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DIESEL CARS IN THE UNITED STATES

June 1978

Prepared for:

U.S. Department of Energy
Washington, D.C.

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SRI International
333 Ravenswood Avenue
Menlo Park, California 94025
(415) 326-6200
Cable: SRI INTL MPK
TWX: 910-373-1246

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Prepared by:

Richard L. Goen and Mary E. Ivory
Center for Resource and Environmental Systems
Studies
Chemicals and Resources Group

Prepared for:

Dr. Daniel P. Maxfield
Division of Transportation
Energy Conservation
Department of Energy
20 Massachusetts Avenue, N.W.
Washington, D.C. 20545

Contract EY-76-C-03-0115
SRI Project CRU 6782
CRESS Report No. 52

AM03-76SF00115

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DIESEL CARS IN THE UNITED STATES

EXECUTIVE SUMMARY

Is there a message in climbing diesel car sales?

In 1977, nearly 45,000 diesel cars and pickup trucks were sold in the United States. By the end of 1978, sales are expected to reach 125,000. And some U.S. manufacturers are predicting that by 1985 25% of the new cars made in the United States may be diesel powered. Who buys diesels, what are their perceived and actual advantages, and what are their disadvantages? SRI looked at the "why" behind the growing popularity of diesel vehicles and their viability as an energy-efficient alternative to gasoline powered vehicles.

Who buys diesels and why?

Respondents to market surveys of diesel car buyers conducted by various groups listed fuel economy, low maintenance, and durability as primary reasons for choosing diesels. Discussions with diesel owners have also revealed a deep interest in technological innovation — many owners are "car buffs" to whom quality engineering is important. Also important among some owners is prestige. Nearly one third of the motorists surveyed said they would buy a reasonably priced diesel; two-thirds said they would wait until others had had experience with diesels before buying one. Those who leaned toward diesels generally had a high level of education and income. Positive response to diesels appears to ignore the generally lower horsepower of diesels and their lower acceleration performance compared with that of gasoline powered cars. Negative response to diesels appears to stem from the perception of possible maintenance/reliability problems, their noise, odor, poor cold weather starting, and the difficulty of finding fuel stations.

...and why not?

What about fuel availability?

Diesel car buyers surveyed, however, have not indicated that fuel availability has been a major concern in their decision to purchase. Diesel fuel is available in more than 10,000 fuel stations throughout the United States. Most of these are truck stops along the major highways intended to serve cross country trucking and farm equipment users — only about 5% of gasoline service stations also carry diesel fuel. Little growth is expected in diesel fuel stations at the present sales volume of diesel vehicles.

What about fuel economy?

The price of diesel fuel ranges from about 8¢ per gallon less than unleaded gasoline at full service pumps to about 3¢ per gallon less at self-service pumps of independent stations. At current prices this offers diesel car owners a potential saving of about 8% per gallon of fuel purchased. Diesel cars get an average of about 25% more miles to a gallon of fuel than do gasoline powered cars of comparable performance. Thus, savings in fuel costs to motorists are realized more through using less fuel than through lower priced fuel.

What about energy saving?

Although diesel cars get more miles to the gallon than gasoline-powered cars, diesel fuel has a higher energy content than gasoline. When this is taken into account, the energy saving associated with the use of a diesel vehicle, assuming 25% more miles to the gallon, is relatively small — about 11%. However, an additional energy saving could possibly be realized at the refinery. The present ratio of gasoline output to distillate output in U.S. refineries is about 1.7. If the gasoline/distillate ratio were lowered to 0.9 to make more diesel fuel, then, according to some analyses, 10% less energy would be used in the refining process relative to the energy in the additional diesel fuel produced. (Below a ratio of 0.9, the energy saving would drop sharply because hydrocracking would become necessary to produce the diesel fuel.) Adding this potential saving at the refinery to that realized in diesel car operation would bring the total energy saving to about 20%. A nationwide gasoline/distillate ratio of 0.9 could provide enough diesel fuel to convert 20% to 30% of the gasoline vehicle fleet to diesel, depending on how much of the distillate output is required for jet aircraft fuel. Converting this percentage of the gasoline fleet to diesel would result in a 4% to 6% net national saving of automotive petroleum energy.

What about emissions control?

Diesel cars have been able to meet interim auto exhaust emission standards without the necessity of adding emission control equipment. But meeting 1981 standards may be a different story, particularly for nitrogen oxides (NO_x) and particulates. Under these standards, NO_x will be reduced from 2 to 1 grams per mile (gpm), and auto makers doubt they can meet that requirement by 1981. Under some situations, a four-year waiver allowing up to 1.5 gpm for NO_x may be granted. A new standard for particulates for 1981 is expected to be announced in 1979. Since diesels emit a higher volume of particulates than gasoline cars (20 to 80 times more at comparable power), meeting this new standard is also in doubt.

What will determine future availability of diesel cars?

Auto makers are pursuing technological advances such as turbocharging to increase the horsepower and fuel economy in diesel engines and to reduce exhaust emissions. But the availability of diesel cars with their potentially substantial energy saving and inherently low carbon monoxide (CO) emissions will depend heavily on the development of adequate controls for NO_x and particulates or on the relaxation of standards for these pollutants.

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PREFACE

The project leader and principal author of this study was Richard L. Goen. Mary E. Ivory gathered most of the information and prepared Chapters III and VII. Benjamin E. Suta provided advice on statistical procedures. Robert E. Freeman and other diesel car owners at SRI provided insight into views and motivations of the diesel car buyer.

Michael A. Moore of SRI's Energy Center reviewed Chapter V, Fuel Economy, and contributed important suggestions. Philip D. Umholtz of SRI's Manufacturing Industries Center contributed to Chapters II and VI, and prepared the section on car manufacturers in Chapter VIII. Thomas F. Mandel of SRI's Center for the Study of Social Policy, and Robert H. Schwaar of SRI's Chemical Industries Center, reviewed the entire report.

Representatives of the auto companies producing or marketing diesel cars provided descriptive information and sales figures. The authors particularly acknowledge the assistance of Leo Levine, General Manager of Public Relations, Mercedes-Benz of North America, Inc., Andrew Schupack, Public Relations Manager of Volkswagen of America, Inc., and Cookie Martin of the Marketing Department at Peugeot, Inc.

I INTRODUCTION

The purpose of this study was to develop a better understanding of the causes of the recent increased interest in diesel cars, thereby providing insight into the related behavior of institutions and individuals. This knowledge may improve the formulation of federal policies for diesel, electric, and other more energy-efficient car systems.

The study describes developments in the diesel car field over the past few years, and discusses the present status of diesel cars. Historical data were assembled on diesel car sales and on parameters that might have affected the sales. SRI obtained the information by contacting the automobile companies and from a review of the automotive literature.

Our intent had been to conduct a statistical analysis to discover relationships between the diesel car sales in a region and parameters such as the number of diesel fuel outlets and diesel fuel prices in the region. However, we found that for the predominant diesel car in the United States--the Mercedes--the potential demand has exceeded production, and Mercedes-Benz has allocated cars to dealers. Because the pattern of diesel car sales has reflected the allocation method rather than demand, the intended statistical analysis would have been misleading. Consequently, we redirected our additional effort to summarizing the status of diesel cars, and to analyzing the implications that diesel cars have for fuel economy.

Although we did not conduct a questionnaire-type survey, we do present the results of surveys of diesel car buyers made by J. D. Power & Associates, and others. Also, we held informal discussions with SRI employees who own diesel cars.

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II STATUS OF DIESEL CARS

A. Diesel Car Sales

Sales of diesel cars in the United States have increased approximately seven-fold since 1973, when Mercedes-Benz, which offered the only diesel car in the country, sold 6,252 diesels. By the beginning of the 1978 model year, Mercedes-Benz had been joined by four other automakers--Peugeot, International Harvester (Scout), Volkswagen, and Oldsmobile. In 1977, more than 42,000 diesel cars were sold in the United States. Table 1 shows the sales of diesel cars by make and year since 1973.

Table 1

DIESEL CAR SALES IN THE UNITED STATES

	<u>1973</u>	<u>1974</u>	<u>1975</u>	<u>1976</u>	<u>1977</u>
Mercedes	6,252	10,107	18,578	20,051	22,434
Peugeot	0	n.a.	1,944	4,203	4,823
Scout	0	0	0	1,200	2,000
Volkswagen	0	0	0	0	12,861
Oldsmobile	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>n.a.</u>
Total	6,252	11,000	20,522	25,454	43,000

B. Status of Diesel Cars for Each Manufacturer

1. Mercedes-Benz

Mercedes-Benz has been marketing diesel cars in this country for 20 years. The engine displacement of the diesel engines has increased periodically. The 220D model replaced the 200D in 1968. (The numerical designation, 220, refers to an engine displacement of 2.2 liters, and the D stands for diesel.) In 1974, the 220D was replaced by the 240D. The 240D has a four-cylinder engine. In 1975 the model 300D with a five-cylinder engine was added. Since 1977, the models 240D and 300D, as well as the

gasoline models 230 (not available in California because of emissions regulations) and 280 have shared the same W123 body designation. Other, higher-priced gasoline models have larger bodies. In late 1977 a diesel coupe, the 300 CD, was added. The 300 SD, a turbocharged edition of the five-cylinder diesel, will be launched in June 1978, intended especially for the United States market. A diesel station wagon will be introduced in the fall of 1978.

A history of the sales of Mercedes diesel cars in the United States for the past 20 years is shown in Figure 1. Sales increased steadily through 1973. In 1974 and 1975, the sales of Mercedes diesel cars increased sharply, but then leveled off in 1976 and 1977.

During all of those years, demand for all Mercedes cars, and diesels in particular, exceeded production. The factory output of the cars was limited by the capacity of the production lines. Employment policies in West Germany emphasize stability of employment, and inhibit increases in capacity to meet possibly temporary surges in demand with possible subsequent lay-offs. Also, the policy of Daimler-Benz (the manufacturer of Mercedes-Benz cars) has been to hold production below demand to avoid fluctuations in production. Uncertainty about the future of Mercedes cars in the United States because of standards for fuel economy and emissions may also have contributed to the decision not to expand capacity to meet the demand. As a result, fewer diesel cars have been allocated to individual dealers in the United States than could have been sold if more cars had been available.

As a percentage of total U.S. Mercedes sales, diesels increased to 28% in 1965, but declined to 14% in 1972. However, the diesels' percentage increased sharply in 1974 and 1975, and has remained at approximately 46% during the past two years. Among the smaller Mercedes, diesels accounted for 47% of sales in 1974, increasing their share to 81% in 1977.

According to the Kelley Blue Book, the price of the Mercedes diesel model in 1973 was approximately \$200 higher than the price of the corresponding gasoline model (Table 2). The 240D introduced in 1974 was priced lower than the corresponding 230 in 1974 and 1977, but cost more in 1975 and 1976.

FIGURE 1. HISTORY OF MERCEDES DIESEL CAR SALES IN THE UNITED STATES

Table 2

PORT-OF-ENTRY PRICES OF NEW MERCEDES DIESEL
AND CORRESPONDING GASOLINE MODELS*

<u>Model</u>	<u>Fuel</u>	<u>1973</u>	<u>1974</u>	<u>1975</u>	<u>1976</u>	<u>1977</u>
220	Gasoline	\$8,525				
220D	Diesel	8,742				
230 [†]	Gasoline		\$8,530	\$10,631	\$12,116	\$14,283
240D	Diesel		8,250	10,760	12,296	14,149
280	Gasoline			12,900	14,457	17,114
300D	Diesel			12,338	14,218	16,590

* Price includes automatic transmission, power steering, air conditioning, and power windows.

[†] Not available in California

Source: Kelley Blue Book, November-December 1977.

Figures from Mercedes-Benz, however, show the diesel 220D without automatic transmission priced approximately \$230 lower than the gasoline 220 without automatic in 1973. With an automatic transmission, the diesel 240D in 1974 cost \$295 more than the corresponding gasoline 230 model. In 1975, 1976, and 1977, the 300D model was priced lower than the corresponding 280 model. The primary reason reported for the lower prices of the diesel models is that the elimination of the emissions control equipment required for the gasoline models offsets the higher costs of the diesel engines.

Always an expensive luxury car, the Mercedes has nonetheless increased dramatically in price in recent years. In 1974, for example, a 230 cost \$8,530. In 1977, the same model sold for \$14,282, a 68% higher price. The cost of the corresponding diesel car, the 240D, has also risen comparably. Part of the increase is from inflation, but much of the boost has been powered by the soaring value of the West German mark relative to the dollar. Since 1970, international exchange rates have dropped the dollar from a value of four marks to an exchange rate of two marks in March 1978.

As Table 2 shows, a diesel model has usually been the lowest-priced or near the lowest-priced Mercedes available. Indeed, in California, a diesel model has been between \$2,000 and \$3,000 less than the least expensive gasoline model Mercedes on the market. However, the acceleration of the diesel models is substantially lower than that of the corresponding gasoline model with approximately equal engine displacement. In terms of horsepower, the diesel 300D would be more nearly equivalent to the gasoline 230. Thus, for equivalent horsepower, a diesel would cost approximately \$2,000 more. Some performance parameters of the diesel and gasoline Mercedes are listed in Table 3.

Table 3

SELECTED PERFORMANCE CHARACTERISTICS OF MERCEDES 1977 DIESEL
AND CORRESPONDING GASOLINE MODELS

	Gasoline 230	Diesel 240D	Gasoline 280	Diesel 300D
Net horsepower @ rpm	86 @ 4800 ^b	62 @ 4000 ^a	142 @ 5750 ^a	77 @ 4000 ^a
Net torque (ft-lbs @ rpm)	n.a.	97 @ 2400 ^a	149 @ 4600 ^a	115 @ 2400 ^a
Acceleration,* 0-60 mph (seconds)	n.a.	30 ^e	11.4 ^d	20.3 ^c
Curb weight - lbs	n.a.	3210 ^a	3530 ^a	3515 ^a

* Considerable variation exists in the figures for acceleration listed in different sources. Consequently, comparisons of acceleration of different cars based on different sources may not be valid. The times to accelerate from 0 to 60 mph given by Consumer Reports tend to be higher than the times reported by other sources.

^a Mercedes-Benz Technical Specifications

^b Ward's 1977 Automotive Yearbook

^c Road & Track, September 1977

^d Road & Track, November 1977

^e Consumer Reports, August 1974

In addition to publicity about the energy problem, three other factors may have contributed to the sharp increase in the sales of Mercedes diesel cars since 1973. The first is the introduction of the 240D in 1974 and the 300D in 1975. Those diesel models provided a substantial improvement in performance over the earlier 220D. The second is the pricing of the diesel models near or below the price of the equivalent* gasoline models. The third is that in California, a diesel model is much less expensive than the lowest-priced gasoline model available.

2. Peugeot

Peugeot has been producing diesel cars for 50 years. But it was only in 1974 that diesel Peugeots were introduced in the U.S. market. Two diesel models are sold in the United States: the 504 four-door sedan, and the 504 station wagon.

Table 4 shows the prices of the diesel and gasoline Peugeot models since 1974. The price for the diesel in 1977 was \$1300 more than for the gasoline model. In spite of such a large premium for the diesel, nearly half of the Peugeots sold in this country have been diesels.

Table 4

NEW CAR PRICES FOR PEUGEOT DIESEL AND GASOLINE MODELS*

<u>Model</u>	<u>Fuel</u>	<u>1974</u>	<u>1975</u>	<u>1976</u>	<u>1977</u>
Sedans					
504/504GL	Gasoline	\$4,830	\$5,610	\$6,665	
504SL	Gasoline			7,180	\$7,360
504A	Diesel	5,800	6,630	8,260	8,660
Station Wagons					
504	Gasoline	5,380	6,220	n.a.	7,840
504	Diesel	6,350	7,240	8,725	9,140

* Without optional equipment

Source: Kelley Blue Book, November-December 1977.

* In engine displacement.

In 1977, the displacement of the diesel engine was increased to 2.3 liters from the previous 2.1 liters. The previous, smaller-displacement engine had 62 net horsepower at 4500 rpm. The present diesel engine has a net horsepower of 71 at 4500 rpm (Road & Track, September 1977), compared with 88 hp at 5500 rpm for the gasoline engine (Ward's 1977 Automotive Yearbook). The curb weight of the diesel sedan is 3046 pounds (Consumer Reports, August 1974). The acceleration from 0 to 60 mph takes 21.7 seconds (Road & Track, September 1977) or 27.5 seconds (Consumer Reports, August 1974) depending on the source.

3. Volkswagen Rabbit

A diesel model of the Volkswagen Rabbit was introduced in the United States in the spring of 1977, although the diesel had previously been marketed in Europe. The diesel engine design is a modification of the Rabbit gasoline engine.

Demand for the Rabbit diesel has greatly exceeded the production, resulting in several months' wait for the buyers. In 1977, Volkswagen sold 165,000 gasoline Rabbits in the United States, and 12,900 diesel Rabbits. Volkswagen of America expects to sell 20,000 diesel Rabbits in 1978, and believes it could sell more if they were available.

Up to February, 1976, Volkswagen had not advertised the diesel Rabbit, except for mailing a brochure to previous Rabbit buyers. Sales of the diesel have been stimulated by the prior marketing in Europe and the good press received there. The diesel Rabbit has also received good reviews in car magazines in the United States. The diesel Rabbit is selling evenly across the country because it is distributed evenly to all dealerships as a standard percentage of their total Volkswagen deliveries. In the view of Volkswagen's public relations manager, the people who buy the diesel Rabbits are interested in economy or are diesel buffs, or are merely interested in new, innovative cars and engines (Andrew Schupack, personal communications, 16 February and 21 March 1978).

The extra price of the optional diesel engine is \$195. The base price of the diesel Rabbit C in California (January 1978) is \$5,300, and \$5,600 for the Rabbit L. However, most diesel Rabbits come equipped with additional

accessories at extra cost. The diesel model cannot be obtained with automatic transmission or air conditioning.

Table 5 compares the performance of the diesel and gasoline Rabbits. The curb weight of the diesel two-door Rabbit is 2,042 pounds. The data in Table 5 are from Volkswagen brochures. Other sources list both higher and lower values for acceleration.

Table 5
PERFORMANCE OF RABBIT DIESEL AND
GASOLINE MODELS

	Gasoline	Diesel
Engine displacement, liters	1.46	1.47
Net horsepower @ rpm	71 @ 5800	48 @ 5000
Net torque ft-lb @ rpm	n.a.	46.5 @ 3000
Acceleration, 0-60 mph, seconds	13	18

4. Oldsmobile

The Oldsmobile division of General Motors has also introduced diesel cars. The Oldsmobile diesel engine, like the Rabbit's, was developed from a gasoline engine, in Oldsmobile's case from a 350-cubic-inch (5.7-liter) displacement V-8. The Oldsmobile diesel engine is used in the full-sized Oldsmobile Eighty-Eights, Ninety-Eights, and Custom Cruiser car models. It is also used in another General Motors product, the Chevrolet light-duty truck. It will also be used soon in General Motors' Cadillac Seville. Oldsmobile had planned to build 100,000 diesel engines in the first model year, 1978, with half of them to be used in cars. However, a problem with durability on the camshafts of the engines has slowed the deliveries of diesel cars and light trucks.

As of February, Oldsmobile had delivered only 3,200 diesel cars and had unfilled orders for 6,000 (Autoweek, 17 February 1978). About 3,600 diesel pickups had been delivered to dealers, but nearly 10,000 orders remained unfilled. The originally-targeted production rate of 400 diesel engines per day was expected to be reached soon. Oldsmobile expects to produce 70,000 to 80,000 diesel engines in 1978 (F. W. Bennet, personal

communication, 30 March 1978). Production of 250,000 diesel engines is planned for 1979.

The additional cost of the diesel engine option is either \$740 or \$850, depending on whether the vehicle's base engine is the 350 V-8 or the 231 (3.8 liters) V-6 (Automotive Engineering, November 1977).

The basic Oldsmobile diesel block is 111 pounds heavier than the gasoline version. The same block could also be used as a 450-cubic-inch (7.4-liter) displacement gasoline engine. The entire installation, counting two batteries, a bigger radiator and starter, etc., weighs about 180 pounds more than the gasoline version.

Net horsepower of the diesel Oldsmobile is 120 at 3600 rpm and net torque is 220 foot-pounds at 1600 rpm. It accelerates from 0 to 60 mph in 14.4 seconds (Road & Track, November 1977).

5. International Scout

The International Scout, a four-wheel drive sport and utility vehicle, has an optional diesel engine. Supplied by Nissan Motors (Japan), the engine is a six-cylinder with a 198-cubic-inch (3.2-liter) displacement, and net horsepower of 81 at 3800 rpm. For comparison, the standard four-cylinder gasoline engine has 86 horsepower.

The optional diesel engine adds \$2,600 to the representative price of \$6,153 (Kelley Blue Book, November-December, 1977).

International expects to sell only 1,300 diesel Scouts in 1978 because the engine manufacturer cannot provide enough engines to produce more (R. Sabel, personal communication, 30 March 1978).

C. Plans for the Future

Several auto manufacturers have discussed plans for substantial use of diesel engines in their cars. General Motors expects to build 250,000 diesel engines for cars and light trucks in 1979 (Autoweek, 17 February 1978) and to use diesel engines in 25% of its cars by 1985 (Christian Science Monitor, 15 February 1978). Chrysler will use Mitsubishi (Japan) diesel engines in pickup trucks beginning some time in the 1978 model year,

and is reported to be working on its own passenger car diesel engine for 1979-1980. Eugene A. Cafiero, President of Chrysler, expects 25% of all cars made in the United States in 1985 to be diesel-powered (Road & Track, January 1978). Ford is offering diesel engines now on the European-built Granada, with the engines bought from Peugeot. Lee A. Iococca, the President of Ford, said Ford would probably take the same route if it decided to put diesels in pickup trucks (Autoweek, 9 December 1977).

Most of the world's major auto manufacturers have plans for converting a number of their present gasoline engines into diesels. Some of the more likely and immediate prospects for conversion include the General Motors 260-cubic-inch (4.3-liter) displacement V-8 and the Chrysler 225-cubic-inch (3.7-liter) displacement Slant-6.

Opel, Citroen, and Alfa Romeo offer diesel models in Europe, in addition to Mercedes-Benz, Peugeot, and Volkswagen. A Fiat 131 with a diesel engine went on sale in Italy in the spring of 1978 (Road & Track, December 1977). Nissan (the maker of Datsun) offers diesel engines in its cars in Japan (Road & Track, November 1977). As mentioned previously, Nissan supplies the diesel engines used in the International Scout.

1. Dependence of Plans on Consumer Acceptance

The realism of these plans has been questioned by many sources, both in and out of the industry. As with any significant innovation, plans are made on a positive, success-oriented basis, but progress is adjusted to a rate that allows close observation of consumer acceptance and the solution of developmental, production, and operational problems.

Consumer acceptance is difficult to define and measure. As discussed in Chapter VII, evidence indicates that there is a group of people who would be much more interested in owning a diesel than a conventional car. Motivations include:

- A desire to be different--a matter of image
- Technical interest
- Operational economy
- The high-mileage user who stands to reduce overall costs
- Concern for the environment and conservation.

This group has been large enough to create a strong demand, and indeed a shortage when production has been limited. How big this group is, and how the rest of the car-buying public will react to diesels, is unknown. Cost will be a major factor in any widespread acceptance, and no matter what the sticker price indicates, the "bottom line" difference between a diesel and a gasoline-powered car or light truck ranges from somewhere over \$500 all the way to \$2,500. It is believed that in the future, pricing strategies could be adjusted to allow about a \$500 differential. Both Volkswagen and General Motors are apparently holding back production until they have more information and experience.

2. Developmental and Operational Problems

Developmental and operational problems have also arisen and are being addressed as rapidly as possible. In the case of Volkswagen, it was found that U.S. diesel fuel is not as highly refined as that used in Europe, and a variety of injector problems developed. Improved fuel filtration is believed to have solved the problem. General Motors is reported to be having problems with the durability of internal engine parts. Both the General Motors and Volkswagen cars could not be started on numerous occasions during the cold spell in the winter of 1977-1978 in the northern part of the midwest. Apparently neither car can be started at about -20° F, and there are no fuel options easily available that will solve the problem.

3. Alternative to Diesel Engines

As one little-publicized alternative, Ford may use its PROCO (Programmed Combustion) engine instead of diesels. The PROCO is a stratified-charge, high-pressure, direct-injection, gasoline-fueled engine that operates at intermediate compression ratios and uses spark ignition. It is claimed by its proponents to be superior to the diesel engine in all respects (emissions, economy, particulates, noise, smoke, odor, weight, durability, cost, etc.) except developmental experience. A decision on its production is expected in mid-1978, and the first size to be considered would be about 300-cubic-inch (4.9-liter) displacement.

4. Effects of Air Emission Standards

Volkswagen is thinking of converting the engines in the Scirocco and the Dasher to diesels, but is waiting to see what Congress decides to do about air emissions standards (Andrew Schupack, personal communication, 13 February 1978). To meet fuel economy standards, Mercedes will have to sell mostly diesel cars in this country. Hence, that company is particularly concerned about the 1981 NO_x standards of 1.0 gram per mile, which it does not expect to be able to meet with its diesel cars.

In fact, the future of diesel engines in passenger cars in this country may be dependent on NO_x emissions standards and future standards on particulates, noise, or odor. This issue will be discussed more in Chapter VI.

5. Potential Technological Advances

Turbocharging is the major potential future advance in diesel car engines. Turbocharging provides a substantial increase in horsepower with the same size engine, yields an increase in fuel economy, and decreases exhaust emissions. The turbocharged version of the Mercedes five-cylinder diesel car, the 300 SD, to be introduced in June 1978, develops 110 hp, a 44% gain over the non-turbocharged engine (Automotive Engineering, January, 1978). Volkswagen is also working on turbocharged diesel engines, and has demonstrated a turbocharged diesel Research Vehicle in the United States to EPA and the National Highway Traffic Safety Administration. It is about 200 pounds heavier than the standard Rabbit, has a five-speed manual transmission, and got 60 miles per gallon in the highway test model. The car could be put into production in three years, and the engine and drive train in less time than that.

Another potential technological advance is the Adiabatic Diesel Engine under development by the Army Tank-Automotive Research and Development Command (Research/Development, January 1978). The engine concept insulates the diesel combustion chamber to allow high temperature operation. The engine is expected to improve fuel economy by 30%, compared with conventional diesel engines. However, the engine is only a very long-range prospect for passenger cars.

III GEOGRAPHICAL DISTRIBUTION OF DIESEL CAR SALES

This chapter shows the geographical distribution of Mercedes and Peugeot diesel cars, the only two makes with sufficient sales history to warrant compilation.

A. Mercedes-Benz

Sales of any car in the United States are affected by a number of variables, including availability, price, style, options, color, fuel availability, and so on. Mercedes sales are affected by those variables, as well as two other more important factors: the allocation system, and production line capacity. Because the demand for Mercedes cars was exceeding production, Mercedes-Benz of North America instituted an allocation system in 1974. The cars are distributed to individual dealers on the basis of their sales for the preceding rolling 12-month period (W. Armstrong, personal communication, 20 March 1978). When allocating the cars, Mercedes-Benz tries to provide the dealers with their historical mix of models. Naturally, that is not always possible because of the changes made in various models through the years. Also, the diesel share of the model mix has increased. Other factors, such as buying and selling among dealers, dock strikes, and factory strikes have also affected allocations. Consequently, the sales of Mercedes in the sales zones reflects more the allocation method than the relative demand for the cars. The allocation of diesel cars to the dealers is not even a reflection of the relative demand for diesel cars before the present allocation scheme was imposed in 1974 because the diesel models have always been in short supply. Therefore, no attempt has been made to do a regression analysis to determine the effect of geographical variables on Mercedes diesel car sales because the results would be misleading.

Production capacity is an important consideration because often the demand in the U.S. market and in other countries is more than Daimler-Benz can meet. As discussed in Chapter II, Daimler-Benz policy has been to refrain from expanding production capacity so that employees hired for peak production would not be laid off once the demand stabilized.

Table 6 lists the annual sales of Mercedes diesel and gasoline models from 1974 to 1977 in each of Mercedes' sales zones in the United States. The sales zones themselves are shown in Figure 2. After 1975 the Cleveland zone was divided between the Chicago and Washington zones.

The proportion of diesel sales has been similar among the zones, except for the Los Angeles zone, where the proportion of diesel sales has been lower. The difference may reflect the heavy demand in the Los Angeles area for the larger, more prestigious models, which have not included a diesel option.

We have estimated the total sales of all new cars in the United States in the Mercedes-Benz sales zones from the state new car registrations (Ward's, 1977). For states that are divided between two Mercedes-Benz sales zones, the new car registrations in each zone were estimated on the basis of the 1977 population (American Map Company, 1977). New car registrations by state for 1977 were estimated on the basis of the ratio of total 1977 sales (11.2 million) (Automotive Industries, 1 January 1978) to total 1976 sales (10.1 million) (Automotive Industries, 1 February 1977).

Table 7 shows the sales of Mercedes--gasoline and diesel--in relation to total new car registrations in the Mercedes-Benz sales zones for the past four years. The Chicago zone (Midwest) has had the lowest proportion of Mercedes and diesel Mercedes. The Los Angeles zone has been the highest in both categories, even though the percentage of diesel Mercedes sold in that zone has been below the national average.

An automotive marketing study by The New Yorker magazine provides a further indication of the geographical distribution of Mercedes diesel car sales. Table 8, derived from that study, shows the concentration of the 1976 Mercedes-Benz sales in the seven primary trading areas with the highest sales. Those areas, with 23% of the population of the United

Table 6

GEOGRAPHIC DISTRIBUTION OF SALES OF
MERCEDES DIESEL AND GASOLINE CARS

Zone	1974				1975			
	Diesel	Gasoline	Total	Pct. Diesel	Diesel	Gasoline	Total	Pct. Diesel
New York	2,166	5,424	7,590	29%	3,322	5,064	8,386	40%
Washington	1,597	3,310	4,907	33	2,990	3,359	6,349	41
Jacksonville	1,333	3,071	4,404	30	2,364	2,924	5,288	45
Chicago	1,273	2,955	4,228	30	2,046	2,905	2,951	41
Houston	949	2,672	3,621	26	2,096	2,473	4,569	46
San Francisco	1,132	2,850	2,982	28	2,278	2,631	4,909	46
Los Angeles	800	6,197	6,997	11	2,031	5,902	7,933	26
Cleveland	661	1,461	2,122	31	1,102	1,338	2,440	45
Home Office	195	120	315	62	349	85	434	80
Total	10,106	28,060	38,166	26%	18,578	26,681	45,259	41%

Zone	1976				1977			
	Diesel	Gasoline	Total	Pct. Diesel	Diesel	Gasoline	Total	Pct. Diesel
New York	3,398	4,402	7,800	44%	3,641	5,031	8,672	42%
Washington	3,174	3,345	6,519	49	3,485	3,514	6,999	50
Jacksonville	2,456	2,648	5,104	48	2,663	2,984	5,647	47
Chicago	2,777	3,243	6,020	46	2,784	3,599	6,383	44
Houston	2,385	2,055	4,440	54	2,529	2,356	4,885	52
San Francisco	2,614	2,368	4,982	52	3,185	2,969	6,154	52
Los Angeles	3,013	5,005	3,018	36	3,666	5,880	9,546	38
Home Office	235	85	319	73	481	105	586	82
Total	20,051	23,151	43,202	46%	22,434	26,438	48,872	46%

Source: Mercedes-Benz, 1974, 1975, 1975, 1977.

FIGURE 2 MERCEDES-BENZ SALES ZONES

Table 7

SALES OF MERCEDES AND DIESEL MERCEDES AS A PERCENTAGE
OF TOTAL NEW CAR REGISTRATIONS, BY ZONE

Zone	Mercedes				Diesel Mercedes			
	1974	1975	1976	1977	1974	1975	1976	1977
New York	0.53%	0.63%	0.53%	0.53%	0.15%	0.25%	0.23%	0.22%
Washington	0.42	0.57	0.38 [*]	0.36 [*]	0.14	0.27	0.18 [*]	0.18 [*]
Jacksonville	0.40	0.53	0.43	0.42	0.12	0.24	0.20	0.20
Chicago	0.26	0.33	0.21 [*]	0.20 [*]	0.08	0.14	0.10 [*]	0.09 [*]
Houston	0.34	0.47	0.36	0.35	0.09	0.20	0.19	0.18
San Francisco	0.54	0.69	0.61	0.68	0.15	0.32	0.32	0.35
Los Angeles	1.37	1.72	1.45	1.55	0.16	0.44	0.54	0.60
Cleveland	0.18	0.20	*	*	0.06	0.09	*	*
Total United States	0.44%	0.55%	0.44%	0.45%	0.12%	0.22%	0.21%	0.20%

* Cleveland zone divided between Washington and
Chicago zones after 1975.

Sources: Derived from Ward's, 1977, and Mercedes-Benz, 1974 to 1977.

States, accounted for 42% of 1976 Mercedes sales. The Mercedes sales in the Los Angeles and Miami-Fort Lauderdale areas were three times as great in relation to population as the national average. The San Francisco and Washington areas also show high sales in relation to population.

Table 8
CONCENTRATION OF 1976 MERCEDES SALES IN
PRIMARY TRADE AREAS

<u>New Yorker Primary Trade Area</u>	<u>Pct. of U.S. Population*</u>	<u>Pct. of 1976 Mercedes Sales†</u>
Los Angeles	4.3%	15.1%
New York	8.6	10.7
San Francisco	2.1	5.4
Chicago	3.7	4.0
Washington	1.3	2.9
Miami-Fort Lauderdale	0.9	2.6
Philadelphia	<u>2.6</u>	<u>2.5</u>
Total	22.5%	42.2%

* The New Yorker, 1974.

† Derived from The New Yorker, 1977.

Although the data do not separate the sales of the diesel and gasoline Mercedes, a similar concentration of diesel car sales can be inferred.

B. Peugeot

Table 9 presents the annual sales of Peugeot diesel and gasoline cars for 1975 to 1977 in each of Peugeot's eight sales regions in the United States. The states included in each region are shown in Figure 3.

Peugeot sales have been highest in the West Coast region--approximately twice as much, in relation to population, as the national average. However, the proportion of Peugeot sales that are diesels in that region has been close to the national average. The proportion of diesel sales has been highest in the Southwest region and lowest in the Empire region. Diesel car sales increased 60% between 1975 and 1977, although total Peugeot sales declined. The increase in diesel car sales, however, was from a very low base.

Table 9

GEOGRAPHICAL DISTRIBUTION OF PEUGEOT DIESEL
AND GASOLINE CAR SALES

Region	1975				1976			
	Gasoline	Diesel	Total	Pct. Diesel	Gasoline	Diesel	Total	Pct. Diesel
New England	1,321	212	1,533	14%	689	392	1,081	36%
Empire	1,571	155	1,726	10	932	340	1,272	27
Mid-Atlantic	939	184	1,123	16	480	285	765	37
Midwest	1,293	261	1,554	17	607	558	1,165	48
Southeast	392	115	507	23	155	227	382	59
Southwest	537	204	741	28	332	487	819	59
Independent East								
Coast Distributor	927	216	1,143	19	382	360	742	49
West Coast	2,400	597	2,997	20	1,423	1,554	2,977	52
Total U.S.	9,380	1,944	11,324	17%	5,000	4,203	9,203	46%
-								
Region	1977							
	Gasoline	Diesel	Total	Pct. Diesel				
New England	768	577	1,345	43%				
Empire	916	460	1,376	33				
Mid-Atlantic	434	363	797	46				
Midwest	516	557	1,073	52				
Southeast	167	226	393	58				
Southwest	305	503	808	62				
Independent East								
Coast Distributor	347	441	788	56				
West Coast	1,550	1,696	3,246	52				
Total U.S.	5,003	4,823	9,826	49%				

Source: C. Martin, personal communication, 20 March 1978.

FIGURE 3 PEUGEOT SALES REGIONS

IV DIESEL FUEL STATIONS AND PRICES

A. Diesel Fuel Stations

Only a small proportion of U.S. service stations carry diesel fuel. Consequently, some drivers have to go out of their way to find diesel fuel. However, the diesel car buyer surveys (Chapter VII) have not indicated that the availability of fuel has been a major concern affecting the purchase decision.

The problem of finding diesel fuel has been made easier by the availability of the Diesel Stop Directory, published by Hammond, Inc. The publication contains maps showing the locations of diesel fuel stations, and a directory listing the names and addresses of the diesel fuel stations in each town. Mercedes-Benz provides a version of the directory with each diesel Mercedes.

The number of diesel fuel stations listed in the Diesel Stop directories for 1976 and 1977, by state, are given in Table 10. The total number of diesel fuel stations listed for the United States increased from 6,990 in 1976 to 9,718 in 1977, an increase of 39%. However, Mr. C. D. Hammond of Hammond, Inc. believes that the increase represents primarily better coverage in the directory, and that there has been no substantial growth in the number of stations that carry diesel fuel (C. D. Hammond, personal communication, 17 March 1978). The information for the directory comes from petroleum companies and trade organizations. As they have become more aware of the directory, they have been supplying more comprehensive listings of their diesel fuel stations. The 1978 edition of the directory will include approximately 1,000 more diesel fuel stations for the United States and Canada, above the 11,200 locations listed in the 1977 directory. Most diesel fuel outlets are established to serve trucks or farm equipment. In South Dakota, for example, the Cenex Co-op has many diesel fuel stations to serve farmers, which accounts for the high proportion of diesel fuel

Table 10
DIESEL FUEL STATIONS, BY STATE

	Diesel Fuel Stations			Service Stations		Diesel Fuel Stations as Pct. of Service Stations	
	1977	1976	Increase 1976-1977 *	1977	1976	1977	1976
Alabama	223	222	0.5%	3,667	3,716	6.1%	6.0%
Alaska	58	34	70	196	199	29.6	17.1
Arizona	81	71	14	1,916	1,942	4.2	3.7
Arkansas	147	114	29	2,556	2,591	5.8	4.4
California	524	395	33	15,571	15,782	3.4	2.5
Colorado	177	122	45	2,577	2,612	6.9	4.7
Connecticut	82	62	32	2,275	2,306	3.6	2.7
Delaware	29	25	16	453	459	6.4	5.4
District of Columbia	14	14	0	259	262	5.4	5.3
Florida	341	245	39	7,479	7,580	4.6	3.2
Georgia	324	257	26	5,471	5,546	5.9	4.6
Hawaii	17	17	0	390	396	4.4	4.3
Idaho	99	51	94	970	983	10.2	5.2
Illinois	279	220	27	8,302	8,413	3.4	2.6
Indiana	180	147	22	5,069	5,138	3.6	2.9
Iowa	218	160	36	3,616	3,665	6.0	4.4
Kansas	287	141	103	2,934	2,974	9.8	4.7
Kentucky	148	119	24	3,188	3,231	4.6	3.7
Louisiana	158	127	24	3,189	3,233	5.0	3.9
Maine	84	59	42	996	1,009	8.4	5.8
Maryland	193	140	38	2,449	2,482	7.9	5.6
Massachusetts	153	107	43	3,819	3,871	4.0	2.8
Michigan	264	146	81	7,251	7,349	3.6	2.0
Minnesota	248	114	118	3,728	3,778	6.7	3.0
Mississippi	163	143	14	2,215	2,247	7.4	6.4
Missouri	349	250	40	5,106	5,175	6.8	4.8
Montana	160	74	116	967	981	16.5	7.5
Nebraska	244	178	37	1,841	1,866	13.3	9.5
Nevada	58	47	23	649	658	8.9	7.1
New Hampshire	67	33	103	722	732	9.3	4.5
New Jersey	237	206	15	4,689	4,753	5.1	4.3
New Mexico	106	73	45	1,489	1,509	7.1	4.8
New York	278	217	28	9,235	9,360	3.0	2.3
North Carolina	277	246	13	5,647	5,724	4.9	4.3
North Dakota	161	44	266	740	750	21.8	5.9
Ohio	321	210	53	9,531	9,660	3.4	2.2
Oklahoma	251	175	43	3,376	3,422	7.4	5.1
Oregon	113	99	14	2,299	2,330	4.9	4.2
Pennsylvania	322	265	22	9,151	9,275	3.5	2.9
Rhode Island	28	12	133	733	742	3.8	1.6
South Carolina	159	132	20	3,024	3,065	5.3	4.3
South Dakota	134	71	89	952	965	14.1	7.4
Tennessee	171	159	8	4,210	4,249	4.1	3.7
Texas	849	558	52	13,917	14,105	6.1	4.0
Utah	112	69	62	1,223	1,239	9.1	5.6
Vermont	64	38	68	485	491	13.2	7.7
Virginia	198	202	-2	3,779	3,830	5.2	5.3
Washington	134	79	70	3,187	3,251	4.2	2.4
West Virginia	70	52	35	1,753	1,777	4.0	2.9
Wisconsin	264	182	45	4,213	4,270	6.3	4.3
Wyoming	100	67	49	628	636	15.9	10.5
Total United States	9,718	6,990	39%	183,803	186,579	5.3%	3.7%

* The increase in the number of diesel fuel stations listed in the directories is thought to reflect better coverage of stations rather than an increase in the number of stations carrying diesel fuel.

Sources: Diesel Stop Directory, 1976 and 1977; 1977 National Petroleum News Factbook Issue.

stations in that state shown in Table 10. Little expansion in the number of diesel fuel stations is expected until a larger proportion of the cars are diesels.

Menlo Park, California (headquarters of SRI International), offers an example of a special situation in which service stations have added diesel fuel in the last three years; two of them in the last year and a half. Atherton, an affluent, suburban town on the San Francisco peninsula, adjacent to Menlo Park, has a high concentration of Mercedes. Some owners of diesel cars have noticed many new Mercedes outlets for diesel fuel in the last five to 10 years, but no definite statistics are available to verify whether or not any substantial net growth has taken place.

Table 10 also shows the number of service stations in each state. The data are from the 1977 National Petroleum News Factbook Issue. The diesel fuel stations listed in 1977 constituted only 5.3% of the service stations in the country. The percentage of diesel fuel stations varied widely among the states. Alaska and the Rocky Mountain and northern plains states have the highest percentage of diesel fuel stations.

In most areas, for long trips, there are enough diesel fuel stations along the major highways so that fueling restrictions are minimal. Along California freeways, service signs sometimes include identification of turnoffs for diesel fuel. However, driving outside of normal station operating hours may introduce some uncertainty about finding a particular station open. The main problem of fuel availability appears to be for drivers in some parts of the metropolitan areas, or in some rural areas, where their normal driving patterns may not take them close to any diesel fuel stations. In addition, eight states--Arizona, Colorado, Massachusetts, Michigan, Oregon, Montana, New Mexico and Wyoming--require operators of diesel automobiles to obtain a license to buy diesel fuel.

B. Diesel Fuel Prices

The prices of diesel fuel are generally lower than the prices of gasoline which offers additional incentive to purchase diesel cars above their advantage of using less fuel. Because most new cars have required unleaded gasoline since 1975, the prices of unleaded gasoline are the most appropriate basis for comparison with diesel fuel prices.

The principal source of data on motor fuel prices is the Lundberg Survey, which collects data monthly on motor fuel prices from a sampling of stations in 30 representative cities throughout the country. We obtained Lundberg data on the retail prices of diesel fuel and unleaded gasoline for late 1977 from the files of the DOE Energy Information Administration. The gasoline prices are given separately for full-service and self-service, and separately for major companies and independents under each category of service. The diesel fuel prices are given separately for service stations and truck stops, and separately for majors and independents under each category of station.

There are wide variations in the pump prices within a given geographical area among the different categories of filling stations--majors and independents, truck stops and diesel service stations, full-service and self-service. Because of the variations and the consumer's ability to choose among stations, specification of a meaningful price differential between diesel fuel and gasoline is difficult. A person considering the purchase of a diesel car for fuel economy might be more likely to buy gasoline from the stations with the lowest prices, which would affect his perception of the price differential between gasoline and diesel fuel. Because stations that carry diesel fuel are relatively few, the consumer may have little chance to shop for low prices. Consequently, we have used the price for diesel fuel averaged over the four categories of stations to compare with the prices of unleaded gasoline in each category of gasoline stations, and also with the price for unleaded gasoline averaged over the four categories.

Table 11 shows the price differentials between diesel fuel and unleaded gasoline in the 30 cities for October 21, 1977. Averaged over the 30 cities and the categories of stations, diesel fuel cost 8.1¢/gal less than unleaded gasoline. However, in comparison with unleaded gasoline from self-serve independents, the average price differential was only 2.8¢/gal.

The differences in diesel fuel prices among the four categories of stations are less than the differences in gasoline prices among the station

Table 11

DIFFERENCE BETWEEN AVERAGE DIESEL FUEL PRICES
AND PRICES OF UNLEADED GASOLINE*

October 21, 1977

(cents per gallon)

City	Type of Gasoline Service Station				All
	Full Service		Self Service		Gasoline
	Major	Independent	Major	Independent	Service Stations
Atlanta	14.4¢	6.2¢	9.9¢	3.9¢	10.2¢
Boise	15.6	12.5	9.7	6.2	11.4
Boston	5.5	3.2	2.9	1.2	3.6
Charlotte	9.7	3.3	5.2	-0.5	6.0
Chicago	13.6	8.4	10.5	6.3	11.6
Cincinnati	6.9	2.9	4.8	-0.5	4.5
Denver	16.0	.7	11.8	4.4	11.5
Detroit	10.3	8.0	10.2	4.1	8.9
Houston	10.4	4.4	6.2	2.2	7.3
Indianapolis	11.3	4.8	8.1	2.4	7.5
Las Vegas	16.3	11.3	13.3	8.1	13.6
Los Angeles	12.2	4.5	8.9	4.6	10.0
Memphis	10.4	4.5	6.2	1.0	7.0
Miami	9.4	3.1	5.7	1.1	6.7
Milwaukee	9.8	4.1	5.9	2.1	6.4
Minneapolis	14.2	6.9	10.0	5.4	10.1
New Orleans	10.8	1.9	6.2	0.7	7.3
New York	5.0	0.9	3.5	0.2	4.0
Norfolk	8.0	1.5	4.7	-0.3	5.3
Phoenix	11.4	4.2	6.8	2.2	8.1
Portland	9.5	4.1	6.7	3.2	7.3
Sacramento	11.5	4.4	8.1	2.2	8.6
Salt Lake City	13.5	7.5	9.6	4.7	9.4
San Diego	10.0	4.8	6.4	1.4	7.3
Seattle	8.7	4.3	5.6	1.8	6.6
San Francisco Bay Area	10.6	5.1	7.6	2.3	8.2
Spokane	9.7	6.2	5.7	2.7	6.7
Tampa/St. Petersburg	12.0	4.2	8.9	2.4	8.4
Tucson	10.6	4.5	7.0	1.3	7.0
Washington, D.C.	11.1	3.4	7.7	2.2	8.9
Average	10.8¢	4.8¢	7.6¢	2.8¢	8.1¢

* Pump prices, including tax

categories. In 1976 and 1977, the average price at truck stops was roughly 0.5¢ to 2¢/gal, less than at service stations. The average price at independent stations was roughly 2¢ to 4¢/gal less than at major oil company stations (Lundberg letter, 12 August, 1977, plus Lundberg Surveys, July-December 1977. Naturally, variations among stations are considerably greater than these variations in the average diesel fuel price among the categories of stations--as much as 25¢/gal difference between the lowest and highest prices in July 1977.

The federal tax rate of 4¢/gal is the same for diesel fuel and gasoline. The motor fuel tax rates of 38 states plus the District of Columbia were the same for gasoline and diesel fuel, as of the end of 1975 (Federal Highway Administration, 1975). In six states--Alabama, Arkansas, Iowa, Kansas, Mississippi, and Tennessee--the tax on diesel fuel was 1¢/gal higher; in Texas, 1.5¢/gal higher; in Montana and New York, 2¢/gal higher; and in Michigan, 2¢/gal lower. Vermont and Wyoming do not have a tax on diesel fuel, and instead charge by registration fees or ton-miles. The average state tax is approximately 8¢/gal.

The lower price of diesel fuel appears to be a minor consideration in any decision about purchasing a diesel car. The savings in fuel cost come more from the greater fuel economy of the diesel car than from the lower price of diesel fuel. The following example illustrates the relative importance of the two factors. The annual fuel cost for 15,000 miles per year for fuel economies of 20 mpg or 30 mpg and fuel prices of 60¢/gal and 65¢/gal would be:

<u>mpg</u>	<u>65¢/gal</u>	<u>60¢/gal</u>
30	\$325	\$300
20	488	450

The annual cost savings is \$188 for a diesel car that gets 30 mpg (e.g., Peugeot), with diesel fuel at 60¢/gal, compared with a gasoline car that gets 20 mpg with gasoline at 65¢/gal. Of that \$188 cost savings, \$163 (\$488 - \$325), or 87%, is attributable to the fuel economy of the diesel, and only 13% to the lower price of diesel fuel.

V ENERGY SAVINGS

A. Factors

Several factors are involved in calculating the potential energy savings that could be achieved by a transition to a vehicle mix with a substantial proportion of diesel cars. Included are (1) the direct fuel economy advantage of diesel cars compared with gasoline cars, (2) the higher energy content per unit of volume of diesel fuel, (3) the differences in energy use in the refineries for producing more diesel fuel and less gasoline, and (4) federal fuel economy standards.

Present diesel cars have substantially higher fuel economy than their gasoline counterparts. Although diesel engines are more energy-efficient than gasoline engines, the fuel economy advantage is attributable in part to the use of diesel engines comparable in displacement to their gasoline counterparts, but lower in power and acceleration. If smaller gasoline engines, comparable in performance to the diesel engines, were used, the difference in fuel economy between diesel and gasoline cars would be less.

In estimating the potential for saving energy, one must decide whether to make the comparisons on the basis of diesel and gasoline cars of comparable performance, or on the basis of engines of comparable displacement. Although the comparable-performance basis is usually used, it can be argued that people appear to be willing to accept lower performance from a diesel car than they would accept in a gasoline car, to obtain the perceived advantages of diesel engines. Probably the appropriate basis for comparison lies somewhere between comparable performance and the present levels of lower diesel performance.

Diesel fuel is denser than gasoline and contains more energy per unit of volume. The heating value of diesel fuel is approximately

5.83×10^6 Btu/bbl (higher heating value); for gasoline, it is approximately 5.25×10^6 Btu/bbl, or 11% more for diesel fuel.

Within certain limits of the gasoline/distillate ratio, the production of diesel fuel instead of gasoline uses less energy in the refineries. As will be discussed later in this chapter, some analyses show that the energy saved by producing diesel fuel instead of gasoline is approximately the same as the difference in heating value per unit of volume between diesel fuel and gasoline. If that is the case, comparisons of energy use between diesel and gasoline cars could be approximated by their relative fuel economy without correcting for the greater heating value of diesel fuel. However, other studies indicate much lower energy savings from producing diesel fuel instead of gasoline.

Federal law has established an average fuel economy standard of 27.5 mpg for 1985 passenger autos. The standards for prior years are: 1978, 18 mpg; 1979, 19 mpg; 1980, 20 mpg; 1981, 22 mpg; 1982, 24 mpg; 1983, 26 mpg; and 1984, 27 mpg. The standards were established in part on the expectation of some market penetration by diesel or other more fuel-efficient engines (National Highway Traffic Safety Administration, 1977). However, given that the standards now exist, the expansion of diesel cars may not contribute to energy savings. It appears likely that the auto manufacturers will match their average fuel economy to the federally-mandated standards, even if they are using diesel engines in a portion of their new cars. By using diesel engines with greater fuel economy than gasoline engines, they will be able to offer larger cars than they would otherwise be able to, and still meet the fuel economy standards. Thus, the introduction of increased numbers of diesels into the auto fleet is unlikely to result in a better average fuel economy for all new cars than mandated by the standards. However, if and when fuel economy standards are set for years beyond 1985, consideration of the fuel economy potential of diesel engines will make it possible to establish higher fuel economy standards than would be feasible without the use of diesel engines or some other engine with equivalent potential for fuel economy.

B. Comparisons of Fuel Economy

A comparison of the fuel economy of present diesel cars with that of their gasoline counterparts is shown in Table 12. Except for the Oldsmobile, the diesel cars get approximately 50% greater fuel economy than their gasoline counterparts. However, as shown by the acceleration figures in Chapter II, the performance of the diesel cars is lower.

Table 12

COMPARISON OF FUEL ECONOMY OF DIESEL AND GASOLINE CARS

	Transmission	Combined Fuel Economy-mpg		Pct. Increase With Diesel
		Gasoline	Diesel	
Mercedes 230/240D	Automatic	19	28	47%
280/300D	Automatic	16	25	57
Peugeot 504 Sedan	Manual	20	30	50
504 Station Wagon	Manual	20	30	50
Rabbit	Manual	29	45	55
Oldsmobile 88 (350 CID)	Automatic	19	24	26

Source: EPA/DOE, 1976, 1977, 1978

(Mercedes 1977, Peugeot 1976, Rabbit and Oldsmobile 1978)

A summary of comparisons of the fuel economy of diesel cars with gasoline cars with comparable performance was given in a paper by Barry, et al. (1977). They concluded that "...an improvement of about 25% in miles per gallon...is a reasonable estimate of the fuel economy advantage to be achieved with diesel passenger cars compared to gasoline powered vehicles, with both giving the same performance and meeting comparable low emissions standards."

Turbocharging of a diesel engine provides improvements in both performance and fuel economy. A turbocharged diesel engine installed in a standard 1977 Rabbit yielded 50 mpg on the composite EPA cycle (Wiedemann, et al., 1977). The Volkswagen Integrated Research Vehicle with a turbocharged diesel engine and a five-speed transmission yields 60 mpg and accelerates from 0 to 60 mph in 13.5 seconds (Wiedemann, et al., 1977).

C. Potential for Energy Savings with Diesel Cars

In this section we show (1) the decrease in energy use in the refinery from producing more diesel fuel and less gasoline, (2) the proportion of the gasoline-fueled fleet that could be changed to diesel fuel with that change in refinery output, and (3) the total energy savings from the increase in diesel vehicles. The three factors are shown as functions of the ratio of gasoline/distillate output of the refinery, and are derived from a paper by Shearer and Wagner (1977).

1. Refinery Model

In their paper, Shearer and Wagner used a linear program computer model of a "typical refinery" to simulate an operation that produced about 150,000 barrels per calendar day (BCD) crude run. The configuration of the refinery was optimized initially for a product mix equal to the current United States average. Then the refinery substituted increasing amounts of diesel fuel for motor gasoline. The refinery made leaded and unleaded motor gasolines, diesel fuel, kerosene/jet fuel, No. 2 fuel oil, and a xylene concentrate, all to budgeted volumes. It was also permitted to make additional by-products whenever their costs were less than stated market prices. The cases studied are identified by the ratio of total gasoline volume to total distillate volume--the gasoline/distillate ratio. The first case, a 1.7 gasoline/distillate ratio, corresponds to the present average product mix for the United States refining industry. At that ratio, diesel fuel from the simulated refinery was 7,000 BCD, and was used mostly for truck and off-highway driving. As the diesel fuel output was increased, the sum of gasoline and diesel fuel was held constant at 83,000 BCD. When the refinery output shifted, crude oil consumption increased slightly. Since diesel fuel weighs more per gallon than gasoline, the weight of products increased with increased diesel fuel output, so the refinery had to run more crude. A summary of the refinery energy balances for the several gasoline/distillate ratios is shown in Table 13, and Table 14 shows the refinery products.

Table 13

REFINERY ENERGY BALANCE
(10⁹ Btu/CD)

<u>Input, Output, and Fuel Use</u>	<u>Gasoline/Distillate Ratio</u>					
	<u>1.7</u>	<u>1.5</u>	<u>1.3</u>	<u>1.1</u>	<u>0.9</u>	<u>0.7</u>
Input from crude and butane	834	839	847	851	848	853
Output in products	723	730	740	745	744	744
Refinery fuel and coke	111	109	107	106	104	109

Source: Shearer and Wagner, 1977

Table 14

REFINERY PRODUCTS

<u>Products</u>	<u>Gasoline/Distillate Ratio</u>					
	<u>1.7</u>	<u>1.5</u>	<u>1.3</u>	<u>1.1</u>	<u>0.9</u>	<u>0.7</u>
Motor Gasoline, 10 ³ BCD	76	72	68	63	57	49
Diesel fuel, 10 ³ BCD	7	11	15	20	26	34
Kerosene and jet fuel, 10 ³ BCD	14	14	14	14	14	14
Fuel oil, xylene concentrate, LPG, butanes, 10 ³ BCD	38	39	40	41	40	10
Coke, sulfur, and propylene, tons/CD	811	810	810	766	644	464

Source: Shearer and Wagner, 1977

2. Refinery Energy Savings

Starting with the energy balances in Table 13, we derived the refinery energy savings as a percentage of the increase in diesel fuel output (measured in energy units) at the given gasoline/distillate ratio over the output at the base 1.7 gasoline/distillate ratio. First, the input, output, and refinery fuel use were adjusted to a constant energy output (in Btu's). Table 15 shows those adjustments and the savings in energy to the refinery.

Table 15

REFINERY ENERGY SAVINGS WITH INCREASED DIESEL FUEL OUTPUT

10 ⁹ Btu/CD	Gasoline/Distillate Ratio					
	1.7	1.5	1.3	1.1	0.9	0.7
Input from crude and butane*	834	831	828	826	824	829
Output in products*						
Motor gasoline	399	374	349	321	291	250
Diesel fuel	41	64	85	113	147	193
Other products	283	285	289	289	285	280
Total product output	723	723	723	723	723	723
Refinery fuel and coke*	111.0	108.0	104.5	102.9	101.1	105.9
Increase in diesel fuel		23	44	72	106	152
Energy savings		3.0	6.5	8.1	9.9	5.1
<u>Percentages</u>						
Refinery energy savings as percentage of increase in diesel fuel		13.2%	14.6%	11.2%	9.3%	3.4%

* Normalized to constant output.

Source: Derived from Shearer and Wagner, 1977.

The results from Table 15 are illustrated in Figure 4. Figure 4 shows the energy savings in the refinery (as a percentage of the increase in the diesel fuel output) from the increase in diesel fuel output and decrease in gasoline output. For gasoline/distillate ratios above 0.9, the refinery energy savings are more than 10%. Because of the savings in energy to the refinery, the input energy required to produce a gallon of diesel fuel is approximately the same as for gasoline, even though the volumetric heating value of diesel fuel is 11% greater than gasoline.

FIGURE 4. REFINERY ENERGY SAVINGS FROM CONVERSION TO DIESEL FUEL

Thus, the volumetric fuel savings from the use of diesel fuel instead of gasoline provide a reasonable approximation of total energy savings without compensating for the higher energy content of the diesel fuel. The percentage of energy savings to the refinery drops off sharply for gasoline/distillate ratios below 0.9, because hydrocracking becomes necessary to produce the larger amounts of diesel fuel.

Similar results can also be derived from Barry, et al., 1977. In that paper also, a linear program was used to simulate the effects on an existing refinery of increases in the output of diesel fuel. When the change was made from the present typical gasoline/distillate ratio of 1.7 to a ratio of 1.05 (with a constant volume of gasoline plus diesel fuel), the decrease in the energy use for refining equaled the increase in the energy content of the constant volume of gasoline and diesel fuel.

Because the volumetric energy content of the diesel fuel is 11% greater than that of gasoline, the energy savings was approximately 11% relative to the increase in diesel fuel output. (This result is comparable to that derived from the Shearer and Wagner paper for a gasoline/distillate ratio of 0.9.) With the change to a gasoline/distillate ratio of 0.6, the decrease in energy use for refining also equaled the increase in the energy content of the combined gasoline and diesel fuel output. However, that energy savings was largely offset by a decrease in the output of other products.

Substantially different results for energy savings in the refinery were obtained by Moore (1978). In that paper the energy savings in the refineries was held to be only about 1.1% relative to the increase in the amount of diesel fuel. In the refining industry, there is wide variation in the qualities of crude oils processed, the relative volumes of the product mix, and the relative capacities of refining processes used. Different assumptions about those variables produce differences in the calculations of the energy effects of changing the gasoline/distillate ratio from current practice. One of the differences in assumptions between the Shearer and Wagner paper and the Moore paper is the type of crude oil used. Shearer and Wagner assumed the use of Arabian light crude, which favors diesel fuel manufacture; Moore assumed that domestic crude would be used. Another important difference is that Shearer and Wagner simulated the operation of a particular refinery, while Moore simulated the operation of the U.S. refinery industry. Moore also assumed that refined products were imported to balance domestic demand. As a result, in Moore's analysis, less change was required in the product mix of the domestic refineries; hence, less energy was saved from the change in the product mix.*

* It should be noted that the hydrocracking required to produce the high proportion of gasoline characteristic of U.S. refinery operations is particularly energy-intensive. Consequently, a reduction in the output of gasoline may produce greater energy savings per unit of decrease in gasoline output than the average refinery energy use per unit of output for all products.

3. Fraction of Fleet Converted to Diesel Fuel (No Increase in Jet Fuel)

Next, we derived the fraction of the gasoline vehicle fleet that could be converted to diesel, if the refinery output changed from the 1.7 gasoline/distillate ratio to a lower ratio. For this derivation, we assumed that the output of jet fuel and other distillates (except diesel fuel) remained the same. First, we calculated the percent decrease in gasoline output, and the percent increase in diesel fuel output (measured in energy units) relative to the gasoline output at the base 1.7 gasoline/distillate ratio. Then we changed the percent increase in diesel fuel output to a percent increase in vehicle miles, based on an assumed 25% more miles per gallon for diesel vehicles (13% more miles per Btu).

Because the increase in vehicle miles with diesel fuel exceeded the decrease in vehicle miles with gasoline, the total motor fuel output was adjusted slightly downward to provide constant vehicle miles with the changes in diesel fuel output. The resultant percentage of the gasoline fleet changed to diesel fuel, with the same total vehicle miles, is shown in Table 16 and illustrated in Figure 5. With a change to a 0.9 gasoline/distillate ratio, 29% of the gasoline vehicles could be changed to diesel.

Table 16

DERIVATION OF FLEET CHANGE AND TOTAL ENERGY SAVINGS ASSOCIATED WITH INCREASED DIESEL FUEL OUTPUT

Percentage Changes	Gasoline/Distillate Ratio				
	1.5	1.3	1.1	0.9	0.7
Decrease in gasoline output	6.1%	12.6%	19.6%	27.1%	37.3%
Increase in diesel fuel energy relative to gasoline output at 1.7 gasoline/distillate ratio	5.7	11.2	18.1	26.7	38.0
Increase in diesel fuel miles relative to gasoline miles at 1.7 gasoline/distillate ratio, based on 25% more mpg for diesel (13% more miles/Btu)	6.4	12.7	20.5	30.2	42.9
Percentage of gasoline fleet changed to diesel (with same miles)	6.4	12.7	20.3	29.3	40.6
Total energy savings as percentage of energy use for gasoline fleet	1.5	3.1	4.4	5.8	5.8

FIGUR 5. PERCENTAGE OF FLEET CHANGED TO DIESELS

In a paper concerning the fuel economy standards from 1981 to 1984, (National Highway Traffic Safety Administration, 1977), it was concluded that a 20 to 25% market penetration by diesel cars might be achieved. A fleet mix with 25% diesels could be met before reaching levels of the gasoline/distillate ratio where the refinery's energy savings begin dropping sharply. The paper also postulated diesel penetration for the major auto manufacturers on the following schedule: 1981-5%; 1982-10%; 1983-15%; 1984-20%; and 1985-25%. With that schedule, and assuming 10-year vehicle lifetimes, the diesel vehicles would constitute only 7.5% of the fleet by 1985, which is well within the limits that could be supported by the refineries.

4. Fraction of Fleet Converted to Diesel Fuel (Increase in Jet Fuel)

The previous calculation of the percentage of the gasoline fleet that could be changed to diesel assumed that the ratio of the distillate products other than diesel fuel remained the same. However, consumption of jet fuel is expected to increase. At the same time, improvements in motor vehicle fuel economy will offset the increases in the number of vehicles, so consumption of motor gasoline (apart from any switch to diesel cars) will remain constant, or even decline. Thus, a decrease in the

refinery gasoline/distillate output ratio would be required just to meet the increased demand for jet fuel. The percentage of the gasoline fleet that could be switched to diesel, for a given gasoline/distillate ratio, would then be less than was calculated in the last section, where it was assumed that there would be no change in the output ratio of distillate products other than diesel fuel. To show the effect of an increase in the use of jet fuel on the percentage of the gasoline motor vehicle fleet that could be switched to diesel, we assumed for the present section a 50% increase in the consumption of jet fuel.

The Federal Aviation Administration in 1976 projected jet fuel consumption for domestic civil aviation of 9,096 million gallons in 1978 and 14,535 million gallons in 1988 (Shonka, Loebel, and Patterson, 1977). Military use of jet fuel has been about 40% of total jet fuel consumption, or about 6,000 million gallons (Goen, Clark and Moore, 1974). (Note, however, that much of the military jet fuel is JP4, a naphtha-type and not a middle distillate.) If military use of jet fuel does not increase, the total increase in the use of jet fuel by 1988 would be 36%. Thus the assumed 50% increase appears to provide a reasonable representation of the increase in use of jet fuel over the next 10 to 15 years.

The refinery output of kerosene and jet fuel at a gasoline/distillate ratio of 1.7 was twice the diesel fuel output (Table 14). A 50% increase in the output of jet fuel would be approximately 41×10^9 Btu/CD. At a gasoline/distillate ratio of 0.9, the increase in diesel fuel output shown in Table 15 was $10^6 \times 10^9$ Btu/CD. If the 41×10^9 Btu/CD of jet fuel replaced part of the diesel fuel, the increase in diesel fuel output would be reduced to 65×10^9 Btu/CD. In relation to the 399×10^9 Btu/CD gasoline output at the 1.7 gasoline/diesel ratio, this increase in diesel fuel output would be 16.3%. Since diesel cars were assumed to get 25% more miles per gallon (13% more miles per Btu), the additional diesel fuel would provide 18.4% of the vehicle miles of the 399×10^9 Btu/CD of gasoline output, while the gasoline output (and vehicle miles of the gasoline output) would be reduced 27%. With output normalized to provide the same mileage, the increase in diesel fuel output would permit 20% of the gasoline fleet to be switched to diesel fuel, compared with the 29% switch to diesels if there were no increase in consumption of jet fuel.

5. Total Energy Savings

Finally, the total energy savings, expressed as a percentage of the energy use for the gasoline-fueled vehicle fleet without any switching to diesel fuel, were calculated from the following formula:

$$\text{Energy savings} = (1 - \text{VHR}) F$$

where

- V = the ratio of diesel fuel volume to gasoline volume per vehicle mile ($V = 0.8$ for 25% more mpg for diesel fuel),
- H = the ratio of heating value for diesel fuel per unit of volume to that of gasoline ($H = 1.1$),
- R = energy use for refineries at a given gasoline/distillate ratio as a fraction of the energy use at the 1.7 ratio, and
- F = fraction of the gasoline fleet changed to diesel fuel.

Table 16 and Figure 6 show the total energy savings that can be achieved with the increase in output of diesel fuel (assuming no change in the output of jet fuel). The energy savings are expressed as a percentage of the energy content of the motor gasoline that would be used if there were no partial changeover to diesel fuel. At the 0.9 distillate/gasoline ratio, the energy savings is 5.8%.

FIGURE 6. TOTAL ENERGY SAVINGS FROM CONVERSION TO DIESELS

The calculations for energy savings assume that the diesel vehicles actually get 25% greater fuel economy than the gasoline vehicles that would otherwise have been produced. However, as previously mentioned, manufacturers might use the fuel savings that can be obtained with the use of diesel engines to produce a fleet with larger cars than would otherwise be possible, that still just meets the same statutory fuel economy standards. In that case, because there is more energy in diesel fuel than in gasoline, the energy use by the vehicles would be increased. However, that increase in energy use by the vehicles would be partially offset by the lower energy use in the refineries.

The 25% increase in fuel economy for diesel engines assumes that vehicles will have comparable performance. However, as previously discussed, some people have been willing to accept lower performance for diesel cars. Furthermore, technological advances may improve the fuel economy of diesel engines more than is possible with the already well-developed present type of gasoline engine. If diesel engines are assumed to provide a 40% increase in fuel economy over gasoline engines, then, with a refinery gasoline/distillate ratio of 0.9, 32% of the gasoline vehicles could be changed to diesel fuel, and the energy savings would be 9.2%. (That also assumes that the production of jet fuel is not changed and that the increase in fuel economy is not offset by the production of larger cars.)

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VI EFFECT OF AUTO EMISSION STANDARDS

A. Evolution of Auto Emissions Standards

The Clean Air Acts amendments of 1970 required a 90% reduction in exhaust emissions of HC, CO, and NO_x (by the 1975 model year for HC and CO, and by the 1976 model year for NO_x), relative to the 1970 standards for HC and CO, and the 1971 uncontrolled levels for NO_x. The resulting emission standards for 1975/1976 were 0.41 grams per mile (gpm) for HC, 3.4 gpm for CO, and 0.4 gpm for NO_x. Interim standards were set for the years before the effective dates of the ultimate standards. Delays experienced in meeting those dates resulted in the revision of interim standards at various times; the latest was in August 1977.

The history of the revisions in the federal emissions standards is summarized in Table 17. Standards for California are more stringent (Table 18). The latest federal revision delays the original goals to 1981, and relaxes the original goal for NO_x to 1.0 gpm, with the original 0.4 gpm NO_x standard left only as a research objective. However, the 1981 NO_x standard is more stringent than the 2.0 gpm standard of the four prior years. Under certain circumstances, diesel and other "innovative technology" cars could receive a four-year waiver to 1.5 gpm NO_x. California, however, still requires 0.4 gpm NO_x in 1982 and later.

In addition, a standard for particulate emissions for the 1981 model year is expected to be issued by 1979. Because diesel cars have much higher particulate emissions than gasoline cars (on the order of 20 to 80 times the amount at comparable power), the particulates standard may have a heavy impact on the future of diesel cars.

Concern has also been raised about a potential carcinogenic hazard from diesel hydrocarbon emissions. A "Precautionary Notice" issued by EPA in November 1977 stated that extracts from diesel fumes had been

Table 17

HISTORY OF AUTO EMISSION STANDARDS*

<u>Date Standard Set</u>	<u>Type of Emission</u>	<u>Model Year in Which Standards Become Effective</u>						
		<u>1975</u>	<u>1976</u>	<u>1977</u>	<u>1978</u>	<u>1979</u>	<u>1980</u>	<u>1981</u>
1970	HC	0.41	0.41					
	CO	3.4	3.4					
	NO _x	-	0.4					
1973	HC	1.5	0.41	0.41				
	CO	15	3.4	3.4				
	NO _x	3.1	2.0	0.4				
1975	HC		1.5	1.5	0.41			
	CO		15	15	3.4			
	NO _x		3.1	2.0	0.4			
1977	HC				1.5	1.5	0.41	0.41
	CO				15	15	7	3.4
	NO _x				2.0	2.0	2.0	1.0

*
gpm

Table 18

CALIFORNIA EXHAUST EMISSION STANDARDS
FOR PASSENGER CARS (gpm)

<u>Model Year Effective</u>	<u>HC</u>	<u>CO</u>	<u>NO_x</u>
1975	0.90	9.0	2.0
1976	0.90	9.0	2.0
1977	0.41	9.0	1.5
1978	0.41	9.0	1.5
1979	0.41	9.0	1.5
1980	0.41	9.0	1.0
1981	0.41	3.4	1.0
1982 and later	0.41	7.0	0.4

Source: Condensed from California Resources Board, 1977.

found to cause genetic changes in bacteria. Such findings often indicate that a substance can cause cancer in animals and people. Concrete results from a larger research program that EPA is now conducting on the subject are not expected until June 1978 at the earliest (New Engineer, April 1978).

B. Comparison of Exhaust Emissions of Diesel and Gasoline Cars

Table 19 shows the exhaust emissions of the present diesel cars, and the corresponding gasoline models, which were tested for compliance with the federal standards. The diesel engines meet the present auto emission standards (shown in Table 17) without the complications and expense of the catalytic converters and exhaust gas recirculation required to control emissions in most gasoline engine cars. The CO emissions, in particular, are lower for the diesel cars without controls than for the gasoline cars with controls, and are also lower than the 1981 standard. However, the NO_x emissions of the diesel cars exceed the standard slated to take effect in 1981.

There is, however, one very preliminary test result that could be of importance to the future of diesel powered passenger cars. Tests on a fleet of diesel-powered taxis in New York City indicate that the diesel-powered cabs not only are entirely comparable in performance and driver acceptance, but also show a 50% improvement in fuel economy and one-tenth the degradation of emission controls as a matched fleet of gasoline-powered cabs at mileages of 60,000 to 80,000. The cabs were Dodge Coronets with gasoline and Nissan diesel engines of comparable horsepower. Considerably more testing is required, however, before those preliminary results can be extended to cover general passenger car use.

C. Implications

The ability of diesel engines to meet the interim emissions standards without the controls required for gasoline cars has provided an incentive for the car manufacturers to consider diesel cars. However, the incentive has been dampened by the uncertainty about the levels of the later NO_x and particulate standards and the car manufacturers' ability to meet those standards. To meet the 1981 NO_x standard of 1.0 gpm may require exhaust

Table 19

EXHAUST EMISSIONS FROM 1978 DIESEL CARS
AND CORRESPONDING GASOLINE CARS*

<u>Makes and Models</u>	<u>Transmission</u>	<u>grams per mile</u>		
		<u>HC</u>	<u>CO</u>	<u>NO_x</u>
1978 Federal Standard		1.5	15	2.0
1981 Federal Standard		0.41	3.4	1.0
<u>Mercedes</u>				
240D diesel	Automatic [†]	1.11	1.0	1.7
	Automatic [†]	0.25	1.1	1.4
	Manual	1.37	1.2	1.4
230 gasoline	Automatic [†]	0.45	2.6	1.4
	Automatic [†]	0.68	9.2	1.2
300D diesel	Automatic [†]	0.48	1.4	1.8
	Automatic [†]	0.10	1.2	1.9
300SD diesel, turbocharged	Automatic [†]	0.22	1.2	1.9
	Automatic [†]	0.21	0.9	2.0
<u>Peugeot</u>				
504 diesel wagon	Automatic	0.56	1.9	1.5
504 gasoline wagon	Manual	1.00	3.9	1.2
504 diesel sedan	Automatic	0.67	1.7	1.5
	Manual	0.97	3.1	1.3
504 gasoline sedan	Automatic	0.62	5.7	1.3
<u>Volkswagen Rabbit</u>				
Diesel	Manual	0.22	0.6	1.2
Gasoline, fuel injection	Manual	1.10	7.8	1.8
Gasoline, carburetor	Manual	1.35	3.8	1.1
<u>Oldsmobile</u>				
Diesel	Automatic	0.78	1.8	1.9
Gasoline, 350 cu in engine	Automatic	0.29	4.8	1.1

* EPA preliminary certification results

† Two cars tested

Source: A. Kaupert, personal communication,
February 1978

gas recirculation (EGR). However, EGR has an adverse effect on smoke, particulates, odor, driveability, durability, maintenance, and fuel economy, and may create a requirement for additional effort to meet the HC standard (Wiedemann, 1977).

It appears likely that some of the diesel car manufacturers will request the four-year waiver to 1.5 gpm NO_x from the 1.0 gpm 1981 standard, but it is uncertain whether the Environmental Protection Agency will grant the waivers. If meeting the 1.0 gpm NO_x standard is not feasible, the waiver decision involves complex tradeoffs between the higher NO_x emissions and the lower CO emissions and higher fuel economy provided by diesel cars.

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VII OPINIONS OF OWNERS AND OTHER MOTORISTS ABOUT DIESEL CARS

The increase in diesel popularity has spurred many surveys of both diesel car owners and of motorists in general. Most of the surveys were attempting to answer one or more of the following questions: Why did people decide to buy a diesel? What did people like and dislike about diesels? How did they find out about diesels? and what are the problems with owning diesel cars, both from the owner's perspective and the potential buyer's perspective?

A. Surveys by J. D. Power & Associates

The two most thorough surveys of diesel owners have been conducted by J. D. Power & Associates. A survey of purchasers of Mercedes and Peugeot diesel cars was conducted in 1974, and another survey of Mercedes 300D diesel car purchasers in 1975. The objectives of the surveys were (1) to determine the characteristics of the purchasers of the diesel models, (2) to determine why they purchased a particular model, (3) to determine why they purchased the diesel specifically, (4) to determine how the owners used their cars, and (5) to determine the owners' attitudes and opinions about their cars.

The samples for the Mercedes 240D and Peugeot surveys were drawn from the new car registration files of R. L. Polk and Company for a four month period in 1974, and for the Mercedes 300D, from the Mercedes-Benz retail sales list for December 1974 and January 1975. The Peugeot sample did not distinguish between gasoline or diesel cars. Table 20 summarizes the sample sizes and returns on the questionnaires.

Table 20

SAMPLE SIZES FOR MERCEDES AND PEUGEOT SURVEYS

	<u>Mercedes</u>		<u>Peugeot</u>		
	<u>240D</u>	<u>300D</u>	<u>Gasoline</u>	<u>Diesel</u>	<u>Total</u>
Mail out	700	500	---	---	1,537
Usable returns	379	251	391	453	844

1. Owner Profile

As might be expected because of the high price of the cars, the diesel buyers are usually older, married men with high education and income levels and occupations in the professional, managerial, and executive sales categories. Table 21 summarizes some of the selected characteristics of the buyers.

Table 21

SELECTED CHARACTERISTICS OF PRINCIPAL PURCHASER

	<u>Mercedes</u>		<u>Peugeot</u>	
	<u>240D</u>	<u>300D</u>	<u>Diesel</u>	<u>Gasoline</u>
Median age (years)	46.4	51.1	44.1	38.5
College grad./post grad. (%)	57%	57%	50%	67%
Some college	20%	20%	20%	17%
Expected family income for 1974 (%)				
\$15,000 - \$24,999	27%	13%	34%	30%
\$25,000 or over	53%	74%	34%	47%
Occupation (%)				
Professional/technical and kindred workers	32%	36%	30%	38%
Managers, officials, and proprietors	18%	25%	15%	22%
Sales workers	17%	10%	11%	10%
Retired	5%	11%	6%	4%

Sources: J. D. Power & Associates, 1974 and 1975.

2. Reasons for Choosing a Particular Model

The two J. D. Power surveys included several similar questions about the reasons for purchasing a particular model. The questions traced how the buyer first became interested through the reasons why he or she decided to purchase the car. Recommendations from friends were important for diesel Mercedes buyers and for buyers of gasoline-powered Peugeots, but not so significant for buyers of diesel Peugeots. Magazine articles were very important to Mercedes 300D and diesel Peugeot buyers, but had little influence on buyers of the Mercedes 240D. Table 22 compares the various stimuli that first interested buyers in purchasing their automobiles.

Table 22

HOW CAR BUYERS FIRST BECAME INTERESTED IN BUYING A PARTICULAR MODEL

	<u>Mercedes</u>		<u>Peugeot</u>	
	<u>240D</u>	<u>300D</u>	<u>Diesel</u>	<u>Gasoline</u>
Recommended by friend or relative	36%	21%	14%	32%
Magazine article	8	21	27	7
Newspaper advertisement	7	19	23	8
Recommended by salesman	3	16	8	6
Shopped around for various makes and models	15	15	20	40
Magazine advertisement	4	14	19	4
Owned one previously	20	11	5	14
Television advertising	2	2	2	*
Other advertising	3	6	4	2
News mention in magazines	12	30	41	11

* Less than 1%

Sources: J. D. Power & Associates, 1974, 1975.

Magazine articles and advertisements apparently influenced the decisions of many buyers. Table 23 lists all of the magazines that were mentioned either for their articles or their advertisements. The car enthusiast magazines were heavily represented. Road & Track was the magazine most frequently mentioned, both for its articles and its advertisements.

Table 24 shows why buyers first became interested in their cars. Economy, fuel economy, and the diesel engine were the reasons most mentioned by the diesel car owners.

Table 25 gives the response to a question asking the car buyers to select the most important feature in their decision from a given list of features. Fuel economy was in first place for the diesel buyers, while engineering was first for the gasoline Peugeot buyers.

The reason given most often by diesel car owners was overall economy, followed by fuel economy and low maintenance. Table 26 lists all of the reasons stated. However, it should be noted that it is difficult for consumer surveys to determine why a person buys a particular product, and asking a person that question directly may not produce a reliable answer.

B. Amoco Oil Company Survey

Amoco Oil Company surveyed 1,600 motorists on their opinions of diesel versus gasoline-powered cars in April 1977. The major finding of Amoco's survey was that approximately one-third of American motorists would probably purchase a diesel-powered automobile if one were available at a reasonable and affordable price (Amoco, 1977a).

Nine percent of the motorists said they would "definitely buy" a reasonably-priced, diesel-powered car, and another 25% said they would "probably buy" one. Two-thirds of those surveyed would wait to buy diesel-powered cars until others had experience with them.

Motorists surveyed believed diesels rated better than gasoline-powered cars in fuel prices, fuel consumption, engine life, safety from fuel fires, engine breakdowns, number of repairs, and pollution. Gasoline-powered cars were rated better on availability of fuel, qualified mechanics, original

Table 23

SPECIFIC MAGAZINE IN WHICH CAR BUYERS SAW
ADVERTISEMENT OR ARTICLE
(Among Those Owners Who Saw Advertisement Or Article)

<u>Magazines for Advertisements</u>	<u>Mercedes</u>		<u>Peugeot</u>	
	<u>240D</u>	<u>300D</u>	<u>Diesel</u>	<u>Gasoline</u>
Road & Track	27%	14%	10%	26%
New Yorker	--	14	--	--
Car and Driver	7	11	3	5
Scientific American	--	8	--	--
Business Week	--	8	--	--
U.S. News and World Report	13	8	4	--
Motor Trend	20	3	6	11
Time	7	3	11	26
Newsweek	--	--	14	5
All Other	--	8	19	26
Magazine Not Specified	40	43	40	16
<u>Magazines for Articles</u>				
Road & Track	9%	40%	21%	34%
Motor Trend	19	11	10	3
Popular Mechanics	6	9	6	--
Car and Driver	6	8	7	6
Popular Science	19	6	19	6
Consumer Report	13	6	4	13
All Other	13	15	10	22
Magazine Not Specified	19	8	19	13

Sources: J. D. Power & Associates, 1974, 1975

Table 24

WHY CAR BUYERS FIRST BECAME INTERESTED IN A PARTICULAR CAR

	<u>Mercedes</u>		<u>Peugeot</u>	
	<u>240D</u>	<u>300D</u>	<u>Diesel</u>	<u>Gasoline</u>
Fuel economy	26%	25%	24%	11%
Economy/Economy of operation	31	23	29	10
Diesel engine	12	20	31	--
Prior ownership	11	15	5	12
Quality	7	10	3	6
More power/Acceleration	--	8	--	--
Comfort/Roominess				
Size	2	4	4	12
Engineering/Construction	6	4	3	8
Durability	12	3	11	4
Drove one in the past	2	3	4	7
5-cylinder diesel	--	3	--	--
Price/Resale value	*	2	7	6
Styling/Appearance	3	1	2	7
All other mentions	36	18	24	45

Sources: J. D. Power & Associates, 1974, 1975.

Table 25

FEATURE CONSIDERED TO BE THE MOST IMPORTANT
IN CAR BUYERS' DECISION TO PURCHASE

	<u>Mercedes</u>		<u>Peugeot</u>	
	<u>240D</u>	<u>300D</u>	<u>Gasoline</u>	<u>Diesel</u>
Fuel economy	27%	30%	11%	39%
Engineering	20	20	21	7
Durability	15	10	18	14
Comfort	3	2	16	3
Low upkeep	6	3	2	10
Dealer servicing	2	1	10	2
Safety	7	7	4	1
Appearance/Styling	1	1	5	1
Purchase price	1	n.a.	3	1
Resale value	4	4	1	1

Sources: J. D. Power & Associates, 1974, 1975.

Table 26

HOW AND WHY OWNERS DECIDED TO PURCHASE
A DIESEL-POWERED CAR

	<u>Mercedes</u>		<u>Peugeot</u>
	<u>240D</u>	<u>300D</u>	
Overall economy	34%	30%	34%
Fuel economy	20	25	30
Low maintenance	12	16	19
Availability of fuel during gasoline shortage	7	14	7
Durability of diesel engine	17	10	22
Prior ownership of diesel auto automobile	8	8	4
Engineering/engine design	3	7	3
Prior experience with non- automotive diesel engine	6	5	7
Clean emissions	4	4	8
Reliability of diesel	7	4	5
Recommended by friend/relative	7	4	4
Energy crisis	7	3	6
Pollution control devices required on gasoline engines	3	3	7
Lower cost of diesel fuel	3	2	8
Wanted to try it/experiment	3	2	3
Suits my needs	3	--	3
All other reasons	31	9	24

Sources: J. D. Power & Associates, 1974, 1975.

cost, availability of parts, cold-weather starting, acceleration, and cost of repairs. (See Table 27).

A shift from the cautious reception of diesel cars would depend heavily on solving or lessening the perceived problems of service, parts, fuel availability, cold-weather starting,^{*} and engine acceleration. Amoco attributed all responses but those related to cold-weather starting and acceleration characteristics mainly to the historical dominance of the gasoline engine. At present, the powerful motivators for purchase are fuel efficiency and engine durability (see Table 20). The Amoco survey found that 52% of Americans have at least some knowledge about diesel engines. Only 5% of those surveyed owned a diesel, but 11% had driven a diesel car.

When asked to indicate the body style and size of the diesel-powered vehicle they would prefer, motorists checked seven alternatives, as shown in Table 28.

The overall implication of the Amoco survey is that a small but solid nucleus of pro-diesel motorists exists. Most other motorists are cautiously favorable, and only a small number are anti-diesel. The survey appears to suggest that diesel-powered cars should be able to capture a substantial portion of the U.S. private passenger car market if the experiences of early owners are positive.

C. Wall Street Journal Survey

Marketing and Research Counselors and the University of Michigan each conducted a survey on behalf of the Wall Street Journal, asking Journal subscribers about their attitudes and expectations concerning the automobile (Wall Street Journal, 1978). Many aspects of the surveys directly concerned the purchase and leasing of a car.

* It should be mentioned that the precombustion chamber in the Mercedes diesel engine greatly reduces the cold-weather starting problems experienced by drivers of diesel trucks.

Table 27

HOW MOTORISTS COMPARE DIESEL- AND GASOLINE-POWERED AUTOMOBILES

Characteristic	Diesels Definitely or Generally Better	About the Same	Gasoline Definitely or Generally Better	Don't Know
<u>Diesels Rated Better</u>				
Fuel cost per mile	80%	9%	5%	6%
Miles per gallon	64	20	8	8
Engine life	59	27	6	8
Safety from fuel fires	54	35	4	7
Engine breakdowns	48	39	5	8
Amount of repairs	43	41	8	8
Pollution	35	28	29	8
<u>Diesels and Gasoline About the Same</u>				
Warm-weather starting	20%	58%	14%	8%
Smoothness of ride	13	58	19	9
Do-it-yourself maintenance	8	47	37	8
Do-it-yourself repairs	6	46	40	8
Routine service requirement	41	41	10	8
Routine service requirement	35	35	22	8
<u>Gasoline Rated Better</u>				
Availability of qualified mechanics	2%	18%	72%	8%
Original cost of automobile	9	18	65	8
Availability of parts	2	28	61	9
Availability of fuel	12	23	58	7
Cold-weather starting	15	29	48	8
Performance (acceleration, responsiveness, etc.)	11	35	45	9
Cost of repairs	15	38	39	8

Source: Amoco Oil Company, 1976b.

Table 28

MOTORISTS' PREFERENCE FOR SIZE AND BODY
STYLE OF DIESEL VEHICLE

<u>Vehicle Preference</u>	<u>Percentage of Motorists</u>
<u>Passenger Car Size</u>	
Full size	21%
Intermediate	38
Compact	12
Subcompact	3
<u>Other Body Styles</u>	
Pickup truck	8
Station wagon	7
Van	4
No answer	7

Source: Amoco Oil Company, 1977b.

Two questions were asked specifically about diesel cars. The first question asked subscribers about their familiarity with the diesel engine. The second question asked if the subjects would consider the diesel engine as an option of the next car purchased. The responses to these two questions are shown in Table 29.

Table 29

MOTORISTS' FAMILIARITY WITH AND
RECEPTIVITY TO DIESEL ENGINES

<u>Familiarity with Diesel Engines</u>	<u>Percentage of Responding Wall Street Journal Households</u>
Very familiar	30.7%
Somewhat familiar	51.0
Heard of it, but don't know anything about it	16.2
Not aware of it at all	2.1
<u>Would Consider Diesel Engine as an Option</u>	<u>Percentage of Respondents Who Are Aware of Diesel Engines</u>
Yes	55.1%
No	39.2
Uncertain	5.7

Source: Wall Street Journal, 1978.

The majority of the respondents (85%) were at least somewhat aware of the diesel engine. A smaller majority (55%) would also consider the diesel engine as an option on the next car purchased.

D. Views of Diesel Car Owners at SRI International

The study team held focused discussions with 14 diesel car owners at SRI to obtain information and impressions of the diesel car directly from diesel car owners. The owners described their reasons for buying their cars, and discussed what they liked about them, as well as telling how they found out about diesels.

Many reasons were given for buying a diesel. All of the diesel car owners mentioned fuel economy as one of the primary reasons for the purchase. (Fuel economy included both the price of fuel and the fuel efficiency.) Low maintenance was another feature frequently cited as a major reason for the purchase. Other reasons given were the longevity of the car, safe construction, comfort, reliability, low pollution, and finally, status (see Table 30).

Table 30

PURCHASE REASONS AND INFORMATION SOURCES FOR
DIESEL CAR OWNERS AT SRI INTERNATIONAL

	<u>Mercedes</u>	<u>Volkswagen Rabbit</u>	<u>Peugeot</u>
Number of represented owners	8	4	2
<u>Reasons for Buying</u>			
Fuel economy	7	4	2
Longevity	3	-	2
Safety/comfort	3	-	1
Reliability	1	-	-
Low maintenance	5	1	1
Status	2	-	-
Low on pollution	2	-	-
Fascination	1	2	-
<u>Learned about diesel cars from:</u>			
Friends	2	2	-
Research	1	1	2
Magazines	-	1	-

The SRI diesel car owners listed a variety of sources from which they had learned about diesel cars. Several stated that they had been "diesel fanatics" for years and learned about them chiefly through various automotive magazines such as Road & Track. Others had friends who owned diesels and who expressed such great satisfaction with the car that it was stimulus enough for them to buy one. Others simply saw articles about them and through a little personal research, determined that it was the car for them.

All but one of the 14 diesel car owners said they had no trouble finding diesel fuel. Most said it was fairly easy and some people even found it entertaining. They enjoyed fueling up at the large truck stops.

Most of the Volkswagen Rabbit owners had been driving their cars for a very short time, generally only weeks or at most a few months. All were pleased with their cars thus far. They were optimistic that the cars would be dependable and would have the positive diesel characteristics of low maintenance and fuel economy.

Many of the Mercedes owners had either owned a diesel before, or had owned their car for an extended period of time. One employee, for example, had owned a 1959 diesel Mercedes for eight years. The car now has been driven approximately 310,000 miles. Mercedes owners were all extremely pleased with their cars. They were impressed with the fuel economy, the low maintenance, and the longevity, as Table 30 indicates.

The two Peugeot owners had owned their cars for about a year. Both were impressed by the fuel economy and low maintenance. Both people had done some research into diesels and on the basis of that information had decided to buy one.

On the whole, the SRI International diesel car owners were highly enthusiastic about their cars. Those that had owned them for long periods claimed that diesel cars really do have good fuel economy, lower maintenance, and longevity. One caution, however, is appropriate: most of the diesel car owners at SRI International are professional researchers, and their reactions may be atypical. Also, people who have made a choice tend to defend it, finding good points and discounting disadvantages.

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VIII REASONS FOR INTEREST IN DIESEL CARS

This chapter presents our conclusions concerning the reasons for interest in diesel cars on the part of both the consumers and the manufacturers.

A. Consumers

As was discussed in Chapter VII, the principal reasons given by diesel car buyers for choosing a diesel car are: (1) fuel economy, (2) low maintenance, and (3) durability.

In our discussions with diesel owners, another reason became apparent: a high interest in technological innovation. Also, many of the diesel car buyers are car buffs. In most cases, the diesel car owners were enthusiastic about their cars. That attitude must have sparked the interest of other prospective buyers.

Other unstated reasons may reasonably be inferred. The Mercedes, the predominant diesel car, has been noted for its engineering and quality, and over the past several years has become preeminent as a prestigious automobile. Many buyers of diesel Mercedes may have been primarily interested in owning a Mercedes, per se, rather than a diesel car. And the diesel Mercedes have been the lowest or nearly the lowest-priced Mercedes cars available.

The importance of prestige, then, seems apparent. It appears doubtful that "economy" would be a valid reason for buying a car that costs between \$15,000 and \$20,000. The savings in fuel costs could never recover the difference in purchase price between a Mercedes and a less expensive car. However, most purchasers do not make the discounted cash flow calculations that would show the "present value" of the future fuel savings. Furthermore, the sharp increases in the prices of new Mercedes have created higher prices for used Mercedes also. In some cases, used diesel Mercedes still

command their original purchase price. Thus, the depreciation expense has been lower for a Mercedes than for most other cars. Also, fuel economy may be perceived as a virtue apart from the actual cost savings.

The motivation for fuel economy, however, makes economic sense in the purchase of a diesel Rabbit. The purchase price differential for the diesel Rabbit can be recovered in a few years, even considering that the effective price differential between the diesel and gasoline Rabbits may be considerably more than the \$200 difference in list price, because of discounts that are sometimes available on the gasoline Rabbits, and because the diesel Rabbit can only be bought equipped with extras. The problem of a higher effective price differential, however, may diminish in the future.

The principal cause for reluctance or doubt about buying a diesel car appears to be the perceived possibility of problems with maintenance or reliability. That would affect the Rabbit and the Oldsmobile, with their diesel engines modified from gasoline engines, and with little operations history. For Mercedes and Peugeots, with engines developed as diesels, and with years of operating history, that factor would be much less applicable.

The issue of maintenance and reliability consists of several elements that the typical owner usually views as a single consideration. The elements include:

- Frequency and ease of obtaining scheduled maintenance.
- Extent and cost of scheduled maintenance and parts replacement.
- Frequency and cost of unscheduled maintenance--and extent of warranty coverage.
- Longevity before major repairs--and cost.

As an example, Oldsmobile's rigorous requirement for engine oil and filter change at 3,000 miles (which is more frequent than required for gasoline engines) is viewed as a distinct annoyance by owners. Also, much of the diesel advantage will disappear because by 1980 most U.S. gasoline-powered passenger cars will have non-adjustable carburetors and will not need a tune-up before 50,000 miles.

Most U.S. full-sized passenger cars are designed to provide an average life of 100,000 miles and that indeed has been the general outcome for over 15 years. Major components in the engine and drive train usually last for much longer periods (e.g., 150,000 miles or more) with modest attention and care. Diesel passenger cars (either conversions or purpose-designed) have essentially the same goals, and the final resulting longevity is less a matter of whether the car is diesel or gasoline than of design decisions about component durability, and the number of years of experience with a particular engine model.

The other perceived negative factors for acceptability of diesels such as noise, odor, the starting problem in cold weather, and the difficulty in finding diesel fuel stations appear to be more than offset by the perceived positive factors. The latter include a general image of the diesels as virtuous because of their fuel economy, durability, and low maintenance. The consumer interest in diesel cars has implications for the development of other new-technology vehicles such as electric cars. There exists a small group of people that avidly follows new automotive developments and that is enthusiastic about technological innovations. With some overlap, there also exists a supplementary group with a strong environmental and conservation ethic. These two groups would be highly receptive to innovations in cars perceived as being energy efficient, even if the cars entailed moderate sacrifices in function, higher costs, and greater risks, provided the cars were perceived as offering some substantial advantages, and were not perceived as posing greater maintenance problems.

There also exists a much larger group of people that would be favorably inclined toward a new-technology car, but that would be much more cautious about buying one. This group would wait until sufficient operating experience with the cars had been accumulated so that they could be assured that the cars were reliable and would not impose greater maintenance problems. A perception of the cars as being more reliable and requiring less maintenance would be an important factor in gaining acceptance by this group.

B. Car Manufacturers

The reasons for the interest of the car manufacturers in diesels are numerous.

- It is generally agreed that a diesel-powered car of the same weight, performance, and capacity as a gasoline-powered counterpart can give about 25% better fuel economy measured on the basis of fuel volume. Thus, a larger and presumably more saleable and more profitable car can be made, and still stay within the Corporate Average Fuel Economy (CAFE) standards for the applicable year.
- So long as add-on emission controls are not required to meet federal standards with the diesel (e.g., exhaust gas recirculation, spark-assisted ignition timing, variable injection timing and rate, and the like), the diesel can probably show an advantage in simplicity and maintainability, and still command a price premium that allows high profitability.
- In many cases, converting a large, existing gasoline engine to a diesel allows production to continue with no change to most of the engine production line. Only the heads and intake manifold are different, and they could probably be made on the same lines with minor tooling changes. If the alternative were to go to a smaller gasoline engine, that could, in some cases, lead to a significant additional capital expenditure for machinery and tooling.
- Corporate image in regard to compliance with emission control and fuel economy regulations will probably benefit, although the way the regulations are arranged, all companies end up producing cars that achieve the maximum amount of emissions and fuel consumption that still gives a safe margin below the regulated levels. For example, if one company were to offer all of its cars in configurations capable of meeting the stricter California emission levels, its product line would probably be less competitive, and that is avoided.
- A recently-perceived potential advantage of the diesel is the possibility of its being much better at retaining its factory level of emission control than the gasoline engine. If the emission control regulatory emphasis shifts, as seems likely, toward enforcement of in-use performance standards, this could be a very important advantage for diesels.
- The light truck and recreational vehicle segment of the market has a more legitimate claim toward needing larger and more powerful engines, and diesels are probably the best way to achieve it. Hence, diesel passenger cars, which could use the same engines, would improve the economies of scale in production.

- The diesel provides a welcome addition to the list of options available in the continuing struggle to meet the combined goals of emission control and economy. As the economy standards tighten progressively each year, situations may arise where a need for improvement in Corporate Average Fuel Economy (CAFE) appears suddenly (e.g., consumer purchase patterns do not match those needed to meet the CAFE standard). Offering some diesel-only models could be an effective option.
- The technological options available to improve the diesel in terms of economy and emissions may be greater than those remaining for the conventional gasoline engine. In any case, the sum of the two technologies may offer greater growth potential.
- Mercedes-Benz was already well established in diesel cars when the emissions and fuel economy standards appeared. With Mercedes-Benz' commitment to luxury cars, the opportunity for improving fuel economy by downsizing the cars is limited. Hence, Mercedes-Benz will likely depend on a sales mix in this country that will include mostly diesels to meet the increasing fuel economy standards.

Uncertainty about the future emissions standards, particularly NO_x and particulates, and their ability to meet those standards has been the principal inhibiting factor to the interest of car manufacturers in diesel cars. If diesel emissions prove to be as serious a carcinogenic problem as some researchers fear, prospects for diesels will diminish drastically. Diesels are very poorly suited to the use of catalytic converters (air flows are too high and exhaust is too cool to initiate and sustain the reaction), and any presently conceived particulate traps would be much too large and complex to be practical. Also, the traps would require replacement or servicing very frequently--on the order of every 1,000 miles.

Uncertainty about consumer acceptability has also been a factor. And, naturally, the large investment required for developing and establishing the production of diesel engines has been a negative factor.

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Appendix

STUDY TEAM'S IMPRESSIONS OF A DIESEL CAR

To obtain a first-hand impression of a diesel car, three people from the study team drove a Mercedes 300D for between four and 10 days. Each person drove the car "around town" as well as on lengthy trips of between 400 and 600 miles. Their impressions of the diesel car characteristics were generally favorable, as shown in the following tabulation:

	<u>Acceleration</u>	<u>Noise</u>	<u>Odor</u>	<u>Handling</u>	<u>Comfort</u>	<u>Climbing Hills</u>
Driver 1	+	x	x	+	+	N.A.
Driver 2	+	x	+	+	+	+
Driver 3	-	x	+	+	+	-

+ favorable
- unfavorable
x neutral
N.A. never attempted

It should be noted that the three researchers are average drivers, without much experience in driving a variety of cars. Each driver did have slightly different views on the car overall. Driver 1 thought that the car drove better than gasoline cars because there was no hesitation or stalling. Driver 1 was very impressed with the way in which the car handled as well as the comfort and luxury features (naturally, those accouterments had nothing to do with the car's being a diesel). Also, Driver 1 drove for long stretches of U.S. Highway 101 and discovered many signs along the road that identified diesel fuel stations. Driver 1 "fueled up" in two stations, one in Santa Maria, and one in Menlo Park. The price of diesel fuel was identical (59.9¢/gal) at both stations. In contrast, the price of unleaded gasoline was 74.9 in Santa Maria, but identical to the cost of diesel fuel in Menlo Park.

The second driver traveled over more hills and mountains. The diesel car performed on that terrain, keeping a speed always between 50 and 55 mph while climbing hills. However, it would not accelerate above those speeds. The car performed nicely around town and on small hills. For the car's long trip, it was driven from the Bay area to Lake Tahoe in the Sierra Nevada. There was no problem starting the car at Lake Tahoe, even with the temperatures below freezing. It never took longer than 30 seconds for the glow plugs to warm up. The second driver's overall impression was that the car handled very well and was very easy to drive because of the extra luxury features.

The third driver was the least impressed with the car overall. Driver 3 thought that it was difficult to single out any outstanding feature, even though Driver 3 considered it a very good car. Driver 3 believed, as did Driver 2, that the car had more than adequate acceleration for commute and freeway travel. Driver 3 did think, however, that the performance was not as satisfactory on steep climbs even though the car maintained a speed of between 55 and 60 mph.