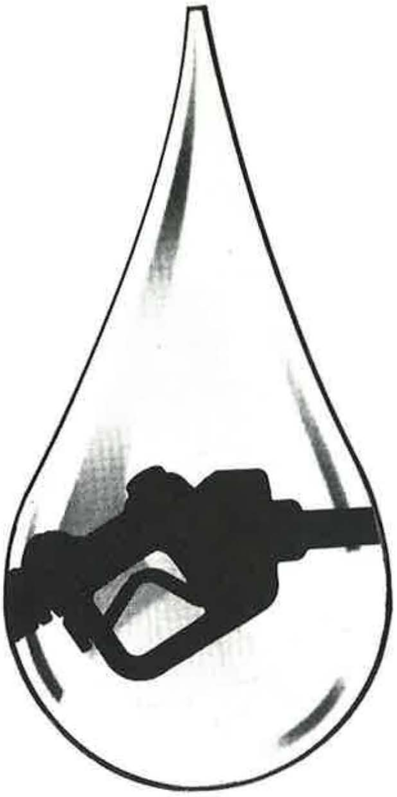

STRETCHING THE GASOLINE GALLON

An engineering approach

Stephen E. Blake

Most of the inconveniences associated with the energy crisis have disappeared, but this does not mean that the problem has been resolved. The growing worldwide demand for petroleum will rapidly deplete known reserves in the next few decades, and we must find better ways to reduce the demand for energy and to achieve maximum efficiency in its use.

There are several ways to achieve greater efficiency in the use of energy for transportation: Reduce demand for those scarce resources, shift travel from high-energy modes such as the automobile to more energy-efficient modes such as public transit, and reduce energy demand per vehicle-mile by more energy-efficient vehicles.

In this article, discussion is limited to methods for reducing energy demand per vehicle-mile and is divided into 3 parts: engine improvements and alternatives, weight, size, and safety factors, and other design features.

Engine Improvements and Alternatives

Probably half the cars on the road waste fuel needlessly simply because they are not properly tuned; timing and carburetor adjustments would decrease fuel consumption 10 to 15 percent.

Improved fuel economy, however, is not simply a matter of setting the carburetor to deliver the chemically correct 15:1 proportions by weight of air and fuel. A piston engine requires a rich 13:1 fuel mixture for maximum power and a weaker mixture of around 16:1 for maximum economy and thermal efficiency. Modern carburetors deliver a weak mixture on part throttle and a rich mixture at more than 75 percent of full power. Weak mixtures burn slowly, and most cars are equipped with vacuum mechanisms to advance their ignition. These mixtures give up much of their energy as heat rather than mechanical work, and this can easily cause engine damage if used at greater than moderate speeds and load.

For many years designers have considered the possibility of devising mechanisms to vary the valve timing so that it could be adjusted for high and low engine speeds; thus, the usual compromise of weak and rich mixtures is avoided. One such mechanism has been developed by engineer Giuseppi Torazza of Fiat and increases the standard Fiat engine efficiency 50 percent.

Improved fuel economy can also be attained by redesigning the carburetor with a variable-lift mechanism in place of the normal butterfly valve used to regulate the

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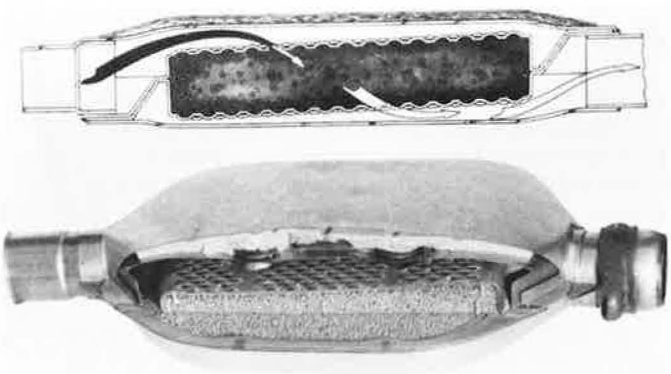
1 Among the 1975 innovations designed for better fuel economy and emission controls are the high-energy ignition system, the integrated fuel-control carburetor, the quick heat-intake manifold, and the catalytic converter located in the exhaust system. As the exhaust gases flow through the converter, as shown at the bottom of the picture, the hydrocarbons and carbon monoxide are chemically converted to harmless water vapor and carbon dioxide. The system shown is that of General Motors. Other manufacturers are offering similar equipment.



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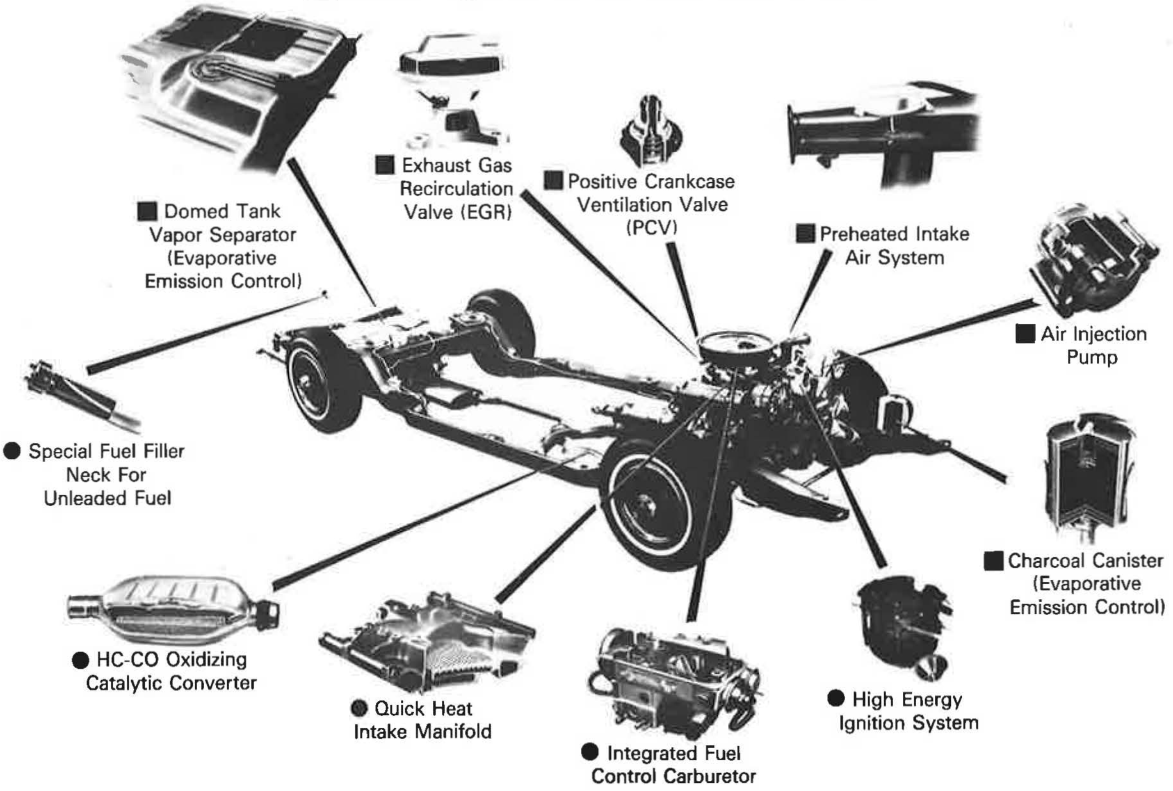
■ 1974 ● PLANNED FOR 1975 MODELS



2 Chevrolet's Vega ranks near the top of the list in fuel economy. It is powered by an aluminum block, 4-cylinder, 140-cubic inch engine with a 1-barrel carburetor as standard equipment.

3 Small automobiles such as Ford's Mustang II are becoming increasingly popular as gasoline prices rise. The Mustang II replaced the larger, heavier Mustang and proved to be one of the best sellers in the Ford Motor Company range.

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amount of mixture induced into the cylinder. General Motors has developed the technique to vary the lift continuously so that mixtures as lean as 22:1 will burn successfully without damaging the engine.

Another method of achieving greater fuel economy and lower emissions is to stratify the mixture in the cylinders. This can be accomplished in 2 ways. The first is to give the inlet air a circular swirling motion, which concentrates the fuel around the spark plug; the other is to use a small secondary combustion chamber to communicate with the main one. The latter is the method employed on the 1488-cc Honda CVCC engine. The unit is essentially a stratified charge engine embodying an auxiliary combustion chamber close to the spark plug that contains a tiny additional inlet valve of its own. The auxiliary inlet valve admits a small dose of rich mixture that is ignited by the spark plug. The mixture expands into the main combustion chamber and there burns the very weak mixture that is admitted by the ordinary inlet valve.

Honda kept the cost low by using special carburetors rather than fuel-injection pumps and by sticking to simple mechanical, electrical, or vacuum-operated components for the elaborate control system needed to time and phase the ignition and carburetion. The Honda CVCC engine was designed to meet the 1975 exhaust emission standards as well as to provide fuel economy.

The application innovations in fuel carburetion and ignition to the present automobile powerplant might achieve a substantial increase in fuel economy as well as low emissions. The exact extent to which these innovations might conserve fuel has not been determined; however, the improvements if applied to all vehicles might be substantial.

The alternative power plants that are in various stages of development and actual use offer a different means of conserving fuel. These power plants can be divided into 2 categories: those that operate with existing fuels and those that are capable of using a variety of fuels.

Included in the first category are the stratified charge and Wankel rotary engines. We have already discussed the stratified charge engine. The Wankel rotary engine has shown higher emissions in EPA testing and poorer fuel economy than the internal combustion engine, but some mention should be made of its advantages. The first advantage is that the engine is as much as 50 percent smaller than a comparable piston engine, a feature that gives it a high power-to-bulk ratio. In addition, it is about 30 percent lighter than a comparable piston engine and thus has a power-to-weight ratio. It also has about 40 percent fewer major components and is extremely smooth and quiet. If the problems with seals, emissions, and fuel economy are overcome, this engine will present a viable economic alternative to the reciprocating piston engine.

The 3 engines in prototype form that are being tested are the gas turbine (Brayton cycle), Rankine (steam), and Stirling engines.

The gas turbine has been under development by GM for the past 25 years. The technology of the engine is well known and is in use in jet aircraft, test automobiles, and high-speed boats. The basic problems with gas turbine automobiles are the requirement of relatively low-power engines that can operate over a wide load range with reasonable fuel economy, loss of fuel economy when the engine is operated at partial load, low efficiency and economy as power is scaled down, and low acceleration. Present technology can produce a high-powered, efficient gas turbine, but the price would be unreasonably high to the consumer. Although the gas turbine has the advantage of being able to use a number of different fuels, this advantage does not now outweigh the cost associated with its development and maintenance.

The closed Rankine cycle engines with water as a working fluid (steam engines) have been used to power vehicles in the past but were discontinued with the advent of the internal combustion engine. Problems associated with this engine are weight, bulk, freezing, and poor fuel economy. However, there is continuing research, and advanced versions of the Rankine cycle engine offer the promise of considerable improvements in fuel economy compared with the conventional engine. The current design of the Rankine engine, a steam reciprocating model developed by EPA's Advanced Automotive Power Systems Program, is expected to yield 13 miles per gallon for the family sedan and proposed ad-


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vanced engines may exceed 20 miles per gallon. The ability of the Rankine cycle engine to use various fuels is a potential advantage also.

Ford Motor Company is currently engaged in research to develop the Stirling engine for passenger car application. The most recent research concerns an engine that is compact and lightweight (less than 5 pounds per horsepower) and is expected to have exhaust emissions well below the 1976 standards. It is expected to perform much like a standard engine, have excellent fuel economy, and most likely be expensive.

The engine design is a major departure from earlier Stirling engines (employing rhombic drive). It is most easily described as a 4-cylinder in-line engine that has been pulled into a circle so that the first and fourth cylinders are adjacent. The crankshaft is replaced by a swashplate on an axle parallel to the center lines of the cylinders. The cylinders are interconnected to permit the working gas (9 grams of hydrogen) to flow from one to the next. The piston in each cylinder plays a dual role as the power piston and as the displacer piston of the more familiar rhombic drive version. The main problem with this engine is cost and use of scarce materials such as nickel in its production.

The major reason that these engines may not be produced is that, after 75 years of continual development, the modern internal combustion engine is highly refined, sophisticated, and tuned to particular markets. Demands of most car buyers for low capital cost, high specific power, low maintenance requirements, and reasonable fuel consumption are well satisfied by these engines.

Weight, Size, and Safety

The primary factors contributing to fuel economy are size and weight, type of transmission, and accessories. Vehicle size and weight are the most important of these factors.

Selecting 1965 as a starting point, because it precedes most emission-control devices that have had an appreciable effect on fuel comsumption, we find that there has been a decrease of more than 21 percent in fuel economy between that model and 1973 models. This may be attributed to weight and emission-control devices.

For example, a typical new, standard-sized, 4-door sedan with optional small V-8 engine, automatic transmission, power steering, and power brakes weighed about 3,550 pounds in 1965 and could be expected to average approximately 15 miles per gallon in normal driving situations—city and suburban driving at varying speeds. The 1967 model standard-sized car with the same equipment weighed approximately 3,750 pounds—a 4.2 percent increase—and fuel economy was reduced by about 3 percent.

By 1971 the standard-sized car had increased in weight to 4,150 pounds, including the weight of air-conditioning equipment, which, although not standard, is installed on a large number of vehicles. This was also the first year that safety and damageability standards contributed substantially to car weight. Larger engines were substituted by manufacturers in an effort to maintain performance, resulting in a loss in economy. The base V-8 of 300 cubic inches was replaced by power plants of 350 cubic inches or larger. The resulting mileage was an average of 13 miles per gallon, a decrease of more than 15 percent over the 1965 level.

A further loss has been incurred on the 1973 and 1974 models with the addition of stricter emission controls and new bumpers able to sustain a 5-mph impact. The average standard-sized sedan in 1973 weighed 4,275 pounds, an increase of 725 pounds over the 1965 model. This 20 percent increase in weight has resulted in a drop to 12 miles per gallon or less, which represents a 21 percent decrease in economy over 1965.

Clearly fuel economy has deteriorated substantially because of a number of factors, weight being a significant one. An alternative to achieve greater energy efficiency per vehicle-mile, therefore, is to reduce the size and weight of passenger vehicles.

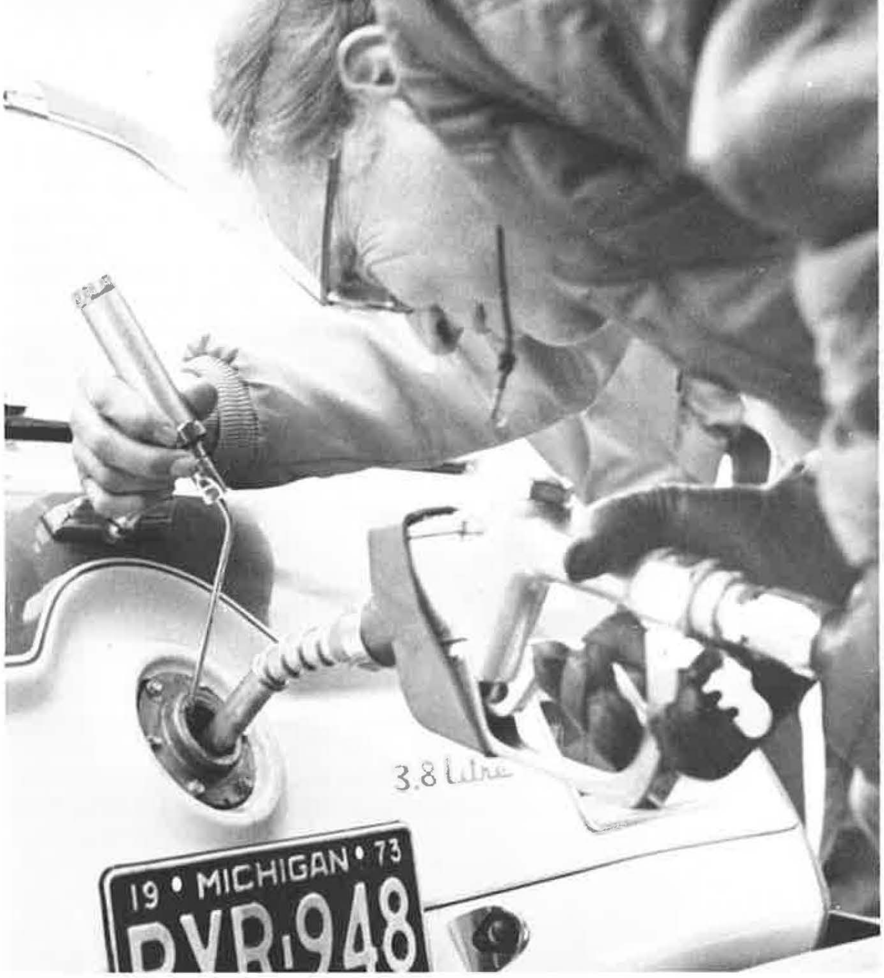
The sales of standard- and medium-sized cars fell 18 to 20 percent for the first months of 1974 while sales of subcompact cars rose 25 percent and compact cars rose 18 percent over sales in 1973. In 1969 approximately 20 percent of the new passenger cars registered were small cars; in 1973 this proportion had increased to 40 percent, and the trend is accelerating.

Subcompact and compact cars range in weight from 2,000 to 3,000 pounds. In an assessment of the effect of reducing the average weight of U.S. automobiles, EPA described how zero growth in automobile fuel use could be achieved by 1985, even if vehicle-miles traveled increased 45 percent. If no improvements are made in fuel economy technology and no shift is made to the use of the best fuel economy for each class, average vehicle weight would have to be reduced from 3,500 to 2,500 pounds by 1985 if zero fuel growth is to be achieved. However, using available technology already demonstrated and applying it to the entire class would require a weight reduction to 2,900 pounds to achieve the same result. If the average weight of automobiles were reduced to 2,500 pounds and the average fuel consumption were 26 miles per gallon and if these vehicles constituted 50 percent of all passenger vehicles on the road, a savings of 12.2 billion gallons a year could be realized.

One means of reinforcing the trend toward smaller cars is a progressive weight tax applied to all cars heavier than a minimum weight. This might discourage the use of large vehicles and act as an incentive to manufacturers to produce more small cars.

The switch to small cars involves trade-offs with safety. Studies conducted at the Insurance Institute for Highway Safety and at the North Carolina Highway Safety Center indicate that occupants of a small car are at a disadvantage in a collision with a large car because of various factors such as compartment size, safety restraints, and interior design.

The risk of severe injury is about twice as great in a



In 1 of 3 Collegiate Economy Runs sponsored by the American Motors Corporation during 1974, the winning 6-cylinder Gremlin covered 25.29 miles per gallon. Here an official takes the temperature of the gasoline before the start to permit measuring fuel accurately by volume regardless of expansion or contraction caused by outside temperature variations.

crash between 2 small cars as in a similar crash involving 2 large cars, and unbelted drivers of large cars tend to sustain severe injuries less often than unbelted drivers of small cars during car-to-car crashes. But there is evidence that weight might not be the overriding factor.

University of North Carolina researchers, studying the relation between passenger-car weight and driver injuries in automobile accidents, have found that relation diminishing progressively in new model cars. Pure weight does not seem to be an overriding factor in the vehicle crashes, the report concluded. Researchers found this fact encouraging for smaller cars because it suggests that adequate protection for the driver is attainable in many crashes even though the small car protection may be marginal in a crash with a large car. These factors must be examined to determine what improvements can be made to safeguard the lives of the occupants of smaller, lighter weight vehicles.

Other Design Features

After engine design is improved and weight is reduced, several other factors need to be improved to develop a more energy-efficient automobile.

One factor is the power loss that occurs between the flywheel of the engine and the driving wheels. This is created by frictional and oil-churning losses in the transmission system—the gearbox, the differential, and the crown wheel and pinion or final drive gears. About 10 percent less fuel is used by a typical manual transmission than by an automatic.

Another factor is rolling resistance. At all but very low speeds this resistance is dwarfed by the resistance exerted on the body of the car by its passage through the air. The principal contributor to rolling resistance is the friction provided by the loaded tires of the vehicle. Newer tire designs, in particular the steel-belted radial-ply tires, provide a substantial reduction, ranging from 15 percent on ice to 45 percent on sand. This may be translated into fuel economy of 5 to 10 percent on the average road.

Another factor is aerodynamic drag, which is determined by the shape of the body being pushed through air. Moderate levels of research and development to improve the aerodynamic design of vehicles would result in major energy savings.

Summary

Changes and improvements must obviously be made in engine design, vehicle size and weight, and safety to meet the growing demand for transportation services and at the same time achieve efficiency in the use of energy. If all the available technology is applied to existing passenger vehicles, the savings could be as great as 30 percent of the estimated 1985 projected fuel use. This would substantially extend the supply of fossil fuels.