TECHNOLOGY

- **What major technological developments in automobile systems can we expect by 1985?**
- **What advanced automobile technology may be available by 2000?**

Most technological changes in the automobile system have been evolutionary and have been directed toward improved performance, handling, comfort, convenience, versatility, and styling. Manufacturers have developed and introduced those features which they felt could be successfully marketed as standard equipment or extra-cost options. Starting in the *1960's*, however, Government regulations concerning safety, followed by emissions and fuel-economy standards, caused technological development to take new directions.

Some of these new directions are summarized in this section. The discussion is divided into two parts: near-term technical developments to 1985, and long-term technical developments in the period from 1985 to 2000 and beyond.

Technical Developments to 1985

Leadtimes in the automobile industry are such that technological developments that can be expected by 1985, as a result of either Federal Government stimulus or industry enterprise, are already well underway.

The basic technological concerns of the U.S. automobile industry in the near term are:

- achieving the currently mandated 1985 fuel-economy standards,
- meeting the 1981 emission standards, and
- improving vehicle safety, notably occupant protection.

These objectives cannot be approached separately. Technical achievement in one area must be carefully balanced against possible losses in the others.

A more thorough discussion of the subjects addressed in this section is contained in chapter 10 of the Technical Report.

Fuel Economy

The Energy Policy and Conservation Act of 1975 mandated fuel economies of 20 mpg by 1980 and 27.5 mpg by 1985 on a fleet-average basis for each manufacturer. It appears that these goals can be met. Many new models now on the market have fuel-economy ratings equal to or higher than 27.5 mpg. Methods for meeting the goals include weight reduction, more fuel-efficient engines, improvements in transmission and drive-train efficiency, reduced power requirements for accessories, and improved aerodynamics. The engineering and production problems in introducing these technological changes are not insurmountable. The challenge lies in achieving a proper combination that will attain the required fuel economy while satisfying consumer demand for performance, capacity, durability, low cost, and general subjective appeal.

The diesel engine is appearing on the passenger-car market in increasing numbers. Diesels have a significant advantage over spark-ignition engines in fuel efficiency, and they are viewed as a way of meeting fuel-economy standards while retaining the large passenger car. At present, diesels are heavier for a given horsepower and more expensive than a spark-ignition engine. Also, diesels may not meet the 1981 Federal standards for NO_x emissions. A further disadvantage is that diesel exhaust contains high concentrations of particulate matter that is suspected to be carcinoqenic.

Emissions

The early approach to control of vehicle emissions involved "detuning" the engine and resulted in penalties in fuel economy. This approach has been abandoned in favor of technologies, such as after-treatment and cleaner burning engines, that allow substantial reductions in emissions and operation at near optimum fuel economy.

Progress toward meeting regulatory emission goals is being made along two lines. Improved after-treatment systems, such as the three-way catalytic converter, have been developed and are now being placed in use. Advances are also being made in reducing the pollutants created in the combustion process through techniques such as stratified-charge engines and electronic control of ignition timing and fuel-air mixture. There is a high probability the industry will meet the 1981 Federal emission standards of 3.4 grams per mile for CO, 0.41 gram per mile for HC, and 1.0 gram per mile for NO_x and still be able to attain fuel-economy goals. Different manufacturers will choose different combinations of emission-control techniques, but it is expected that electronic control of ignition and fuel-air mixture will be virtually universal by the earl y 1980's.

The 1982 California NO_x standard of 0.4 gram per mile introduces a more difficult technical problem than the 1981 Federal standard of 1.0 gram per mile. To date, no method has been demonstrated to meet the California standard with typical large U.S. spark-ignition engines. Volvo, Saab, and GM have shown, however, that they can meet the 0.4 gram per mile requirement with a three-way catalyst system on a four-cylinder engine.

Safety

Vehicle safety improvement falls into two categories—accident avoidance and occupant protection.

Accident avoidance includes features such as better brakes, improved lighting and visibility, and improved handling. Such features are marketable commodities, but some of them can be costly. Evidence that they would contribute significantly to reductions in the number of traffic crashes is not clear for all of these features.

Occupant protection, on the other hand, is effective and is reasonably amenable to evaluation. Because occupant protection is partly a function of crush distance and relative vehicle weights, the expected shift to small cars could lead to increased occupant injury and fatality rates. Improved vehicle crashworthiness would be required to reduce the hazards of small cars.

Safety and fuel-economy goals are sometimes in opposition (i. e., a higher margin of safety or additional safety equipment may mean more weight and, hence, lower fuel economy). Although an integrated approach to safety design has not been thoroughly examined, the Department of Transportation's (DOT) Research Safety Vehicle (RSV) program indicates that higher levels of safety can be attained without unreasonable penalties in weight or cost.

Passive restraint systems are currently mandated for automobiles in the 1982-84 model years. This technology is reasonably well-developed, and no insurmountable technical difficulties are foreseen.

Summary

Several major technological developments are expected by 1985:

- Downsizing programs will reduce the average size and weight of the vehicle fleet. Waste space from styling and image requirements will be greatly reduced.
- Materials substitution—greater use of lightweight materials such as aluminum, plastics, and high-strength low-alloy steels—will reduce vehicle weight further.
- Changes in vehicle layout, such as front-wheel drive, will allow further size and weight reduction.
- Additional improvements in fuel economy will be achieved by improvements in transmission and drive-train efficiency and by reduced power requirements for accessories. The application of electronic controls for fuel metering and ignition will help the engine maintain efficient performance and reduce the need for tuneups.
- Several new or refined engines may be widely offered:
  –diesels (several now offered),
  —stratified charge (now offered by Honda),

—single-chamber stratified charge (under development by Ford, GM, and Texaco),
—valve selector (expected on the market by 1980), and
—turbocharging (now offered by GM and Ford),

These engines will afford greater fuel economy and/or reduced emissions.

- Vehicle safety will be improved by the addition of passive restraints. However, the decrease in vehicle size may offset these gains unless additional crashworthiness is designed into small cars.
- Advanced propulsion technologies (such as Stirling and turbine engines) and electric vehicles will not significantly penetrate the market by 1985.

Technological Developments Beyond 1985

The principal factors influencing automotive technology in the period after 1985 are expected to be:

- The need to develop and utilize energy sources other than conventionally derived petroleum,
- The need for further fuel-economy improvement—up to 35 or 40 mpg by 2000, and
- The need to reduce hydrocarbon, carbon monoxide, and nitrogen oxide emissions and to control other pollutants—such as sulfates, particulate, and nitrosamines — present in automobile exhaust or associated with the production of alternate fuels.

Substitute Fuels

The technology for producing, distributing, and utilizing alternate energy sources, as a supplement or replacement for conventional petroleum, may be the most significant development in the 1985-2000 period. These fuels could be:

- liquids from oil shale and tar sands,
- liquids from coal,
- alcohol, and
- hydrogen.

Oil Shale and Tar Sands.—Oil shale is a rock containing a petroleum-like substance called kerogen. The recovery process involves heating the shale to evaporate the oil, which is then drawn off and condensed. The resulting crude shale oil can then be refined to produce a synthetic fuel with properties close to those of gasoline or diesel fuel produced from petroleum. Tar sands are sand and clay saturated with a heavy oil. The extraction and refining processes are similar to those for oil shale. The final product has properties similar to conventional motor fuel.

There are large reserves of oil shale in the Western United States, and oil shale conversion could reach the commercialization stage by 1990-2000. The technology to advance from pilot plants to full-scale production has not yet been fully tested. At present, the estimated cost of fuel from oil shale is not competitive with motor fuel refined from petroleum. The price differential at present deters investment in commercial facilities—the cost of which is estimated at $1 billion for a 50,000 barrel-per-day plant. Uncertainty about Federal Government policy on petroleum and substitute fuels also contributes to industry's reluctance to invest in full-scale commercialization of oil shale processing.

A major obstacle to large-scale exploitation of oil shale is the environmental impacts of extraction and processing. These include land disturbance and subsidence, disposal of spent shale, gaseous emissions from shale retorting, and contamination of ground water. Also, processing requires large amounts of water—a scarce commodity in the semiarid regions of the Western United States, where the shale deposits exist. If these production problems can be resolved, fuel from oil shale can be readily substituted for petroleum products since it would not necessitate a different engine technology.

Commercial production of fuel from tar sands presents many of the same technical, environmental, and economic problems as oil shale. Compared to oil shale, the United States has only very small deposits of tar sands—about 2 percent of the world supply. The bulk of tar sand reserves are in Canada and South America. Consequently, tar sands are not considered a major domestic energy resource.

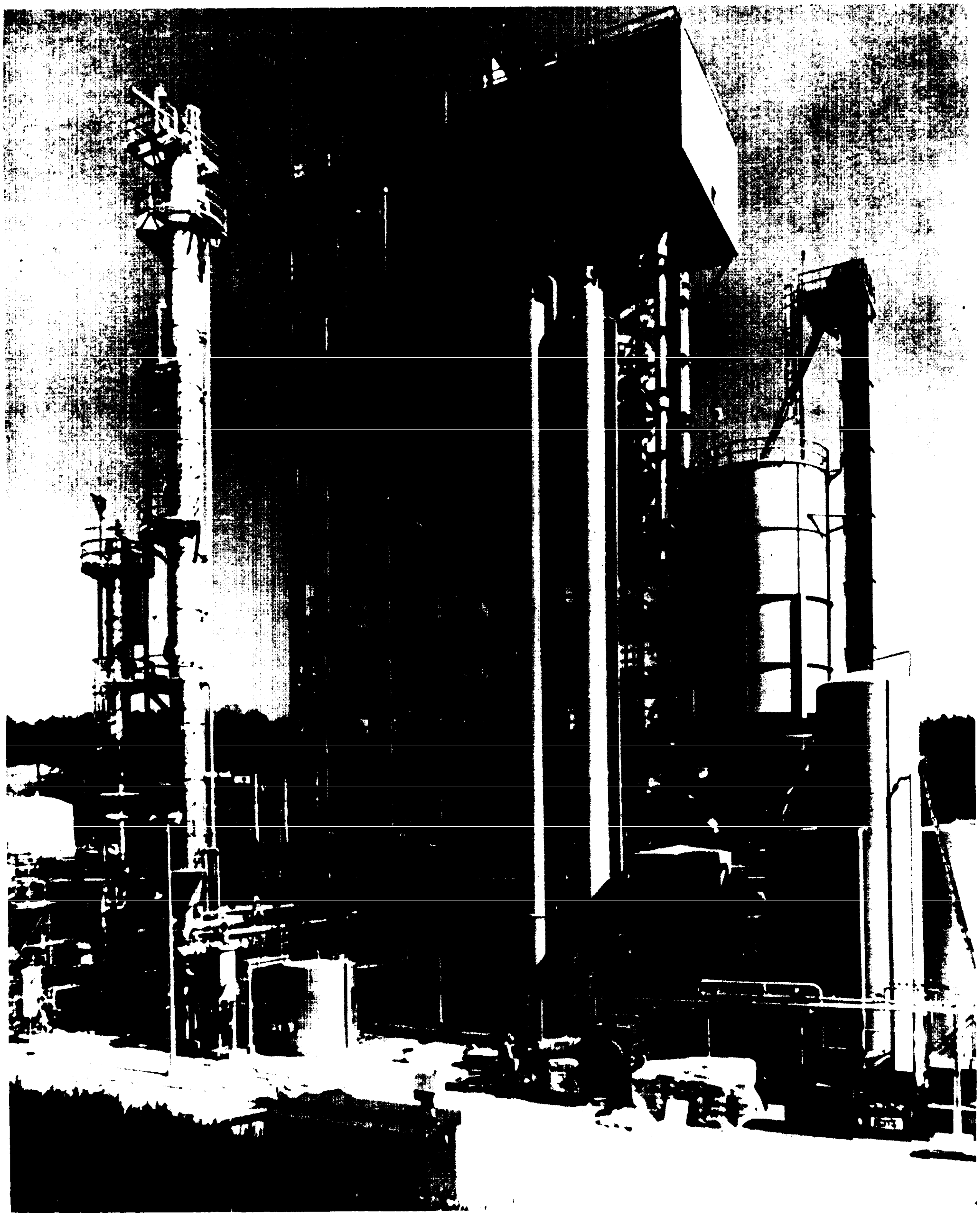

Photo Credit: U.S. Department of Energy

. . . **utilizing alternate energy sources** . . .

Coal.—The basic process for producing liquid fuel from coal involves breaking down the hydrocarbon molecules, removing contaminants such as ash and sulfur, and enriching the hydrogen content. The resulting liquid can be refined to a product suitable for use as a motor fuel.

Coal liquefaction on a large scale was carried out in Germany during World War II, and a commerical facility is now in operation in South Africa. There are several pilot plants in the United States, but extensive commercialization is not expected until the 1990's at the earliest.

Coal liquids are attractive as an alternative automobile fuel because the United States has an abundent supply of coal. The major barriers to large-scale production of coal liquids are technical, economic, and environmental. Coal liquefaction generally requires high pressures, carefully controlled temperatures, and large reactors for coal conversion. Research is continuing on the development of equipment and facilities for commercial application. Because of the need for specialized equipment, coal liquefaction plants are highly capital-intensive, and the cost of the resulting fuel exceeds the present price of petroleum products. In addition to the environmental problems associated with coal mining, there are air- and water-pollution problems at refining facilities and the inherently hazardous nature of some of the compounds present in the resulting motor fuel. The effects on air quality of extensive use of coal-derived fuels in automobiles have not been fully explored. It is conjectured that automobile exhaust would be higher in NO_x and various aromatic and benzene compounds if coal liquids were used.

Alcohol.—Alcohols such as ethanol or methanol can be used in pure form or in **a** mixture with gasoline (gasohol) to fuel automobiles. Methanol can be produced from organic waste, natural gas, heavy petroleum residues, or naphtha. It can also be derived from coal. Ethanol can be produced from biomass, which includes municipal and agricultural waste, grain, plants, and other biological matter. Alcohol fuels offer the attractive possibility of a renewable source of energy for the automobile. With present production techniques and volumes, the price of pure alcohol as a motor fuel is not competitive with gasoline. The price of gasohol in mixtures of 10 to **20** percent, if the alcohol is not subject to Federal fuel tax, is close to the current price of gasoline.

Ethanol blends have been used as an automobile fuel in Brazil for several years. Gasohol is now being sold in Illinois, Iowa, and Nebraska. California has initiated a gasohol program, and Colorado has approved one. It is estimated, however, that it would take 10 to 15 years to build the industrial capacity sufficient to meet 10 percent of our daily automotive fuel demand.

Alcohols have the inherent advantage of a high octane rating, which permits more efficient engine operation. The emissions from an engine burning pure alcohol or gasohol are lower in HC, CO, and NO_x. However, it is suspected that there would be a higher proportion of unburned fuel in the exhaust and an increase in aldehyde emissions. The significance of these emissions in terms of reactivity and toxicity is not fully understood at present.

Gasohol containing less than **20** percent alcohol can be burned in present-day automobile engines with only slight carburetor adjustment. The use of alcohol as a motor fuel, either in pure form or in blends of more than **20** percent with gasoline, requires some modification of the engine and fuel system to maintain proper carburetion and to prevent corrosion and deterioration of parts in contact with the alcohol. Transportation, storage, and distribution of alcohol requires special precautions to prevent contamination by water.

Hydrogen.—Hydrogen is an ideal fuel for heat engines because its energy content is very high per pound and because it burns cleanly. However, the use of hydrogen in automobiles presents technical problems. As a gas, it is of very low density and has to be stored and transported under high pressure. As a liquid, hydrogen must be kept at an extremely low temperature, which requires thermal insulation and special handling. Hydrogen can be stored in solid form as a metal hydride, but it is heavy and bulky— making it impractical with present technology to store in a passenger car.

Although hydrogen is the most plentiful element in the universe, processes to obtain hydrogen by breaking down natural compounds such as water or coal are very costly under present methods and consume more energy than they deliver. Extensive use of hydrogen as a motor fuel depends on development of a practical, low-cost, energy-efficient process to extract hydrogen, probably from water.

Advanced Propulsion Systems

The desire for cleaner and more efficient propulsion systems has stimulated a search for alternatives to the conventional spark-ignition engine. Among the candidates are:

- gas turbines,
- Stirling engines,
- compound engines, and
- electric and hybrid vehicles.

All are in various stages of development now, but more work will be needed to determine their potential. However, each can be considered a contender to provide a partial or complete substitute for the conventional spark-ignition engine of today. The advantages and disadvantages of each are discussed in chapter 10 of the Technical Report and summarized briefly here.

Interest in the gas turbine (Bray ton cycle engine) has been prompted by the need to develop an automobile engine with emission characteristics superior to those of the spark-ignition engine. The turbine is also of interest because it is theoretically a very efficient engine that can use a wide variety of fuels. However, to achieve high operating efficiency a turbine must run at a very high temperature. This necessitates using high-temperature metal alloys or ceramics for engine components. High-temperature alloys are expensive and difficult to mass produce. Ceramic technology has not yet been perfected. If the problem of production of high-temperature materials can be solved, the gas turbine promises to be a small, efficient, and durable automobile engine with smooth operation, low emissions, and ease of maintenance.

The Stirling engine is an external combustion engine, The heat from burning fuel is used to expand a confined working fluid (usually helium or hydrogen under high pressure) which drives a piston to provide motive power. The expanded working fluid is recompressed and reheated for the next piston stroke.

The Stirling offers the potential of very high fuel economy and can use nearly any liquid, gaseous, or solid fuel. Since it is an external combustion engine, it is theoretically cleaner than an internal combustion engine burning comparable fuel. The Stirling engine can also be made quiet and smooth running.

There are many technical problems that will have to be solved before the Stirling engine can be put to use in passenger cars. The engine operates at very high temperature and pressure. Special high-temperature materials are required. Maintaining tight seals is a problem. The Stirling is mechanically complex, which makes it difficult to produce in quantity at a competitive cost. For these reasons, the Stirling engine is not expected to be on the market until 1990 or later.

Along with research on turbine and Stirling engines, attention is also being given to other advanced propulsion systems that augment one type or another of heat engine with additional power cycles such as turbocharging, regeneration, compounding, and other mechanical and thermodynamic variations. One such engine is the adiabatic turbocompound diesel that is currently being developed for trucks. The efficiency of the diesel is improved by shielding the engine to prevent radiant heat loss and then adding a turbine driven by the exhaust gases, which serves to capture some of the energy that would otherwise be lost. As a further refinement, a Rankine cycle power system (a steam engine) can be added to utilize even more of the waste heat in the exhaust stream. These features can raise the thermal efficiency of the engine to perhaps twice that of a conventional diesel or spark-ignition engine but may result in a large weight penalty. The adiabatic turbocompound diesel, or some other form of compound-cycle engine, could find its way into automobile use, but probably not before the end of the century.

In the early days of the automobile, the battery-powered electric motor was a strong competitor with the gasoline-powered spark-ignition engine, which eventually prevailed because of its superior power, range, and convenience. Recently, interest in the electric vehicle has been revived because the EV can derive energy from sources other than petroleum and because the vehicle itself emits virtually no air pollutants. The EV is also quiet in operation.

The electric vehicle has some major disadvantages, however, that deter its use as an all-purpose passenger car. The performance of the EV does not compare favorably with that of the conventional automobile in terms of speed, acceleration, range, and load-carrying capacity. The solution to these problems lies in the development of a battery that will provide higher energy and power density than the present lead-acid battery at a moderate cost. One possible alternative, the nickel-zinc battery, which offers about twice the energy capacity of the lead-acid battery, is nearly ready for production. Other advanced high-temperature batteries such as the lithium-sulfide battery, are in early stages of development.

Electric automobiles have been given a boost by the passage of the Electric and Hybrid Vehicle Development and Demonstration Act of 1976. This act emphasizes the near-term deployment and demonstration of vehicles using available technologies. This demonstration program is helping to define the attributes, deficiencies, and problems of electric vehicles. The marketing of a special-purpose, limited-range vehicle may become a reality in the period 1985 to 2000.

Research is also being directed **toward** methods to supplement the performance of the basic electric vehicle. One approach is to use regenerative braking, which converts some of the vehicle's momentum back into electrical energy. Another approach is to store energy mechanically by means of a flywheel, which can be used separately or in combination with a battery storage system. Further improvements in EV performance can be obtained by combining a combustion engine with the electrical energy storage system. This combination, known as a hybrid vehicle, provides greater range and performance than can be obtained with a vehicle powered by electricity alone. Demonstration of hybrids is also a part of the program being conducted by the Department of Energy (DOE), but so far very few have been built and tested. It is too early to predict the role that hybrid vehicles might play as a future form of automobile transportation.

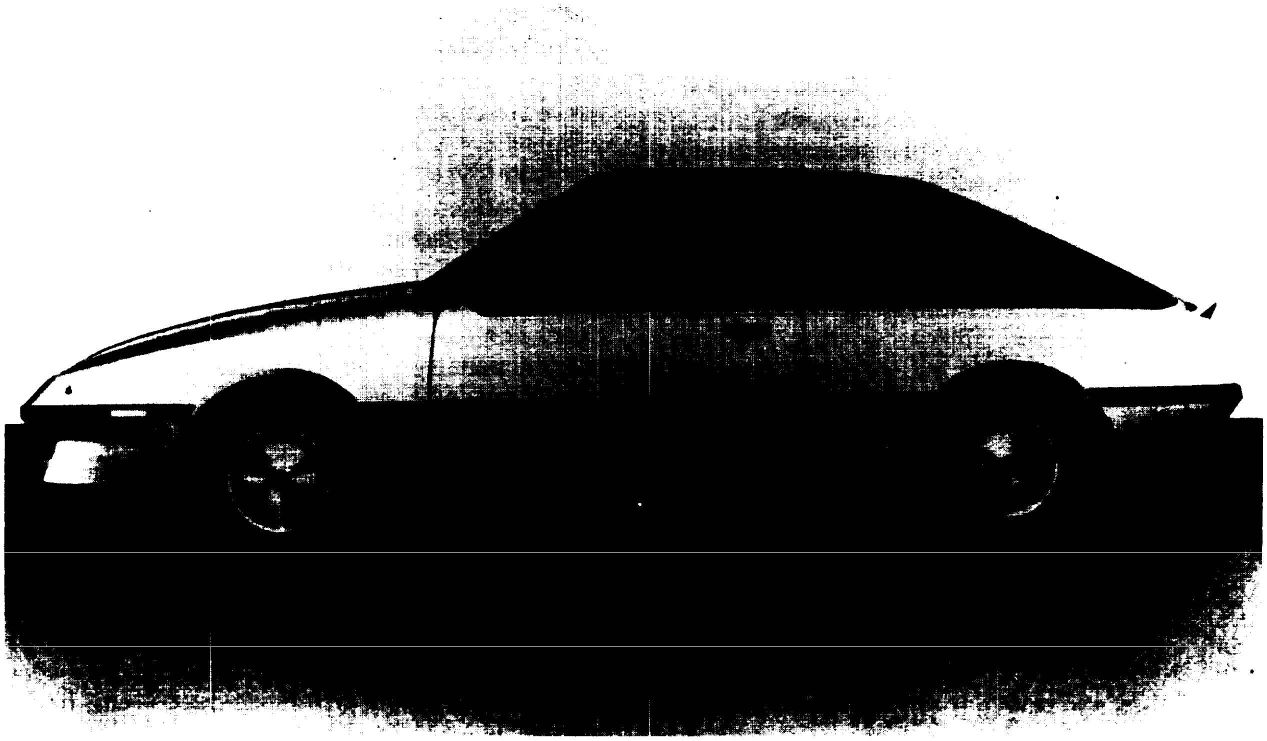

Photo Credit: General Electric

. . . interest in the electric vehicle has been revived . . .

FINDINGS

Based on analysis of near-term and far-term prospects for development of automobile technology, we find that:

- The 1985 fuel-economy goal appears to be technologically achievable, but at the expense of some large-car production.
- It is possible to meet the currently mandated emission standards without serious penalty in fuel economy.
- Small cars can be designed to be more crashworthy at a nominal weight and cost penalty.
- Diesels presently offer a substantial advantage in fuel economy over spark-ignition engines, but the problem of particulate emissions must be solved before the diesel can be suitable as a wide-scale substitute for the spark-ignition engine.
- Liquid fuels from oil shale, coal, and tar sands can be used to power automobiles, but deposits of only the first two are sufficient to be considered significant domestic energy sources for automobiles. Production of liquid fuels from either oil shale or coal is not expected to reach commercial scale until the 1990's at the earliest, and even then only if large capital investments in extraction and processing facilities are made soon. The environmental and safety hazards of producing and using these substitute fuels need further examination.
- Alcohol is an attractive fuel that can be used as a blend with gasoline in present engines at a cost slightly greater than gasoline. The use of pure alcohol as a motor fuel requires some changes in the engine and may require modification of the fuel transport, storage, and distribution system. Pure alcohol is not cost-competitive with gasoline at present. The environmental impacts of alcohol fuels need further study.
- The use of hydrogen as a motor fuel is not a practical alternative until sometime after 2000. There are many problems of production, storage, and handling to be overcome.
- As long-term options, the gas turbine and Stirling engines are attractive in terms of fuel economy, reduced emissions, and multifuel capability. Development is under way, but they are not expected to reach the automobile market until 1990 at the earliest.
- The benefits of electric vehicles are reduced petroleum consumption and the virtual elimination of air pollution from the vehicle itself. The development of improved batteries is the critical technological problem. Electric vehicles, designed for special purposes and limited use, may be on the road in significant quantities by the mid-1980's.

CONGRESS OF
THE UNITED STATES
Office of Technology Assessment

U. S. GOVERNMENT PRINTING OFFICE : 1979 O - 40- 064