343880

NHTSA-05-22223-21

POTENTIAL FOR MOTOR VEHICLE FUEL ECONOMY IMPROVEMENT

REPORT TO THE CONGRESS

24 October 1974

(Second Printing Issued 18 November 1974)

PREPARED BY
THE
U. S. DEPARTMENT OF TRANSPORTATION
AND THE
U. S. ENVIRONMENTAL PROTECTION AGENCY

24 October 1974

Honorable Warren G. Magnuson
Chairman, Committee on Commerce
United States Senate
Washington, D. C. 20510

Dear Chairman Magnuson:

Section 10 of the Energy Supply and Environmental Coordination Act of 1974 (Public Law 93-319) directed the Department of Transportation and the Environmental Protection Agency to conduct jointly a study to determine the practicability of establishing a fuel economy improvement standard of 20% for new motor vehicles manufactured during and after model year 1980. The Act further directed that the study be conducted in consultation with the Council on Environmental Quality, the Federal Energy Administration, and the Department of the Treasury and delivered to your committee within 120 days.

Accordingly, the staffs of our respective agencies carried out the study and prepared a report that is based on their research and findings. The report is transmitted herewith.

Claude S. Brinegar
Secretary
Department of Transportation

Russell Train
Administrator
Environmental Protection Agency

24 October 1974

Honorable Harley O. Staggers
Chairman, House Interstate and
Foreign Commerce Committee
House of Representatives
Washington, D. C. 20515

Dear Chairman Staggers:

Section 10 of the Energy Supply and Environmental Coordination Act of 1974 (Public Law 93-319) directed the Department of Transportation and the Environmental Protection Agency to conduct jointly a study to determine the practicability of establishing a fuel economy improvement standard of 20% for new motor vehicles manufactured during and after model year 1980. The Act further directed that the study be conducted in consultation with the Council on Environmental Quality, the Federal Energy Administration, and the Department of the Treasury and delivered to your committee within 120 days.

Accordingly, the staffs of our respective agencies carried out the study and prepared a report that is based on their research and findings. The report is transmitted herewith.

Claude S. Brinegar
Secretary
Department of Transportation

Russell Train
Administrator
Environmental Protection Agency

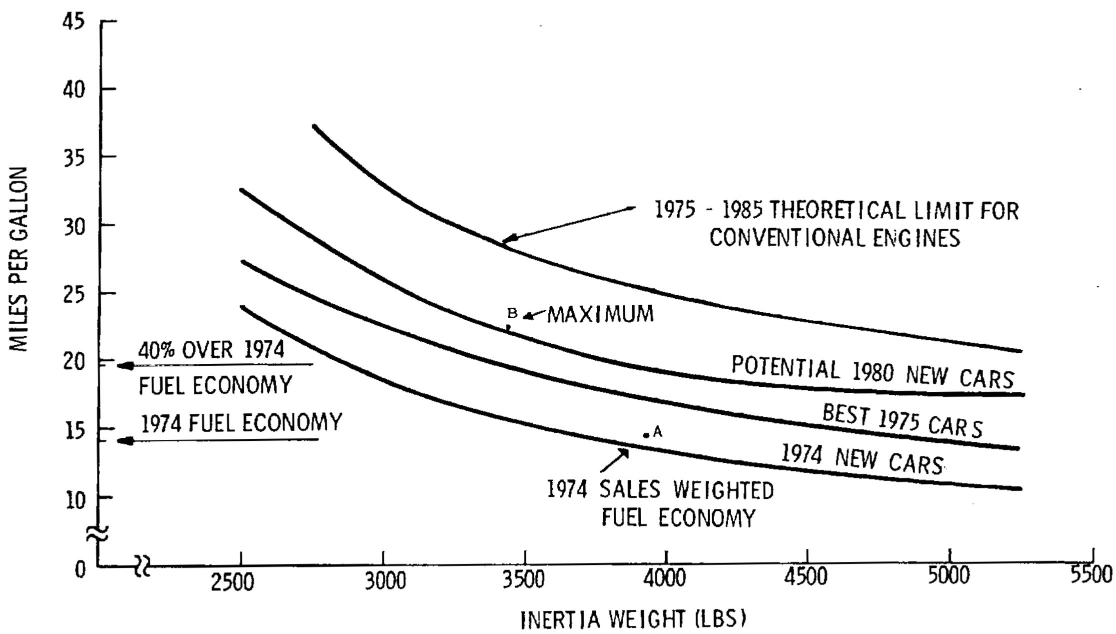
CHANGES

Page/Line	Oct. 24,'74 Printing Was	Nov. 18,'74 Printing Is
2/Figure 1		Asterisk (*) added to Item 3 of "1980 Potential."
6/Line 5	$4.5 billion in petroleum	$5.0 billion in petroleum
7/Line 14	Safety and damage-ability	Safety and damage-ability requirements.
35/Figure 6	(See Next Page.)	Fuel economy curves reshaped
41/Title Table 8a	ENGINE TECHNOLOGY	ENGINE TECHNOLOGY EXAMPLES
41/Title/Col. 2	EMISSIONS:	TARGET EMISSIONS
41/Item 2	EGR/EFE	EGR/QHI
41/Item 4	EGR/EFE	EGR/QHI
41/Item 6	Triple Asterisks(***)	Removed to Item 5
41/Item 11	DUALCAT/AIR	DUALCAT/MAIR
41/Footnote***	6-12	5-12
42/Item 14	-400 (FE)	-250
42/Item 15	+9 (FE & change)	+12
	+500 (S)	+300
	-1000 (FE)	-500
		Added to comments (-1000 lbs., +300 lbs.)
42/Item 16	0 (FE % change)	+9
	+1000 (S)	+450
	-1000 (FE)	-500
		Added to comments (-1000 lbs., +450 lbs.)
62/Section 3.2.2.4	comprising the compliance test fleet	comprising the test fleet
62/Section 3.2.2.4	should include all configurations.	should include those configurations.
63/Item 6	Assume the continuing correlation of the EPA city	Provide the continuing correlation to the EPA city

Page/Line	Oct. 24,'74 Printing Was	Nov. 18,'74 Printing Is
65/Table 9 (4th Column)	194	204
91/Table 16		Delete - Issued Standards Not Yet in Effect section. Delete bottom line and replace with:
	Part 581 No Damage Bumper	∿45-100 lbs.
	After 1980 FMVSS 208 (45-50 mph)	∿150-270 lbs.
	Total	∿250-400 lbs.
A4	IMPROVED QUICK HEAT INTAKE (QHI) SYSTEM	QUICK HEAT INTAKE (QHI) SYSTEM

Note: On Page 22/Line 1 - Ford Motor Company indicates its production potential for small cars is 2.0 million cars per year.

Figure 6, page 35, WAS:



PREFACE

This report, prepared in compliance with Section 10 of the Energy Supply and Environmental Coordination Act of 1974, P.L. 93-319 (the Act), addresses the potential for fuel economy improvement for new motor vehicles. The Act directed the Administrator of the Environmental Protection Agency (EPA) and the Secretary of the Department of Transportation (DOT) to conduct jointly a study and report on the practicability of a fuel economy improvement standard of 20% for new motor vehicles in the 1980 time frame.

As required by Section 10 of the Act, the information on fuel economy improvement potential presented in this report includes an assessment of the technological problems of meeting any such standard, including lead times involved, the test procedures required to determine compliance, the economic costs and benefits, the enforcement means, the effect on energy and other resources, and the relationship of safety and emission standards.

A Task Force was established under the joint chairmanship of DOT and EPA to conduct the study. Materials used in the preparation of this report were developed by panels addressing the major impact areas. These panels drew on a variety of sources, including previous DOT and EPA research, and solicited both industry and public comments. In accordance with Section 10, the Task Force consulted with the Council on Environmental Quality (CEQ), the Federal Energy Administration (FEA), and the Department of the Treasury.

This report consists of three basic Sections: an Executive Summary, an Introduction, and a Discussion of the Potential for Fuel Economy Improvements and their Impacts. Also included is a list of Public Docket submissions and a summary of their content.

CONTENTS

CONTENTS (CONTINUED)

LIST OF ILLUSTRATIONS

LIST OF TABLES

1.0 EXECUTIVE SUMMARY

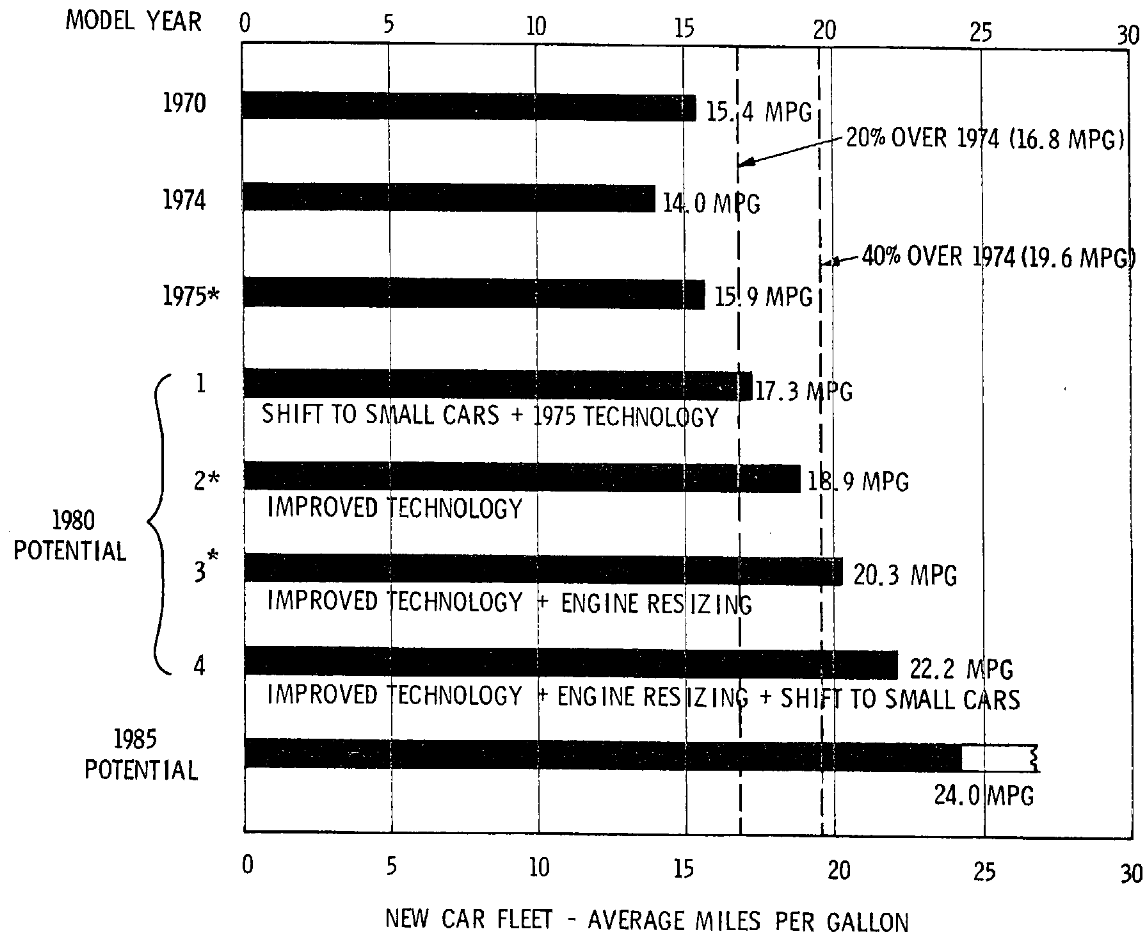
The major findings of the study for automobiles are given below. More detailed conclusions and an assessment of the fuel economy potential for trucks and buses complete the summary.

- It is practicable to achieve by a variety of means a 20% fuel economy improvement in the new model fleet of 1980 compared to 1974 with little further price increase. The full range of potential improvements, which is from 40 to 60 percent, is shown in Figure 1.
- Fuel economy improvements obtained while simultaneously achieving interrelated objectives such as low emissions and occupant safety will involve competition for capital, expertise, and other resources. Impacts, some of which may require compensating action, include:

  a. The price of new cars will rise due to fuel economy improvements. For example, a 40 percent improvement over 1974 would increase the price up to 10 percent. Savings in operating and maintenance costs, however, will more than offset these price increases for the vehicle owner.

  b. A sustained or increased shift to the more fuel economical small cars, without a concurrent upgrading of their crashworthiness or increased utilization of effective passenger restraints, will result in a rise in the serious injury and death rate on the highway. There is some limited evidence which indicates that the crashworthiness of the smaller car can be upgraded without serious weight penalties.

  c. Achievement of the statutory emission standards for hydrocarbons and carbon monoxide with substantial fuel economy improvement is feasible in the new car fleet of 1980 compared to 1974. The issue of the level and cost of the oxides of nitrogen emission achievable by 1980 concurrent with substantial fuel economy improvement is unresolved.



*1974 NEW MODEL PRODUCTION MIX ASSUMED.

Figure 1. Potential for Automobile Fuel Economy Improvement

d. Dramatic savings in petroleum requirements can result from fuel economy improvements to motor vehicles. The savings in petroleum may not be fully realized since the resulting gain in operational economy may induce additional vehicle travel and increased sales of larger (although improved) cars.

- A number of alternative Federal strategies for improving fuel economy have been examined in terms of their effects on producers and consumers, and ease and cost of their administration. No one approach clearly dominates the others. Each has risks, costs, and problems. A uniform 20 percent improvement standard for every manufacturer, for example, would require larger absolute fuel economy gains on already efficient cars while requiring only minor improvements on inefficient cars which have the greatest potential for improvement.

The study does not make the judgment of whether a Federal improvement standard is needed inasmuch as a 20 percent or greater improvement goal may be reached solely through the forces of the market. There has been a 13.5% increase in automobile fuel economy from 1974 to 1975. Consumer demand for better fuel economy may not be strong enough to induce manufacturers to opt for the substantial improvement possible.

The following detailed conclusions summarize the main results of the study for automobiles.

1. <u>What is the Fuel Economy Improvement Potential by 1980 and 1985?</u>

- Fuel economy improvements may be obtained by three major methods. They are: technological improvements in the engine and drive train to increase efficiency and in the tires and body structures to reduce drag and weight; an engine size reduction for the larger cars; and a shift to a larger proportion of small cars in the fleet.

- Figure 1 indicates that from the 14.0 mpg[1] in 1974 a 25 to 60 percent (17.3 to 22.2 mpg) fuel economy gain is possible for 1980 model cars depending on the improvement strategies used. Because of production constraints, improved technology and engine resizing offers more improvement than the strategy of shifting to small cars by 1980. The 1975 fleet (15.9 mpg) has demonstrated a 13.5% improvement over 1974 (14.0 mpg) by technology. The 1970 fleet averaged 15.4 mpg. Thus a combination of technological improvements in 1975 cars and changes in the model mix (i.e., a larger portion of smaller cars) have recouped the fuel economy lost between 1970 and 1974 due to emission control and added weight.

- Estimates of the average mpg for the 1980 new car fleet shown in Figure 1 vary depending upon which of the above methods are assumed to achieve it (e.g., various forms of technological upgrading, shift in sales mix, and combinations thereof). Each assumes the best feasible effort possible. Shift in mix was limited to that possible given the availability of production facilities, but no limitations due to consumer demand were assumed. Some of the technological options considered require further development; however, their implementation is deemed feasible by 1980. Technological options were screened for consumer acceptability prior to their inclusion, but once selected, eventual 100 percent application to the new car fleet was assumed.

[1]The fleet fuel economy in miles per gallon is based on the miles traveled and fuel used in the city and highway driving schedules developed by EPA. The single number is obtained by assuming that 55% of the driving is represented by the city cycle and 45% by the highway cycle. Finally, the results for individual cars are weighted by the percentage of the production attributable to that car to obtain an average indicative of the fuel economy of the entire fleet.

- The impact, timing, and cost of emission and safety standards were considered in arriving at the potential gains. The tradeoffs among them are addressed in the following sections. Simultaneous achievement of improved fuel economy, low emissions, and occupant safety will increase the first cost of new vehicles.

2. What are the Economic Costs and Benefits Associated with Fuel Economy Improvements?

   - A 20% improvement in fuel economy should not result in an appreciable increase in the first cost of cars. Technological improvements should add up to $200 for 30% and up to $400 for 40% fuel economy improvements to new car selling prices by 1980 (in 1974 dollars). Lower operating and maintenance costs would pay for the increased first cost at a discount rate of 10% in about one year of normal use for the largest, and 3 to 4 years for the smallest, cars. The main difference in the pay-back time is due to the greater absolute amount of fuel used by improved large cars over small cars.

   - Fuel economy improvements require changes which may decrease maintenance costs compared to 1974 cars. Potential increased complexity of the engine system due to emission control may be offset by the improved reliability and low maintenance potential of state-of-the-art improvements combined with the use of unleaded gasoline.

   - The effects on the automotive industry of a 20% to 40% improvement in fuel economy by 1980 are requirements for increased capital investment and engineering and manufacturing changes. Such investments range from $50 million per year for a modest increase in fuel economy to $200 million per year for a large increase in fuel economy. The estimated capital investment of the domestic industry is $2.0 to 2.5 billion annually.

- The savings in gasoline due to fuel economy improvements have potential for dramatic savings in petroleum. For example, using a modest growth rate (2.6%) in vehicle miles travelled and a fuel economy improvement of 40% by 1980, savings in 1980 alone of $5.0 billion in petroleum demand (1974 dollars) at $11/barrel would ensue.

3. <u>What are the Relationships Between Fuel Economy and Safety?</u>

- Safety and fuel economy are related through a vehicle's weight and body structure. Today, a larger car with more crush space and heavier structure provides better protection but poorer fuel economy than the small car.

- Of equal importance to the crashworthiness of cars are the availability and usage rate of effective passenger restraint systems. Even in today's fleet, where the probability of being involved in an accident is relatively independent of car size, the belted occupant of a small car has approximately the same protection as the unbelted occupant of a large car.

- Recognizing that present national policy is to reduce the serious injury and death rate on the highways, safety standards which would improve the crashworthiness and effectiveness of passenger restraint systems, especially for small cars, are necessary. If fuel economy improvements are achieved by a shift to a higher percentage of small cars in the fleet without concurrently upgrading their occupant protection capability, it is probable that the serious injury and death rate would rise.

- It is important to note that the relationship between weight and safety is opposite to that of weight and fuel economy. Consequently, the fuel economy penalty chargeable to increased occupant safety may be proportionately greater for a small car than for a large car. Bumper standards have added about 140 pounds while safety standards have added about an additional 120 pounds, for a total of 260 pounds of weight added to the average vehicle of today. The fuel economy penalties have been on the order of three to four percent for this additional weight.

- Presently identified future safety standards will add approximately 80 pounds to the average vehicle. An advanced notice of proposed rulemaking issued in 1974 (FMVSS No. 208) contemplates an upgraded occupant protection standard in the 1980-81 time frame. Such a standard could add 150 pounds or more to the average car. The weight picture for future bumper standards is unclear, because the effects of various possible designs are as yet undefined.

- The fuel economy improvement feasible for the 1980 vehicles would be offset in part by the weight penalties of future safety and damageability requirements. It is possible that weight increases have been greater than technically necessary, because the manufacturers have used proven engineering approaches and standard materials to increase structural strength. The increased cost of fuel and the emphasis on fuel economy is now causing the manufacturers to consider alternative designs including lighter weight materials. Such technology advances combined with increased use of effective passenger restraint systems could greatly reduce the weight penalties of upgraded vehicle safety, particularly in vehicles manufactured after 1980.

- If engine size reduction for large cars is used to improve fuel economy, there may be no adverse effect on safety. Moderate reductions in acceleration capabilities and top speed characteristics for the large vehicles in the fleet may be beneficial for safety.

4. <u>What is the Relationship Between Fuel Economy and Emissions?</u>

- Significant fuel economy improvements are feasible by 1980 compared to 1974 while meeting the statutory HC and CO standards.[1] Significant gains have already been achieved in 1975 with lower emissions of HC and CO than in 1974. Such gains, while maintaining the fuel economy achievable with 1975 HC and CO emission standards, will come at increased first cost for the car and complexity of the engine system.

- The issue of the level and cost of the oxides of nitrogen emission achievable by 1980 concurrent with substantial fuel economy improvement is unresolved.

- Several alternative engine systems have the potential in 1985 and beyond to improve fuel economy significantly compared to the conventional spark ignition engine. The diesel and Stirling cycle concepts are examples. It would require on the order of 15 to 25 years, respectively, to realize the full benefits of such alternative engines and fuels. The ultimate target level for the oxides of nitrogen standard, as well as emissions for which there is now no standard, has a major impact on which alternative engine systems, if any, can realistically be considered by the industry for large scale implementation. An oxides of nitrogen level much below 1.0 to 1.5 gm/m would greatly discourage commitments to the development of the diesel engine or some stratified charge engine concepts which could be offered in new vehicles in appreciable numbers in the 1982-1985 time frame.

---

[1]The 1975 emission standards are 1.5 gm/m HC, 15 gm/m CO, and 3.1 gm/m NO_x. Statutory emission standards, currently applicable in 1978, are 0.41 grams per mile (gm/m) of hydrocarbons (HC), 3.4 gm/m of carbon monoxide (CO), and 0.4 gm/m for oxides of nitrogen (NO_x).

While it is assumed for the purposes of this report that the statutory emission standards for hydrocarbons and carbon monoxide (0.41 gm/m and 3.4 gm/m, respectively) will be required to be met, the public record raises questions about the future NO_x standards. (Continued at bottom of page 9.)

5. Do Engineering and Manufacturing Lead Times Forestall the Potential Fuel Economy Improvement?

- Present manufacturing capacity is sufficient to permit a model mix in which 60 percent of all new cars would be compacts or subcompacts.
- Four years lead time for structural changes, some transmission changes and other component modifications is required in the automotive industry. About six years lead time is required for a new engine configuration of the current type. Eight to fifteen years are required for a major technological advancement and change such as an alternative power system. An additional 10 years may be required to change the total motor vehicle fleet so as to realize the full benefit of such an advance.
- Lead times, however, begin from the date on which a manufacturer decides to pursue a given course of action. Current uncertainty about future safety standards and the NO_x emission standard inhibit manufacturers from making firm decisions to commit resources to the development and utilization of fuel conserving technologies.

6. What Test Procedures Should be Used to Measure Fuel Economy?

- No single measure of fuel economy suffices for the needs of all users. Standardized tests which are either dynamometer-based or track-based and involve a range of driving conditions are currently used for the measurement of fuel economy.
- The driving cycles used to measure city and highway fuel economy must be as representative as possible of actual driving under such conditions. The EPA city and highway

---

As regards the emission standard for oxides of nitrogen, it is assumed that the Congress will concur in the Administration's legislative recommendations of March 22, 1974, to the effect that the 1978 and subsequent model year emission standard for oxides of nitrogen be established by the Administrator of EPA after taking into consideration the requirements of air quality, energy efficiency, availability of technology, costs, and other pertinent considerations.

In that context, it is expected that the Administrator would--as he recommended to the Senate Public Works Committee on November 26, 1973--continue the NO_x standard at a level of 2.0 gm/m through the 1981 model year; that beginning in the 1982 model year the emission standard would be at or near 1.0 gm/m; and that EPA would contemplate establishing the 0.4 gm/m NO_x emission standard effective with approximately the 1990 model year.

driving cycles are suitable for this purpose. Use of these cycles on a dynamometer would be an appropriate fuel economy test if the dynamometer procedures are modified to improve the road load factors used for individual cars. Since there are possible tradeoffs between fuel economy and emission control, the EPA emissions measurement procedure would need to be utilized at least on a sampling basis to assure that fuel economy test cars comply with applicable emission standards. A track test procedure could also be acceptable provided that adequate representation of driving characteristics and test accuracy and repeatability are reflected in the procedures. Track procedures do, however, present special problems because broad variations in ambient conditions can significantly affect fuel economy.

- In determining the fuel economy for a manufacturer's entire fleet, as well as for individual vehicles, to an accuracy adequate to permit more informed consumer choice, several options are available. Prototype testing by the Federal government (as is now done by EPA for emissions) is one feasible option. Another is for manufacturers to determine the fuel economy of their production fleet with Federal verification of the manufacturer's testing and results. The selection criteria used to choose among these and other options, as well as the test procedures, should include the total program cost, the administrative problems, and the technical requirements for a given accuracy to verify the results for the fleet.
- Current test procedures provide a measure of fuel economy which has a precision of 2-4% for most vehicles. An increase in this precision would likely result in considerably higher test costs.

7. <u>What are the Various Means for Enforcing an Improvement Standard?</u>

The various means of enforcing an improvement in fuel economy were considered. Each method was assessed with respect to its various impacts and ability to achieve the improvement compared to the market forces. Specific conclusions are:

- The potential of market forces to achieve major fuel economy gains is uncertain although a 13.5% increase was achieved in 1975 compared to 1974. Information on the fuel economy of the individual cars available for purchase would allow those market forces that would influence fuel economy to operate. However, extensive assessment of response to such information is necessary before one can know whether consumer information alone is sufficient to produce the needed fuel economy improvement. If stronger action is deferred until such an assessment is completed, its effect would be deferred well beyond 1980.

- Mandatory labeling is a mild form of Federal action which is relatively easy to administer and operates to motivate market forces without any major adverse impacts. It would probably be an integral part of any stronger Federal regulatory effort oriented toward fuel economy standards.

- With respect to the regulatory alternatives, no one approach appears to dominate the others. Each involves costs, problems, and risks. It may be concluded that if Federal regulatory policy becomes stronger, the certainty of achieving given fuel economy goals will be increased. However, stronger Federal regulation also involves risk of adverse impacts on the economy, industry, consumers, and the costs of governmental administration.

- Analysis of the impacts of various fuel economy standards indicates:

a. A production-weighted standard requiring every manufacturer to improve his average fuel economy by the same percentage would require larger absolute fuel economy gains on already efficient cars while requiring only minor improvements on inefficient cars which have the greatest fuel economy improvement potential.

b. A production-weighted standard establishing one uniform specific fuel economy average for all manufacturers would, if sufficiently stringent to have the needed effect, impact most heavily on manufacturers who now have lower fuel economy while not requiring manufacturers of current good fuel economy vehicles to maintain or improve their performance.

c. Production-weighted standards specifically tailored to each manufacturer would eliminate some inequities of (a) and (b) above, but would be difficult to administer fairly.

d. Establishing standards on the basis of vehicle class would have the effect of inducing technological advances for all vehicles while allowing maximum consumer choice. Class standards would not necessarily ensure attainment of an overall fuel economy goal because of the possibility of increased sales of larger (although improved) models.

e. Two types of tax strategies were considered. The first would be placed on new vehicles, and the second would be assessed annually on each vehicle. Both would depend on the fuel economy of the vehicle. While such taxes maintain a high degree of consumer choice and producer flexibility, they rank below standards for ensuring achievement of a fuel economy goal because of lack of knowledge of their impact. In addition, the amount of tax necessary to produce the desired effect may be inordinately high since the present price and operating cost differential from high to low fuel economy cars is already large.

8. <u>What is the Truck and Bus Fuel Economy Potential for 1980?</u>

- Trucks and buses over 10,000 pounds gross vehicle weight consume 18 percent of the highway fuel used. Intercity (long and short range) trucks account for approximately 40 percent of the commercial vehicle fuel use.
- Individual vehicle fuel economy improvements by 1980 are estimated to be as high as 41%, but the production-weighted average fuel economy may improve only 18 percent.
- Intra-city vehicles with fuel economy improvement potential of 14-17% are the limiting vehicles when gaging the fuel economy improvement of a manufacturer's annual production.
- Bus fuel economy improvement potential appears to be significantly more limited than trucks'.
- Diesel engines (in lieu of gasoline), optimized cooling systems (including fan clutches), radial or widebase single tires, and engine derating offer the greatest fuel economy improvements.
- Accepted driving modes for fuel economy assessment are not now available and are needed to provide a measure of the transportation capability of the vehicle (ton miles or passenger miles per gallon of fuel consumed).

2.2 STUDY LIMITATIONS

The study has been subjected to limitations which should be recognized in making conclusions. They include:

1. Market projections beyond a few model years are highly uncertain; therefore, it is not possible to predict with a high degree of accuracy what will happen in the absence of market intervention in the 1980-and-beyond time frame.
2. Some component improvements for technological considerations and synthesis of improved components have not been developed to the point of mass production and therefore their reliability, durability, maintainability, and production capabilities and costs are not fully known.
3. The time required to conduct the study and prepare the report precluded investigation to answer questions that could not be addressed using existing data.

Solicited estimates from the automotive industry concerning their intended fuel economy improvements were not directly useable because of uncertainties in market projections and the qualifications of their responses by assumptions regarding relaxation of safety and emission standards.

2.3 BASE YEAR FOR THE REPORT

The 1974 model year fleet was chosen for the study as the year on which to base potential fuel economy improvements.

There are special difficulties with any choice of a base year; therefore, the actual achieved miles-per-gallon figure accompanies the improvement potential in most cases. The difficulties in choosing a base year are:

1. There was a 13.5% improvement in 1975 over 1974.[1] Thus, achieving a 20% improvement by 1980 over 1974 has been largely accomplished.

[1] EPA-FEA Announcement, September 20, 1974. This 13.5% fuel economy improvement assumes the same production mix in 1975 as in 1974.

2. The 1974 fuel economy (14 mpg) was the low year for new cars. For example, the 1970 fuel economy of the fleet was 15.4 mpg, 10% better than 1974.

3. The demonstrated automobile fuel economy in some year prior to emissions, safety, and damageability standards, could be a base year, but much less detailed data are available for those years.

The year 1974 was chosen because it was the year of the date of the Act and the last year for which production data were available. Trucks and buses are not so tied to model years as are automobiles; therefore, statistics through calendar year 1973 were used as a basis for the truck and bus analysis.

2.4 DEFINITION OF FUEL ECONOMY

Fuel economy (mpg) should not be confused with fuel consumption which is expressed in terms of gallons of fuel consumed per mile. One is the inverse of the other. A certain percentage increase or decrease in fuel economy does not equal the same percentage decrease or increase in fuel consumption. For example, one car getting 20 mpg has 33% better fuel economy than one with 15 mpg. However its fuel consumption is only 25% less. Thus the 33% increase in fuel economy gained from improving a 15 mpg car to 20 mpg provides only a 25% fuel savings per mile. Fuel economy (mpg) and fuel consumption (gallons per mile) should not be used interchangeably

The fleet fuel economy in miles per gallon is based on the miles traveled and fuel used in the city and highway driving schedules developed by EPA. The single number is obtained by using Federal Highway Administration data which indicate that 55% of the driving is represented by city driving and 45% by highway driving. Finally, the results for individual cars are weighted by the percentage of the production attributable to that car to obtain an average indicative of the fuel economy of the entire fleet.

The equation for computing the fuel economy is given by:

$$\frac{1}{.55/FTP + .45/HWC} = FE$$

Where:

FTP = Miles per gallon obtained on the EPA city driving cycle.

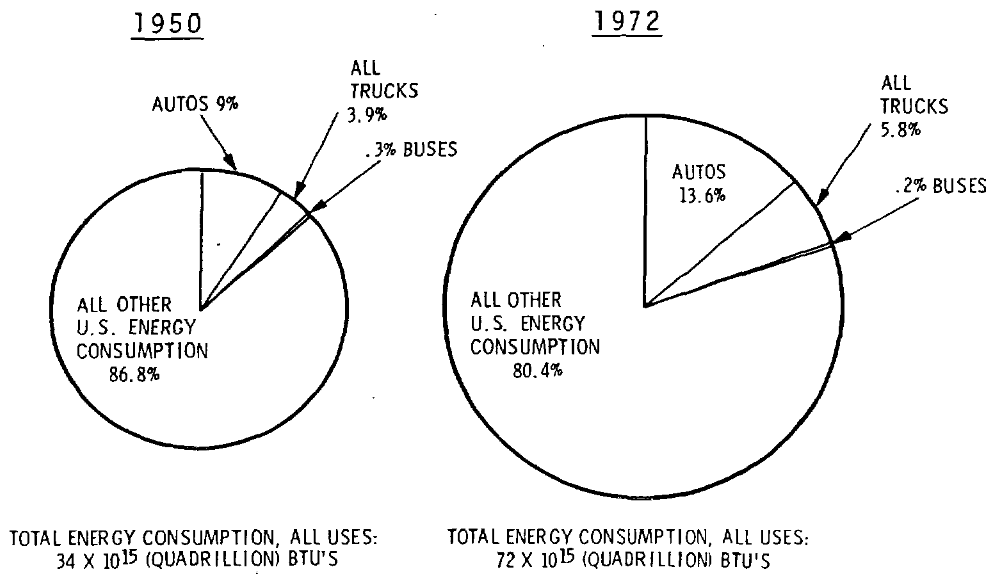
HWC = Miles per gallon obtained on the EPA highway driving cycle.

FE = Fuel economy of individual vehicles.

EPA Composite Driving Cycle

2.5 FUEL ECONOMY TRENDS

The amount of energy consumed by motor vehicles each year in the U.S. has grown from about 13% in 1950 to nearly 20% in 1972. Figure 2 shows motor vehicle energy consumption for passenger cars, buses, and trucks and shows the total use has more than tripled since 1950. (Motor vehicle consumption in 1972 was 14.1 x 10^{15} BTU's, while in 1950 it was 4.5 x 10^{15} BTU's.)



Sources: (1) U.S. Bureau of Mines, Minerals Yearbook
(2) FHWA Highway Statistics, 1972

Figure 2. Share of U.S. Energy Consumed by Motor Vehicles in 1950 and 1972.

Deterioration of fuel economy of automobiles is not the main reason for increased fuel consumption. Although fuel economy (mpg) does show an unfavorable trend, as shown by Figure 3, the decrease has been approximately 10% since 1950.[1] Total vehicle miles travelled in passenger cars has grown by 170% in the same time period. Annual miles per vehicle grew by 13% and fleet size by 140%.[1] Figure 4 shows the relative contribution of these factors to the nearly 300 percent increase in passenger car fuel use from 1950 to 1972. Because of dieselization the efficiency of trucks used in freight service has actually increased so that practically all the increase in truck fuel consumption is attributable to increased demand for truck services.

Rapid growth in motor vehicle population has been the result of a mixture of factors including rising incomes and population, declining real costs of autos and fuel, and a dispersion of both residences and places of work.

Today, population growth is slowing and the vehicle fleet is nearing one per person of driving age. Thus, a slowing of future growth rates for motor vehicle use could have been expected even in the absence of energy shortages. If lower growth in real per capita income occurs, the growth in demand for auto travel could be even further slowed.

Although the growth in motor vehicle fuel consumption is now slowing, there are three apparent reasons for the recent interest in increasing motor vehicle fuel economy:

1. Motor vehicles consume 77% of the transportation energy. They typically operate at efficiencies significantly less than the state-of-the-art, thus the potential benefit of efficiency improvement is larger than that of any other transportation fuel economy improvement option.

[1] Federal Highway Administration, Highway Statistics.

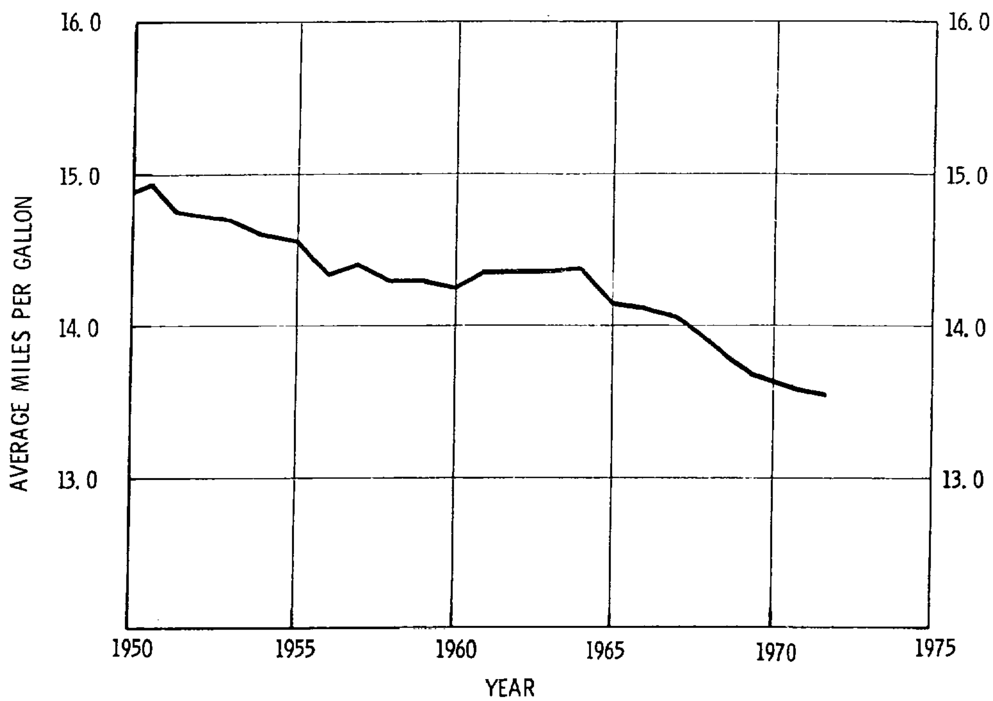


Figure 3. Average Fuel Economy (MPG) of U.S. Passenger Car Fleet 1953-1972

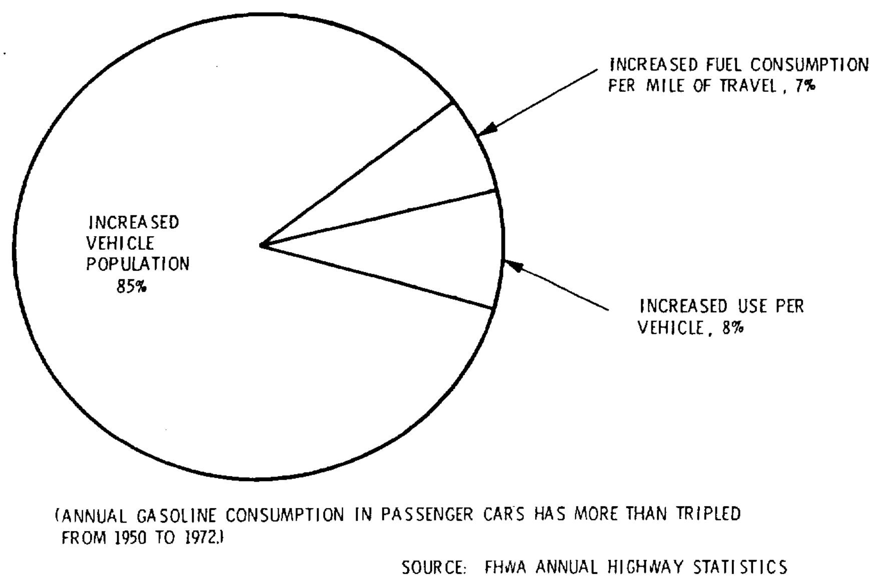


Figure 4. Factors Contributing to Increased Passenger Car Fuel Consumption Between 1950 and 1972

Implementation of efficiency improvement programs would certainly slow the growth in demand for motor fuels.

2. Relative to other transportation conservation options (such as increased carpooling or significant shifts to transit) vehicle fuel economy improvements require little or no behavior change by the public.

3. With increased motor vehicle fuel economy, less fuel is needed for the same service, so operating costs are lowered. This has a definite appeal to both private auto consumers and to commercial bus and truck companies.

The motor vehicle industry has become increasingly responsive to consumer pressures for smaller and more efficient automobiles. Figure 5 shows the strong trend since 1967 toward small automobiles. Recently, domestic manufacturers have significantly expanded their capability to produce small cars, largely as a result of the fuel shortage last winter. General Motors now has the potential to produce 2.3 million small cars per year, while Ford and Chrysler

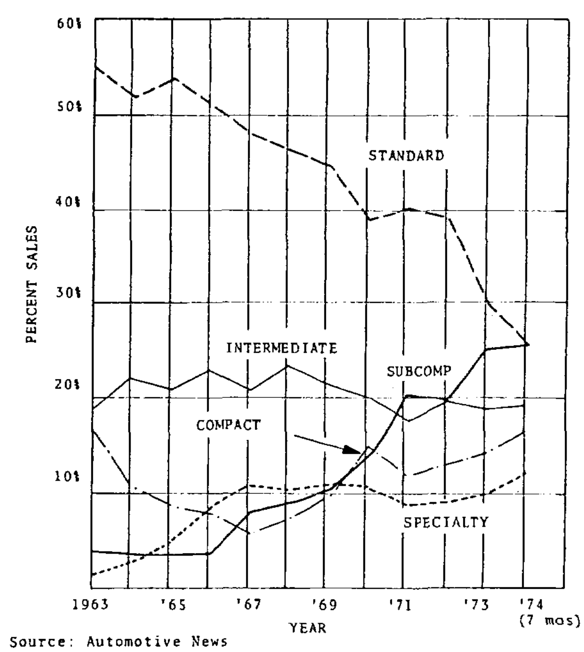


Figure 5. Passenger Car Sales by Market Class (Including Imports)

could produce 1.6 and 0.9 million respectively.[1] These levels vary substantially from the pre-embargo plans for a gradual shift of 3% per year to smaller cars.[2] Additional technological improvements such as engine and transmission optimization are also in current short range plans of the automotive industry.

The sales figures for the automobile industry by market class for the domestic market from January 1, 1974 to August 1, 1974 and from January 1, 1973 to August 1, 1973 are presented in Table 1.

TABLE 1. DOMESTIC AUTO SALES SHIFT BY MARKET CLASS (EXCLUDING IMPORTS)[(1)]

	JANUARY - JULY 1973		JANUARY - JULY 1974	
	%	No. of Cars 1,000's	%	No. of Cars 1,000's
STANDARD	41	2,329.8	23	953.3
INTERMEDIATE	23	1,307.0	23	953.3
COMPACT	15	852.4	25	1,036.2
SUBCOMPACT	9	511.4	12	497.4
SPECIALTY	12	681.9	17	704.6
	100	5,682.5	100	4,144.9

2.6 THE VARIOUS MEANS TO INCREASE FUEL ECONOMY

Fuel economy improvements may be obtained by three major methods. The first is technological improvements in the engine and drive train to increase efficiency and in the tires and body structures to reduce weight and drag. The second is engine size reduction for the larger cars. The third is a shift to a larger proportion of small cars in the fleet.

[1] Automotive News, U.S. Car Production, Aug. 5, 1974. It should be noted that the sales shift to small cars indicated in this chart has changed since the August 5, 1974 data. The sales fraction of larger cars is increasing.

[2] New York Times, "What the Energy Crisis Taught the Automakers", July 21, 1974.

There are many technological improvements that can significantly increase fuel economy without reducing the performance or size of automobiles. Engine improvements offer the largest single potential increase in fuel economy for all automobile classes. The use of a four-speed automatic transmission with a lock-up clutch on the torque converter would permit greater transmission efficiency. Aerodynamic drag, rolling resistance, curb weight, and accessory power requirements can all be reduced within the 1980 time frame. Radial tires and better accessory systems can be installed in all car lines by 1980. Reducing the weight of automobiles without decreasing their performance or useful size is possible through design changes and utilization of lighter weight materials.

Lowering the power-to-weight ratios in certain high performance automobiles would produce fuel economy improvements even if auto size reductions and technological improvements were not made. This reduction of engine size in large and mid-size cars would, of course, bring their acceleration times closer to the acceleration times of the small size cars.

Since compact and subcompact cars are on average much more fuel-economical than intermediates and standard size automobiles, an increase in the proportion of the smaller cars sold would by itself improve production-weighted fuel economy. Recent sales trends in this direction were presented in the preceding section.

These three major methods of fuel economy improvement can be accomplished separately or in combination. Thus, there is considerable flexibility in the way the nation might improve motor vehicle fuel economy. Of course, this flexibility is not equal for every motor vehicle manufacturer, and the need for all three improvement methods increases as the fuel economy improvement goal is raised.

3.0 DISCUSSION OF THE POTENTIAL FOR FUEL ECONOMY IMPROVEMENTS AND THEIR IMPACTS

This chapter presents the findings of this study. The first section (3.1) reviews the technology available for achieving fuel economy improvements by 1980 and beyond. Subsequent sections (3.2 through 3.6) review fuel economy measurement considerations, economic and resources impacts, various strategies for achieving fuel economy goals, and safety and air quality impacts - in keeping with the legislative direction. Trucks and buses exceeding 10,000 pounds gross weight are addressed separately in section 3.7 to facilitate discussion of their special considerations. The last section (3.8) presents a summary of the viewpoints and reactions expressed by the various automobile manufacturers, industry associations, and interested groups and citizens responding to the Federal Register announcement for Public Docket submissions.

3.1 THE TECHNOLOGY AVAILABLE FOR FUEL ECONOMY IMPROVEMENT

3.1.1 Introduction

This section presents an assessment of the technology available for fuel economy improvement. The analyses are based on current automotive research knowledge and the design and production practices of the motor vehicle industry including surveys of the leading automotive manufacturers. Various fuel economy improvement technologies were reviewed for lead time, costs, and impacts with respect to emissions, safety, and scarce natural resources. Measures of possible fuel improvements are given for both individual technology changes and for combinations of changes representing possible synthesized vehicles, not all of which have been proven in practice.

3.1.2 1980 Model Year Cars

The size of a car influences the kind of technology that can practically be used to improve fuel economy. Therefore, the technological improvements needed to improve fuel economy of new cars were considered in three size groups: large size, mid-size, and small size. The large size is represented by today's standard size and large luxury cars which can typically carry six people in comfort. The mid-size car is represented today by the compact and intermediate size class cars and typically carries four or five people in relative comfort. The small size car typically can carry four people in relative comfort and is represented by today's subcompact car and many of the imported cars. It was assumed that functional characteristics of the three car sizes would probably remain much the same for the next 15 years even though exterior dimensions and curb weights may change significantly with the evolution of technology under the influence of market place demand and possible Federal regulations.

Table 2 summarizes, under several composite systems of technical change, conclusions with respect to fuel economy improvements that have reasonably good prospects of being incorporated in the greater part of 1980 model year cars in the three classes. Tables 3, 4, and 5 present emissions, incremental first cost, and incremental maintenance cost data for each class for each system. These tables also provide the average fuel economy of 1974 model year cars in the three size classes. The fuel economy figures are representative of typical driving in the United States and are based upon a composite of fuel economy measured under city and highway driving schedules as described in Section 3.2 Fuel Economy Measurement. The tables also give the present market shares of the size classes and an estimate of the maximum shift in market share toward the small size cars. The capacity to shift production toward smaller cars is governed mainly by limitation in the machine tool industry. No assessment of the market demand for smaller cars is implied by these statements.

TABLE 2. SUMMARY OF SYNTHESIZED VEHICLE FUEL ECONOMY IMPROVEMENT
(1980 VEHICLES)

System*	Large Size FE(%)	Large Size FE(mpg)	Mid-Size FE(%)	Mid-Size FE(mpg)	Small Size FE(%)	Small Size FE(mpg)
Ref. EPA Composite 1974 Vehicle Fuel Economy	0	10.7	0	13.1	0	22.3
1. Improved Engine	+25	13.4	+20.0	15.7	+15.0	25.6
2. System 1 + auto.trans. w/4 spd. + lock-up	+33.7	14.3	+28.7	16.9	+23.7	27.6
3. System 2 + radial tires + wt.red. + aero drag red. + acces. improvement.	+47.1	15.7	+41.1	18.5	+29.1	28.8
4. System 3 with engine resized.	+62.1	17.3	+51.1	19.8	+29.1**	28.8**

*See discussion for explanation of terms.

**System 4 identical to system 3, engine not resized.

NOTES:

1. Fuel economy is computed from EPA composite cycle.
2. Implementation of fuel economy improvements shown in this Table may be in a different order.

TABLE 3. SYNTHESIZED VEHICLE FUEL ECONOMY IMPROVEMENT
1980 VEHICLE - LARGE SIZE

Systems*	Emissions (gm/m) ($HC/CO/NO_x$)	Δ FE(%)	FE(mpg)	Δ First Cost (1974 $) 0.4 NO_x	2.0 NO_x	ΔMaint. Cost 50,000 mi. (1974 $)
Ref. EPA composite 1974 vehicle fuel economy		0	10.7	-	-	-
1. Improved Engine						
a. Dual CAT/MAIR/SEFE PEGR/charcoal/HEI	.41/3.4/0.4	+25.0	13.4	+400	--	-200
b. OXCAT/MAIR/SEFE PEGR/HEI	.41/3.4/2.0	+25.0	13.4	--	+225	-200
2. System 1 + auto. trans. w/4 spd. + lock-up	--	+33.7	14.3	+400	+250	-200
3. System 2 + radial tires + wt. red. + aero drag red. + access. improvement.	--	+47.1	15.7	+300	+150	-275
4. System 3 with engine resized to give lower accel. perf.	--	+62.1	17.3	+275	+125	-275

*See discussion for explanation of terms.

NOTES:
1. Fuel economy is computed from EPA composite cycle.
2. Implementation of fuel economy improvements shown in this Table may be in a different order.
3. Production Volume in 1974: 2.8 million automobiles, 27%.
4. Projected Practical 1980 Production Share = 10%.
5. All of the technical options considered have not been fully developed as yet but are considered feasible for implementation by 1980. Similarly, the costs are best estimates.

TABLE 4. SYNTHESIZED VEHICLE FUEL ECONOMY IMPROVEMENT
1980 VEHICLE — MID-SIZE

System*	Emissions (gm/m) ($HC/CO/NO_x$)	Δ FE(%)	FE(mpg)	Δ First Cost (1974 $)		ΔMaint. Cost 50,000 mi. (1974$)
				0.4 NO_x	2.0 NO_x	
Ref. EPA composite 1974 vehicle fuel economy		0	13.1	--	--	
1. Improved Engine						
a. Dual Catalyst MAIR/SEFE/PEGR/ Charcoal/HEI	.41/3.4/0.4	+20.0	15.7	+300	--	-150
b. OXCAT/MAIR/SEFE/ PEGR/HEI	.41/3.4/2.0	+20.0	15.7	--	+200	-150
2. System 1 + automatic transmission w/4 speed + lockup	--	+28.7	16.9	+300	+200	-150
3. System 2 + radial tires + wt. reduction + aero drag reduction + access. improvement	--	+41.1	18.5	+250	+150	-225
4. System 3 with engine resized to give lower acceleration performance	--	+51.1	19.8	+225	+125	-225

*See discussion for explanation of terms.

NOTES:
1. Fuel economy is computed from EPA composite cycle.
2. Implementation of fuel economy improvements shown in this Table may be in a different order.
3. Production volume in 1974: 4.7 million automobiles, 45%.
4. Projected Practical 1980 Production Share = 50%.
5. All of the technical options considered have not been fully developed as yet but are considered feasible for implementation by 1980. Similarly, the costs are best estimates.

TABLE 5. SYNTHESIZED VEHICLE FUEL ECONOMY IMPROVEMENT
1980 VEHICLE - SMALL SIZE

System*	Emissions ($HC/CO/NO_x$ (gm/m))	Δ FE(%)	FE(mpg)	Δ First Cost (1974$) 0.4 NO_x	Δ First Cost (1974$) 2.0 NO_x	ΔMaint. Cost 50,000 mi. 1974 $
Ref. EPA Composite 1974 veh. fuel economy		0	22.3			
1. Improved Engine						
a. Dual CAT/MAIR/SEFE PEGR/Charcoal/HEI	0.41/3.4/0.4	+15.0	25.6	+275	--	-125
b. OXCAT/MAIR/SEFE/ PEGR/HEI	0.41/3.4/2.0	+15.0	25.6	--	+150	-125
2. System 1 + automatic transmission w/4 speed + lock-up		+23.7	27.6	+300	+150	-125
3. System 2 + radial tires + wt. reduction + aero drag reduction + access. improvement		+29.1	28.8	+350	+200	-200

*See discussion for explanation of terms.

NOTES:
1. Fuel economy is computed from EPA composite cycle.
2. Implementation of fuel economy improvements shown in this Table may be in a different order.
3. Production Volume in 1974: 2.9 million automobiles, 28%.
4. Projected practical 1980 production share = 40%.
5. All of the technical options considered have not been fully developed as yet but are considered feasible for implementation by 1980. Similarly, the costs are best estimates.

In 1974, the production-weighted average fuel economy of the three size classes was 14.0 mpg on the EPA composite driving cycle. By 1980, fuel economy of small size cars could increase by 29% from 22.3 mpg to 28.8 mpg; of mid-size cars by 51% from 13.1 mpg to 19.8 mpg; and of large size cars by 62% from 10.7 to 17.3 mpg; but not in all models produced, since not all of the improvements can be implemented on all production lines by then.

Fuel economy improvements are achievable without adversely impacting the ability of vehicles to carry passengers and their luggage. Driveability, ride and handling can be maintained or improved. Durability, reliability and maintainability should be comparable to current vehicles. Acceleration performance would be affected by engine size reduction.

Engine modifications provide the largest single increase in fuel economy for each of the three size classes, as shown in item 1 of the Tables 2 through 5. Some manufacturers have obtained the bulk of the fuel economy increase due to engine changes in the 1975 model year. Other manufacturers can probably make the improvements to their engines in the next few years with the emission standards for 1975 and 1976 model cars (see Table 6 for emission standards for light duty vehicles by year). The major uncertainties in projecting engine fuel efficiency improvements attainable through technology modifications derive from the fact that it is not presently possible to predict what fuel penalties may result from technology modifications required to meet future emission standards, especially the 0.4 gm/m NO_x standard. There is an indication that increasingly stringent emission standards can be met by manufacturers with little fuel economy penalty by use of more sophisticated emission control technology at greater first cost to the consumer, although the necessary technology has not been fully developed. An engine emission control system that may permit the statutory emission standards to be met with about the same fuel economy benefit is given in item 1.a of Tables 3 through 5 as dual catalysts with modulated air injection (MAIR), super early fuel evaporation (SEFE), programmed exhaust gas recirculation (PEGR), high energy ignition (HEI), and a charcoal trap for cold start HC emissions. Tables 3 through 5 also give estimates for a less

TABLE 6. EMISSION STANDARDS FOR LIGHT DUTY VEHICLES

Applicable Date	HC	CO	NO_x
		(grams/mile)	
Uncontrolled	(8.7)	(87)	(3.5)
1968	*	*	(4.3)
1970	4.1	34	(5.0)
1972	3.0	28	(5.0)
1973	3.0	28	3.1
1974	3.0	28	3.1[2.0]**
1975 Federal Auto	1.5	15	3.1
1975 Federal LD Truck	2.0	20	3.1
1975 California	0.9	9	2.0
1977 Federal Auto	0.41	3.4	2.0
1978 Federal Auto	0.41	3.4	0.4

*Standards for 1968 and 1969 were expressed in concentration by volume: 275 ppm for HC, and 1.5% CO.

**2.0 NO_x on 1974 California Cars.

NOTES:

All emission standards listed above are expressed in terms of the 1975 Federal Test Procedure (FTP). Figures in parentheses show actual values during periods when no Federal emission standard was in effect.

complex engine which meets a less stringent standard for oxides of nitrogen.

Several other potential engine modifications have been screened by supporting studies[1, 2] and rejected from further consideration in this study as likely technologies to be implemented by 1980. These include turbo-charged engines, compound engines, variable valve timing and water injection carburetors. Still other engine modifications in various stages of development have been deleted from consideration due to anticipated lead time before technological readiness could be achieved in the 1980 time frame. Examples include: (1) pre-engine converters such as the hydrogen injection system, and (2) automatic engine cutoff devices, to minimize engine idle fuel consumption. Many of these hold promise for later implementation.

Drive train changes will also yield substantial fuel economy improvements. An attractive approach that does not affect acceleration performance is the use of a four-speed automatic transmission with a lock-up clutch on the torque converter. It provides reduced power losses in the transmission and permits the engine to be used with greater efficiency. About 8.7% improvement in fuel economy can be obtained with this type of modified transmission when it is developed. This modified transmission type can probably be put into production by 1980 for a substantial fraction of cars. The current status of industry commitments to improved transmissions and the requisite changes in production tooling is unknown. The combination of the improved engine and transmission is shown as item 2 on Tables 2 thru 5.

The third item in Tables 2 through 5 adds changes to the vehicle which affect the aerodynamic drag, rolling resistance, curb weight, and accessory power requirements. Radial tires and

---

[1] Arthur D. Little Inc. A Study of Technological Improvements to Automobile Fuel Consumption. Report prepared for the U.S. Department of Transportation and U.S. Environmental Protection Agency, July 1974. (Draft)

[2] Southwest Research Institute. A Study of Technological Improvements to Automobile Fuel Consumption. Report prepared for the U.S. Department of Transportation and U.S. Environmental Protection Agency, July 1974. (Draft)

better accessory systems can almost certainly be installed in all car lines by 1980 and should provide about 4% increase in fuel economy for typical driving cycles and accessory usage. Reductions in aerodynamic drag of 10% and a net reduction in weight of 10% most practically can be achieved by phasing them with significant changes to car bodies. The changes to aerodynamic drag improve fuel economy by 1.5%. The large and mid-size cars obtain 8% and 7% increases in fuel economy at constant acceleration performance due to reduced weight. The likely practical weight reduction in small cars is offset by potential safety related weight increases.

One manufacturer reported that significant weight and aerodynamic drag reductions are planned for 1978 models. It is likely that the remaining manufacturers could follow suit within a few years so that by 1980 more than half of the potential fuel economy improvement due to weight and aerodynamic drag reduction can be achieved in production practice. Estimated cost savings to the consumer due to weight reductions are about $0.50 per pound in addition to the resultant fuel savings.

With the technology changes through item 3 in Tables 2 through 5, for the large, mid, and small size 1980 vehicles, the cumulative fuel economy improvement percentages are 47%, 41%, and 29%, respectively; corresponding fuel economies are 15.7 mpg, 18.5 mpg, and 28.8 mpg, respectively, compared to 1974. The fuel economy of 1975 model year cars is 13.5% greater than 1974 for the same production mix as in 1974.[1]

There is still another way to improve fuel economy that is practical only with the large and mid-size cars. This technique is to reduce engine size so that the engine operates more efficiently on the average. The effect of the change is to reduce the power to weight ratio and thereby to lengthen the time required to accelerate from one speed to another. Reduction of engine size

[1]EPA-FEA Announcement, September 20, 1974.

in the large and mid-size cars to bring their acceleration times under loaded conditions closer to the acceleration times of the small size cars can increase their fuel economy by 15% and 10%, respectively. There are no significant production lead time problems with engine size reduction before the 1980 model year, but there are questions about the marketability of low performance cars. This type of change is relatively inexpensive; and item 4 of Tables 3 and 4 summarize the cumulative fuel economy and costs of this change with the other systems.

Tables 3 through 5 also give the sales volume percentages of the 1974 large, mid, and small size cars. Using these sales percentages and the fuel economy figures of item 4, the production-weighted fuel economy is 20.3 mpg by comparison with the 1974 production-weighted fuel economy of 14.0 mpg (point A on Figure 6). By 1980 most of the changes shown in Tables 3 through 5 can probably be in production throughout the entire fleet with the exception of the weight reduction, aerodynamic drag reduction, and modified transmission options, which may take two to three years beyond 1980 for

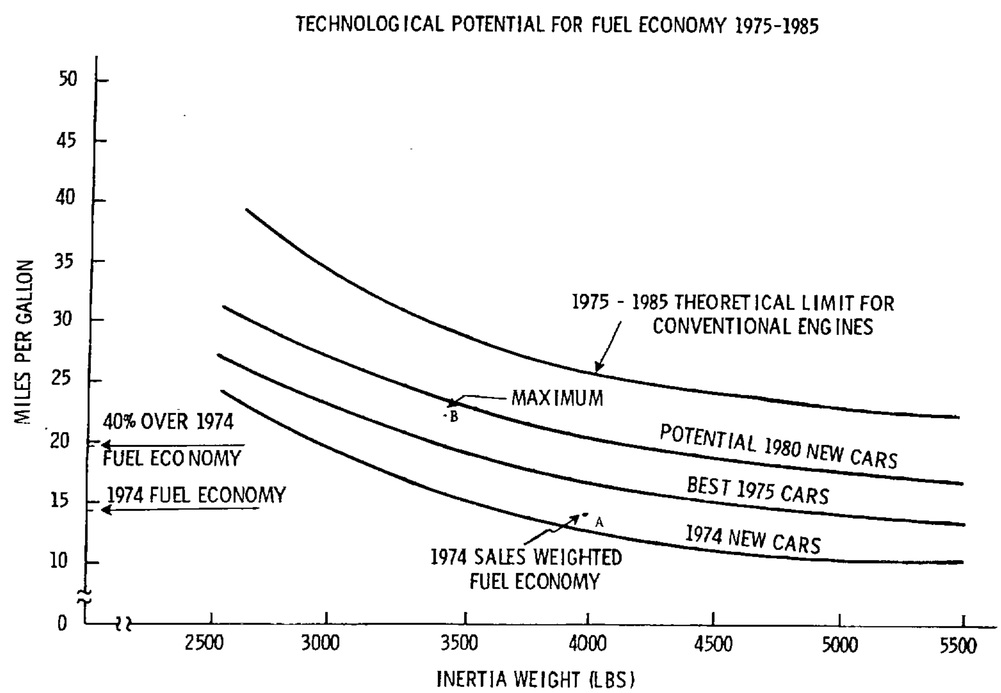


Figure 6. 1975 - 1985 Technological Potential for Fuel Economy

complete implementation. Taking into account the phasing of most of the system changes, it appears feasible for production-weighted fuel economy in 1980 to be as high as 20.3 mpg, if all the necessary developments can be successfully accomplished.

It appears to be technically feasible to change the 27% large size, 45% mid-size, and 28% small size production distribution of 1974 to a 10% large size, 50% mid-size, and 40% small size production distribution by 1980 while simultaneously making the technological changes in the vehicle size classes listed in Tables 3 through 5. The resulting sales-weighted fuel economy would be 22.2 mpg. This figure is shown as point B on Figure 6. Even without any further improvements in the fuel economy of cars in the various size classes, the new car fleet fuel economy would be increased to 17.3 mpg by a shift to small car production with the percentages given above. It is not known, of course, that the market will exist for such a changed distribution.

Figure 6 gives four curves of fuel economy (mpg) versus vehicle inertia weight. The curve marked "1974 NEW CARS" represents the fuel economy of 1974 cars based upon the EPA composite cycle. The "BEST 1975 CARS" curve was obtained by averaging the fuel economy of the better 1975 cars in each weight class. Data from 76 different cars made by 13 different manufacturers were used to construct this curve. Cars with low power-to-weight ratios were excluded from this sample. (Differences in power-to-weight ratios between the 1974 and 1975 models considered in the analysis are estimated to be less than 4.7%). The "POTENTIAL 1980 NEW CARS" curve represents the fuel economy deemed achievable in the composite EPA cycle by representative 1980 vehicles with improved technology. The upper curve labeled "1975-1985 THEORETICAL LIMIT FOR CONVENTIONAL ENGINES" represents the results of a fuel economy analysis based on the assumption that the car engine of the conventional spark ignition type operates at all times at its most efficient operating point. The typical energy expended (horsepower-hours per mile) for the several car classes multiplied by the lowest specific fuel consumption typically observed on the performance maps of conventional engines (0.5 lb./BHP-HR) yield this curve. This curve is not representative of practical systems.

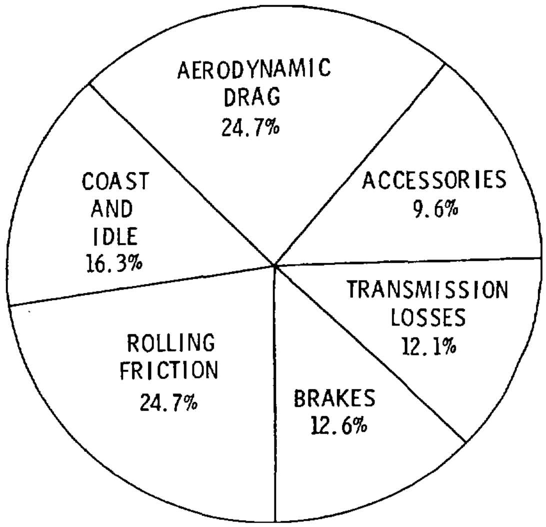
Figure 6 shows that there is still room for improvement of automobile fuel economy beyond 1980 with technology based on the spark ignition engine. Even greater improvements in fuel economy may be achievable post-1980 by diesel engines or other highly efficient engines.

3.1.3 Individual Technological Improvements in Fuel Economy

3.1.3.1 Background

Vehicle power is required for accelerating the mass inertia of the vehicle, lifting the vehicle weight over changes in elevation, overcoming resistance to motion created by rolling friction and aerodynamic drag, and driving accessories. The vehicle powerplant provides this power by converting chemical energy of the fuel to mechanical energy. The mechanical energy is then transmitted to the wheels by a transmission and drive train to provide motion.

Fuel requirements may be reduced while maintaining constant performance by making the powerplant more efficient in its fuel consumption, by improving the efficiency of the transmission of energy, and by reducing the power required to operate the vehicle (e.g., by lowering vehicle inertia, rolling resistance, aerodynamic drag and accessory power needs). If acceleration potential is reduced, then an additional efficiency gain may be made. The fraction of the total power requirement for each need is highly dependent on the particular driving schedule. During high speed, steady state cruising most of the engine power is required to overcome the aerodynamic drag, while no power is required to accelerate the car's mass. During full power accelerations from a stop, almost all of the delivered power required is to overcome inertia (weight). During low speed cruise most of the power is required to overcome rolling resistance. At idle all power goes just to turn the engine. Figure 7 displays the proportion of each of these for the EPA composite cycle.



SOURCE: DOT/TSC, ANALYSIS OF 1973 AUTOMOBILES AND INTEGRATION OF AUTOMOBILE COMPONENTS RELEVANT TO FUEL CONSUMPTION (SEPT. 1974) (DRAFT)

Figure 7. Apportioned Energy Requirements for Reference 3500 Pound Operation in the EPA Composite City/Highway Test Cycle

The size of a passenger car's engine is determined primarily by the acceleration performance, not the steady state cruise speed of today's highways. The power required to accelerate the vehicle is determined primarily by the vehicle's mass or inertia.

In general, reducing the power-to-weight requirement of a vehicle tends to increase fuel economy; however, during some operating conditions the reduction in power requirement may be more than offset by a reduction in efficiency of engine operation. For conventional engines, the efficiency of operation increases with load up to a point between half and full power. The benefits to fuel economy derived from reductions in power-to-weight requirements will thus be increased if the engine is resized to the vehicle.

The various technological changes relating to fuel economy are summarized in Table 7, while Table 8 (parts a. and b.) presents a more comprehensive description of the findings. Table 8a shows engine technology options and Table 8b shows other vehicle technologies.

For each engine system the change in fuel economy compared to 1974 is given as a percentage value. Note that more than one system is shown for all post-1974 emission standards. For any given emission standard there is a variety of different engine systems capable of achieving compliance. The system choice, therefore, depends on considerations other than emissions capability. Some of these other considerations, quantified in Table 8a as differences relative to the 1974 baseline, are fuel economy, first cost and maintenance cost. Lead time required for development of each system is also indicated.

For each emission level considered, the first engine system shown is the one that is considered the "prime" system by the industry. These "prime", or lowest-first-cost, systems have historically been ones that have been most utilized when cost/fuel economy/driveability tradeoffs were made. It can be seen from the summary table (Table 8a) that, while the "prime" systems have the lowest first cost for a given emission level, they result in the lowest fuel economy compared to 1974.

The second system listed for each emission level is a system which allows optimization of fuel economy when using conventional engine technology. The basic philosophy of trading off system cost vs. fuel economy was assumed. In every case the second system yields improved economy at higher first cost.

The first cost of each system is broken into three areas.

1. that portion related to meeting the emission standards;
2. that portion related to meeting safety standards;
3. that portion related to fuel economy optimization.

TABLE 7. FUEL ECONOMY IMPROVEMENTS THROUGH TECHNOLOGY CHANGE BY 1980 COMPARED TO 1974

Technological Change	Full Size	Mid-Size	Small Size
	(Fuel Economy Improvement in % of MPG)		
1. Power Requirement Reduction			
• weight reduction	8.0	7.0	0
• rolling resistance reduction (radial tires)	2.5	2.5	2.5
• aero drag reduction	1.5	1.5	1.5
• accessory power	1.4	1.4	1.4
2. Driveline			
• extra gear or overdrive	4.0	4.0	4.0
• 4 speed auto transmission with lockup in 4th gear	8.7	8.7	8.7
• 4 speed auto transmission with lockup in all but low	12.0	12.0	12.0
3. Engine*			
• dual catalyst system, or	25	20	15
• lean oxcat system, or	25	20	15
• PROCO stratified charge, or	25	25	15
• turbo-charged Diesel**	50(37)	45(33)	35(23)

*See Table 8a.
**Numbers in parenthesis show the fuel economy improvement percentage on a mile per unit energy basis, since diesel fuel has greater density than gasoline.

Table 8a summarizes the differences in emissions, fuel economy, first cost, and maintenance cost of the principal engine systems considered relative to the 1974 baseline, as they affect the large size vehicles. Emission levels range from the 1974 levels of 3.0 gm/m of hydrocarbons, 28 gm/m carbon monoxide and 3.1 gm/m oxides of nitrogen to the statutory 1978 requirement of 0.41 HC, 3.4 CO and 0.4 NO_x.

Table 8b provides similar information for the non-engine related technologies considered. In the remainder of this section, the individual technological changes for engines are described briefly, followed by a summary of other component changes available (i.e., transmission, aerodynamic drag, rolling resistance, weight reduction, accessories, and reduction of acceleration performance).

TABLE 8.a. 1980 LARGE SIZE VEHICLE: ENGINE TECHNOLOGY EXAMPLES

TECHNOLOGY*	TARGET EMISSION LEVEL -gm/m			FE % CHANGE	Δ1st COST (in 1974 $)			Δ 50,000 MILE MAINTENANCE COST-$**			LEAD TIME (YEARS FOR %)	COMMENT
	HC	CO	NO_x		E	S	FE	E	S	FE		
1. 1974 Baseline	3.0	28	3.1	0	0	0	0	0	0	0	-1	5,000 lb. inertia weight Base Case; Leaded Fuel.
2. EM/AIR/EGR/ QHI/UNLEADED FUEL	1.5	15	3.1	0	+60	NA	0	-100	NA	0	0	Non-Catalyst System to Meet Standards (Unleaded Fuel).
3. OXCAT/AIR/ PEGR/EFE/HEI	1.5	15	3.1	+25	+60	NA	+125	-100	NA	-75	0-10% 2-100%	Like Best '75 Cars with '75 Type System. Cost for FE Improvement Relative to System 2.
4. OXCAT/AIR EGR/QHI/HEI	.9	9.0	2.0	+5	+175	NA	0	-175	NA	0	0	Needed to Just Meet .9/9/2.0.
***5. OXCAT/MAIR/ PEGR/EFE/HEI	.9	9.0	2.0	+25	+175	NA	+25	-175	NA	0	2	System Needed to Optimize at .9/9/2.0.
6. OXCAT/AIR/ QHI/EGR/HEI	.41	3.4	2.0	0	+175	NA	0	-175	NA	0	2	System just to meet Emission Standards.
7. OXCAT/MAIR/ SEFE/PEGR/HEI	.41	3.4	2.0	+25	+175	NA	+50	-175	NA	0	2	Maintain Best '75 Economy with More Sophisticated System.
8. STRATIFIED CHARGE ENGINE (SCE)/OXCAT/PEGR	.41	3.4	2.0	+25	+175	NA	+75	-175	NA	+75	5-20% 11-100%	Six new engine lines per year are possible. Cost for FE Improvements is difference between SCE cost and cost of System 6 above.
9. TURBODIESEL/ PEGR	.41	3.4	2.0	+37 (BTU Basis)	+175	NA	+200	-175	NA	+150	6-10% 12-100%	Fuel Economy on Mile/BTU Basis. Cost for FE Improvements Associated with the Difference Between Diesel and System 6 above.
10. DUALCAT/AIR/ QHI/EGR/HEI	.41	3.4	0.4	-15	+300	NA	0	-25	NA	0	3	More Spark Retard and Richer than '74. OXCAT and 2 Reduction CAT Changed During 50,000 Miles
11. DUALCAT/MAIR/ PEGR/CHARCOAL/ SEFE/HEI	.41	3.4	0.4	+25	+300	NA	+75	-25	NA	-175	3	Advanced Technology not yet Completely Demonstrated, Charcoal Changed Once. No CAT change.
12. SCE/OXCAT/ PEGR/CHARCOAL	.41	3.4	0.4	+25	+300	NA	-25	-25	NA	-75	5-20% 11-100%	Six new engine lines per year are possible. Cost for FE Improvements is difference between SCE cost and cost of System 10 above.

*Technology abbreviations explained in Glossary in Appendix A.
**Negative cost figures represent a savings over 1974 baseline vehicles.
***Systems 5-12 not demonstrated in production.

Code: E = EMISSIONS; S = SAFETY; FE = FUEL ECONOMY; EM = ENGINE MODIFICATIONS

TABLE 8.b. 1980 LARGE SIZE VEHICLE: "OTHER" VEHICLE TECHNOLOGY

TECHNOLOGY	IMPACT CONSIDERATIONS	FE % CHANGE	Δ1st COST (in 1974 $)			Δ 50,000 MILE MAINTENANCE COST-$*			LEAD TIME (YEARS FOR %)	COMMENT
			E	S	FE	E	S	FE		
13. TRANSMISSIONS: (a) 4-SPEED W. LOCK-UP IN HIGH GEAR	--	+8.7	NA	NA	+25	NA	NA	0	6-50%	Industry comments indicate progress already underway. Complete phase-in prior to 1980.
(b) CONTINUOUSLY VARIABLE	Unknown Effect	+20	NA	NA	+125	NA	NA	0	8-10%	CVT might be possible by 1985. (Little enthusiasm).
14. WEIGHT REDUCTION, MATERIAL SUBSTITUTION, PLUS BODY REDESIGN.	Beneficial effect at all emission levels; post-1977 damageability +30 mph barrier	+8	NA	+200	-250	NA	NA	0	5	Combination of materials substitution and body redesign for a 700 lb. reduction in weight with a 200 lb. safety-related weight increase (-700 lbs., +200 lbs.).
15. WEIGHT REDUCTION, MATERIAL SUBSTITUTION, PLUS BODY REDESIGN.	Post-1977 damageability +40 mph barrier	+12	NA	+300	-500	NA	0	0	15-100%	Improved body design, plus safety requirement of 40 mph crashworthiness (-1,000 lbs., +300 lbs.).
16. WEIGHT REDUCTION, MATERIAL SUBSTITUTION, PLUS BODY REDESIGN	Post-1977 damageability +50 mph barrier	9	NA	+450	-500	NA	0	0	20-100%	Improved body designs, and safety weight increases. (-1000 lbs., +450 lbs.).
17. AERODYNAMIC DRAG REDUCTION 10%	Beneficial	+1.5	NA	NA	NA	NA	NA	NA	6-50%	Industry indicated that aero-drag reductions are now underway.
18. ACCESSORIES	--	+1.4	NA	NA	0	NA	NA	NA	2-50%	Improvement in air conditioner drive control.
19. ROLLING RESISTANCE REDUCTION	--	+2.5	NA	NA	+100	NA	NA	-100	1-100%	Radial tires assumed. Will be 91% of market in 1975. Complete conversions for new models shortly thereafter. Initial cost assumption based on large volume sales.
20. REDUCED ACCELERATION PERFORMANCE	Uncertain Impact	+15	NA	NA	-50	NA	NA	NA	2-100%	0-60 acceleration increases from 12 to 18 seconds. Makes Large vehicle perform like the Average Small vehicle. (Less benefit for mid-size vehicle; no benefit for small vehicle.)

*Negative cost figures represent a savings over 1974 baseline vehicles.

Codes: E = EMISSIONS; S = SAFETY; FE = FUEL ECONOMY; EM = ENGINE MODIFICATIONS

None of the engine systems has a significant safety-related cost, so that column is marked "NA" for each of the thirteen systems considered.

For most cases, the "prime" system has a lower first cost than the second system listed and the cost is entirely related to meeting the emission standards. The emissions-related first cost of the "prime" systems is assigned to all other systems designed to meet the same emission level. In short, the portion of total system cost related to just achieving the emission standards is equal to the cost of the lowest price system that would do the job. The difference in first cost between the amount required to just meet the standards and the total first cost of a system appears in the fuel economy related column (FE) of the first cost portion of the table.

The change in maintenance costs compared to 1974 systems over 50,000 miles of service is also tabulated, although the service life of cars is typically 100,000 miles. The conventional engine systems all show a substantial savings in maintenance cost due primarily to the use of unleaded fuel which prolongs exhaust system life, spark plug life, and oil change intervals.[(1)] Additional benefit is obtained with catalyst systems that use high energy ignition because spark plug life is further extended and fewer tune-ups are required. When catalyst changes are required, as with System #10, the cost of the catalyst change reduces the benefit of the unleaded fuel usage considerably. Note that System #11 (a system designed to optimize fuel economy), also reduces maintenance cost because it obviates the need for catalyst replacement. The reduction in maintenance cost due to the elimination of catalyst replacement appears in the "FE" column of the table because it was related to the use of a system for fuel economy optimization.

[1] General Motors Corporation. Comments by General Motors Corporation to the Federal Energy Administration on Passenger Car Fuel Economy, Report prepared for the Federal Energy Administration, August 1974.

The lead time column of the table gives the time from the fall of 1974 required for the system to be produced on 100% of production unless otherwise specified. Included in the lead time estimate is an allowance of any research and development work expected to be necessary before production designs can be formulated and tooling orders placed.

3.1.3.2 Engine Improvements

a. Baseline Engines

The capability for improvements in engine efficiency is a function of the efficiency of the baseline engines. Since currently available engines are not equally efficient, the use of an engine with a specified (high) efficiency for all vehicles in the future will result in different percentages of fuel economy improvement for different vehicles.

The differences in efficiency of the engines currently used to power passenger cars are due to many factors including:

1. differences in spark timing;
2. differences in carburetion;
3. differences in the exhaust gas recirculation (EGR) systems;
4. differences in friction;
5. differences in pumping losses.

b. Conventional Gasoline Engine

Several conventional spark ignition gasoline fueled engine systems were considered as candidates. They included:

1. Oxidation catalyst and EGR
2. Dual Catalyst

3. Lean burn engine with oxidation catalyst
4. Lean Thermal Reactor (LTR)
5. Rich Thermal Reactor (RTR)
6. 3-way Catalyst (3-way)
7. RTR-NO_x Catalyst-RTR (Questor System)

Of the candidate systems, the first three were selected for more detailed analysis, whereas the other four systems were screened out for a variety of reasons.

1. Oxidation Catalyst (OXCAT) and EGR - Based on an analysis of available data and technical reports, the oxidation catalyst system which may best provide the ability to optimize fuel economy while meeting stringent emission standards would use the following hardware.

   1. Large Volume High Efficiency Catalyst
   2. High Energy Ignition System (HEI)
   3. Programmed Exhaust Gas Recirculation (PEGR)
   4. Improved Quick Heat Intake System (QHI)
   5. Modulated Air Injection System (MAI)
   6. Cold Start HC Emission Reduction System (charcoal).

2. Dual Catalyst - Dual catalyst emission control systems for the conventional engine have had a reputation for poor fuel economy. The variables that affect engine fuel economy are related to the basic engine operating parameters, however, and are not necessarily related to exhaust emission control after-treatment devices. Thus, improved fuel economy may result using a dual catalyst after-treatment emission control system by designing it to be compatible with an engine tuned to best economy.

3. Lean Burn & Oxidation Catalyst - The lean calibration approach to improving fuel economy was at the forefront of potential ways to improve the economy of conventional engines. The fuel economy benefit results from reduced

pumping losses. Ultra-lean burning has also shown promise for simultaneously reducing HC, CO, and NO_x emissions.

The fuel economy potential of each of these three conventional engine systems was determined by analysis of the best deomonstrated technology to date. The capability of the oxidation catalyst and EGR systems was determined from an analysis of the better 1975 production models. It was assumed that what is being done currently on some cars can be done in the future for all cars. This assumption may be conservative since it does not allow for further improvements in the technology that is now on today's better cars. Compared to the average 1974 models the fuel economy improvements being demonstrated by the better 1975 models are:

- Large cars +25%
- Mid-size cars +20%
- Small Cars +15%

An analysis of data on prototypes using lean burn technology showed equivalent improvement possibilities.

No data were available on the complete dual catalyst system. Data were available, however, that indicated recent advancements in EGR optimization would allow a conventional engine to be calibrated for optimum economy while having an exhaust composition that is compatible with the dual catalyst control system (i.e., low oxygen level).[1] This finding allowed the same percentage improvements to be assumed for the dual catalyst system.

Of all conventional engines considered, the dual catalyst system was judged to have the highest potential for achieving the 0.4 NO_x level; however, only limited data were available on advance dual catalyst systems.

There are indications that the capability to achieve 0.4 NO_x with optimum economy is possible, but as a consequence HC emissions will require more attention. The procedure used to achieve optimum economy with an engine matched to a dual catalyst system is known

[1]James J. Gumbleton, et. al. "Optimizing Engine Parameter with Exhaust Gas Recirculation." SAE Paper No. 740104.

to increase HC emissions. Several advanced HC emission control systems have been investigated and the capability to achieve 0.41 HC also appears feasible. However, the dual catalyst system requires much development and the estimates made are based on data from several different partial systems.

c. Stratified Charge Engine

The concept of charge stratification in gasoline engines is not new. Some examples of engines employing this principle were proposed around the turn of the century. The characteristic common to all of the stratified charge engines discussed here is that at the time ignition is initiated (by a spark plug) the air/fuel mixture is stratified within the combustion chamber; that is, the air/fuel ratio is different at different locations in the combustion chamber with some locations having fuel rich air/fuel ratios, and some having lean air fuel ratios.

The two basic types of stratified charge engines are discussed below.

1. Divided Chamber Stratified Charge Engine - The performance potential of the divided chamber stratified charge engine concept is typified by the CVCC engine developed by Honda. This engine is carbureted, with a separate induction system and intake valve for each of the two parts of the combustion system. An exhaust manifold reactor has been used with many of the prechamber stratified charge engines to provide extra control of HC and CO. No air injection is used.

   Fuel economy at the 0.41 HC, 3.4 CO, 2.0 NO_x level is about equivalent to a 1974 conventional engine. Ford has reported that fuel economy depends on the emission level that the divided chamber engine is calibrated to meet, decreasing as the emission levels become lower.

2. Open Chamber Stratified Charge Engines - It is believed that the open chamber stratified charge engine has more fuel economy potential than divided chamber concepts. Two major types of open chamber stratified charge engines are now under development - the Ford PROCO engine and the Texaco TCCS engine. Both concepts use direct cylinder fuel injection,

The PROCO engine was considered to be more developed for automobile use than the TCCS engine. It has greater potential for production since a major automobile manufacturer is developing it; and because its fuel economy potential is high, it was selected for more intensive analysis.

The estimates used for the open chamber stratified charge engine, based on the PROCO performance are shown below. The estimates are the same at both 2.0 and 0.4 gm/m NO_x levels. The 0.4 gm/m NO_x would be more difficult and costly to meet.

OPEN CHAMBER STRATIFIED CHARGE ENGINE
PERCENT CHANGE IN FUEL ECONOMY FROM 1974

Vehicle Type	Percent Change in Fuel Economy
Large car	+25
Mid-size car	+25
Small car	+15

No significant difference from the advanced conventional engines is apparent. This is due in large part to the fact that throttling appears to be required to meet HC emission levels with open chamber stratified charge engines. Further development may improve this engine's potential for increased fuel economy.

d. Diesel Engine

Diesel engines are in widespread use today wherever efficient power generation is required. Diesel engines power ships and boats, heavy duty trucks, construction equipment, farm equipment and some automobiles. The diesel is not now as acceptable as the conventional gasoline engine since it has a lower power-to-weight ratio, requires a complex fuel injection system, is difficult to start, and is associated with odor and noise. However, currently available technology appears to be capable of making the diesel more competitive in these areas.

Diesel engines are more efficient than conventional gasoline engines at wide open throttle because the compression ratio used in diesel engines is much higher than the compression ratio in conventional gasoline engines; and since the diesel does not have a throttle, pumping losses are reduced at part load and idle compared to the conventional gasoline engine.

The range of economy improvements that have been estimated for the conversion to naturally-aspirated diesel engines from gasoline engines on an equal performance basis is shown as a % change in miles per gallon as follows:

Vehicle Type	Data From Ref (1)	Data From Ref (2)	Data From Ref (3)
Large	+20%	+35%	-
Mid-size	+25%	-	+46%

[1] op. cit., ADL Report

[2] op. cit., SWRI Report

[3] Monaghan, M.L., C.C.J. French, and R.G. Freese. A Study of the Diesel as a Light-Duty Power Plant. Report prepared by Ricardo and Company Engineers, Sussex, England, for the U.S. Environmental Protection Agency, July 1974.

1. Naturally-Aspirated Diesel Engine - Even though economy gains can be shown for the naturally-aspirated diesel, some problems will remain. Using today's technology, a naturally-aspirated diesel will be significantly heavier and somewhat bulkier than a conventional gasoline engine of equal power. Use of light alloy construction may reduce the weight penalty somewhat, but not eliminate it.

   In addition, currently demonstrated technology does not appear to be sufficient to allow a full range of diesel-powered passenger cars to be certified at 0.4 gm/m. NO_x although a level of 1.0 - 1.5 appears achievable. This and the concern that diesel particulate emissions may also be a problem are cited by the industry as reasons for the lack of interest in a major development effort on diesel engines for passenger cars.

   Public acceptance of an engine that requires a new fuel, different starting procedure, and new maintenance requirements is surely a question with which auto manufacturers must contend. The manufacturers may consider the risk of successful development and public acceptance to be out of line with any benefits they would accrue by converting to diesel.

2. Turbocharged Diesel Engine - Another way to increase the power-to-weight ratio of a diesel engine is to increase the pressure in the inlet manifold with a supercharger or turbocharger. The turbocharger is a widely used method of boosting the diesel power. The fuel economy improvement for turbocharged diesel is as given in Table 7 (37% for large, 33% for medium and 23% for small cars on a mile per unit energy basis). One of the advantages of turbocharging is that the same power can be obtained from a lighter engine, thus offsetting some of the weight penalties associated with the diesel engine.

3.1.3.3 Other Technological Changes

In the remainder of this section the other technological changes are described (improved transmissions, aerodynamic drag reduction, rolling resistance reduction, weight reduction, accessories, reduction of acceleration performance). The impacts of these changes are summarized in Table 8b.

a. Transmission and Drive Train Improvements

Transmission improvements can be offered for nearly all classes of passenger cars with resulting fuel economy improvements.

1. Axle Ratios - One of the simplest ways to improve fuel economy is to reduce the ratio of engine speed to car speed. This is accomplished by adding a fourth gear to the transmission and choosing the optimum axle ratio for economy or by just choosing an "economy" rear axle ratio. The proper choice of rear axle ratio is assumed in all the following transmission analyses.

2. Manual Transmissions - While the manual transmission may be more efficient, it must be operated properly or it may actually use more fuel. Since manual transmissions are mainly in small cars at present, a fuel economy improvement of only 4% is estimated for the 1980 small cars due to transmission improvements.

3. Improved Automatic Transmission - Improvements to the present automatic transmission that would have a beneficial effect on fuel economy were grouped into two general classes: addition of an extra gear or gears to provide better load matching and reduction or elimination of torque converter slip.

The first approach is the addition of an extra gear and lock-up in high gear only. The second approach is the addition of an extra gear and lock-up in all but the lowest (first) gear. Allison Division of GM currently sells an example of the latter approach for trucks.

The fuel economy improvements for the automatic transmission types considered of all size cars are 8.7% with an additional gear and lock-up in high gear, and a 12% gain with an additional gear and lock-up in all gears but low gear.

4. Continuously Variable Transmission - The continuously variable transmission is an advanced automatic transmission concept. Considerable development would be necessary, however, and lead times would preclude its large scale utilization before 1985. A fuel economy gain of 20% or more is estimated if the engine-transmission control and sizing were optimum.

b. Aerodynamic Drag Reduction

Reducing the aerodynamic drag of a vehicle can provide a small percentage improvement in fuel economy.[1] While aerodynamic drag accounts for 24.7% of the energy required for typical vehicle operation under the EPA composite driving cycle, its potential reduction, and the associated improvement in fuel economy, are limited because:

1. Vehicle design characteristics, primarily frontal area and vehicle shape, cannot be radically changed without impacts upon passenger compartment size and shape.
2. Aerodynamic drag is most significant at high speeds (which comprise only a portion of the composite driving cycle).
3. Each 1.0 percent reduction in drag yields only a fraction of 1.0 percent improvement in fuel economy.

[1] op. cit., SWRI

A reduction in drag is expected by 1980 in typical cars, and it is conservatively estimated that such reduction will contribute about a 1.5 percent improvement in fuel economy.

c. Rolling Resistance Reduction

Rolling resistance reductions can be made independently of weight reduction by altering tire characteristics. Several things affect the rolling resistance characteristics of a tire including principally:

1. construction technique
2. compound
3. tread depth
4. inflation pressure

Probably the most significant change which can be made is in the area of construction technique. Steel-belted radial tires show improvements of 2.5 to 4%, depending upon the test source. The figure of 2.5% has been chosen for use in this study and improvements related to changes in other tire characteristics have not been assumed. Tread compound, tread depth, and inflation pressure are all inter-related and must meet other criteria such as safety, ride characteristics, tire life, etc. No certain reduction in rolling resistance is credited to these considerations.

d. Weight Reduction

Reducing vehicle weight reduces both the power requirements to accelerate the vehicle and to overcome rolling resistance. A 10% reduction in weight in large and mid-size cars would increase fuel economy by 7-8%. The potential for fuel economy improvements through weight reduction can be achieved to the greatest extent if the engine is sized to operate near its peak efficiency.

There are three methods of reducing vehicle weight: (1) materials substitution; (2) chassis redesign, and (3) car size reduction.

Materials substitution involves the replacement of certain components with nominally identical components of different composition. Prime candidates for expanded usage in a weight reduction effort would be aluminum, plastic and high strength, low alloy steel. However, it was decided not to rely heavily on the use of aluminum body panel replacement in light of concerns over the continued availability of aluminum at costs that would keep it competitive with steel in the auto industry. The use of aluminum body panels, however, probably will be an option open to manufacturers who want to continue marketing large cars.

Chassis redesign appears to offer the greatest potential weight reduction improvement, at least for most U.S. manufactured cars. Major areas for improvements are:

1. Increased use of unibody construction;
2. Increased use of front-wheel drive;
3. Increased use of independent rear suspension;
4. Exterior dimensions held to those required to enclose passengers, power train, and trunk, rather than set by styling constraints.

Design change approaches will have the greatest potential for weight reduction in model year 1980 and beyond.

In conclusion, a 10% weight reduction in 1980 large and mid-size cars would achieve 7-8% increases in fuel economy without lowering acceleration. No increase in fuel economy for small cars was attributed to weight reduction. Weight reduction in small cars may be offset by safety-related weight increases.

e. Accessories

Major vehicle accessories include items such as the cooling fan and the air-conditioner. In 1974 model cars approximately 70% of the passenger vehicles and 30% of domestic light duty trucks have air-conditoners.

A significant saving could be obtained by incorporating a thermostatically controlled cyclic air conditioner in all vehicles. On the average the fuel economy penalty of an operating air conditioner is 6%. Considering a market penetration of 70%, six month usage during the year and a duty cycle of one-third, the fuel economy improvement would be 1.4%.

f. Engine Size Reduction

Large automobiles generally have sufficient capacity to accelerate rapidly, to pull trailers at highway speeds with reserve power, or to maintain high speed and acceleration on moderate grades. The penalty for this kind of acceleration margin appears as reduced fuel economy. One option for improvement of fuel economy is to reduce the power-to-weight ratio to the level comparable to that in small cars. The effect is to increase from 12 seconds to 18 seconds the time needed to accelerate from 0 to 60 mph under full load. For large size cars the fuel economy improvement would be about 15% and in the range of 10% for mid-size cars. This improvement includes the weight reduction of a smaller engine which allows structural and other weight reductions in the rest of the car. There would be no improvement in the fuel economy of an average small car. There is a double benefit from smaller engines in cars.

There are two ways to accomplish this power-to-weight change. One is to move the lower CID engines to the next larger size car line. The second is to change a given engine design. About 5-10% reduction in engine displacement can be obtained with relative ease by changing the engine stroke. In addition, a given engine design can be "de-bored"; that is, the cylinder bore diameter can be reduced. Typical fuel economy savings for vehicles with the power-to-weight ratio reductions are given below:

Vehicle Type	Percent Change in Fuel Economy
Large car	+15%
Mid-size car	+10%
Small car	0%

3.1.4 1985 Model Year Cars

More extensive changes are potentially achievable in 1985 model year vehicles.

a. Engine Improvements

The 1985 timeframe provides sufficient lead time for the development of an advanced light weight, low noise and low odor diesel engine. Major development efforts would be needed in the area of NO_x control if 1978 statutory emission standards are to be met. The NO_x reducing catalyst requires a rich air/fuel mixture and can not be used with the lean burning diesel engine. Particulate emission control may have to be developed if further health studies associate diesel particulate with potential air quality problems. While the development program must be considered high risk, it is considered feasible because inadequate R&D efforts have been exerted to rule the diesel out as a long-term contender. The nominal impact of the diesel engine is shown below:

Diesel Engine - 1985 Over 1974 Engines

	Large	Mid-Size	Small
Economy effect (Mile/BTU equivalent)	+37%	+32%	+23%
Best Spark Ignition	+25%	+20%	+15%

The diesel is about 12% more fuel efficient than the improved spark ignition engine, but is approximately $150 more expensive initially and more expensive to maintain.

b. Transmission Improvements

Although successful development of the continuously variable transmission may be possible by 1985, attaining the operational efficiency necessary to increase driveline efficiency beyond the capabilities of a well controlled automatic 4-speed with lock-up in the top gears is still considered a high risk. Therefore, no further improvements over the 1980 potential for transmissions were assumed.

c. Weight

For the 1985 case, the average car was assumed to become as weight efficient as the more weight efficent 1974 models. Materials replacement was not assumed. This would leave the use of alternate materials as an option available to each manufacturer to insure a greater degree of design flexibility.

The nominal weight changes and their impact are shown below:

Weight Changes - 1985
(1974 Base)

	Large	Mid-size	Small
%Weight change	-20	-18%	-17%
Economy effect	+16%	+13%	+10%

d. Aerodynamic Drag

More extensive restyling than is assumed for the 1980 case is assumed here. Again frontal area is left unchanged but the drag coefficient is reduced by 20 percent.

Aerodynamic Drag Changes - 1985
(1974 Base)

	Large	Mid-size	Small
%Change Drag Coefficient	-20%	-20%	-20%
Economy Effect	+3%	+3%	+3%

e. Rolling Resistance

No further changes were assumed.

3.1.5 Light-Duty Truck Improvements

Approximately 2.5 million light-duty trucks have been registered in the U.S. in 1973. This number represents one new light-duty truck registered for every 4.5 new passenger cars. Typically, these vehicles travel 10,600 miles per year, consume 13.1% of the highway fuel, and have an average fuel economy of 11.5 mpg.

The light-duty trucks (i.e., trucks of gross vehicle weight up to 10,000 lbs.) are technologically similar to the passenger car and are used for passenger service. Technological improvements for light-duty trucks are the same as those described for passenger cars, but are limited to engine improvements, substitution of radial tires for conventionals, and improved transmissions. The following improvements in fuel economy are deemed feasible for the majority of domestic light-duty trucks in production by 1980: engine improvements, 20%; tire improvements, 2.5%; and transmission improvements, 6%. The estimated total fuel economy benefit for the domestic light-duty truck by 1980 is 25% as compared to a 1974 base light-duty truck.

The estimated improvements in fuel economy for the small imported 1/2 ton pick-up trucks (representing less than 10% of all light-duty truck sales per year) is 20% by 1980 due to engine, transmission and tire improvements.

3.2 FUEL ECONOMY MEASUREMENT

3.2.1 Summary

There are currently two "standard" test procedures being used to measure fuel economy. The first is one developed by EPA which is a dynamometer procedure measuring fuel economy for two types of driving: city and highway. The city test is also used to determine compliance with Federal emissions standards. These tests allow the fuel consumed to be measured directly from the emissions data, or by weight or volume. The second, a track procedure developed by the Society of Automotive Engineers (SAE), determines fuel economy for three types of driving: city, suburban, and highway, but without a cold start. Fuel consumption is measured directly either by weight or volume. The Society of Automotive Engineers is also preparing a dynamometer procedure. Although a proposed version has been analyzed, it is not yet available for final evaluation. Both of the procedures, if conducted properly, can be used to determine automotive fuel economy. However, both of the procedures have specific limitations which restrict their range of applicability.

The variables which influence fuel economy generally can be grouped into three categories: (1) driving variables - including the route over which the driving takes place, the ambient and road conditions, trip conditions such as trip length, cold or hot start, etc.; (2) vehicle variables - such as basic configuration (engine, weight, drive train, body style, tires), break-in mileage and state of tune; (3) driver habits - such as rate of acceleration from a stop and ability to maintain a constant speed while cruising.

A primary goal for a fuel economy test procedure is the generation of a fuel economy value for a specific vehicle configuration which will adequately represent typical vehicle operation and which will be valid for comparisons. The driving schedules and test conditions should be designed to accurately simulate the critical driving variables. The test and measurement methodology should be designed for maximum reproducibility and accuracy.

This discussion has been limited to a consideration of fuel economy test procedures; the larger question of a total Fuel Economy Test Program (including vehicle selection criteria, regulatory philosophy, program administration, etc.) could not be addressed within the time frame of this report.

3.2.2 Standard Fuel Economy Test Procedure

Fuel economy measurements performed on a chassis dynamometer using two driving schedules, one corresponding to city travel and one to highway travel are suitable for a Federal test procedure. The test procedure can be based on current EPA procedures with modifications to include more realistic road load simulation and distance measurement. The fuel economy value should be calculated from a weighted average of the fuel consumed during the city and highway driving schedules in accordance with the vehicle miles travelled (VMT) in each driving category (55% - city, 45% - highway).

There is no technical problem involved in having Federal fuel economy testing and Federal emissions testing accomplished simultaneously. Since there are possible trade-offs between fuel economy and emission control, the EPA test would in any case need to be utilized on a sampling basis to assure that fuel economy test cars comply with applicable emissions standards. If the fuel economy compliance test is combined with the emissions certification test, cold start weighting should be included as part of the test procedure (per the 1975 Federal Procedure for Emissions).

It should be recognized that a dynamometer test is a simulation of an actual road test and thus must be carefully designed to insure that all factors critical to fuel consumption are properly considered. Aerodynamic drag and tire rolling resistance are two specific areas which enter strongly into the trade off between test accuracy and test sophistication (i.e., cost). The primary advantages of dynamometer testing are: (1) that it is not sensitive to adverse weather conditions; (2) the test conditions can be more carefully controlled; (3) a more realistic driving schedule can be used; and (4) emissions can be tested concurrently.

Track tests, such as recommended by the SAE, obviously allow a test of a vehicle under actual operating conditions. The test accuracy, however, may be affected by the track and weather conditions, driving schedule, driver habits and test instrumentation. In addition, any test track procedure must be able to accommodate a cold-start of the test vehicle. Cold starts have a major impact on city driving fuel economy. The combined effects of these factors can serve to reduce the overall accuracy to a level commensurate with a moderately sophisticated dynamometer procedure. In addition, the strict limits on weather conditions and track design required for a repeatable track test severely impact the logistical aspects of testing a large number of vehicles.

Fuel Economy Testing might be accomplished by the auto manufacturers themselves, private certified testing laboratories, or by an agency charged with overall responsibility for the fuel economy standard. In any case, the Federal Fuel Economy Test should be carefully monitored to ensure impartiality, accuracy, and public and industry confidence in the results. The main criteria for deciding who will test should be the program cost, the ease for a given accuracy to test, and the administration problems and costs.

3.2.2.1 Test Variability

The precision to which a fuel economy measurement can be made is a function of test variability (reproducibility of a test made on a single vehicle), and facility variability (differences between dynamometer or tracks). The current state-of-the-art in fuel economy measurements yields a possible test variability of $\pm$ 2-4% for most vehicles. However, vehicle and facility differences may increase the total measurement variability to ± 3-6%. It is possible to reduce the overall variability by using more sophisticated test procedures and dynamometers; however, the rationale for doing so should be carefully weighed against the anticipated increase in test costs. Also the basic vehicle-to-vehicle variability may prove to be the limiting factor in achieving an accurate fuel-economy measurement in a practical fuel economy test program. This variability can be reduced only by increasing the number of vehicles tested.

3.2.2.2 Driving Cycles

Two driving cycles should be used during the compliance test, one representing city driving and one representing highway driving. The current EPA cycles are suitable; however, periodic studies should be performed to monitor nationwide driving patterns and identify any changes which should be reflected in the schedules.

3.2.2.3 Fuel Consumption Measurement

Fuel consumed during the test may be measured with any of the following techniques: carbon-balance, volumetric, or gravimetric. (Note: specifications for each technique will be tightened over current practice.) Each technique, if used properly, can be expected to exhibit variabilities of less than ±2%.

3.2.2.4 Vehicle Selection

The vehicles comprising the test fleet should be selected according to projected sales. The sampled vehicles should include those configurations of weight, engine, drive train and aerodynamic load factors that may be expected to have significant impact on fuel economy

3.2.2.5 Additional Work Necessary

1. Evaluate the SAE dynamometer procedures (when available in final form) for possible adaptation into the Federal Standard Test Procedure;

2. Develop a better understanding of tire behavior on dynamometer rolls;

3. Determine the necessity for decreasing the inertia weight increment to increase test accuracy;

4. Develop more accurate road load curves for the dynamometer;

5. Evaluate the possibility of simplified test procedures for use in statistically-based production-line testing or in-use inspections, should such be required by law. Note: this test procedure must be correlatable to the certification procedure, however it may not have the same overall variability.

6. Provide the continuing correlation between the EPA city and highway driving cycles and nationwide driving patterns.

3.3 ECONOMIC AND RESOURCES IMPACTS

3.3.1 Summary

Estimated savings in fuel and maintenance costs resulting from fuel economy improvements are substantially greater than associated increases in the initial purchase price of autos. The combined effect of these changes on auto sales is not great. Fuel savings are substantial and help ease pressure on the balance of payments.

Table 9 summarizes estimates resulting from an economic impact analysis of four automobile fuel economy improvement scenarios. The table reveals that each scenario offers the nation substantial net economic benefits. The scenarios and the basis for the estimates of their economic impact are discussed in this section.

3.3.2 Scenarios of Fuel Economy Improvements

An effort is made in this report to cover a range of fuel economy improvement scenarios. A summary description of the scenarios is provided in Table 10.

Several points regarding these scenarios should be mentioned. First, Scenarios B and D include conversions to diesel engines, although there is considerable uncertainty as to whether diesel engines can meet the statutory NO_x emission requirements without sacrificing some fuel efficiency. There are also reservations regarding consumer acceptance of the diesel. Current diesel engines are associated with odor, noise, and other problems. Second, the sales shift in Scenario D would probably not occur "voluntarily" because of market demands for larger cars; i.e., Scenario D would probably require more substantial government pressure on manufacturers and/or consumers than would be the case under Scenarios B and C.

3.3.3 Impacts on Auto Costs

Achieving improvements in fuel economy will generally result in an increase in capital investment by manufacturers, and decreases

TABLE 9. SUMMARY OF ECONOMIC IMPACTS

Scenario	Net Present Value Consumer Savings, 1980 Model Year[a] (1974 dollars)		Average Annual Incremental Investment ($ Millions)		Total Gasoline Consumption (Billions of gallons)		Annual Import[b] Savings ($ Billions)	
	Subcompact	Standard	1976-1980	1981-1985	1980	1985	1980	1985
A MODEST IMPROVEMENTS	330	1,103	10	None	80.8	85.6	3.8	6.3
B GRADUAL IMPROVEMENTS THRU 1980's	374	1,217	204	528	80.1	78.2	4.0	8.5
C MAXIMUM IMPROVEMENT BY 1980	747	1,490	175	None	76.6	76.8	5.0	8.9
D SCENARIO B PLUS SHIFT TO SMALLER CARS	NA[c]	NA[c]	480	528	73.1	66.0	6.0	12.0

(a) Present values calculated over 10 years using a 10% discount rate and a price of 55¢ per gallon for gasoline.

(b) Imports valued at $11 per bbl.

(c) Not calculated because incremental retail prices could not be estimated.

TABLE 10. SCENARIO SUMMARIES

Scenario	PERCENT GAIN IN MPG 1980	PERCENT GAIN IN MPG 1985	FUEL ECONOMY IMPROVEMENTS
Baseline	0	0	No improvements in fuel economy relative to 1974 vehicles. Minimum changes to meet statuatory emission standards.
A Modest Improvements	28%	27%	Optimized conventional engines, radial tires, slight weight and aerodynamic drag reductions (in line with announced industry goals). No improvements after 1978.
B Gradual Improvement Thru 1980's	33%	52%	Steady technological improvement through the 1980's: Weight reduction through materials substitution and minor redesign during the 1970's; further changes (unitized body) in the 1980's. Some aerodynamic drag reduction and substantial transmission improvements fully accomplished by 1984. Diesel engines phased in for larger cars from 1981 to 1989 plus some stratified charge engines for smaller cars. No performance degradation.
C Maximum Improvement by 1980	43%	44%	Maximum rate of improvement through 1980 with little further gain during the 1980's. Rapid weight reduction, aerodynamic drag reduction, and transmission improvements. Displacement reduction of optimized conventional engines, but no diesel or stratified charge engines.
D Scenario B Plus Shift to Smaller Cars	63%	84%	Same as B with 1980 sales mix assumed at 10 percent large cars, 25 percent intermediates, 25 percent compact, and 40 percent subcompact.

in the cost of operation and maintenance. As shown in Tables 11 and 12, the net effect is to reduce costs to the consumer over the lifetime of the car. Although the present value of these net savings will typically amount to hundreds of dollars, these dollar savings are not necessarily large enough to offset price increases due to meeting future emission, safety and damageability standards.

These figures are sensitive not only to assumptions about the costs and effectiveness of the basic technology, but also to the following economic factors:

a. The future price of gas. This was assumed to be 55¢ per gallon. An assumed price 10% or 20% higher would result in correspondingly higher fuel cost savings.
b. The discount rate chosen for converting annual savings in the cost of operation and maintenance to a present value. A rate of 10% was used. A 20 percent discount rate would reduce the present value of fuel savings by approximately 24 percent over a 10 percent discount rate.
c. The average life of a car is assumed to be 10 years.

3.3.4 Impact on Auto Sales

The impact of fuel economy improvements on sales is the result of two opposing forces: a higher initial purchase price and a lower cost of operation and maintenance. Different forecasting models all show 1980 auto sales at least two million units above the present level because of population trends and some growth in real per capita income. Fuel economy improvements and their associated cost changes can be included in these models. The results are to add or subtract from the basic trend, but they do not reverse the trend and in all cases the differences are no more than plus or minus 300,000 units.

The price and fuel efficiency changes also affect the relative number of cars purchased in the various size classes. Increased fuel economy of all cars tends to increase the sales of large cars as a percentage of all cars sold. Sales of large cars increase steadily above their low 1974 levels, until in the 1980's

TABLE 11. ESTIMATED 1980 IMPACTS OF FUEL ECONOMY IMPROVEMENTS UNDER SCENARIO C (DOLLARS/CAR)

	% Gain in MPG	Increase in Initial Price	PV[1] of Fuel Savings	PV of Maintenance Savings	Net Savings
SUBCOMPACT	24.4	242	335	213	306
COMPACT	42.6	249	688	308	747
INTERMEDIATE	42.6	249	937	308	966
STANDARD	61.0	296	1,397	389	1,490
LUXURY	61.0	296	1,465	389	1,558

[1]PV = Present value calculated with a 10% discount rate, gasoline price of 55¢ per gallon, and a ten year period. A 20 percent discount rate would lower the present value of fuel savings by 24 percent.

TABLE 12. NET PRESENT VALUE SAVINGS FROM THE PURCHASE OF FUEL EFFICIENT VEHICLES[1] (DOLLARS/CAR)

	SCENARIO				
CAR SIZE	A	B	B[2]	C	C[3]
SUBCOMPACT	330	374	513	306	354
COMPACT	612	685	873	747	838
INTERMEDIATE	868	911	1,510	996	1,117
STANDARD	1,103	1,217	1,824	1,490	1,504
LUXURY	1,151	1,276	1,900	1,558	1,543

[1]Computations follow the outline of Table 11 above.

[2]Post 1980 vehicles with diesel engines and/or other improvements.

[3]1982 vehicles under Scenario C.

they reach approximately the same percentage levels they held in 1972 prior to the fuel crisis (except under Scenario D).

3.3.5 Investment Requirements

The investment costs for the improvements anticipated in Scenario B are estimated to total about $1.0 billion by 1980 for the domestic auto companies, or less than $200 million per year. Scenarios A and C require less investment, while the shift to smaller cars under Scenario D would require more investment. Motor vehicle industry spending for the longer lasting items of capital goods has been running approximately $2.5 billion per year. In the absence of industry planning information, the alternative investment policies are unknown, so it is not known whether the investment level would be kept at $2.5 billion or increased. Some of the auto industry research and development expenditures would most likely have to be used for fuel economy improvements. Finally, about $1.0 billion is being spent by the tire industry on new equipment for radial tire production.

3.3.6 Supplier Impacts

Although total new car sales are expected to change slightly as a result of fuel economy improvements, the effects on many suppliers is unclear. Certain industries, such as aluminum, plastics and electronics may experience increased demand, while the comparative lightness of future cars implies that iron, steel, rubber and a few other materials will experience slower automobile demand growth.

3.3.7 Petroleum Requirements

Projections of total passenger car fuel consumption in future years under alternative technology scenarios are given in Table 13 below. These projections take into account the expected shift towards larger cars as fuel efficiency is improved as well as fuel efficiency improvements themselves. All projections (including the baseline) assume that vehicle miles travelled (VMT) will increase at 2.6% per year.[1] While dramatic savings in petroleum requirements can result from fuel economy improvements to motor vehicles, however, the savings in petroleum may not be fully realized since the resulting gains in operational economy may induce additional travel and increased sales of larger (although improved) cars.

TABLE 13. ANNUAL FUEL CONSUMPTION IN PASSENGER CARS
(billions of gallons)

YEAR		SCENARIO			
	Baseline	A	B	C	D
1975	81.0	79.5	79.6	79.1	79.0
1980	93.8	80.8	80.1	76.6	73.1
1985	107.2	85.6	78.2	76.8	66.0
1990	122.0	96.1	80.0	84.6	66.8

Table 14 provides the estimated savings in crude oil for each scenario expressed in millions of barrels per day. The savings given are simply the difference in consumption between the baseline and the relevant scenario with an adjustment for refining losses and a shift in the unit of measurement.

TABLE 14. NET SAVINGS OF CRUDE OIL
(millions of barrels/day)

YEAR		SCENARIO			
	Baseline	A	B	C	D
1975	0	0.1	0.1	0.1	0.1
1980	0	0.9	1.0	1.2	1.5
1985	0	1.6	2.1	2.2	3.0
1990	0	1.9	3.0	2.7	4.0

[1] "Transportation Energy Conservation Options," by D. Rubin, J.K. Pollard, et al., U.S. Department of Transportation, Transportation Systems Center, May 1974. (Draft Report).

Table 15 provides estimates of the corresponding annual dollar savings. The amounts indicated are substantial and would be expected to help ease pressures on the balance of payments.

TABLE 15. IMPACT ON ANNUAL OIL IMPORT COSTS AT $11/bbl (billions of dollars)

YEAR		SCENARIO			
	Baseline	A	B	C	D
1975	0	0.4	0.4	0.6	0.6
1980	0	3.8	4.0	5.0	6.0
1985	0	6.3	8.5	8.9	12.0
1990	0	7.5	12.2	10.9	16.1

3.3.8 Macroeconomic Impact

Because of the time constraints in preparing this report, it was not possible to use a general macroeconomic/econometric model to integrate fuel economy changes into forecasts for comparison to a baseline. However, the macroeconomic impacts of automotive fuel economy improvements on car prices, car sales, automotive investment, automotive employment, and U.S. international trade were estimated. Information relating to impacts on these individual variables suggest that the macroeconomic effects are generally limited, except that large improvements in the balance of payments are likely. A brief discussion of these considerations follows.

3.3.8.1 Car Price and the Consumer Price Index

The initial real price of new cars may rise by 5% to 10% as a result of fuel economy improvements. Little effect on the Consumer Price Index, however, would be expected since, in its calculation, the Bureau of Labor Statistics eliminates costs for "product quality improvement." In addition, since the analysis indicates fuel savings would exceed the new car price increases, the real cost of automobile ownership due to fuel economy improvements would be reduced.

3.3.8.2 Automobile Sales

The analysis indicates that automobile sales may be increased by the fuel economy improvements contemplated in this report. The likely impacts are probably no more than 200,000 cars per year more than would be the case had no economy improvements been made. Such sales changes are quite small in comparison to the fluctuations of more than 2,000,000 units associated with the business cycle.

3.3.8.3 Employment Effect

There is no evidence to suggest that improvements in fuel economy of automobiles would have an effect on employment in the auto industry.

3.3.8.4 Macroeconomic Investment Impact

The rate of investment required for the most capital intensive automobile fuel economy improvements considered is estimated to be less than one-half billion dollars per year, which is less than 1% of the total annual U.S. investment in plant and equipment.

3.3.8.5 Impact on U.S. Foreign Trade

The interrelationships between fuel economy improvements, foreign trade balances, and the general level of economic activity are complex. However, two foreign trade consequences of U.S. automobile fuel economy improvements are identifiable. First there would be reductions in U.S. oil imports that could dramatically alter the U.S. balance of trade and provide further funds for domestic investment and consumption. Secondly, fuel economy improvements in U.S. autos could improve their domestic competitive position.

3.4 VARIOUS STRATEGIES FOR ACHIEVING THE FUEL ECONOMY GOALS

3.4.1 Summary

A variety of alternative strategies can be considered by which to achieve the desired 20% or higher improvement in auto fuel economy. They range from complete reliance on market forces to various forms of government intervention.

- The potential of market forces to achieve major fuel economy gains is unclear. This uncertainty implies a risk that without some form of government intervention the potential of this energy conservation target may go unrealized or experience some shortfall. This analysis does not presume to make a judgement on the desirability of assuming such a risk.
- With respect to the regulatory alternatives, none appears to recommend itself above the others. Each involves costs and risks. It may be concluded, however, that as Federal regulatory policy becomes stronger, the certainty of achieving given fuel economy goals will be increased. But stronger Federal regulation also involves risk of adverse impacts on industry and consumers, and would require coordination with Federal safety and emission programs.
- Mandatory labeling is a mild form of Federal action which is relatively easy to administer and operates to motivate market forces to their utmost potential without any major adverse impacts. Also, it would probably be an integral part of any stronger Federal regulatory effort to establish fuel economy standards.
- A production-weighted standard requiring every manufacturer to improve his average fuel economy by the same percentage would require larger absolute fuel economy gains on already efficient cars while requiring only minor improvements on inefficient cars which have the greatest fuel economy improvement potential.

A production-weighted standard establishing one uniform specific fuel economy average for all manufacturers would, if sufficiently stringent to have the needed effect, impact most heavily on manufacturers who have lower fuel economy, while not requiring manufacturers of current good fuel economy vehicles to maintain or improve their performance. Production-weighted standards specifically tailored to each manufacturer would eliminate some inequities, but would be difficult to administer fairly.

- Establishing standards on the basis of vehicle class would have the effect of inducing technological advances for all vehicles while not restricting consumer choice of car size. Class standards would not necessarily ensure attainment of an overall fuel economy goal requiring shifts to small cars because of the possibility of increased demand for larger (although improved) models. However, this demand may be created irrespective of any standard, given improved larger cars.

3.4.2 Background

This section examines alternative implementation strategies and enforcement means available to elicit a fuel economy improvement. With respect to the matters of practicability and enforcement stipulated in the Act, programs to encourage an improvement in auto fuel economy may be viewed as operating on either the demand side or the supply side of the market for new automobiles. Those applied to the demand side would encourage the consumer's preference for vehicles with better fuel economy, indirectly inducing manufacturers to produce better performing vehicles to satisfy that need. Those applied to supply would cause manufacturers to employ technological options that are more efficient, such as those described in Section 3.1. Action directed to demand is exemplified by a government policy of improving consumer information so he can make the most economical choice. Action directed to supply would be a voluntary program of technological improvement, or the establishment of regulatory standards for the manufacture of new automobiles. Still another policy, that of imposing taxes which favor more efficient autos, can be fashioned to act on either demand or supply.

The Act to which this report responds defines the "Fuel Economy Improvement Standard" in terms of a required "... percentage increase in the number of miles of transportation provided by a manufacturer's entire annual production of new motor vehicles per unit of fuel consumed...." The fuel economy standards were thus intended to be articulated in terms of the production-weighted averages of the fleet produced by each manufacturer.[1] Standards based on fuel economy performance objectives tailored to individual classes of automobiles would also improve the production-weighted average fuel economy.

[1] If a manufacturer produces 100,000 units of Model A, and 500,000 units of Model B, and it is assumed that all vehicles will be expected to travel 100,000 miles, then it produces 100 billion miles of Model A transportation and 500 billion miles of Model B transportation for a total of 600 billion miles of transportation. In terms of fuel economy performance for its entire annual fleet, it may be seen that overall performance would be the performance of A weighted by the number of units of A produced plus the performance of B weighted by the number of B units produced. The averaging of rates requires use of the values for fuel consumption in gallons per mile for each model.

The manner in which improvement standards are articulated would probably produce different reactions among the manufacturers. Standards oriented around production-weighted averages provide the manufacturer more freedom of action: he can exploit improved technology, or he can work to change sales mix to smaller cars, or he can combine both to achieve the overall fleet performance objective. It also allows for the possibility of no improvement on some cars. Alternatively, standards can be articulated in terms of fuel economy performance for a given class vehicle, which would tend to force technological improvement. While this represents a more direct form of intrusion, it exploits the capability to assure some improvement in fuel economy performance for all vehicles. The objectives and the actions necessary on the part of the manufacturers to meet them are understood with better precision, and there is less uncertainty about what will result.

3.4.3 Evaluation of Implementation Strategies

As a first step toward understanding the implications of a fuel economy standard, several representative implementation strategies were considered.[1] These were:

1. Voluntary Fuel Economy Goals with Fuel Economy Labeling
   Description - Using input from the auto manufacturers, the responsible agency would establish voluntary goals and a fuel economy label format. These goals would call

[1]Because it is impossible to answer the question of practicability of standards without some comparison of alternative means of implementation, strategies other than those relating solely to establishing standards were reviewed. The fact that they were selected for consideration does not in any way imply advocacy.

for a specified fuel economy performance level from the production-weighted average of the manufacturer's new car fleet. Different goals would be set for different manufacturers. A publicity campaign would be used to exert pressure on the manufacturers to participate as well as to educate the consumers about fuel economy. Variations under this policy would be

(A) Voluntary Labeling (current EPA and FEA programs)

(B) Mandatory Labeling

2. <u>Direct Regulations by Establishing Federal Fuel Economy Standards</u>

   The articulation of a performance standard can take two modes:

   <u>As a Production-Weighted Average Standard</u>

   <u>Description</u> - Under this mode, the responsible agency would establish a standard articulated as the production-weighted average fuel economy of each manufacturer's entire fleet of new vehicles. Variations include:

   (C) A common standard (e.g., 16.8 mpg for all manufacturers)

   (D) A standard stated as a uniform per cent improvement (e.g., 20% improvement for each manufacturer)

   (E) A variable standard based on the costs or potential to improve for each manufacturer.

   <u>As a Fuel Economy Standard Tailored to Individual Classes of Vehicles</u>

   <u>Description</u> - The responsible agency would classify all models into classes, perhaps according to their passenger capacity, or their weight, or their performance on the official fuel economy test during a specified base year. The improvement required for each class would be translated into a minimum performance standard to be attained by every vehicle within that class. New models could not be introduced which did not meet their class standard. Variations under this mode are:

(F) A standard stated as uniform quantity of improvement (e.g., 2.8 mpg for all classes).

(G) A variable standard based on the potential to improve each class.

3. Taxes on Vehicles

Taxation, as a means of inducing fuel economy in new vehicles, can take on numerous forms. For purposes here, it is sufficient to examine only two basic forms.

(H) Vehicle Excise Taxes

Description - A tax would be imposed directly on sales of new vehicles based on their fuel efficiency. It would be progressive, (e.g., exponentially increasing) so that it would increasingly dissuade purchase of autos with increasingly poor fuel economy. It would also inhibit the sale of cars with less than a specified level of fuel economy.

(I) Annual Vehicle Fuel Efficiency Tax

Description - An annual tax would be imposed on all vehicles after a selected future model year, inversely related to fuel economy. It would induce consumers to heighten their demand for better fuel efficiency in new vehicles.

Each of the above implementation standards or strategies was analyzed in terms of its impact on manufacturers, its impact on motor vehicle consumers, and its administrative practicability. The evaluation intentionally excluded the ramifications of emissions, and effects on the national economy that might also be implicit in the various implementation policies. It may be seen in other sections of the report that action in those areas of concern would be relatively independent of the alternatives evaluated here. The specific assessment criteria used in the analysis were as follows:

1. Impact on Producers

   a. Producer Flexibility - The degree to which the manufacturer can exercise choices in complying with the requirements, i.e., technological improvements, shift to small car production, etc.

   b. Incentive for Post 1980 Improvement - The degree to which the alternative will motivate the manufacturer to further invest in order to continually improve the fuel efficiency of his vehicles.

   c. Comparative Impact on Producers of Efficient Models - The degree to which the alternative unfavorably impacts those auto manufacturers who through their own initiative have already upgraded the fuel efficiency of their models.

2. Impact on Consumers

   a. Increase in First Cost of Autos - The increase in price of new automobiles caused by compliance with the standard.

   b. Distribution of Cost Increases - The degree to which the resulting increases in automobile first cost relatively impacts the larger vis-a-vis the smaller models.

   c. Maintenance of Consumer Choice - The degree to which the standard limits the choices of automobiles available to the consumer.

   d. Safety Costs - The degree to which consumers are induced to buy lighter and possibly less safe cars; or the degree to which the consumer must pay more in first costs to maintain present levels of occupant safety.

3. Impact on Administration

a. Reliance on the Market - The degree to which the strategy alternative relies upon market price and consumer preference signals to achieve the standard, thereby minimizing administrative intervention

b. Cost of Administration - The costs to administer the standard.

c. Effectiveness of Ensuring Achievement of the Standard - The degree of assurance that the standard, expressed as the desired increase in fuel economy of 1980 model year motor vehicles, will be obtained.

3.4.4 Enforcement Options

Practicability of standards also requires consideration of viable enforcement schemes to ensure compliance. There is need for balancing the industry's right to due process with the need for strong and quick government action. This necessitates the development of acceptable testing procedures and implementation of effective enforcement remedies with appropriate procedural safeguards.

The points in time relative to model year production at which compliance with fuel economy standards can be determined are:

1. Pre-production Certification - Most appropriate if it is desired to insure that standards will be met before cars are allowed to be built and sold. Further, certification may also be preferred where the fuel economy standards are required to be met throughout the life of the vehicles and the possibility of degradation exists.

2. Assembly Line Test of Production Vehicles - Has an advantage in that actual production vehicles are tested rather than prototype vehicles.

3. In-use Vehicle Tests - Would involve selected tests of vehicles in use to see whether their level of fuel economy remains acceptable. However, determination of compliance might be made long after the production of any given model car, with limited opportunity for corrective action.

The enforcement mechanism associated with a fuel economy standard can be implemented with government performing all required testing, industry performing all testing with government surveillance, or a combination where both industry and government perform testing. The industry testing approach is the least disruptive in terms of cost and government intervention but does not offer as high a degree of certainty that the fuel economy goal will be met as in the case where some government testing is involved.

In the case where government testing is contemplated in any enabling legislation, the issue as to whether the cost of such testing should be paid for by the general public or the vehicle buyer is raised. In the event it is desirable that the cost be associated with the product, a government testing user fee should be provided for.

Once the enforcement techniques are identified, violations could be remedied through the assessment of civil penalties, implementation of recall campaigns, and requiring the manufacturers to give a manufacturer's fuel economy warranty.

3.4.5 Findings

1. Inasmuch as the 20% or greater improvement goal may be reached solely through the forces of the market, it is not clear that any intervention is needed. If buyers' preference for smaller cars increases and industry continues to make fuel saving improvements such as were introduced in 1975 cars, federal intervention would be superfluous and possibly counterproductive (e.g., the goal may be set too low). On the other hand, the trend toward smaller cars may not be sustained, and the demand for better mpg performance may be insufficient to induce manufacturers to opt for the substantial fuel economy improvements feasible.

   There is considerable uncertainty about market trends and how effective they will be in forcing improved performance. The existence of this uncertainty carries with it the risk that in the absence of some form of government intervention, the potential of this energy conservation target may go unrealized. This risk could be better evaluated with more information, but this entails more time and continued prospects of missing the target, or experiencing some shortfall. To decide whether or not the risk is unacceptable is beyond the purview of this study.

2. The results of a preliminary analysis of various forms of government intervention appear in Figure 8. This chart shows the relative merits and shortcomings of each policy alternative in terms of the assessment criteria. The evaluation, to be sure, was necessarily subjective and imprecise in light of the complexities involved, and the limitations of time and information.

   It may be seen from the chart that none of the policies emerge as clearly preferable over all the others. Each has pronounced strengths and weaknesses: for example, alternatives which appear more favorable in terms of "Reliance on the Market" in general appear less favorable in terms of "Effectiveness of Ensuring Achievment" of the goal.

3. Different alternative strategies would have different effects depending on the level to which the fuel economy goals are set. This may be seen in Figure 8 by comparing the effects of two standards: C_{20}, a common production-weighted average improvement of 20% (16.8 mpg for all manufacturers); and C_{30}, (18.2 mpg for all manufacturers). The remaining standards in Figure 8 are predicated on a 20% fuel economy improvement.

Impact On:	BEST										WORST
Producers											
Affords Producer Flexibility	(More)	I B A	H	C_{20}	E	G	F	C_{30}	D		(Less)
Incentive for Post 1980 Improvement	(High)	H	I	B	A	G D F C_{20} E C_{30}					(Low)
Comparative Impact on Efficient Producers	(Low)	I H B A	C_{20}	E	G	C_{30}	F	D			(High)
Consumers											
Increase in First Cost of Autos	(Low)	I B A	E	G	F	C_{20}	H	D C_{30}			(High)
Distribution of Cost Increases	(Large Models)	H	C_{30}	C_{20}	G	B A	I	E	F	D	(Small Models)
Maintains Consumer Choice	(More)	I B A	H	E	G F D C_{20}	C_{30}					(Less)
Safety Costs	(Low)	G F	B A	I	E	C_{20}	H	D C_{30}			(High)
Administration of the Standard											
Reliance on the Market	(High)	B A	I	H	E D C_{20}	C_{30}	G F				(Low)
Cost to Administer	(Low)	A	B	F G	D C_{30} C_{20}	E	H	I			(High)
Effectiveness of Ensuring Achievement	(High)	G F	E C_{20}	D	C_{30}	H	I	B	A		(Low)

A. Voluntary Fuel Economy Goals and Labeling
B. Mandatory Fuel Economy Labeling
C. Production Weighted Average Common Standard* (16.8 mpg. for all mfrs. at 20%, 18.2 mpg. for all at 30%)
D. Production Weighted Average Uniform Percentage Improvement Standard (20% improvement for all)
E. Production Weighted Average Variable Improvement Standard (Unique standard for each mfr.)
F. Class Standard - Uniform Fuel Economy Improvement for each (2.8 mpg for all classes)
G. Class Standard - Variable Fuel Economy Improvement for each class
H. Vehicle Excise Tax
I. Annual Vehicle Fuel Efficiency Tax

*20% (C_{20}) and 30% (C_{30}) improvement illustrated. All other standards are 20%

Figure 8. Evaluation of Alternatives

4. The comparisons between standards expressed as a production-weighted average and standards expressed as technological performance objectives by class highlight some of the inherent tradeoffs.

a. Production-Weighted Average Standards (C, D, and E)

The standard can be met by either altering production mix or upgrading technological performance. Even without any technological improvement, sales of many smaller cars (which are above the fuel economy standard) can balance out sales of some larger (below standards) cars. An estimate of the extent to which improvements in fleet mpg can be realized by shifts in production is shown in Figure 1, line 1 of "1980 Potential."

Incentive for continued technological improvement prevails for all classes, but is reduced by the prospects of attaining the standard through shifts in production mix. Some very inefficient cars may not be improved at all.

First costs of autos would be higher under production-weighted standards than under the class standards, except in the case of variable standards. The larger, more expensive below-standard cars would require relatively more technological upgrading and their prices would experience a higher relative increase compared to the smaller, lower priced cars. Consumer choice would be constrained to about the same degree as with class standards, but there would probably be more promotion of the above-standard cars.

Since the above standard cars would tend to be the lighter ones, more motorists would be in autos with poorer occupant safety, or alternatively, costs of the vehicle would be increased by the improved safety features necessitated to maintain the same level of occupant safety.

Production-weighted standards rely more on the market forces than technological class standards. Manufacturers may be forced to reduce profit margins and exhort customers to buy at the above-standard end of the line, as their production-weighted average tends to fall below standard. Costs to administer would be somewhat higher than under class standards. The probability of achieving the overall fuel economy goal is high but the ability to control through production mix is unproven.

b. <u>Performance Standards by Class (F and G)</u>

Performance standards would be set for each class of car. Option G would base the standard upon the potential to improve that class. The extent to which improvements can be realized, without any reduction in weight may be seen in Figure 6. Existing models which outperform the standard would remain unchanged, but it is assumed that technological improvements would be required for most models. An estimate of the extent to which higher mpg performance of the nations fleet can be realized through technological improvements is shown in Figure 1, line 2 of "1980 Potential."

Producer flexibility takes the forms of upgrading existing models, shifting to models in a different class but adhering to that standard, or dropping some models. All classes would become good economy performers, but there would be no incentive for continued improvement unless there is a phased standard. This form of standard would require manufacturers to make some technological improvements, but those who have already improved efficiency of their larger cars would have to do less upgrading. Those who produce inefficient small cars would also have to upgrade them.

In administering such standards, there would be little reliance on market forces. Instead, society depends upon the process of a complex bureaucracy dealing with a complex industry over a complex set of standards. Nevertheless, the statement of fuel economy performance standards would be much more precise. There would be some uncertainty about achieving an overall mpg improvement, because of the possibility that sales of the less efficient (although improved) models would increase.

5. Within the two basic kinds of standards, additional options have been described, each with their own merits and deficiencies. A common production-weighted fuel economy standard for all manufacturers (C) would place a disproportionate burden on those manufacturers whose annual production includes substantial numbers of large cars. Further, there would be no incentive for those who are already markedly outperforming the standard to improve, and they may in fact degrade their performance.

6. A uniform percent increase in the production-weighted average fuel economy for every manufacturer (D) would require the best fuel performers to make the biggest absolute improvement. A 20% improvement for a manufacturer producing cars with a weighted average of 10 mpg requires a 2 mpg improvement; a 20% improvement for manufacturer with a 25 mpg average would require a 5 mpg improvement.

7. The ability to test, rate, and label the fuel economy of each vehicle is a requirement for all options. There are alternative ways by which this rating can be organized, placing varying burdens on elements from the public or private sector. These include pre-production certification, assembly line test, and in-use tests.

Compliance can be assured through use of civil penalties, recall campaign or manufacturer's warranty. Enforcement of a reasonable standard for fuel economy is quite practicable as long as the standard makes automobile manufacturers directly accountable for fuel economy improvements.

8. Mandatory Fuel Economy Labeling is straightforward, non-discriminatory, and most consistent with market forces. It does not ensure a 20% or better fuel economy improvement by 1980. However, since the administrative testing, and public information requirements inherent in it are fundamental to any implementation policy, adoption of Mandatory Fuel Economy Labeling could reasonably precede more stringent standards.

   The most informative labeling scheme would display the basic fuel economy of the model and list the degradation or improvement to it for each accessory in much the same way that the present price sticker shows base price and then the added costs for added features on that particular vehicle. If possible, this information should be augmented with readily available data in the showroom on the fuel economy payoff associated with each feature, ranked in the order of increasing fuel economy per increased cost. Evaluation of consumer reaction to the provision of such complete information would provide the opportunity to further observe and judge market trends and to gather data upon which to design a fuel economy standard.

9. The amount of tax on the initial purchase price of a fuel inefficient car, and on the annual use of such a car, that would be necessary to insure achievement of the goal of fuel economy improvement is not known. In considering how large a tax would be needed, one must also consider that today the purchaser of a fuel efficient car already assumes voluntarily very much higher costs (in terms of

cost of transportation per mile) than is required of the purchaser of a fuel efficient car. To illustrate, a small car can cost half as much or less to buy, incurs lower insurance and local tax costs, and in the extreme case gets up to four times as many miles per gallon as a larger car. Taxes that would equal these voluntarily accepted extra costs would have to be extremely high.

3.5 SAFETY

The relationship between a fuel economy improvement standard and safety is difficult to predict. The reason for this uncertainty is that it is not known how the automobile industry and the nation would go about meeting safety, damageability or fuel economy improvement regulations.

One possible way for manufacturers to improve fuel economy is to introduce a greater proportion of small, light cars into the market place. Tests indicate that there is a direct relationship between automobile weight and fuel consumption; i.e., as weight decreases, fuel consumption decreases.

Various studies using accident data to investigate the relationship between car weight and safety have shown that:

1. The probability of a car being involved in an accident is relatively independent of its weight.
2. The chance of serious injury when a car is involved in an accident varies significantly with car weight.
3. Belted drivers in small cars have about the same level of protection as unbelted drivers in heavy, large cars.

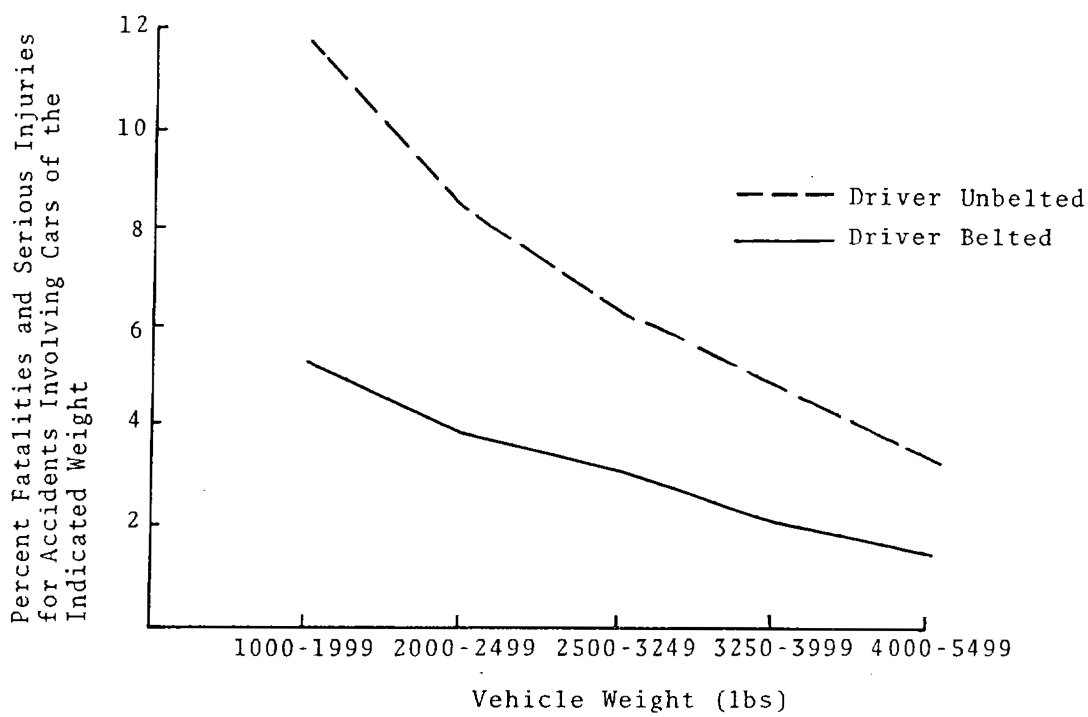
In a recent publication by the National Highway Traffic Safety Administration,[1] the impact of car weight on safety was examined with emphasis on accident involvement and injury rates. The differences in involvement rates of various weight classes were found to be much less than the differences in injury rates.

It is well known that today's large cars offer considerable occupant protection because of their greater crush space, passenger compartment volume, and heavier structure. As illustrated in Figure 9, belted drivers of light small cars, have about the same occupant protection as unbelted drivers of heavy, large

[1] "How Safe Can We Be in Small Cars" by Donald F. Mela, National Highway Traffic Safety Administration, July 1974.

cars. Consequently, an increase in the usage of passenger restraint systems could reduce the negative impact on the serious injuries and fatalities of a greater number of small cars of today's design. It is, however, a current national goal to reduce the present fatality and injury rates. Thus, the serious injury and death rate for even the large cars is not acceptable. Therefore, even though belted drivers of small cars have the same fatality and injury rates as unbelted drivers of large cars, the change to a higher percentage of small cars without a basic upgrading of their occupant protection will be counter to this goal.

The possibility exists that the response of manufacturers to a fuel economy improvement standard will involve engine resizing. The result of such an action will be production of automobiles with reduced power-to-weight ratios, acceleration, and top speeds.



Source: "A Safety Comparison of Compact and Full-Size Automobiles," by Basil Y. Scott, N.Y. State Department of Motor Vehicles, presented at 3rd International Congress on Auto Safety, Vol. I, 15 July 1974 in San Francisco.

Figure 9. Percentage Fatal/Serious Injury vs. Vehicle Weight

Little information is available concerning the effects of lower power-to-weight ratio and the resulting decrease in speed and acceleration capability on traffic safety. However, they may have a beneficial impact on safety. For example, a preliminary assessment of the impact of the recently adopted 55 mph speed limit has shown that several thousand lives have been saved in the first six months of 1974 compared to the same period of 1973.

Recent safety and bumper standards have added approximately 260 pounds to the weight of an average car, resulting in a fuel economy penalty of about 3 to 4%. The following table (Table 16) is a breakdown of automobile weight changes due to the implementation of successive safety and damageability standards.

TABLE 16 BREAKDOWN OF AUTOMOBILE WEIGHT CHANGES DUE TO IMPLEMENTATION OF SUCCESSIVE SAFETY AND DAMAGEABILITY STANDARDS

Standards in Effect	Weight Increase (lbs)
100 Series	5
201 - 204, 207, 210	32
208 (Belts)	35
214 (Side Door Strength)	50
215 (Bumper)	141
	263
Issued Standards Not Yet In Effect	
215 (Bumper Corner Requirements) 9/1/75	9
105-75 (Hydraulic Brakes) 9/1/75	5 -25
Possible Future Standards	
Before 1980 FMVSS 208 (30 mph)	~ 55 - 80 lbs.
Part 581 No Damage Bumper	~ 45 - 100 lbs.
After 1980 FMVSS 208 (45-50 mph)	~150 - 270 lbs.
Total	~250 - 450 lbs.

The connection between weight increases and future safety and damageability standards is unclear primarily because the effects of "soft-nose" bumpers and various other designs are as yet undefined. Reasonable estimates place weight increases in the range of 300 to 450 pounds for the average car. However, these are conservatively high estimates based upon present experience. To date weight increases have been greater than necessary, because, as material and fuel costs have not been high enough to constitute overriding considerations, direct design approaches using conventional materials were used to increase structural strength.

The increased cost of fuel and the emphasis on fuel economy will quite likely encourage the automobile manufacturers to develop more sophisticated weight reducing designs including both improved materials and changes in the ratio between passenger compartment volume and total volume. However, capital costs of new equipment and increased costs of petroleum based plastics and nonferrous metals will undoubtedly affect design decisions and perhaps limit usage of alternative materials.

The fuel economy improvement for 1980 vehicles will be offset in part by the weight penalties of future safety and consumer standards. Vehicle technology advances combined with effective passenger restraint systems, however, may greatly ameliorate the weight penalties of upgraded vehicle safety, particularly in vehicles manufactured after 1980.

3.6 AIR QUALITY

The technology chapter concluded that it would be possible to achieve fuel economy improvements and 1978 statutory HC and CO emission standards. The achievement of these standards, as well as NO_x simultaneously with good fuel economy, is judged to be possible, but has not been demonstrated.

The oxides of nitrogen emission standard currently required by Congress to apply to 1978 and subsequent model automobiles is 0.4 gm/m. In November 1973, EPA recommended that a less stringent NO_x standard be applicable over the near term. EPA analysis concluded that the attainment and maintenance of the ambient air quality standard for NO_2 was not generally dependent upon a stringent NO_x emission standard for light duty vehicles. This largely results from the fact that NO_x emissions from stationary sources are the major contributors to present and projected NO_2 ambient air levels. In general, NO_2 projections do not predict significant future air quality improvement if the automobile NO_x standard were lowered from current levels to 0.4 gm/m. The NO_x emission issue is being further assessed by EPA.

3.7 TRUCKS AND BUSES (VEHICLES OVER 10,000 POUNDS GROSS VEHICLE WEIGHT)

The fuel economy potential for trucks and buses with gross vehicle weight ratings in excess of 10,000 pounds was investigated as a separate element of this study. This group of vehicles presently consumes 18 percent of the highway fuel used annually. Intercity (long and short range) operations consume 40 percent of the fuel used by trucks and buses.

Analyses of available data indicate fuel economy improvements for some individual trucks can be as great as 41% by the 1980 production year. Assessment of such technology applied without cost or production capacity restraint yields an estimate of aggregate reduction in the fuel consumed by the new trucks and buses manufactured in 1980 of 25%.

When considerations of cost benefit tradeoffs to the purchaser and production capacity by 1980 are taken into account, the maximum fuel savings for the new 1980 vehicles is reduced to 18%.

On a sales weighted average basis the 1980 new vehicle fuel economy improvements also appear to be 18% (based on assessment of four representative vehicles). More importantly the 1980 intracity vehicles exhibit fuel economy improvement potential of only 14-17%, hence manufacturers with a preponderance of such vehicles would find it extremely difficult to comply with a legislated 20% fuel economy improvement. Manufacturers of intercity and transit buses would find it very difficult to achieve 20% fuel economy improvements by 1980.

The analysis found the most significant payoff technology options to be: increased utilization of diesel engines (vs. gasoline engines); optimized cooling systems (including variable speed fan drives); radial tires (or wide base singles) and engine power and speed derating. Greater fleet-wide improvements could be realized by 1980 if production of diesel engines and radial (or wide base single) tires could be expanded more rapidly than present trends indicate.

No environmental or safety degradation could be identified with the suggested technology options. Noise would be reduced by the cooling system and tire changes but somewhat increased by the expanded diesel engine use. Exhaust emissions are substantially reduced by the substitution of diesel engines, and are not expected to increase as a result of other options. On the other hand industry has expressed concern over the detrimental effects on fuel economy of existing and proposed safety, emission and noise regulations. There is uncertainty as to future air emission standards to be applied to trucks and buses. Therefore,estimates of their impact on fuel consumption of 1980 vehicles are not attempted. There is no fuel economy penalty associated with current EPA or California standards using best technology.

The major technological shortcoming identified is in the realm of viable and equitable fuel economy measurement techniques. At the present time no accepted set of driving modes for either road tests or dynamometer tests exists by which fuel economy claims can be adequately judged. Furthermore, no viable scheme is evident by which a determination can be made for any particular vehicle as to the appropriate operational mode by which it should be evaluated. High priority needs to be given to the development of viable fuel economy test procedures. The final measure of commercial vehicle fuel economy should reflect productivitiy (such as ton miles or passenger miles per gallon of fuel consumed), since the real efficiency of the commercial vehicle fleet is determined by the fuel consumed relative to the work performed (the transportation of material and people).

3.8 PUBLIC DOCKET SUBMISSIONS

Public docket submissions were received from the following manufacturers, organizations, and individuals:

- Chrysler Corporation
- American Motors
- Volkswagen of America
- AB Volvo, Car Division
- Bayerische Motoren Werke
- Automobile Club of Southern California
- American Trucking Associations
- International Harvester Company
- Cummins Engine Company
- National Association of Motor Bus Owners
- Recreation Vehicle Industry Association
- Norton Triumph Corporation
- State of Connecticut Department of Transportation
- Nalco Chemical Company
- Lee-Norse Company
- Individual letters from three private citizens, G.E. Buske, Thomas May, and E.F. Jones

Certain points recur throughout the submissions. These repeated points do not exhaust everything of interest in the docket material, but they do show much of what is felt most strongly by manufacturers who would be affected by fuel economy improvement standards. These point are presented below.

3.8.1 Uncertainty about the Future Extent of Emissions and Safety Standards Make Prediction and Planning for Fuel Economy Difficult

There are frequent statements that the uncertainty surrounding emissions and safety standards make it impossible to predict whether a particular fuel standard could be reached.

There are less frequent statements that a 20% improvement standard cannot be met, with varying estimates of the shortfall.

Chrysler says, "We do not believe it will be possible to achieve the projected fuel savings by vehicle improvements alone," but that it would be if due attention is also given maintenance, operating speed, and driving habits.

3.8.2 Market Forces are Sufficient to Bring About Fuel Economy Improvements in New Cars

Manufacturers have for a long time spent considerable efforts in improving fuel economy. Consumers are sensitive to fuel economy, particularly so with the current fuel shortage, and manufacturers respond to consumer desires. This is markedly so for commercial vehicles.

3.8.3 There is Insufficient Reason to Limit Consumer Choice

Consumers may well have good reasons, such as safety considerations, for choosing large cars.

3.8.4 There are Numerous Practical Problems Attendant to Setting Any Particular Standard and Testing Procedure

A blanket requirement of a 20% improvement in fuel economy would discriminate against those manufacturers who are already fuel-efficient. Makers specializing in small cars state this with particular vehemence.

A variety of other problems are listed in various submissions, and the total list would be moderately long. Standards and test procedures which do not take into account the multiplicity of relevant variables can be shown to generate inefficient and occasionally paradoxical results.

Appendix A

GLOSSARY

APPENDIX A
GLOSSARY

AUTOMOBILE ENGINE CUTOFF DEVICE

Device which automatically turns off the engine when the automobile is stopped. One such device is a mini-computer receiving signals from sensors and turning the engine on and off in accordance with these signals.

AXLE RATIO

The ratio between the rpm of the engine propeller shaft and the rpm of the wheels.

COLD STORAGE CONCEPT

This concept stores HC emissions in a charcoal trap during cold start and warm up operation. During this time the exhaust gases are directed to the charcoal trap after they pass through the catalyst. When the catalyst reaches light-off temperature, an air pump is used to purge the HC from the trap back into the catalyst where they are oxidized.

DUAL CATALYST (DUAL CAT)

Dual catalytic converters are emission control devices attached to the exhaust manifold of the engine. The first converter is a reducing catalyst which changes nitrogen oxides to nitrogen and oxygen but does not remove hydrocarbons or carbon monoxide from the exhaust. This is the function of the second converter, an oxidation catalyst, which changes hydrocarbons and carbon monoxide into carbon dioxide and water.

ENGINE PERFORMANCE MAP

A chart containing plots of fuel consumption (lbs per HP-HR) over a range of possible loads and speeds.

EARLY FUEL EVAPORATION (EFE)

See Improved Warm Up Systems.

EXHAUST GAS RECIRCULATION (EGR)

In this system some of the exhaust gas is diverted back to the carburetor where it decreases the oxygen content of the air/fuel mixture and the peak combustion temperature, both of which result in lower nitrogen oxide formation.

THE FEDERAL TEST PROCEDURE 1975 (FTP)

The two-stage test used by the Environmental Protection Agency (EPA) to measure the exhaust emissions and fuel economy from individual automobiles during simulated urban driving. The first stage consists of a simulated 7.5 mile urban drive at an average speed of 19.5 mph in a speed range of zero (representing stops) to 56.7 mph. The test starts with the vehicle at ambient conditions (cold start) and the vehicle warms up as the test proceeds . Eighteen stops are incorporated in the test (a frequency of 2.4 stops per mile) and about 18% of the test time in this phase is devoted to idling. The sequence lasts about 23 minutes. The first 505 seconds of the schedule are run again from a hot start. Test Data are then combined to represent the empirically measured mixture of hot to cold start driving reported in studies of actual driving conditions.

HARMONIC MEAN

The average used in time and rate problems. It is the reciprocal of the arithmetic mean of the reciprocals. Given in N position numbers $x_1, x_2, x_3 \ldots\ldots\ldots\ldots x_n$, the harmonic mean H is defined as:

$$\frac{1}{H} = \frac{\frac{1}{x_1} + \frac{1}{x_2} + \ldots\ldots\ldots + \frac{1}{x_n}}{N}$$

HIGH ENERGY IGNITION (HEI)

The use of a spark of longer duration and higher energy providing more reliable ignition.

HIGHWAY CYCLE (HWC OR HDC)

The E.P.A. test used to measure the fuel economy of individual automobiles during simulated highway driving. The test is with a warmed-up vehicle over a 758 second simulated 10.25 mile drive average test speed is 48.6 mph with speeds ranging from zero (at the start and finish) to about 60 mph.

IMPROVED WARM UP SYSTEMS

Systems for enabling the choke to cut out quickly after starting, without stalling, in order to minimize exhaust emission. Among these systems are:

Quick Heat Intake (QHI) systems allows heat transfer from the exhaust system to the intake system by means of routing hot exhaust gasses against an intake manifold wall.

Early Fuel Evaporation (EFE) systems utilize a special heat exchange plate for the same purpose as QHI shows.

Super Early Fuel Evaporation (SEFE) systems provide greater exhaust gas flows at the heat exchanger plate and thus provide superior performance as compared to EFE.

INERTIA WEIGHT

Determined from the curb weight of the vehicle plus 300 lbs. Inertia weights are divided into finite groups which are defined in accordance with FR, section 85.073-15.

LEAN BURN ENGINE

"Lean burn engines" refer to all spark-ignition carbureted engines which operate on leaner air/fuel mixtures (i.e., mixtures with more air and less fuel) than normally used.

LOCK-UP CLUTCH

A device designed to prevent fluid friction losses in the torque converter of an automatic transmission.

MODULATED AIR INDUCTION REACTOR (MAIR)

A system in which air is injected into the exhaust manifold or the exhaust port of an engine, providing more oxygen so that oxidation is more complete and less carbon monoxide and hydrocarbons are formed.

OXIDATION CATALYST (OXCAT)

Oxidation catalysts serve to lower the reaction temperature required to oxidize hydrocarbons and carbon monoxide in a catalytic converter to water and carbon dioxide. This method when used in conjunction with EGR is an effective complete emission control system.

PROPORTIONAL EXHAUST GAS RECIRCULATION (PEGR)

A system for controlling the mixture of exhaust gases and fresh air, by means of a valve modulated by engine load, before they enter the carburetor.

QUICK HEAT INTAKE (QHI) SYSTEM

See Improved Warm Up Systems.

SUPER EARLY FUEL EVAPORATION (SEFE)

See Improved Warm Up Systems.

TARE WEIGHT

The weight of a loaded vehicle less the weight of the cargo and occupants.

THERMAL REACTOR

A non-catalytic thermal reactor is normally in the form of an oversized exhaust manifold. It extends the oxidizing time of the exhaust gases. There are two basic types - rich and lean. "Rich" thermal reactors need a pump to supply additional air while "lean" reactors do not require a secondary air pump.

THREE-WAY CATALYST

This type of catalyst converts all three combustion produced pollutants (hydrocarbons, nitrogen oxides and carbon monoxide) to harmless emissions. To use this catalyst, an engine must be very carefully calibrated and only a very narrow range of carburetor air/fuel ratios is possible.

TORQUE CONVERTER

A hydro-kinetic device that couples the engine to the gear train. A torque converter also allows a wide variation of torque multiplication between engine and drive shaft augmenting the torque multiplication of the gear train.

TURBOCHARGED ENGINE

An engine which uses an air blower to provide extra oxygen to the combustion chamber. The air blower is powered by a turbine driven by exhaust gases.

UNIBODY CONSTRUCTION

Body construction which allows the body to carry the load in lieu of a frame.

APPENDIX B

BIBLIOGRAPHY

Alcoa Corporation. "The Automobile and Aluminum." 1972.

Ambs, L.L. "Passenger Car Design Influences on Fuel Consumption and Emissions." 8th Intersociety Energy Conversion Engineering Conference Proceedings, University of Pennsylvania, August 13-17, 1973. Paper 739113.

Artinian, L. and S.L. Terry. "The Total Cost of Weight." Society of Automotive Engineers Transactions, 1961. Paper 325D.

Austin, T.C. and K.H. Hellman. "Passenger Car Fuel Economy--Trends and Influencing Factors." Society of Automotive Engineers, 1973. SAE Paper 730790.

Berry, R. Stephen and Margaret Fels. "The Energy Cost of Automobiles." Science and Public Affairs (Bulletin of the Atomic Scientists) December, 1973, pp. 11-17, 58-60.

Bishop, I.N. "Effect of Design Variables on Friction and Economy." Society of Automotive Engineers, 1964. SAE Paper 812A.

Bishop, I.N. and A. Simko. "A New Concept of Stratified Charge Combustion-- The Ford Combustion Process." Society of Automotive Engineers, 1968. SAE Paper 680041.

Brennan,T.J., A.G. Steinert, and R.N. Taylor. "Cost Estimating Techniques for Advanced Technology Engines." Society of Automotive Engineers, 1970. SAE Paper 700271.

Bundorf, R. Thomas, M.C. Hardin, and Donald E. Pollock. "Vehicle Handling Response to Aerodynamic Inputs." Society of Automotive Engineers, 1963. SAE Paper 716B.

Callahan, Joseph. "Chrysler's Weight Watchers." Automotive Industries, October 15, 1972, pp. 27-31.

Clayton, P.M. "Forecasting Specific Fuel Economy." Society of Automotive Engineers, 1960. Paper 199B.

Cleveland, A.E. and I.N. Bishop. "Fuel Economy." Society of Automotive Engineers Journal, August 1960, p. 27-31.

Cleveland, A.E. and I.N. Bishop. "Several Possible Paths to Part-Load Economy of Spark-Ignition Engines." Society of Automotive Engineers, 1960. SAE Paper 150A.

Coppoc, W.J., E. Mitchell and M. Alperstein. "A Stratified Charge Multifuel Engine Meets 1976 U.S. Standards." American Petroleum Institute, Division of Refining, 38th Mid-Year Meeting, May, 1973.

Craver, R.J. et al. "Spark Plug Design Factors and Their Effect on Engine Performance." Society of Automotive Engineers, 1970. SAE Paper 700081.

Curtiss, W.W. "Low Power Loss Tires." Society of Automotive Engineers, 1969. SAE Paper 690108.

Davis, C.W., E.M. Barber, and E. Mitchell. "Fuel Injection and Positive Ignition-- A Basis for Improved Efficiency and Economy." Society of Automotive Engineers, 1960. SAE Paper 190A.

Elliott, D.R., W.K. Klamp, and W.E. Kramer. "Passenger Tire Power Consumption." Society of Automotive Engineers, 1971. SAE Paper 710575.

Ellis, J.R. "Performance Prediction-- A Comparison of Various Methods of Estimating the Performance of a Vehicle." Automobile Engineer, March 1958.

Eltinge, Lamont. "Fuel Air Ratio and Distribution from Exhaust Gas Composition." Ethyl Corporation.

Eltinge, Lamont, Frederick Marsee and Joel Warren. Potentials of Further Emissions Reduction by Engine Modifications. Ethyl Corporation, January 8, 1968.

Ethyl Corporation, Petroleum Chemicals Division. Brief Passenger Car Data, 1961 thru 1969.

Everett, R.L. "Measuring Vehicle Driveability." Society of Automotive Engineers, 1971. SAE Paper 710137.

Fawkes, Emerson E. "The Mixture Requirements of an Internal Combustion Engine at Various Speeds and Loads." Thesis, Massachusetts Institute of Technology, 1941.

Fisher, Walter. "Performance Effects of VehicleVariables." Society of Automotive Engineers, 1973. SAE Paper 730002.

Floyd, C.W. "Power Loss Testing of Passenger Tires." Society of Automotive Engineers, 1971.. SAE Paper 710576.

Flynn, Harold and Kyropoulos, Peter. "Truck Aerodynamics." Society of Automotive Engineers, 1961. SAE Paper 284A.

Freeman, J.H. and R.C. Stahman. "Vehicle Performance and Exhaust Emission Carburetion Versus Timed Fuel Injection." Society of Automotive Engineers, 1965. SAE Paper 650863.

French, Alexander. "The Petroleum Challenge." Paper presented at the Sixtieth Road School, Purdue University, March 6, 1974.

French, Alexander. "HighwayPlanning and the Energy Crisis." Paper presented at the 1973 Spring Training Conference, Federal Highway Administration, Kansas City, May 3, 1973.

French, Alexander and H. Bishop. "Analysis of Fuel Saving Through Reduced Speed Limits." Federal Highway Administration, April 16, 1974.

Gilbert, R.F. "Flywheel Drive Systems Study, Final Report." Lockheed Missiles and Space Company, July 31, 1972.

Giles, J.G. Automatic and Fluid Transmissions. London: Odhams Press, Ltd. 1961.

Greenshields, R.G. "150 Mpg Is Possible." Society of Automotive Engineers Journal, March 1950, pp. 34-38.

Heywood, John. "Fuel Economy as a Function of Emission Controls for Internal Combustion Engines." Massachusetts Institute of Technology, June 1973.

Hirst, Eric. Direct and Indirect Energy Requirements for Automobiles. Oak Ridge National Laboratory, March 1974.

Hirst, Eric. Energy Intensiveness of Passenger and Freight Modes, 1950-1970. Oak Ridge NationalLaboratory, April 1973.

Hirst, Eric. "Transportation Energy Conservation: Opportunities and Policy Issues." Testimony submitted to the Subcommittee on Conservation and Natural Resources, Committee on Government Operations, U.S. House of Representatives, July 1973.

"How Much is Air Drag Costing You?" Heavy Duty Trucking, October 1969, pp. 25-28.

Huebner, G.J. and D.J. Gasser. "Energy and the Automobile--General Factors Affecting Vehicle Fuel Consumption." Society of Automotive Engineers, 1973. SAE Paper 750518.

Hurter, Donald A. New Developments in Automotive Engines. Arthur D. Little, Inc., March 30, 1972.

Hussman, A.W., F. Kahoun, and R.A. Taylor. "Charge Stratification by Fuel Injection into Swirling Air." Paper presented at the 1962 Society of Automotive Engineers Combined National Fuels and Lubricants, Power Plant, and Transportation Meeting.

Hwang, David N. "Fundamental Parameters of Vehicle Fuel Economy and Acceleration." Society of Automotive Engineers, 1969. SAE Paper 690541.

Kelley, Kent B. and Harry Holcomb. "Aerodynamics for Body Engines." Society of Automotive Engineers, 1963. SAE Paper 649A.

Kelley, Kent, P. Kyropoulos, and W.F. Tanner. "Automobile Aerodynamics." Society of Automotive Engineers, 1960. Papers 148B, 148C, 148D, 148F.

Killackey, J., R. Morgan, C. Morse et al. Condenser and Fan

Development for Rankine Cycle Engines. Report prepared by AiResearch Manufacturing Company, Torrance, California, for the U.S. Environmental Protection Agency, Alternative Automotive Power Systems Division, November 1973.

Kruse, R.E. and T.A. Huls. "Development of the Federal Urban Driving Schedule." Society of Automotive Engoneers, 1973. SAE Paper 730553.

LaPointe, Clayton. "Factors Affecting Vehicle Fuel Economy." Society of Automotive Engineers, 1973. SAE Paper 730791.

Lay, W.E. "Is 50 Miles Per Gallon Possible with Correct Streamlining?" Part 1. Society of Automotive Engineers Journal, April 1933, pp. 144-156.

Lay, W.E. "Is 50 Miles Per Gallon Possible with Correct Streamlining?" Part 2. Society of Automotive Engineers Journal, May 1933, pp. 177-186.

Lienesch, John H. and Wallace R. Wade. "Stirling Engine Progress Report: Smoke Odor, Noise and Exhaust Emissions." Society of Automotive Engineers, 1968. SAE Paper 680081.

Little (Arthur D.) Inc. A Study of Technological Improvements to Automobile Fuel Consumption. Report prepared for the U.S. Department of Transportation and U.S. Environmental Protection Agency, July 1974.

Louden, R.K. and Ivan Kukey. "Computer Simulation of Automotive Fuel Economy and Acceleration." Society of Automotive Engineers, 1960. SAE Paper 196A.

Ludvigsen, Karl. "The Time Tunnel-- An Historical Survey of Automotive Aerodynamics." Society of Automotive Engineers, 1970. SAE 700035.

Malliaris, A.C. and R.L. Strombotne. "Demand for Energy by the Transportation Sector and Opportunities for Energy Conservation." In Energy: Demand, Conservation and Institutional Problems. Proceedings of a conference held the Massachusetts Institute of Technology, February 12-14, 1973. Cambridge: MIT Press, 1974.

Marks, Craig. "Which Way to Achieve Better Fuel Economy?" Paper presented at the California Institute of Technology Seminar, "Energy Consumption of Private Vehicles," December 1973.

Marshall, Kenneth D. "The Economics of Automotive Weight Reduction." Society of Automotive Engineers, 1970. SAE Paper 700174.

Mela, Donald F. How Safe Can We Be in Small Cars? National Highway Traffic Safety Administration, July 1974.

Mitchell, E.M., M. Alperstein, J.M. Cobb, and C.H. Faist. "A Stratified Charge Multifuel Military Engine-- A Progress Report." Society of Automotive Engineers, 1972. SAE Paper 720051.

Monaghan, M.L., C.C.J. French, and R.G. Freese. A Study of the Diesel as a Light-Duty Power Plant. Report prepared by Ricardo and Company Engineers, Sussex, England, for the U.S. Environmental Protection Agency, July 1974.

Motor Vehicle Manufacturers' Association. Motor Vehicle Facts and Statistics. 1972.

Mullins, P.J. "New Low Cost Fuel Injection System." Automotive Industries, February 1, 1973, pp. 40-42.

National Academy of Sciences. Panel on Manufacturing and Producibility. Manufacturability and Costs of Proposed Low-Emission Automotive Engine Systems. Report and appendices to the National Academy of Sciences, Committee on Motor Vehicle Emissions. Washington, D.C.: National Academy of Sciences, January 1973.

National Academy of Sciences. Panel on Testing, Inspection and Maintenance. Feasibility of Meeting the 1975-1976 Exhaust Emission Standards in Actual Use. Washington, D.C.: National Academy of Sciences, June 1973.

National Academy of Sciences/National Academy of Engineering. Coordinating Committee on Air Quality Control. Air Quality and Automobile Emission Control. Committee Print prepared for the Committee on Public Works, U.S. Senate. Volume I, Summary report. Washington, D.C.: Government Printing Office, September 1974.

Niepoth, George W. and Charles E. Scheffler. "Customer Fuel Economy Estimated from Engineering Tests." Society of Automotive Engineers, 1965. SAE Paper 650861.

Nutter, Robert D. A Perspective of Transportation Fuel Economy. Report prepared by the Mitre Corporation, Washington, D.C., April 1974.

Obert, E.F. Internal Combustion Engines. New York: Intext, 1968.

Obert, E.F. Internal Combustion Engines and Air Pollution. New York: Intext, 1973.

Ordorica, M.A. "Vehicle Performance Prediction." Society of Automotive Engineers, 1965. SAE Paper 650623.

Paterson, D.J. and N.A. Henein. Emissions from Combustion Engines and Their Control. Ann Arbor: Ann Arbor Science Publishers, Inc., 1972.

Peitsch, Gerhard and Ivan M. Swatman. "A Gas Turbine Super Transport Truck Power Package." Society of Automotive Engineers, 1965. SAE Paper 650272.

Penny, Noel. "The Potential for a Gas Turbine Car." Gas Turbine International, September/October 1972, pp. 14-16, 18-19.

Peterson, K.G. and R.E. Rasmussen. "Mechanical Properties of Radial Tires." Society of Automotive Engineers, 1973. SAE Paper 730500.

Prudhomme, R.K. "Automobile Emissions Abatement and Fuels Policy." American Scientist, March/April 1974, pp. 191-199.

Quinn, B.E. and S.A. Sattaripour. "Measurement and Prediction of the Dynamic Tire Forces of a Passenger Vehicle on a Highway." Prepared for the Federal Highway Administration, August 1972.

Raggio, David. "Stratified Charge Engine Development Sponsored by the Army Tank-Automotive Command." Presented at the U.S. Environmental Protection Agency, Ann Arbor, Michigan, October 1973.

Reid, John. "Aerodynamics of Motoring." Part 1. The Autocar, June 8, 1951, pp. 656-659.

Reid, John. "Aerodynamics of Motoring." Part 2. The Autocar, August 3, 1951, pp. 904-907.

Rice, Richard A. "Energy Efficiencies of the Transport Systems." Society of Automotive Engineers, 1973. SAE Paper 730066.

Rivard, J.G. "Closed Loop Electronic Fuel Injection Control of the Internal Combustion Engine." Society of Automotive Engineers, 1973. SAE Paper 730005.

Roberts, G.B. "Power Wasteage in Tires." In: International Rubber Conference, November 8-13, 1959, Washington, D.C., Proceedings, pp. 57-71.

Roensch, Max M. "The Automotive Engine--Today and Tomorrow." Society of Automotive Engineers, 1971. SAE Paper 710845.

Saal, C. "Performance Prediction Method Proved Valid in Truck Tests." Society of Automotive Engineers Journal, October 1950, pp. 17-21.

Schweikert, J.F. and J.H. Johnson. "A Turbocharged Spark Ignition Engine With Low Exhaust Emissions and Improved Fuel Economy." Society of Automotive Engineers, 1973. SAE Paper 730633.

Schweitzer, Paul H. "Correct Mixtures for Otto Engines." Society of Automotive Engineers, 1970. SAE Paper 700884.

Shure, Lloyd I., John T. Milton and James O. Spriggs. "Energy Uses in Transportation--What Does the Future Hold?" Society of Automotive Engineers, 1973. SAE Paper 730708.

Simko, A.M., M.A. Choma, and L.L. Repko. "Exhaust Emission Control by the Ford Programmed Combustion Process-- PROCO." Society of Automotive Engineers, 1972. SAE Paper 720052.

Southwest Research Institute. A Study of Technological Improvements to Automobile Fuel Consumption. Report prepared for the U.S. Department of Transportation and U.S. Environmental Protection Agency, July 1974.

Society of Automotive Engineers. Fuel Economy Measurement Procedures Task Force. "Fuel Economy Measurement--Road Test Procedures." April 1974. SAE Recommended Practice J1082.

Stahman, R.C. and A.H. Rose, Jr. "Emissions from Carbureted and Timed Port Fuel Injection Engines." Paper presented at the Annual Meeting of the Air Pollution Control Association, Houston, Texas, June 1964.

Sundstrand Aviation Corporation. Transmission Study for Turbine and Rankine Cycle Engines. Report prepared for U.S. Environmental Protection Agency, Advanced Automotive Power Systems Development Division, December 1972, APTD-1558.

Taylor, C.F. The Internal Combustion Engine in Theory and Practice. Volumes 1 and 2. Cambridge: MIT Press, 1968.

Thompson, Donald B. "Auto's Weight Reduction Push is Challenge for Steelmakers." Industry Week, September 10, 1973, pp. 26-29.

Tracor, Inc. "Technical Proposal and Business and Cost Proposal for a Feasibility Demonstration of Performance and and Fuel Savings with a Continuously Variable Transmission." July 1973.

U.S. Comptroller General. Cleaner Engines for Cleaner Air: Progress and Problems in Reducing Air Pollution from Automobiles. Office of Air Programs, Environmental Protection Agency, B-166506. Report to the U.S. Congress. May 15, 1972.

U.S. Comptroller General. Review of the Automobile Fuel Economy Testing and Labeling Program. Environmental

Protection Agency, B-166506. Report to the Subcommittee on Conservation and Natural Resources, Committee on Government Operations, U.S. House of Representatives, August 15, 1974.

U.S. Congress. House. "Maximum Desirable Dimensions and Weights of Vehicles Operated on the Federal-Aid Systems." House Document 354. 88th Congress, 2nd Session, 1964.

U.S. Congress. Senate. "Automotive Research and Development and Fuel Economy." Hearings before the Committee on Commerce on S.1055 and S.1903, May/June 1973.

U.S. Department of Transportation. Federal Highway Administration. Cost of Operating an Automobile--Suburban Based Operation. April 1972.

U.S. Department of Transportation. Federal Highway Administration. Economic and Social Effects of Highways. 1972.

U.S. Department of Transportation. Transportation Systems Center. "The Sensitivity of Projected Aggregate Fuel Consumption to the Conditions of Individual Fuel Economy Tests." May 1974.

U.S. Environmental Protection Agency. Emission Control Technology Division. An Evaluation of a 350 CID Compound Vortex Controlled Combustion (CVCC) Powered Chevrolet Impala. October 1973.

U.S. Environmental Protection Agency. Emission Control Technology Division. Mobile Source Pollution Control Program. February 1973.

U.S. Environmental Protection Agency. Office of Mobile Source Air Pollution Control. Report on Automotive Fuel Economy. October 1973.

U.S. Library of Congress. Congressional Research Service. The Prospects for Gasoline Availablilty: 1974. Committee Print for the Committee on Interior and Insular Affairs, U.S. Senate. Washington, D.C.: Government Printing Office, 1974.

U.S. Library of Congress. Congressional Research Service. History and Future of Spark Ignition Engines. Committee Print for the Committee on Public Works, U.S. Senate. Washington, D.C.: Government Printing Office, 1973.

Waddell, Richard L. "How Ford Decides on Plastics--Or Not." Ward's Auto World, September 1973, p. 71.

Waddell, Richard L. "How They're Battling the Bulge: Aluminum--Bumpers Now, Body Parts on the Way." Ward's Auto World, September 1973, pp. 42-43.

Waddell, Richard L. "How They're Battling the Bulge: Plastics--Versatility, Weight, Costs Are the Keys." Ward's Auto World, September 1973, pp. 44-45.

Waddell, Richard L. "How They're Battling the Bulge: Steel--'High Strength Low Alloy' Sums It Up." Ward's Auto World, September 1973, pp. 40-41.

Warren, G.B. "Some Factors Influencing Motorcar Fuel Consumption in Service." American Society of Mechanical Engineers, 1965. ASME Paper 65-WA/APC-2.

White, R.G.S. "Rating Scale Estimate Automobile Drag Coefficient." Society of Automotive Engineers Journal, June 1969, pp. 52-53.

Williams, Marcia et al. Automobile Exhaust Emission Surveillance of the FY 72 Program. U.S. Environmental Protection Agency, Office of Mobile Source Air Pollution Control, February 1974.

Williamson, Don. "Materials Men Stress Reducing Car Weight." Automotive News, March 26, 1973, pp. 29-30.

Witzky, J.E. "Stratification and Air Pollution." Institution of Mechanical Engineers, 1971. IME Paper C136/71.

Witzky, J.E. and J.M. Clark, Jr. "A Study of the Swirl Stratified Combustion Principle." Society of Automotive Engineers, 1966. SAE Paper 660092.

Wolf, Ralph F. "Rubber Use in 1974 Autos." Rubber Age, October 1973, pp. 36-44.

Addenda

Gumbleton, James J., et al. "Optimizing Engine Parameters With Exhaust Gas Recirculation." Society of Automotive Engineers, 1974. SAE Paper 740104.

Johnson, E.M. and C.W. Mortensen. "Passenger Car Trends Affecting Fuels and Lubricants." Society of Automotive Engineers, 1958. SAE Paper 12A.

National Academy of Sciences. Committee on Motor Vehicle Emissions. Automotive Spark Ignition Engine Emission Control Systems to Meet the Requirements of the 1970 Clean Air Act. May 1973.

Newhall, H.K. and I.A. Messiri. "A Combustion Chamber Designed for Minimum Engine Exhaust Emissions." Society of Automotive Engineers, 1970. SAE Paper 700491.

Scott, B.Y. "A Safety Comparison of Compact and Full-Size Automobiles." Paper presented at the Third International Congress on Automotive Safety, San Francisco, July 15, 1974.

Wahrebrock, R.J. Study of the Interactions of Fuel Volatility and Automotive Design as They Relate to Driveability. Ethyl Corporation, April 1972.