A SURVEY OF FUTURE LOW-POLLUTING VEHICLE POWER PLANTS AND THEIR IMPLICATION FOR THE GASOLINE TAX

by

Gary R. Allen
Graduate Economic Assistant

(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

Virginia Highway Research Council
(A Cooperative Organization Sponsored Jointly by the Virginia Department of Highways and the University of Virginia)

Charlottesville, Virginia

January 1973
VHRC 72-R22

SUMMARY

1. Because the standards set for auto emissions are being strictly enforced by the Environmental Protection Agency, it is imminent that the conventional internal combustion engine will not be the only vehicular power plant in widespread use.

2. Both European and United States manufacturers are exploring numerous avenues in an effort to meet 1976 emission standards.

3. It is not too early to consider the likelihood that the use of an electric urban car and mass transit system will have an impact on highway networks; if not on the revenue for financing them, certainly on the projected life, maintenance cost, and the number of lanes for urban roads.

4. Although research and development is progressing well, some clean air advocates are emphasizing that something other than technology may be needed to abate auto pollution in cities; for example, restrictions on the use of autos in cities.

5. Because of the differences in the requirements for a vehicle suitable for urban as opposed to cross-country use, the probability of using different types of power sources for the two types of vehicles is greatly increased.

6. A systems approach is the most viable method of solving the emissions problem, especially for urban areas.

7. It is not apparent that those vehicular power plants most likely to come on the scene will have any quantitative effect on reducing highway revenue.

A SURVEY OF FUTURE LOW-POLLUTING VEHICLE POWER PLANTS AND THEIR IMPLICATION FOR THE GASOLINE TAX

by

Gary R. Allen
Graduate Assistant

INTRODUCTION

Although an automobile with acceptable low emission levels has not yet become a reality, the push for clean air most certainly has. If the major auto manufacturers are to meet 1975 emission standards, and thus comply with the 1970 Clean Air Amendments, they must bring about a 90% reduction in emissions of hydrocarbons (HC) and carbon monoxide (CO) as measured on 1970 model cars. In order to comply with 1976 standards, Detroit must meet the 1975 standards for HC and CO and in addition must reduce oxides of nitrogen (NO_x) by 90% as measured on 1971 model cars. Translated into numbers, for 1975 this means: .41 g/mi. HC, 3.4 g/mi. CO, and 3.0 g/mi. NO_x. The 1976 standard for NO_x is .4 g/mi. 1/

It is clear that the Environmental Protection Agency is not bluffing. EPA's administrator, William D. Ruckelshaus, faced pressure from the Swedish automaker, Volvo, and Detroit's Big Three to extend for one year the 1975 HC and CO standards. At the close of the month long hearings in May, Ruckelshaus turned down the request, stating that the automakers had failed to prove that technology is not available to meet standards. The May 20, 1972 issue of Business Week indicates that the major reason for turning down the request is that the automakers have failed in making a "good faith" effort to comply. 2/ As these observations indicate, the push for clean air is not to be taken lightly. In fact it is directly related to the revenue with which Virginia's system of highways is built and maintained. The relationship lies in the fact that the taxes collected on gasoline could be curtailed if a technological change were to necessitate the widespread use of a vehicular propellant other than gasoline.

1/ Malin, Marty, and Carol Lewicke, "Pollution Free Power for the Automobile", Environmental Science and Technology, August 1972, p. 512.

2/ "Why Detroit Failed to Sway EPA," Business Week, May 6, 1972.

This study was modified as the result of discussion at the June 21-22, 1972, Economics Research Advisory Committee meeting concerning a proposed study entitled "Alternative Taxation Methods for Low Polluting Engines: A Theoretical Approach." As indicated in the minutes of the meeting, the Committee feels since it is uncertain that low-polluting vehicles will be traveling Virginia's highways in significant numbers in the near future, the study "should at least indicate and, if possible, rank the likelihood of the following types of power plants being used in significant numbers in the near future: Liquid petroleum and compressed natural gas, electric, steam, and Wankel (in order that) the method of generating highway revenue can be determined."

Following the suggestions of the Advisory Committee, the author divided the survey into two major sections. The first section considers the positive aspects of the alternatives listed below for reducing auto emissions to meet 1975-76 standards. The second section indicates the negative aspects of the alternatives and which of the alternatives appear most viable.

The alternatives are discussed in the following order, but the listing is in no way indicative of their ranking in importance:

Catalysts
Electric Autos
Liquid Petroleum and Compressed Natural Gas
Steam Cars
Sterling Engine
Stratified Charge
Turbines
Wankel Engine

ENTRANTS IN THE POWER RACE

Catalysts

The development of a successful catalytic converter could solve the dual problem Detroit faces: the cleaning up of emissions while holding down the market price of automobiles.

Basically, a catalyst is a substance which initiates or accelerates a chemical change without itself being changed in the process. Although scientists have long dealt with catalysts, the problem of finding one which will clean auto exhaust effectively and which will last 50,000 miles has been more difficult than first imagined.[3/] There are several reasons.

The first is related to the two chemical classifications of catalysts: Oxidation and reduction. Since HC and CO are the result of incomplete fuel combustion,[4/] whereas NO_x rise sharply under acceleration but have little relation to speed and engine rpm, the conversion of these pollutants to nontoxics requires different types of catalysts. HC and CO must undergo an oxidation process yielding water and carbon dioxide, neither of which are harmful. Oxides of nitrogen must be reduced to nitrogen. Seldom can a single catalyst perform this dual operation. The alternative is to first route the exhaust to one converter for oxidation, then to a second for reduction. However, this type of system adds significantly to the cost of the automobile, up to 10% claim automakers.[5/]

The second reason for difficulty relates to the composition of the catalyst itself. A catalyst may be either a noble metal, such as platinum or palladium, or some combination of base metals, such as copper, molybdenum, or cobalt.[6/] Copper catalysts, although replaceable for approximately $25.00, are severely inefficient converters, and furthermore are degraded by the lead additives in gasoline. Platinum elements are preferred on their efficiency rating and are not so vulnerable to leaded gasoline, but cost $300 or

---

3/ Zmuda, Joseph, "New: A Catalytic Converter That Really Cleans Up Auto Exhaust," Popular Science, December 1970, p. 47.
4/ "System Approach for Reducing Auto Pollution," Science, March 24, 1972, p. 135.
5/ Zmuda, op. cit., p. 48.
6/ Environmental Science and Technology, June 1972, p. 515.

more. This is a low estimate in light of the fact that platinum futures have soared to $100/oz. in recent months.[7/]

The third difficulty is that since lead additives reduce the effective life of any catalyst, regardless of composition, the catalysts have shown poor durability.[8/] On this point, the automakers and the catalyst manufacturers don't agree. Robert Leventhal, president of Englehard Industries, states that "we are aware of no inherent reason why our catalyst will not last 50,000 miles."[9/] This statement, based on experiments with eight test cars, is typical of those issued by the catalyst manufacturers. Ted De Palma, manager of Universal Oil Products' engine laboratory, claims they have developed a system which reduces NO_x 90%, HC 73%, and CO 94%. Also, he claims the converter costs a minimum of $70.00 and will last the life of the car. He qualifies these statements by pointing out that precise engine tuning is necessary for desired results.[10/] The auto manufacturers are more skeptical of converters. Chrysler Corporation, using a platinum catalyst on a mid-size Plymouth V-8, logged 43,000 miles before the system failed in meeting 1975 standards, but admitted that the car had to be "babied" with frequent carburetor adjustments, spark plug changes, and tune-ups. Similarly, Ford's vice president, Herbert Misch, even though Ford has a firm catalyst contract with Englehard Industries, says that realistic tests under actual driving conditions indicate 5,000 miles as the usual failure point for converters.[11/]

A less dramatic method of reducing emissions without significantly changing engine design is to recirculate exhaust gas. Returning exhaust gas to the intake manifold reduces cylinder temperature and cuts thermal formation of NO_x, but precise monitoring of the amount recirculated is required to avoid stalling. In addition, since a rich fuel mixture is necessary for good performance, there is a fuel penalty of up to 20% and a general increase in CO and unburned HC.

Even afterburners cannot easily solve the pollution problem. The temperatures necessary to oxidize HC and CO tend only to aggravate the problem of NO_x emissions.

7/ "Auto Emission Sweepstakes," Business Week, May 6, 1972, p. 78.
8/ Environmental Science and Technology, p. 515.
9/ "Softer Stand on Auto Pollution," Business Week, May 6, 1972, p. 20.
10/ Zmuda, op. cit., p. 49.
11/ "Softer Stand on Auto Pollution," p. 20.

Electric Cars

Although the use of electric vehicles may now appear eccentric, the internal combustion engine (ICE) has not always been the favorite energy source for moving passenger cars. In 1900 both steam and gasoline powered cars took a back seat to the electric automobile. However, the speed and range limitations of the electric cars prohibited their ever becoming long-run competitors of the internal combustion engine.[12/]

The electric movement is back, now, as an outgrowth of rapid technological progress in electro-mechanical conversion efficiency, rapid reduction in the weight of batteries per unit of stored energy, and, possibly more important, the significant increase in pollution from the exhaust of internal combustion engines.[13/] The researcher did not find evidence to indicate that there is an electric car in the near future. However, several papers indicate that the idea, especially for urban transportation, is not farfetched. Robert R. Aronson's company, Electric Fuel Propulsion, Inc., has developed a 3,500 pound prototype with a projected top speed of 90 mph, a range of 300-500 miles, and with a recharging time of 20 minutes. Although these claims are for a prototype, Aronson is experienced in the field. He has a Hornet-bodied EFP electric in production. In the 1970 clean air car race, this EFP car finished first for electric vehicles, accelerating 0-40 mph in 10 seconds, having a sustained top speed of 70 mph and an economical cruising speed of 60 mph, with a battery range of 125 miles. The batteries can be recharged in 30 minutes at a cost of less than 1 penny per mile. A key to this performance is the tri-polar lead-cobalt battery, which lasts 50,000 miles per set and has a replacement cost of $700, and the EFP designed series traction motor with a drive train through a three speed transmission. Because production is on a limited basis, the EFP electrics are priced at $10,000. Even at full-scale production the price may be more than that for conventional autos, although operating costs and pollution would be significantly lower.[14/]

Chemist Phillip Symons, director of Udylite Company's energy development lab, has perfected a new power source for electrics from readily available inexpensive materials. By using a combination of zinc and chlorine, Phillips designed a high density energy source for battery powered vehicles which is not only practical but safe. Although chlorine is extremely dangerous in its normal form, a combination of chlorine and water molecules produces

---

12/ Hoffman, George A., "System Design of Electric Automobiles", Institute of Transportation and Traffic Engineering, University of California, 1967, p. 3.
13/ Ibid.
14/ Zmuda, Joseph P., "New Electrics Make Performance Breakthrough", Popular Science, Feb. 1971, pp. 55-6.

a solid, chlorine hydrate, which is both safe and easily stored. Recently, a Chevrolet Vega equipped with a 40 hp electric motor and Symons' power source achieved a cruising speed of 50 mph for a trip of 150 miles. Although the experiment is impressive, Symons is quick to point out that the system is far from the market.

Liquid Petroleum and Compressed Natural Gas

Like the use of catalysts, the use of LPG and CNG is an attempt to doctor the internal combustion engine to meet EPA standards rather than go through the process of designing an entirely new engine. The proposal is simple; by using a cleaner fuel or fuels, emissions which cause photochemical smog can be significantly reduced. LPG is well suited as a clean air fuel and is nothing new. In fact, Atlantic Richfield used it in automobiles as early as 1931. Although its clean air qualities have been apparent for years, recent testing in California indicated that cars powered with LPG can meet California standards beyond 1975 levels. Because it is almost pure propane, a light hydrocarbon with a high octane rating, LPG provides slow, even combustion. Because it cannot dilute the protective oil film in the combustion chamber, engine wear is reduced. Further, the use of LPG or CNG allows an engine to be critically tuned, thus reducing HC and CO. Finally, their lower burning temperature doesn't emit NOx in quantities comparable to those from gasoline when used in the internal combustion engine.[15/]

Some LPG and CNG cars are actually on the highways. The California Liquid Gas Company has converted a 1969 Dodge to a dual fuel car which runs on either CNG or LPG.[16/] Bosh Stack, president of the Air Pollution Control Corporation of Miami, uses a family car fitted with tanks of CNG. Bosh's system has been tested and accepted by the EPA and the tough California Air Pollution Control Board. The cost of the kit installed is approximately $500, and the General Services Administration has ordered 2,500 such kits for use in Cape Kennedy, the Manned Spacecraft Center in Houston, and the VA Hospital in Sawtelle, California. The fact that the system has already been installed in 10,000 trucks and buses is indicative of its feasibility.[17/] However, the bulkiness and extra weight of tanks in addition to the expense of the kit make it impractical for use by the general public.

15/ Zmuda, Joseph P., "Convert to LP Gas," Popular Science, July 1970, pp. 43-45.
16/ Zmuda, Joseph P., "New Pollution Solution: Dual Fuel Cal-Gas Car," Popular Science, p. 12.
17/ "A Pollution Free Automobile," AP News Release, July 1972.

Steam

Steam propulsion, like electric power, has been around since the horseless carriage, but it failed to compete with the speed and power of the ICE. Recent developments have led steam enthusiasts to produce machines which are not only in the running as far as speed is concerned, but which also have significantly reduced emissions.

Inventors have known for some time that so-called "external combustion engines," whose power source is a rapidly expanding vapor passing over turbines or other methods of conversion to mechanical power, are inherently more efficient than the ICE. Yet the practical problems of applying steam, such as bulkiness, freezing in cold climates, and hazards from hot steam in an accident, have stalled them.[18/] Because the proper engineering of ECE's leaves a residue of only carbon dioxide and water, these engines are especially appealing as a pollution fighter. Several moves havebeen made in this direction.

As of August 1, 1972, William Brobeck and Associates of Berkeley, California had built and had on the road a steam bus in regular operation in Oakland, California. For the 2,600 miles logged, emissions were well below 1975 standards.[19/]

The Department of Transportation, in addition to backing a Freon vapor bus experiment in Dallas, has shown quite an interest in William Lear and his Steam Power Systems steam bus. Lear demonstrated steam powered buses for DOT under a $1.6 million grant; DOT was impressed to the tune of an additional $683,000 grant.[20/] Basically, Lear's bus is a combination steam and turbine system that runs on any liquid hydrocarbon fuel including gasoline, kerosene, and diesel fuel. The working fluid is water, although attempts have been made at using a liquid less susceptible to freezing. The turbine is used because of the mechanical efficiency of rotary as compared to piston mechanics. As for emissions, they're well within 1975 EPA standards.[21/] Quoting Lear,

> There's still a lot of work to be done, but we have made tremendous progress toward an economical vapor system. With expenditure of sufficient money over another

---

18/ Lindsley, E. F., "Minto's Unique Steamless Steam Cars", Popular Science, October 1970, p. 52.
19/ "Steam Buses are Rolling", Popular Science, August 1972, p. 49.
20/ Ibid.
21/ "Lear's New Steam Bus", Popular Science, July 1972, p. 56.

two or three years, we are certain we can boost its efficiency to equal that of present diesels.[22/]

Wallace Minto, developer and president of Kinetics, Inc. of Sarasota, Florida, has applied the principle of the steam engine to the Datsun. The working fluid is a fluorocarbon refrigerant like Freon, which boils at 117 degrees F, a fact of overwhelming importance to safety. Moreover, this fluorocarbon, called R-113, doesn't freeze, it is easily liquified in a practical size condenser, and it can be handled in pipes of relatively small size. These characteristics make for lighter, stronger, less expensive parts that can economically be fitted into an automobile.[23/]

The engine is composed basically of two fluted rotors that intermesh to trap the fluorocarbon between the spaces. As the gas expands, it wedges between the flutes to rotate the engine. According to Minto, this "engine" has much better torque at low speeds than does the turbine engine used in Lear's bus. The fuel used to heat the liquid is kerosene and miles per gallon is approximately the same as for the ICE in the Datsun. As for cost, the on-the-market price of the fluorocarbon powered vehicle is projected to be 10 to 20 percent lower than the ICE powered version. Minto is not just speculating. He has closed a multi-million dollar contract with Nissan of Tokyo, who will use the engine in its Japanese Datsuns. Approximately 100 will be so equipped for 1972 or 1973. [24/]

Sterling Engine

On August 16, 1972, Ford Motor Company announced it had signed an agreement with N. V. Philips, a giant Dutch electronics firm, to develop "hot air" engines for industrial, marine, and automotive use.[25/]

The hot air engine is called the "Sterling," after the Scot who invented it in 1830. At that time, however, it proved too bulky and inefficient to gain widespread use. The Sterling operates on the principle that as gas expands it can do work, but it is not an ICE. The system is a closed one in which helium or hydrogen is heated in a chamber surrounding the cylinder and never mixes with the atmosphere. As the gas expands in this closed

22/ Ibid.

23/ Lindsley, op. cit., pp. 51-52.

24/ Ibid., p. 130.

25/ "Ford, Dutch Agree to Develop 'Hot Air' Sterling Cycle Engine," AP News Release, August 18, 1972.

cylinder it pushes a piston to yield power. Essentially an ECE, the Sterling is relatively quiet, has fewer moving parts than conventional ICE's, will burn a variety of fuels, and offers great potential for emission reductions.26/

Although Ford has agreed to a seven year program with Philips, in which the first three years will consist of building prototype engines for testing by Ford, Philips has had a working four cylinder, 200 hp Sterling operating in experimental buses since 1970. The engine which is comparable to the size and weight of a conventional diesel, displaces fewer cubic inches per horsepower.27/

Stratified Charge

As indicated by the January 10, 1970, Business Week, fuel injection systems in place of carburetors have been around Detroit for a long time. Their expense and troublesome nature have prevented their making headway. 28/ They have recently reappeared on the scene however, in the wake of the Environmental Protection Agency hearings. Their relationship to the anti-pollution movement is that unlike ordinary carburetion systems, fuel injection dispenses an optimum air-fuel mixture to each cylinder for combustion. A lean mixture offers the least emission of HC, CO, and NO_x .

The Ford Motor Company, in conjuction with the U. S. Army, is taking a systems approach to the pollution problem rather than attempting to use a single gadget to make the automobile smog free. Ford has modified the Jeep "mutt" engine to reduce emissions by 29/

1. Fuel injection
2. Metering of air and fuel for the optimum lean mixture
3. Stratified charge combustion for complete burning of the mixture, and
4. Exhaust gas recirculation to combat NO_x emissions

26/ "Dutch on the Road to a Pollution Free Engine," Business Week, January 10, 1970, p. 52.
27/ "Amazing Hot-Gas Engine Powers Clean-Air Bus," Popular Science, June 1971, pp. 54-56.
28/ Business Week, January 10, 1970, p. 54.
29/ Dunne, James, "Ford's New Smog-Free Engine," Popular Science, May 1970, p. 55.

Basically, stratified charge means precision burning. The combustion chamber has been oddly shaped in order to burn the fuel more efficiently. A special spark plug and special metering equipment are the additional necessary components of the system. Ford is confident that even though fuel injection and the use of stratified charge has been extremely expensive in the past that their recent efforts would allow the stratified charge engine to achieve acceptable levels of pollution at a cost far less than that of catalytic converters and afterburners.[30/]

Turbine Car

Although General Motors, Ford, and Chrysler have been engaged in turbine research, the forerunner in this area is Williams Research Corporation, Walled Lake, Michigan. The 80 hp gas turbine installed in a 1971 Hornet produces emissions well within 1975 limits.[31/] The car, built under a $240,000 federal grant for the City of New York's Department of Air Resources, will be compared with other low-polluting vehicles for performance in urban driving conditions.[32/]

Williams, who says his turbine car can be ready for mass production as early as 1978, explains his engine simply. Air is drawn into a compressor, brought to four times normal pressure, and heated by passing through the front half of rotating heat exchangers. The heated air passes to the combustion chamber, into which fuel is sprayed and burned. Hot gases spin the compressor turbine and then the power turbine to turn the rear wheels.[33/]

Wankel

The Wankel engine has only two basic moving parts: The triangular rotor spins around a stationary gear which transmits power to an eccentric

---

30/ Dunne, op. cit.

31/ Dunne, James, and P. Norbye, "Williams Turbine Engine Clean Air Car," Popular Science, November 1971, p. 127.

32/ "A Car That May Reshape the Industry's Future," Fortune, July 1972, p. 76.

33/ Malin and Lewicke, "The Rush to Shape the Cleaner Car," Environmental Science and Technology, June 1972, p. 517.

shaft as the rotor's tips trace out a plump figure eight pattern inside its housing.[34/]

The Wankel has fewer working parts, more power per chamber, and is much smaller than conventional reciprocating engines. Furthermore, its NO_x emissions are as much as 60% lower than those of the piston engine, even though its HC and CO emissions are higher.

That research has been under way for some time is a point in favor of the rotary power plant. In 1926, Felix Wankel, a German engineer and inventor, began a systematic investigation of rotary engines. The bulk of his research centered around three problems:[35/]

1. Reducing the number of arrangements and cycles for rotary engines.

2. Developing the proper gas cycle with adequate port areas and timing of events.

3. Solving the problem of sealing the combustion chamber.

Although Wankel attempted to solve these problems on his own, it took the help of the automotive firm NSU to develop a practical prototype. Shortly after the successful operation of a single rotor Wankel in 1956, Curtiss-Wright Corporation bought the North American rights. In 1965, NSU combined both innovations of its own and Curtiss-Wright to introduce the first Wankel powered vehicle.[36/]

Both NSU and Toyo Kogyo of Japan are making Wankel powered cars on their assembly lines. NSU makes 8,000 per year whereas Toyo Kogyo has marketed over 250,000 Wankel powered Maydas since 1967. The most advanced Wankel is produced by Mercedes-Benz. Their three rotor Wankel weighs 396 pounds but delivers 400 hp.[37/]

34/ "A Car That May Reshape the Industry's Future," Fortune, July 1972, p. 76.
35/ Cole, David E., "The Wankel Engine," Scientific American, August 1972, p. 14.
36/ Ibid., p. 16.
37/ Norbye, P., "Why Detroit is Doing the Double Take on the Wankel," Popular Science, January 1971, p. 55.

Although the American automotive industry has seen fit to pay little attention to the Wankel in the past, they have in recent months begun not only to show interest, but to commit themselves to contracts. GM paid Audi-NSU/Wankel and Curtiss-Wright $15 million for worldwide nonexclusive rights to manufacture and sell the rotary of any size to anyone without royalties as long as not for aircraft use. The total contract is $50 million.[38/] "Technical analysts and engineers who know most about GM's production plans expect it will offer 25,000 or more rotary engines as options in 1974 Vegas."[39/] This move by GM has caused such a stir that every major car manufacturer in the world is either negotiating for or already has a contract for use of the Wankel.

38/ "Is the Wankel the Auto Engine of the Future?", Changing Times, July 1972, p. 43.
39/ Fortune, p. 76.

LEADERS IN THE POWER PLANT RACE

Of the entrants in the power plant race, which ones can reasonably be expected to be put into significant use as pollution fighters? This question is best answered from the viewpoint of what is economically feasible, tempered by what the consumer is willing to purchase.

As pointed out in a recent issue of Science magazine, a systems approach is needed to combat the problem of vehicular pollution.[40/] The problem cannot be solved by simply burning a different fuel, or using a battery, or hanging a can of catalyst behind the engine. Combinations of these and other alternatives must be tried and their effects monitored. For example, the problem of ambient air pollution cannot be viewed solely from the standpoint of automobile emissions. Rather, what is needed is to take a close look at stationary pollution sources at the same time. If the electric automobile were at present marketable in significant numbers, indeed substitution of these vehicles for ICE's would bring about a situation of negligible vehicular pollution. The ract still remains, though, that the pollution from regenerative power sources for the batteries would significantly increase over present levels.

One unshakeable fact stands, regardless of the firmness of the Environmental Protection Agency; whatever is done to meet 1975-76 and later emission standards will be done through, by, and with the consent of Detroit. This is political realism.

All major automobile manufacturers have basically the same tooling techniques and machinery, with minor variations, of course. Their investment in plant and equipment is enormous. Their employees have years of experience and know-how in building conventional ICE's. And, the lead time necessary to make significant changes is four or more years. For these reasons, auto manufacturers will seek the means to meet 1976 standards which minimizes retooling and retraining, and which takes advantage of experience already at hand.

The Wankel seems to best fit these requirements. As pointed out earlier, the Wankel is not an "overnight" engine; it has been developed over a long period of time. The fact that Wankel powered cars have been on the road since 1967 both in Europe and the U. S. means that, unlike most other low polluting power sources, the Wankel has been consumer tested. Even

40/ Science, March 24, 1972, p. 1357.

the April 1972 Consumer Reports gives the Wankel powered Mazda a favorable appraisal. The Wankel's weight and size per horsepower are much less than those of the reciprocating ICE. Therefore, there is more room under the hood for pollution control equipment, hence a better chance for a systems approach to controlling automobile pollution.

Other characteristics of the Wankel place it ahead of other alternatives to meet emission standards. Because it is lighter, smaller, and has fewer working parts, the Wankel offers potential savings in mass production. Says GM's president Edward Cole, "There is a point in savings where you can afford to obsolete tooling. You wouldn't do it for two cents a unit, but for $200 you could write it off and push it in the river."[41/] More than savings on construction is possible. Using the smaller Wankel, the auto manufacturers could redesign the chassis to incorporate a front wheel drive, a lower center of gravity, and a roomier interior without increasing automobile market price. This in itself is quite an incentive to use the Wankel.[42/]

Although first portrayed as a dirty little engine, the Wankel naturally produces fewer NO_x than conventional ICE's, but HC emissions are greater. This however is an advantage in that NO_x emissions are the most difficult to clean up. Another advantage of the Wankel is that the rotary is more easily adaptable to thermal reactors because its exhaust temperatures are higher. Finally, it appears the engine is adaptable to Ford's stratified charge intake system, a good pollution reduction process in itself.

The fact that urban and long distance driving significantly differ offers the electric car and the steam vehicle a good chance to become marketable in the next 15 years. Even though the electric vehicle may not provide the speed or range needed for turnpike travel, it may well serve to provide city transportation or short trips from the suburbs to central bus stations surrounding the central business districts of cities. This is certainly feasible and would serve to reduce air pollution, noise pollution, and

---

41/ Fortune, p. 96.

42/ Scientific American, August 1972, p. 19.

city congestion. As pointed out earlier, DOT's interest in Lear's steam bus is not idle talk. In fact, it is a sign of the time that states like California are offering a contract premium for low polluting fleet vehicles.

In the same race, but possibly slightly ahead of the steam engine and electric vehicle, is the gas turbine (Williams Research). This turbine has fewer parts than the ICE, runs on a variety of fuels, and Detroit has several years' experience with the engine. According to a June 1972 Environmental Science and Technology report, it would seem the gas turbine is a definite competitor of the ICE in the next 10 years. 43/

43/ Malin and Lewicke, "The Rush to Shape the Cleaner Car," Environmental Science and Technology, June 1972, p. 517.

IMPLICATIONS OF STUDY

As indicated in the previous section, present information points to the use of a "cleaned up" ICE running on low octane gasoline to meet 1976 standards. As for the next two decades following, the consensus of the literature is that turbines, perfected steam engines, and urban electrics will come into use. With the exception of electrics, all of these devices to reduce pollution use gasoline, kerosene, or some similar fuel as a propellant.

An educated guess is that without a significant change in technology, those vehicles traveling interstate highways, thoroughfares, and rural roads will burn a fuel as easily metered as gasoline. Further, since the equity of a fuel tax seems well-founded, there is no cause for concern on that front. The only problem which remains then is a technical one of deciding upon the differentials in the tax per gallon of the different fuels.

The use of an electric shuttle car and a mass transit city bus system will, as mentioned earlier, reduce both pollution and congestion. These are in the economists' jargon called public goods and by their very nature the general propositions of economic theory as applied to private consumer goods do not hold. Specifically, in the case of private goods an individual is willing to pay the full or market price in order to acquire the property rights to that object he purchases. An individual will pay the market price for an automobile because he alone acquires the right to use the auto and this right is well enforced. In the case of public goods, for example pollution-free air or absence of congestion, an additional individual can consume the good without anyone else being prohibited from the consumption of the good. In other words, one person's enjoyment of pollution-free air or relatively congestion-free business districts doesn't prohibit another's enjoying the same. This simply means that all individuals who use or who would desire such public goods aren't obligated to pay for them.

The implication this has for taxing policy is that both highway users and nonusers benefit from pollution-freeness and non-congestion; therefore, one can on economic grounds propose that it would be feasible to tax both highway users and those nonusers who receive public benefits from the mass transit system. Although, some may quarrel with this stand, it is well-founded on the benefit principle of taxation, i.e., those who benefit from the production of public goods should bear the burden of taxation. The researcher offers this only as a possibility, not a suggestion of policy.

As for the possible scope of effects which the advent of low-polluting power sources on the scene will have, in the researcher's opinion they will pose no particular problems of revenue generation in addition to any which the state may already face. There may be effects of a more significant nature in other areas relevant to highway development such as the effect on the traffic patterns of the population and in turn the effect which this may have on proposed highway expansion; however, these are beyond the scope of the present paper.

AREAS FOR FUTURE RESEARCH

As pollution control and urban congestion removal become increasingly important public problems, the Highway Department will be led into related controversial areas which may warrant additional research. Some of these areas are listed below.

1. The highway system of a state can be viewed as one of many firms which make up the nation's "highway industry". The product of each "firm" is the provision of relatively congestion-free, safe, comfortable travel within and across the state. However, the normal procedure for determining the optimum firm size is absent. That is, through the interaction of demand for and supply of highways in a state, the price system determines exactly what quantity of highways should be built and where they should be located. As a practical matter the resources allocated to highways must be determined by the state operating through its highway agency. A question then which may arise is: Given the push toward pollution abatement and removal of congestion, will the role of the Highway Department continue to be the construction of highways, i.e., might there be some feasible limit to the size of an efficient highway firm?

2. The case for reciprocity vs. non-reciprocity highway tax agreements between states.

3. What would be the effect on urban highway improvements and construction if the EPA were to restrict urban automobile usage?

4. What will be the social and economic effects of using an electric shuttle car in conjunction with a mass transit bus system for urban transit?