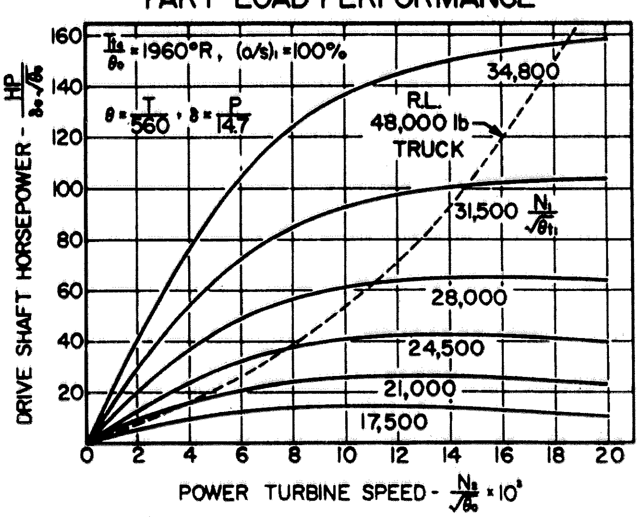
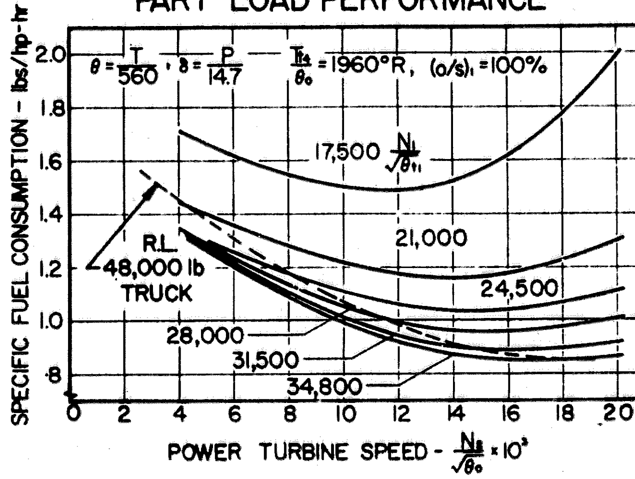
PART LOAD PERFORMANCE

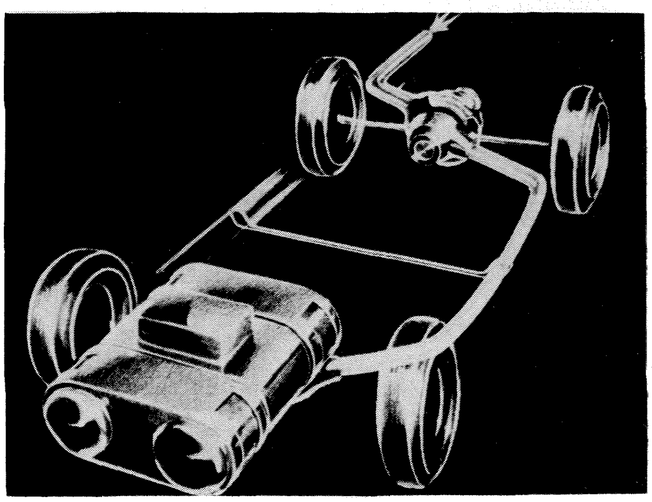


Output vs power turbine speed. R.L. = road load. Numbers on curves are compressor speeds (Ref. 12) (Ford)

PART LOAD PERFORMANCE



Fuel consumption vs power turbine speed. Turbine inlet temperature 1,500°F. (Ref. 12) (Ford)



Free piston gas generator and turbine installation for an automobile (GMR Hyprex, Ref. 16). The gas generator consists of two parallel cylinders.

the difference in cents per mile is not as great as that in mpg.

Cost of and availability of high temperature materials is, at present, a serious handicap for the turbine.

The following table compares the cost of some materials used in turbines with the cost of cast iron:

Cobalt	2.70
Nickel	.65
Molybdenum	1.50
Vanadium	3.10
Tungsten	3.45
Manganese	.30
Chromium	.37
Aluminum	.23
Cast Iron	.05

At present, large amounts of nickel are used (75 lbs in a 700 lb engine). A typical automotive turbine blade material (GMR 235, Ref. 19) is as follows:

Carbon	.10 - .20
Manganese	.25 max
Silicon	.60 max
Chromium	12.00 - 17.00
Molybdenum	4.50 - 6.00
Aluminum	2.50 - 3.50
Titanium	1.50 - 2.50
Boron	.025 - .100
Nickel	Balance

Nevertheless there seem to be excellent prospects for the development of inexpensive materials which will meet the needs of the vehicle turbine.

Manufacturing techniques will have to be developed for high production of such parts as turbine wheels (single casting). This, likewise, should not prove an unsurmountable obstacle. In spite of the fact that the split turbine arrangement (power turbine drives the rear wheels, is not connected to the gas generator turbine) has some of the characteristics of a torque converter, a transmission is needed. The stall torque ratio is of the order of 2.3, which is not enough.

The feasibility of the turbine has been amply demonstrated. Will it replace piston engines? I don't think so. It will rather fit in where the piston engine has nothing to offer, i.e., in the range from 400 - 1500 hp. Trucks need this power range badly. Passenger car turbines will be produced and used if for no other reason than to be different. They do not offer any fundamental advantage.

The free piston engine

By itself, the free piston engine is not a propulsion unit but an air compressor. In conjunction with a gas turbine it becomes a *free piston gas generator.* Its thermodynamic merits have been discussed (Ref. 15). The schematic drawing above shows a twin cylinder free piston engine and gas turbine installed in a car. The turbine operates at a relatively low temperature and does not require expensive materials. Experience with this type of powerplant is limited (Ref. 17) but it looks as though it fits in between the piston engine and the turbine, overlapping both ranges.

To sum up the comparison of existing and future powerplants, the pertinent parameters are listed (Ref. 17) in the table below.

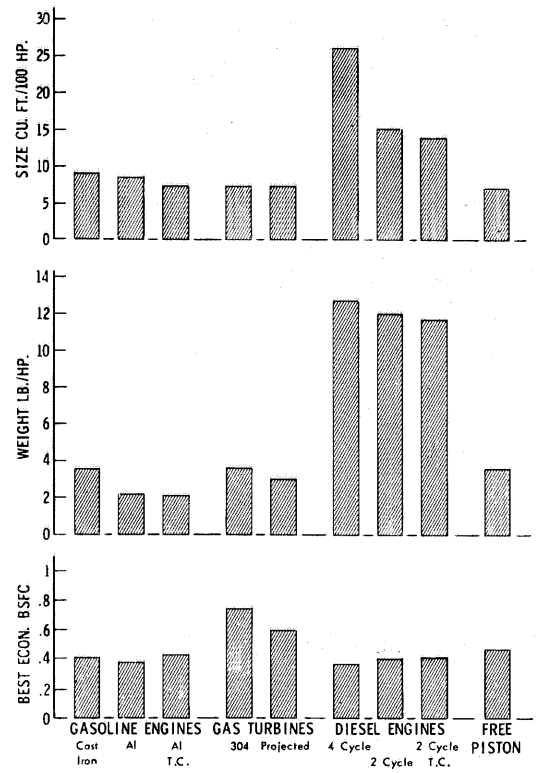
Comparison of automotive powerplants

	Fuel Consumption Lb/bhp/hr		Weight Lb/hp	Size Cu.ft/100hp	Fuel
	@ Max. Power	@ Best Econ.			
Spark Ignition Piston Engine Cast Iron 9:1 Comp. Ratio	.48	.41	3.6	9.1	95 Octane
Spark Ignition Piston Engine Aluminum 12:1 Comp. Ratio	.44	.38	2.2	8.4	110 Octane
Spark Ignition Piston Engine Aluminum 8:1 Comp. Ratio Turbocharged - 30% Boost	.49	.43	2.1	7.3	95 Octane
Gas Turbine - Regenerative	.75	.75	3.6	7.2	Kerosene
Gas Turbine - (Projected) Regenerative	.60	.60	3.0	7.2	Kerosene
Diesel Engine 4-stroke cycle	.41 - .47	.38	12.7	26.0	#2 Diesel
Diesel Engine 2-stroke cycle	.42	.40	12.1	14.8	Kerosene
Diesel Engine 2-stroke cycle Exhaust Turbo Blower	.42	.41	11.7	13.6	Kerosene
Free Piston Engine	.48	.48	3.6	7.0	Kerosene Gasoline, Diesel

The same data are shown here in a bar chart (Ref. 1). It becomes apparent that the diesel is out of line as far as size and weight are concerned, which makes its contiued use in vehicles questionable. The turbine has been treated with optimism in the fuel consumption column. No one powerplant shows a vast superiority over the others, except for the large power range, 400 hp and up, where the turbine is the only practicable engine.

There is, at present, no reason why any one powerplant type should replace the other. The turbine as well as the free piston engine-turbine combination will supplement the piston engine in the areas of their optimum suitability.

Comparison of automotive powerplants



Comparison of fuel consumption, weight, and space requirements for different powerplants (Ref. 1). On the chart, Cast iron = cast iron cylinder block; Al = aluminum cylinder block; and Al T.C. = aluminum engine with exhaust turbo-charger.

Whence come these pearls of wisdom?

In any prediction there is necessarily a lot of guesswork; as the saying goes—"based on incomplete data, rumor and prejudice." The following list of references contains the background information on which my prejudices are based. Anyone with enough stamina to read through the references is entitled to pick my line of reasoning to pieces.

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CREDITS: CHARTS AND DIAGRAMS:

Pages 32, 33, 34, 38—from publications of the Society of Automotive Engineers, Inc., New York City.

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