CHAPTER 5

INTRODUCTION TO PART III

Methanol is most often proposed as a fuel for automobiles. When methanol is considered as an auto fuel it will be judged in terms of its effects on technical and environmental performance of a car and on the cost of ownership and operation. That is, without specific government assistance methanol will penetrate the auto fuel market if and only if it is cost competitive with other conventional and synthetic fuels and if it does not involve a loss in technical and environmental performance.

Part III is meant to evaluate the prospects for methanol as an auto fuel; note this is pure or "neat" methanol not methanol-gasoline blends. Chapter 6 compares methanol and gasoline in terms of technical and environmental performance while Chapter 7 displays cost comparisons of methanol and synthetic gasolines. Finally Chapter 8 presents a very rough market projection of fuel consumption by automotive fleets; fleets are considered the most likely users of methanol in the early stages of its development.

Before getting into the details of auto fuel consumption, it is worth gaining some perspective by asking just how big a disruption or dramatic a change would be caused by a switch to methanol. At the outset, note that alcohol-burning cars are neither brand new nor extinct. The Model-T was equipped with an adjustable carburetor which could burn either gasoline or pure alcohol and alcohol powered cars might have taken a good portion of the market if cheap gasoline had not been readily available. Few alcohol-powered cars are seen on our highways today, but they have been saved from extinction by several small groups including racing enthusiasts -- all thirty-three cars in the Indianapolis 500 in 1978 were fueled by methanol.

Methanol use in cars can be judged as "new" or "disruptive" in only one way. The U.S. auto manufacturing and auto service industry is geared to gasoline; many, many years have been devoted to perfecting the gasoline-powered engine and millions of dollars have been spent to develop an elaborate gasoline distribution system. To the extent methanol use requires modifications to that engine or to that distribution system it can be seen as a new auto fuel.

At the outset note that the rudiments of the methanol auto technology are well understood. Time and money, however, will be necessary to see how the technology can best meet today's performance standards and how important economies of scale in car production and methanol distribution might be realized.

CHAPTER 6

METHANOL AND GASOLINE: A COMPARISON OF TECHNICAL AND ENVIRONMENTAL PERFORMANCE

The relationship between fuel and engine design is critical. As noted before, today's spark-ignition engines have been designed to maximize performance for gasoline blends with respect to fuel economy, environmental impact, vehicle operational costs and other factors. Since methanol has distinctly different physical and chemical characteristics when compared to conventional gasoline, certain modifications must be made by automobile manufacturers to current engine designs and fuel delivery systems.

The first section of this chapter will discuss in a general manner the basic modifications which will have to be made. There are certain difficulties such as cold start and lubricacity problems that must be overcome, though these are difficulties which automobile manufacturers can handle with existing technologies. Engine modifications will be made not only to avoid potential problems but also to take advantage of certain characteristics of methanol. Design for increased fuel economy and specific power are two examples.

The second section herein contains a discussion of the environmental, health and safety impacts of methanol use. A third section compares methanol and gasoline in terms of fuel economy and power output.

ENGINE AND FUEL DELIVERY MODIFICATIONS FOR METHANOL USE

Six possible modifications are discussed briefly in the following paragraphs.

Cold Start and Warm Up

Gasoline-powered engines do not have trouble starting in cold climates, except at very low temperatures, because enough of the smaller, more volatile compounds within gasoline vaporize at low temperatures to form a combustible mixture with air. Methanol is not nearly as volatile as gasoline blends are so at temperatures below 50°F an engine cannot be started without some assistance. Cold start and warmup is probably the most difficult technical problem which must be overcome if methanol is to be widely used. Once the engine has been started and warmed, hot exhaust gas can be recirculated to heat the ingoing fuel and there is no apparent problem with engine operation. There is also no difficulty in restarting an engine once warmed.

Several solutions for overcoming the cold start problems are being explored. One technique is to add at the refinery a small percentage of highly volatile compounds, most likely hydrocarbons, enabling the engine to start at colder ambient temperatures. This approach is not new. Indeed, winter gasoline blends contain more volatile compounds than summer blends. In some recent research, Bechtold and Pullman used two different mixtures, one of 10% isopentane and 90% methanol and another of 10% winter grade gasoline and 90% methanol, with modified carburetion. They report good cold starts down to 30°F; starts became increasingly more difficult between 30°F and 25°F and below 25°F were impossible with the system used in the experiment.[1] Volkswagen researchers report even better results. Adding 8% isopentane to methanol, starts down to -8°F were possible.[2] In both of these studies, the light hydrocarbon blending virtually eliminated warm up difficulties as well.

A second alternative would be to use a dual fuel system. That is, to employ a separate, smaller tank filled with another fuel for starting the car. Once the car has started and warmed the fuel delivery system could be switched to draw from the methanol tank. This technique has been used in the past for farm tractors operating on kerosene or diesel fuel, two fuels with characteristically low volatility. Nichols used a small propane tank to start successfully a methanol car in cold weather. She reports that this dual fueled system started the vehicle even more easily than gasoline at low temperatures.[3]

Another method is to use an electrical resistance heater operated with power from the car's battery to vaporize the fuel. This technique, however, draws heavily on the battery at the same time the starting motor is drawing heavily. After the engine has started by this method, heat must still be applied during early warm up until exhaust heat can assume the task of vaporizing the fuel. Researchers at the University of Santa Clara have

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1/ Richard Bechtold and J. Barrett Pullman; "Driving Cycle Economy Emissions and Photochemical Reactivity Using Alcohol Fuels and Gasoline," pp. 277-298 in Alcohols as Motor Fuels, Society of Automotive Engineers, Inc., Warrendale, PA, 1980.

2/ Holger Menrad, Wenpo Lee and Winfried Bernhardt; "Development of a Pure Methanol Car" pp. 161-174 in Alcohols as Motor Fuels, Society of Automotive Engineers, Inc., Warrendale, PA, 1980.

3/ Roberta J. Nichols; "Modification of a Ford Pinto for Operation on Methanol," paper no. 1-15 in Third International Symposium on Alcohol Fuel Technology, National Technical Information Service, Springfield, VA., Conf-790520, published April 1980.

constructed an electric manifold heater which requires 200 watts.[1/] So as to avoid drawing too heavily on the battery at any one time, Volkswagen elected to heat a small quantity of fuel before starting the engine. This procedure is sometimes used to start diesel engines today. Though idle behavior immediately following cold start was not satisfactory, engines were started down to 14°F with only a 35 to 40 second delay. Volkswagen has apparently dropped this approach and opted for fuel modification.[2/]

It may prove necessary to heat the inline fuel, the carburetor assembly, the intake manifold and the engine block. This would require a great deal of energy. A plug-in system to an electrical outlet or the development of advanced battery systems with increased power per unit would be two possible solutions for meeting this electrical demand.

Fuel Induction Systems

The energy content of methanol per unit volume is about half that of gasoline. For this reason, relative to a gasoline engine, the fuel flow rate to a methanol fueled engine must be doubled to achieve equivalent energy densities within the engine's cylinders. Present carburetors apparently do not have the fuel flow capacity needed for methanol. Consequently, carburetors in many of the methanol engine tests have been modified by increasing fuel passageways and jets and speeding up the fuel pump. This poses no serious engineering difficulties and performance has been satisfactory. The air-fuel mixture produced, however, is not as homogeneous as that produced with gasoline. Though engine performance has still been superior to gasoline's, this maldistribution detracts from the possibility of further improved engine and environmental performance, and could be a cause of unusual engine wear. To overcome this problem, alternative fuel-air induction systems such as electronic fuel injection and sonic carburetors have been tested. Results indicate, as expected, that significant engine and environmental gains can be realized. Several of these induction systems allow the fuel-air mixture at which the engine operates to be further leaned, enabling still further gains in thermal efficiency.[3/]

1/ D. J. Patterson, J. A. Bolt, and D. E. Cole; Modifications for Use of Methanol or Methanol-Gasoline Blends in Automotive Vehicles, p. 94, National Technical Information Service, Springfield, Virginia, ALO-3682-II, January 1980.

2/ Ibid, p. 62.

3/ M. C. McCormack and R. K. Pefley; "Alternate Air-Fuel Induction System Contrasts in Terms of Fuel Economy and Exhaust Emissions for Simulated Driving Cycles with Methanol and Indolene" paper No. 4-2 in International Symposium on Alcohol Fuel Technology, Methanol and Ethanol, National Technical Information Service, Springfield, VA., CONF-77-1175, July 1978.

Material Incompatability, Lubricity, and Engine Wear and Life

The fuel tank and fuel lines currently employed in automobiles are ternplate (lead) coated. This coating is "attacked" by methanol. Some gaskets, the accelerator pump plunger, the fuel filter, and some other parts in the fuel delivery system are also incompatible with methanol. Future automobiles can be designed using materials with which methanol is compatible. Possible substitute coatings and materials have been sited and others should be sought. In the case of retrofitting existing automobiles, the above parts would have to be replaced along with the current carburetor. This would not only prove to be complex but would also be expensive. Therefore, the prospect of producing new automobiles with little or no cost penalty with compatible materials appears much more attractive than retrofitting the existing fleet.

The present lubrication and lubricant formulations that have evolved over the past 70 years have been developed primarily for hydrocarbon fuels. Methanol, with its significantly different chemical structure, does not work as well as conventional fuels do with these lubricants. Evidence suggests that the wear rate of the upper cylinder bore may be an order of magnitude greater than with gasoline. There also appears to be excessive dilution of the crankcase oil by water and some interference with the additives by methanol. It must be noted that not all researchers report unusual wear and that tests for wear thus far have only been of the short-term high mileage type.[1/] Fleet car results are needed to ascertain more reliably the degree of engine wear. Some investigators have added small amounts of castor oil or diesel oil to methanol to improve lubricity. The development of new oils for methanol and/or the use of corrosive inhibitors or other additives to reduce engine wear may indeed be needed in the long run.

Vapor Lock

Since methanol boils at 149°F, vapor lock which might require some modifications to the fuel delivery system could be a problem at very high ambient temperatures. Though this is viewed as a minor problem at present, further study is needed for a conclusive answer.

Fuel Tank

Since methanol has approximately half the energy content of gasoline on a volumetric basis, the fuel tank will have to be enlarged if the vehicle is to have the same traveling distance without refueling. Further discussion of this is found under the fuel economy section.

1/ Edwin C. Owens; "Methanol Effects on Lubrication in Engine Wear" paper No. 206 in International Symposium on Alcohol Fuel Technology, Methanol and Ethanol, National Technical Information Service, Springfield, VA, CONF-77-1175, July 1978.

Camshaft and Compression Ratio Modifications

Because of methanol's high octane rating, the compression ratio of a methanol engine compared to a gasoline engine can be increased. The camshaft can also be shifted to reduce overlap. Both of these changes can be tooled for future cars and result in increased fuel economy and specific power for the methanol engine.

Diesel Engine

The potential for a fuel in a diesel engine can be characterized by its cetane rating, a measure of a fuels ignitability via compression. Diesel fuels commonly have a rating between 40 and 60. Methanol's rating is much lower, somewhat less than 5. For this reason methanol is not a good diesel fuel. A significant amount of a cetane additive has been mixed with methanol to increase its rating. Although this has been successful in increasing the rating so that the fuel can indeed be used, the additive is quite expensive and does not appear to be an economically viable alternative. Various dual fueled systems which use diesel fuel at lower loads and gradually introduce methanol at higher loads are being tested. These systems work well under steady state conditions. However during transient conditions they tend to rely to heavily on the diesel fuel so that the overall use of methanol remains low.1/

The potential for methanol use in diesel engines does not look good at this time. The economics are unfavorable for methanol with a centane additive and a duel fuel injection system which can use a significant amount of methanol is not currently available.

ENVIRONMENTAL AND HEALTH CONSIDERATIONS

The following sections compare air pollution emissions from gasoline and methanol engines.

Nitrogen Oxides (NO_x) Emissions

Virtually all investigators report reduced NO_x emissions for methanol fueled engines, though the estimates vary. The peak temperature within a piston cylinder during combustion is lower for methanol than it is for gasoline, thereby producing lower NO_x emissions. Because of the lower combustion temperature, a methanol fueled engine will remain cooler than a gasoline fueled engine.

Two modifications which will be made for methanol operation apparently lead to increased NO_x emissions relative to an unmodified methanol engine.

1/ E. Holmer; "Methanol as a Substitute Fuel in the Diesel Engine" paper No. 2-4 in International Symposium on Alcohol Fuel Technology, Methanol and Ethanol, National Technical Information Service, Springfield, VA., CONF-77-1175, July 1978.

First, increasing the compression ratio leads to an increase in NO_x formation. However, by retarding spark plug timing NO_x can be maintained at levels usually found for lower compression ratios and the engine can still gain increased fuel economy and specific power. Methanol cars will also modify the camshaft found in today's cars for better fuel economy and power. This will also increase NO_x production somewhat. Even with these two modifications NO_x emissions are still reported at 8-50% less than comparable emissions from a gasoline powered car.[1/]

Carbon Monoxide (CO) Emissions

Carbon monoxide emissions for methanol are less than those of gasoline when fuel-rich mixtures are burned in the engine. In the past, cars were designed to operate with such mixtures in this way in order to obtain enhanced power. With more stringent regulations, cars are now designed to operate at a slightly lean mixture for increased fuel economy and reduced carbon monoxide emissions. In this region, carbon monoxide emissions with methanol are at least as low as those with gasoline and some investigators report a slight, but discernible, advantage over gasoline exhaust.[2/]

Sulfur, Lead and Soot Emissions

Methanol does not produce any sulfur or lead emissions simply because there is none present in the fuel. Gasoline has trace amounts of sulfur present so there is a slight advantage for methanol here. With respect to lead emissions, Methanol is also preferable to leaded gasoline but has no or a slight (unleaded gasoline can contain trace amounts of lead) advantage over unleaded blends. Methanol and gasoline do not produce any soot, but some soot is produced with diesel fuel so there is an advantage for methanol over diesel.[3/]

Aldehyde Emissions

Virtually all the aldehyde produced with methanol is formaldehyde, which is a strong eye irritant and photochemical percursor. These emissions are quite dependent on the fuel air equivalence ratio at which the engine operates and range from 1.2 to 10 times the amount for gasoline, tending to be greatest

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1/ R. Bechtold and J. B. Pullman, "Driving Cycle. Economy Emissions, and Photochemical Reactivity Using Alcohol Fuels and Gasoline," pp. 277-298 in Alcohols as Motor Fuels, Society of Automotive Engineers, Inc., Warrendale, PA., 1980.

2/ F. F. Pischinger and K. Kramer, "The Influence on the Aldehyde Emissions of a Methanol Operated Four-Stroke Otto Cycle Engine." paper No. 11-25 in Third International Symposium on Alcohol Fuel Technology, National Technical Information Service, Springfield, Va., CONF-790510, April 1980.

3/ David L. Hagen; "Methanol as a Fuel: A Review with Bibliography," pp. 189-222 in Alcohols as Motor Fuels, Society of Automotive Engineers, Warrendale, PA., 1980.

under lean operating conditions.[1/] Addition of 1% aniline has been reported to reduce significantly these emissions. In addition, a platinum-rhodium catalyst has been reported to reduce aldehyde emissions by 50% with fuel-rich mixtures and up to 90% when a lean mixture is used.[2/]

Hydrocarbon Emissions

The hydrocarbon emissions from a methanol engine are almost solely methanol and aldehydes. As explained above, the amount of aldehydes in the exhausts varies with the engine conditions and the presence of a catalyst. Pullman and Bechtold found the percentage of aldehydes by carbon mass in exhaust to vary from 2-22% depending on operating conditions. The remainder is almost solely methanol.

For gasoline, hydrocarbons in exhaust seem to be dependent on the type of gasoline used. That is, the percentage of alkane, alkene, aromatic or alkyne molecules in the exhaust will vary with the type of gasoline used. Whatever the makeup of the gasoline blend, the amount of alcohol or aldehydes in the exhaust is almost negligible.

The addition of an oxidation catalyst substantially reduces hydrocarbon emissions for both methanol and gasoline, especially for lean fuel-air mixtures. With a catalyst, a slight but discernible edge in total hydrocarbon emissions by mass is evident for methanol over gasoline. The combined effect of reduced NO_x and hydrocarbon emissions in methanol exhaust in laboratory tests is that less ozone pollution forms. This suggests that the use of methanol fueled cars would have a beneficial impact on urban atmospheres.[3/]

Safety and Toxicity

Based on the flamability limits for methanol, a potentially combustible methanol vapor-air mixture could form above the fuel in the fuel tank at normal ambient temperatures, whereas with gasoline the fuel-air mixture in the tank is to rich (except at extremely low temperatures) to burn. Tests are needed to assess the risk to passengers in the event of a collision or other

1/ Mueller Associates; Status of Alcohol Fuels Utilization Technology for Highway Transportation, p. 9, National Technical Information Service, HCP/M2923-01, June 1978.

2/ F. F. Pischinger and K. Kramer, "The Influence on the Aldehyde Emissions of a Methanol Operated Four-Stroke Otto Cycle Engine." paper No. 11-25 in Third International Symposium on Alcohol Fuel Technology, National Technical Information Service, Springfield, Va., CONF-790510, April 1980.

3/ R. Bechtold and J. B. Pullman, "Driving Cycle Economy, Emissions, and Photochemical Reactivity Using Alcohol Fuels and Gasoline," pp. 277-298 in Alcohols as Motor Fuels, Society of Automotive Engineers, Inc., Warrendale, PA., 1980.

type accident. Addition of volatile compounds to the methanol fuel may enrich the atmosphere within the tank so as to remove this potential hazard. As mentioned earlier, fuel modification could also help overcome cold start difficulties. Still further, methanol burns with a virtually clear flame and therefore if it catches fire during the day it will be difficult to see. The addition of light hydrocarbons could also add some color to the flame.

Methanol is toxic and is currently treated as a hazardous material. Ingestion must be avoided. The public must be educated not to confuse methanol with ethanol and not to siphon the fuel by mouth. Methanol vapors are also toxic and since its odor is not very noticeable the addition of an odorant might also prove necessary.

FUEL ECONOMY AND SPECIFIC POWER

A methanol engine is thermally more efficient than a gasoline engine for several reasons. First, methanol's greater flame speed vis-a-vis gasoline's, produces a more effective expansion of the piston during combustion. Second, methanol has a higher octane rating allowing the engine to employ a greater compression ratio without knocking. Gasoline engines operate with compression ratios between 8 and 10, while methanol engines have been operated as high as 14. Both of these characteristics produce corresponding improvements in fuel economy on an energy basis (miles per million Btus) and specific power. Since methanol engine operation can be leaned further than a gasoline engine, further gains in fuel economy can be realized.

Though virtually all investigators report methanol's increased thermal efficiency, few report specifically the gains in fuel economy and power. Volkswagon reports a 6% increase in thermal efficiency relative to gasoline (from 30 to 36%) by increasing the compression ratio from 9.7 to 14 under storchiometric conditions.[1/] This should produce approximately a 20% increase in fuel economy and power. Similar results were obtained by Conoco, where a V8 engine consumed from 15 to 26% less energy using methanol. This implies a 17 to 35% increase in fuel economy and power.[2/] Bechtold and Pullman modified the carburetor and camshaft of a Ford Pinto (the engine was not optimized any further for methanol use) and used a fuel of 75% methanol and 25% higher alcohols. For these tests, methanol showed no fuel economy improvement for the highway cycle and a 13% increase for the urban cycle.[3/]

1/ W. E. Berhardt and W. Lee, "Engine Performance and Exhaust Emission Characteristics of a Methanol-Fueled Automobile" p. 218 in Future Automotive Fuels edited by J. M. Colucci and N.E. Gallopoulso, Plenum Press, New York, 1977.

2/ Ibid. p.219.

3/ R. Bechtold and J. B. Pullman, "Driving Cycle. Economy, Emissions, and Photochemical Reactivity Using Alcohol Fuels and Gasoline," pp. 277-298 in Alcohols as Motor Fuels, Society of Automotive Engineers, Inc., Warrendale, PA., 1980.

Nichols using a fuel injector, a modified camshaft and increased compression ratio on a Ford Pinto reports a 38% increase in fuel economy using a 90% methanol, 10% higher alcohol fuel relative to the standard gasoline Pinto. Additionally, the overall performance of the car was rated as excellent, with smooth idle and quick throttle response.1/

Based on experimental results, researchers at the University of Santa Clara have modeled expected fuel economy under a variety of different engine conditions. Comparing fuel economies as a function of fuel-air ratio, methanol has an approximate 28% advantage over gasoline on the urban cycle under stoichiometric conditions. As the mixture is leaned, this edge increases slightly. On the highway the methanol fueled car is expected to have a 22% advantage with a stoichiometric fuel-air mixture.2/

Bank of America currently has the first test fleet of methanol fueled cars in the United States, numbering approximatly 80 cars. Though no official reports have been released, the cars are said to be getting much better than a 30% increase in fuel economy. Maintenance costs are said to be lower and overall performance said to be superior to a gasoline car. Encouraged by the economics thus far, Bank of America intends to expand their methanol fleet to almost 200 by the end of the next year.

Methanol has only half the volumetric energy density of gasoline. For a methanol car to travel the same distance as gasoline without refueling the fuel tank would have to be doubled if methanol and gasoline engines operated with the same thermal efficiency. As demonstrated by the tests sited above, methanol engines are certainly thermally more efficient, though the exact percentage advantage in fuel economy for an optimally designed methanol engine over an optimally designed gasoline engine cannot be stated until extensive tests on fleets such as the Bank of America group have been completed. A very conservative estimate would be 15%. A more likely figure though perhaps still a bit conservative based on the most recent tests, would be 25%. Using this latter number, a tank for methanol would have to be roughly 60% larger than one for gasoline to drive a vehicle the same distance without refueling.

A larger tank could require the sacrifice of some storage space in a vehicle. Carrying the greater number of gallons would also increase the weight of the car, thereby causing a slight loss in operational thermal efficiency. Since methanol engines produce greater specific power compared to gasoline engines, future methanol engines can be downsized. This reduction in engine weight should counter the increase due to carrying a greater volume of fuel. Another alternative would be to keep the tanks the same size they are today. This obviously would require methanol users to refill their tanks more often.

1/ R. J. Nichols, "Modification of a Ford Pinto for Operation on Methanol," paper no. 1-15 in Third International Symposium on Alcohol Fuel Technology, National Technical Information Service, Springfield, VA., CONF-790520, published April 1980.

2/ M. McCormack, J. Overbey, and R. Pefley; "Hardware/Software Strategies for Fuel Economy Optimization with Exhaust Emissions Constraints in Methanol Fueled Automobiles" paper no. 111-54 in Third International Symposium on Alcohol Fuels Technology, National Technical Information Service, Springfield, VA., CONF-790520, April 1980.

CHAPTER 7

COST COMPARISONS OF SYNTHETIC FUELS FOR AUTOMOBILES

The purpose of this chapter is to compare the cost of using three alternative automobile fuels: methanol; gasoline from the direct liquefaction processes; and Mobil-M gasoline. These cost comparisons could be shown to vary for several reasons. The variations explored within the four major sections of this chapter concern the following: the extent or scale of methanol use; the method of pricing retail service; the location of synfuel production or use; and the construction date of the synfuel plant.

Also seen within each section is the variation in cost due to type of use. The two classes of users studied here are termed fleet and non-fleet (the next chapter explains in considerable detail the differences between the classes). For these auto cost comparisons note that both classes of cars are assumed to meet and maintain the 1985 average fuel economy standard for new cars - 27.5 miles per gallon, according to the EPA estimate, which is the equivalent of about 22.5 miles per gallon on-the-road. The annual mileage of these two classes, however, is assumed to be quite different - 23,000 miles per year for fleet cars and 12,000 miles for non-fleet cars.

The primary reason for distinguishing between fleet and non-fleet cars is the possibility that some fleets will not be concerned with limited availability in the early stage of methanol development. That is, some fleet cars will be used in a narrow geographic area and can return for refueling to the fleet's central methanol storage area. Methanol use would not be precluded, as it might be for non-fleet or "family" cars, by the fact that it cannot be found in several service stations in most cities.

However, even for fleets which find an operating cost savings with methanol and, in addition, are not bothered by limited availability, there is at least one more disincentive for methanol use in the early stages of its development that is not considered in these cost comparisons. The disincentive concerns the fact that many fleets consider resale value to be a primary criterion for an auto purchase,[1/] and further, fleet cars are most often resold to used car dealers who in turn sell to the general public.[2/] If methanol is not available widely and non-fleet use is thereby precluded, resale value will fall to zero for many fleets when methanol-powered cars are used. Inability to resell is an obvious and a very important disincentive to methanol use in automotive fleets.

Finally, within each section, comparisons will be made using several estimates of synfuel production costs. (All the estimates are explained in Chapter 4 and Appendix A and B). The primary reason for using several instead of just one estimate for methanol and direct liquefaction products is that, as should be expected at this early stage of synfuel development, a considerable range of estimates was found in the literature; no one knows precisely how much synfuels will cost ten years from now and by using several estimates we hope to capture a range of uncertainty in the cost comparisons.

As will be seen, the cost for each fuel has three components.

- The cost of producing and, if necessary, refining the fuel. (These estimates were developed in Chapter 4).
- The cost of transporting the fuel from the plant-gate to the consuming region plus the cost of distributing that fuel within the region.
- The difference in cost of constructing and operating an automobile that uses each fuel.

EXTENT OF METHANOL USE

As noted, the cost comparisons would vary for several reasons. From the perspective of methanol, the most important variation is caused by the extent or scale of methanol use. With limited use, several cost "penalties" may be associated with methanol. In this analyses, the cost penalties are assumed to be as follows:

- The cost of modifying a car for methanol use is $350. With large scale consumption, methanol-powered cars could be mass produced and the difference between constructing a methanol and a gasoline-powered car is assumed to be

1/ Based on a survey reported in Joseph R. Wagner, Fleet Operator Data Book, p. 16 prepared for the U.S. Department of Energy, September 1979.

2/ AUTOMOTIVE FLEET, April 1980, p. 36.

negligible.[1/] (That cost of modification is depreciated over three years with a straight-line method).

- As explained in the previous chapter, methanol-powered cars are likely to be more fuel efficient than gasoline-powered cars. With small scale methanol use, that improvement is assumed to be 15 percent. When methanol-powered cars are mass produced, however, they can be optimized for this fuel and even greater improvements may be realized; the large scale case assumes a 25 percent advantage in fuel efficiency. In both cases, the fuel efficiency improvement is measured in terms of miles per million Btu, not miles per gallon, and then put in terms of million Btu per mile for use in the cost comparison tables).

- In the small scale case, all fuels are assumed to be shipped by rail. With larger scale use, all the synfuels are assumed to enjoy the lower rates of pipeline transport. Because of methanol's lower Btu content, the change to pipeline transport lowers its cost more than the cost of the other synthetic fuels.

As noted, it is important to show separately cost comparisons for fleet and non-fleet automobiles. In addition to the assumed difference in miles driven each year, fleet cars are assumed to be different because they can avoid the extra cost of retailing and government gasoline taxes. For fleet cars, Table 7-1 displays cost estimates for 1990 assuming small scale distribution while Table 7-2 shows the same assuming large scale distribution.

Table 7-3 summarizes the cost comparisons for fleet cars; the Koppers-Totzek estimate is not shown because it is not a second-generation process as are the others. Methanol is shown to have a cost advantage in all of the large scale cases and the advantage ranges from $197 to $479 per car per year depending on the estimates considered. Except in two of the twelve small scale comparisons, where the costs are just about equal, methanol also has a cost advantage; the advantage ranges from $84 to $269 per year.

For non-fleet cars, Table 7-4 show the cost comparisons assuming a small scale industry while Table 7-5 shows the same assuming a large scale industry. Table 7-6 presents a summary of the cost comparisons. In the summary table, it is seen that methanol is at a cost disadvantage in all of the small scale cases; that disadvantage ranges from $47 to $200 per car per year. In contrast, methanol is found to be cheaper in ten of the twelve large scale cases shown in the table. The cost advantage ranges from $47 to $143.

1/ Based on information from the staff and Commissioners of the National Alcohol Fuels Commission.

TABLE 7-1

FLEET AUTO COST COMPARISON IN 1990
FOR SMALL SCALE SYNFUEL DISTRIBUTION TO CHICAGO[a/]

		Koppers Totzek Methanol Estimate	Badger Methanol Estimate	Texaco Methanol Estimate	BGC/LURGI Methanol Estimate	SRC-II Gasoline Estimate	EDS Gasoline Estimate	H-Coal Gasoline Estimate	Badger Mobil-M Estimate
1.	Delivered Fuel Cost (in $1980 per MMBTU)								
	A. Plantgate Cost	8.94	7.02	7.10	6.16	9.15	8.58	7.71	9.15
	B. Long Haul Transport	.57	.57	.57	.57	.28	.28	.28	.28
	C. Local Distribution	1.43	1.43	1.43	1.43	.71	.71	.71	.71
	D. Excise Taxes	0	0	0	0	0	0	0	0
	E. Total	10.94	9.02	9.10	8.16	10.14	9.57	8.70	10.14
2.	MMBtu Per Mile	.0049	.0049	.0049	.0049	.0056	.0056	.0056	.0056
3.	Fuel Cost Per Mile (Line 1x2)	.0536	.0442	.0446	.0400	.0568	.0536	.0487	.0568
4.	Fuel Cost Per Year	1,233	1,017	1,026	920	1,306	1,233	1,121	1,306
5.	Annual Capital Costs ($)	117	117	117	117	0	0	0	0
6.	Total Cost Per Year (Line 4+5)	1,350	1,134	1,143	1,037	1,306	1,233	1,121	1,306

a/ Costs include total annual fuel cost plus, as seen in line 5, the increase in investment cost associated with a methanol-powered car.

TABLE 7-2

FLEET AUTO COST COMPARISON IN 1990
FOR LARGE SCALE SYNFUEL DISTRIBUTION TO CHICAGO[a/]

		Koppers Totzek Methanol Estimate	Badger Methanol Estimate	Texaco Methanol Estimate	BGC/LURGI Methanol Estimate	SRC-II Gasoline Estimate	EDS Gasoline Estimate	H-Coal Gasoline Estimate	Badger Mobil-M Estimate
1.	Delivered Fuel Cost (in $1980 per MMBTU)								
	A. Plantgate Cost	8.94	7.02	7.10	6.16	9.15	8.58	7.71	9.15
	B. Long Haul Transport	.15	.15	.15	.15	.08	.08	.08	.06
	C. Local Distribution	1.43	1.43	1.43	1.43	.71	.71	.71	.71
	D. Excise Taxes	0	0	0	0	0	0	0	0
	E. Total	10.52	8.60	8.68	7.74	9.94	9.37	8.50	9.94
2.	MMBtu Per Mile	.0045	.0045	.0045	.0045	.0056	.0056	.0056	.0056
3.	Fuel Cost Per Mile (Line 1x2)	.0473	.0387	.0391	.0348	.0557	.0525	.0476	.0557
4.	Fuel Cost Per Year	1,089	890	898	801	1,280	1,207	1,095	1,280
5.	Annual Capital Costs ($)	0	0	0	0	0	0	0	0
6.	Total Cost Per Year (Line 4+5)	1,089	890	898	801	1,280	1,207	1,095	1,280

a/ Costs include total annual fuel cost plus, as seen in line 5, the increase in investment cost associated with a methanol-powered car.

TABLE 7-3

SUMMARY OF FLEET COST COMPARISONS
IN 1990 FOR BOTH SMALL AND LARGE
SCALE DISTRIBUTIONS TO CHICAGO[a/]
(Dollar Differences in Annual Cost)

	Direct Liquefaction Estimate						Mobil-M Gasoline	
	SRC-II		EDS		H-Coal			
Methanol Estimate	Small Scale	Large Scale	Small Scale	Large Scale	Small Scale	Large Scale	Small Scale	Large Scale
Badger	172	390	99	317	(13)	205	172	390
Texaco	163	382	90	309	(22)	197	163	382
BGC/LURGI	269	479	196	406	84	294	269	479
Average	201	417	128	344	16	232	201	417

a/ Differences are determined by subtracting total costs of synthetic gasoline from that for methanol. A bracketed figure means methanol was more expensive. This is a summary of the two previous tables.

TABLE 7-4

NON-FLEET AUTO COST COMPARISON IN 1990
FOR SMALL SCALE SYNFUEL DISTRIBUTION TO CHICAGO[a/]

	Koppers Totzek Methanol Estimate	Badger Methanol Estimate	Texaco Methanol Estimate	BGC/LURGI Methanol Estimate	SRC-II Gasoline Estimate	EDS Gasoline Estimate	H-Coal Gasoline Estimate	Badger Mobil-M Estimate
1. Delivered Fuel Cost (in $1980 per MMBTU)								
A. Plantgate Cost	8.94	7.02	7.10	6.16	9.15	8.58	7.71	9.15
B. Long Haul Transport	.57	.57	.57	.57	.28	.28	.28	.28
C. Local Distribution[b/]	4.60	4.60	4.60	4.60	2.29	2.29	2.29	2.29
D. Excise Taxes	2.06	2.06	2.06	2.06	1.03	1.03	1.03	1.03
E. Total	16.17	14.25	14.33	13.39	12.75	12.18	11.31	12.75
2. MMBtu Per Mile	.0049	.0049	.0049	.0049	.0056	.0056	.0056	.0056
3. Fuel Cost Per Mile (Line 1x2)	.0792	.0698	.0702	.0656	.0714	.0682	.0633	.0714
4. Fuel Cost Per Year	951	838	843	783	857	818	760	857
5. Annual Capital Costs ($)	117	117	117	117	0	0	0	0
6. Total Cost Per Year (Line 4+5)	1,068	955	960	904	857	818	760	857

a/ Costs include total annual fuel costs plus, as seen in line 5, the increase in investment cost associated with a methanol-powered car.

b/ Local Distribution costs for non-fleet cars are higher than for fleet cars because a retailing cost is included.

TABLE 7-5

NON-FLEET AUTO COST COMPARISON IN 1990
FOR LARGE SCALE SYNFUEL DISTRIBUTION TO CHICAGO[a/]

		Koppers Totzek Methanol Estimate	Badger Methanol Estimate	Texaco Methanol Estimate	BGC/LURGI Methanol Estimate	SRC-II Gasoline Estimate	EDS Gasoline Estimate	H-Coal Gasoline Estimate	Badger Mobil-M Estimate
1.	Delivered Fuel Cost (in $1980 per MMBTU)								
	A. Plantgate Cost	8.94	7.02	7.10	6.16	9.15	8.58	7.71	9.15
	B. Long Haul Transport	.15	.15	.15	.15	.08	.08	.08	.08
	C. Local Distribution[b/]	4.60	4.60	4.60	4.60	2.29	2.29	2.29	2.29
	D. Excise Taxes	2.06	2.06	2.06	2.06	1.03	1.03	1.03	1.03
	E. Total	15.75	13.83	13.91	12.97	12.55	11.98	11.11	12.55
2.	MMBtu Per Mile	.0045	.0045	.0045	.0045	.0056	.0056	.0056	.0056
3.	Fuel Cost Per Mile (Line 1x2)	.0709	.0622	.0626	.0584	.0703	.0670	.0622	.0703
4.	Fuel Cost Per Year	851	747	751	700	843	805	747	843
5.	Annual Capital Costs ($)	0	0	0	0	0	0	0	0
6.	Total Cost Per Year (Line 4+5)	851	747	751	700	843	805	747	843

a/ Costs include total annual fuel costs plus, as seen in line 5, the increase in investment cost associated with a methanol-powered car.

b/ Local Distribution costs for non-fleet cars are higher than for fleet cars because a retailing cost is included.

TABLE 7-6

SUMMARY OF NON-FLEET COST COMPARISONS
IN 1990 FOR BOTH SMALL AND LARGE
SCALE DISTRIBUTIONS TO CHICAGO a/
(Dollar Differences in Annual Cost)

	Direct Liquefaction Estimate							
	SRC-II		EDS		H-Coal		Mobil-M Gasoline	
Methanol Estimate	Small Scale	Large Scale	Small Scale	Large Scale	Small Scale	Large Scale	Small Scale	Large Scale
Badger	(98)	96	(137)	58	(195)	0	(98)	96
Texaco	(103)	92	(142)	54	(200)	(4)	(103)	92
BGC/LURGI	(47)	143	(86)	105	(144)	47	(47)	143
Average	(83)	110	(122)	72	(180)	14	(83)	110

a/ Differences are determined by subtracting total costs of synthetic gasoline from that of methanol. A bracketed figure means methanol was more expensive. This is a summary of the two previous tables.

PRICES FOR RETAIL SERVICES

In the cost comparisons shown thus far it's been assumed that the charges for retailing and excise taxes are the same per gallon of methanol and synthetic gasoline. Since methanol has fewer Btu's per gallon than gasoline, these charges are higher per Btu of methanol. The purpose of this section is to show the difference in the cost comparisons when this assumption is changed.

To illustrate the uncertainty surrounding this topic, consider the difference between a gasoline and a methanol service station. Assume the stations would serve the same customers; that is, they would supply the fuel for the same number of miles of travel. Obviously, the methanol station would sell a greater number of gallons; with 25 percent superior fuel efficiency for methanol and 50 percent fewer Btu per gallon, sales in terms of gallons of methanol would be 60 percent higher.

The central question here is whether the service station's cost would rise commensurately.

If the station's cost increase by 60 percent, it is appropriate to set retailing cost equal per gallon. That is, it would be assumed new land, fuel tanks, and attendants would be added to handle the increased volume.

In contrast, one might assume the increased volume would be handled without added expense. Since the service station could spread its fixed costs over a greater number of gallons, the cost per gallon of methanol would be lower than for gasoline.

Table 7-7 and 7-8 show the effect of assuming retailers can handle, at no additional cost, the increased volume brought on by a switch from gasoline to methanol. Since no retailing cost was shown for fleet cars, only cost comparisons for nonfleet autos are displayed. Once again, both a small scale case (in Table 7-7) and a large scale case (in Table 7-8) are shown.

Note also in these tables the excise tax is altered. Previously, it was assumed the excise tax would be $.13 per gallon for both methanol and gasoline. Here it is assumed the tax is lowered by federal and state governments to reflect the increased sales at methanol stations.

Table 7-9 summarizes the results of these comparisons for non-fleet uses. Remember that in the previous comparisons, methanol was at a cost disadvantage in all the small scale cases. With the lower retail costs and excise taxes, however, methanol is shown to be cheaper in seven of the twelve small scale cases; the cost advantage ranges from $33 to $84. For the large scale cases, the change to lower retail costs enables methanol to have a cost advantage in all twelve cases; and the level of cost savings increases; the advantage ranges from $102 to $249.

TABLE 7-7

NON-FLEET AUTO COST COMPARISON IN 1990
FOR SMALL SCALE SYNFUEL DISTRIBUTION TO CHICAGO[a/]
WITH LOW RETAIL COSTS

		Koppers Totzek Methanol Estimate	Badger Methanol Estimate	Texaco Methanol Estimate	BGC/LURGI Methanol Estimate	SRC-II Gasoline Estimate	EDS Gasoline Estimate	H-Coal Gasoline Estimate	Badger Mobil-M Estimate
1.	Delivered Fuel Cost (in $1980 per MMBTU)								
	A. Plantgate Cost	8.94	7.02	7.10	6.16	9.15	8.58	7.71	9.15
	B. Long Haul Transport	.57	.57	.57	.57	.28	.28	.28	.28
	C. Local Distribution[b/]	3.25	3.25	3.25	3.25	2.29	2.29	2.29	2.29
	D. Excise Taxes	1.18	1.18	1.18	1.18	1.03	1.03	1.03	1.03
	E. Total	13.94	12.02	12.10	11.16	12.75	12.18	11.31	12.75
2.	MMBtu Per Mile	.0049	.0049	.0049	.0049	.0056	.0056	.0056	.0056
3.	Fuel Cost Per Mile (Line 1x2)	.0683	.0589	.0593	.0547	.0714	.0682	.0633	.0714
4.	Fuel Cost Per Year	820	707	711	656	857	818	760	857
5.	Annual Capital Costs ($)	117	117	117	117	0	0	0	0
6.	Total Cost Per Year (Line 4+5)	937	824	828	773	857	818	760	857

a/ Costs include total annual fuel costs plus, as seen in line 5, the increase in investment cost associated with a methanol-powered car.

b/ Local Distribution costs for non-fleet cars are higher than for fleet cars because a retailing cost is included.

TABLE 7-8

NON-FLEET AUTO COST COMPARISON IN 1990
FOR LARGE SCALE SYNFUEL DISTRIBUTION TO CHICAGO
WITH LOW RETAIL COSTS[a/]

	Koppers Totzek Methanol Estimate	Badger Methanol Estimate	Texaco Methanol Estimate	BGC/LURGI Methanol Estimate	SRC-II Gasoline Estimate	EDS Gasoline Estimate	H-Coal Gasoline Estimate	Badger Mobil-M Estimate
1. Delivered Fuel Cost (in $1980 per MMBTU)								
A. Plantgate Cost	8.94	7.02	7.10	6.16	9.15	8.58	7.71	9.15
B. Long Haul Transport	.15	.15	.15	.15	.08	.08	.08	.08
C. Local Distribution[b/]	3.41	3.41	3.41	3.41	2.29	2.29	2.29	2.29
D. Excise Taxes	1.29	1.29	1.29	1.29	1.03	1.03	1.03	1.03
E. Total	13.79	11.87	11.95	11.01	12.55	11.98	11.11	12.55
2. MMBtu Per Mile	.0045	.0045	.0045	.0045	.0056	.0056	.0056	.0056
3. Fuel Cost Per Mile (Line 1x2)	.0621	.0534	.0538	.0495	.0703	.0671	.0622	.0703
4. Fuel Cost Per Year	745	641	645	594	843	805	747	843
5. Annual Capital Costs ($)	0	0	0	0	0	0	0	0
6. Total Cost Per Year (Line 4+5)	745	641	645	594	843	805	747	843

a/ Costs include total annual fuel costs plus, as seen in line 5, the increase in investment cost associated with a methanol-powered car.

b/ Local Distribution costs for non-fleet cars are higher than for fleet cars because a retailing cost is included.

TABLE 7-9

SUMMARY OF NON-FLEET COST COMPARISONS
IN 1990 FOR BOTH SMALL AND LARGE
SCALE DISTRIBUTIONS TO CHICAGO
AND WITH LOW RETAIL COSTS[a/]
(Dollar Differences in Annual Cost)

	Direct Liquefaction Estimate							
	SRC-II		EDS		H-Coal		Mobil-M Gasoline	
Methanol Estimate	Small Scale	Large Scale	Small Scale	Large Scale	Small Scale	Large Scale	Small Scale	Large Scale
Badger	33	202	(6)	164	(64)	106	33	202
Texaco	29	198	(10)	160	(68)	102	29	198
BGC/LURGI	84	249	45	211	(13)	153	84	249
Average	49	216	10	178	(48)	120	49	216

a/ Differences are determined by subtracting total costs of synthetic gasoline from that of methanol. A bracketed figure means methanol was more expensive. This is a summary of the two previous tables.

LOCATION

Another factor which might affect these cost comparisons is a change in the location of synfuel production or use. All of the comparisons thus far have assumed production around Centralia, Illinois, and use in Chicago. With production, the most likely move would be to the coal fields of the Western United States. At these sites considerably lower coal costs would be enjoyed; while the Illinois coal assumed here costs about $1.40 per MMBtu, Wyoming coal would cost on the order of $.60 per MMBtu.

Offsetting this coal price advantage for Western States is the chance of higher capital cost per unit of product and higher transport cost to market. Higher capital costs may be incurred simply because of the lower Btu content of Western coals, a greater number of tons must be processed to yield the same product yield, and because extensive construction camps may be required at isolated locations.

Both the lowered coal costs and the increased capital costs of a Western site would be incurred, however, by all synfuels. These factors, therefore, are not likely to affect dramatically the cost comparisons shown here, although the level of synfuel production costs could be changed significantly.

In contrast, increased distances from the point of production to the point of use will change the cost comparisons. The reason is that methanol has a lower Btu content per unit volume and its transport cost are higher. To illustrate the effect of increased distances, a comparison is made for methanol and synthetic gasolines produced in Illinois and shipped to New York.

The rail journey to Chicago is 268 miles while the trip to New York is 1,039 miles. Tables 7-10 and 7-11 shows these comparisons. Both a small and a large scale case are shown for non-fleet cars. The so-called low retailing costs are also used in these comparisons.

Table 7-12 summarizes the cost comparisons. Methanol has a cost advantage in only two of the small scale comparisons. However, even with the longer delivery route, methanol is shown to have an advantage in all twelve large scale cases; that advantage ranges from $91 to $238.

These comparisons for New York illustrate the importance of transportation costs to methanol's cost competitiveness. Because a gallon of methanol has half the Btu's, its transport cost per Btu will be double that of the other fuels. For that reason methanol producers will try to minimize that disadvantage by using lower cost pipeline transport whenever possible. Further, those producers will tend to produce in coal fields closer to the final market so that transport distances are minimized.

CONSTRUCTION

The plantgate cost of the synthetic fuels are assumed to increase over time for two reasons. First, the real cost of construction is assumed to

TABLE 7-10

NON-FLEET AUTO COST COMPARISON IN 1990
FOR SMALL SCALE SYNFUEL DISTRIBUTION TO NEW YORK
WITH LOW RETAIL COSTS[a/]

	Koppers Totzek Methanol Estimate	Badger Methanol Estimate	Texaco Methanol Estimate	BGC/LURGI Methanol Estimate	SRC-II Gasoline Estimate	EDS Gasoline Estimate	H-Coal Gasoline Estimate	Badger Mobil-M Estimate
1. Delivered Fuel Cost (in $1980 per MMBTU)								
A. Plantgate Cost	8.94	7.02	7.10	6.16	9.15	8.58	7.71	9.15
B. Long Haul Transport	2.57	2.47	2.47	2.47	1.24	1.24	1.24	1.24
C. Local Distribution[b/]	3.25	3.25	3.25	3.25	2.29	2.29	2.29	2.29
D. Excise Taxes	1.18	1.18	1.18	1.18	1.03	1.03	1.03	1.03
E. Total	15.94	14.02	14.10	13.16	13.71	13.14	12.27	13.71
2. MMBtu Per Mile	.0049	.0049	.0049	.0049	.0056	.0056	.0056	.0056
3. Fuel Cost Per Mile (Line 1x2)	.0781	.0687	.0691	.0645	.0768	.0736	.0687	.0768
4. Fuel Cost Per Year	937	824	829	774	921	883	825	921
5. Annual Capital Costs ($)	117	117	117	117	0	0	0	0
6. Total Cost Per Year (Line 4+5)	1,054	941	946	891	921	883	825	921

a/ Costs include total annual fuel costs plus, as seen in line 5, the increase in investment cost associated with a methanol-powered car.

b/ Local Distribution costs for non-fleet cars are higher than for fleet cars because a retailing cost is included.

TABLE 7-11

NON-FLEET AUTO COST COMPARISON IN 1990
FOR LARGE SCALE SYNFUEL DISTRIBUTION TO NEW YORK
WITH LOW RETAIL COSTS[a/]

		Koppers Totzek Methanol Estimate	Badger Methanol Estimate	Texaco Methanol Estimate	BGC/LURGI Methanol Estimate	SRC-II Gasoline Estimate	EDS Gasoline Estimate	H-Coal Gasoline Estimate	Badger Mobil-M Estimate
1.	Delivered Fuel Cost (in $1980 per MMBTU)								
	A. Plantgate Cost	8.94	7.02	7.10	6.16	9.15	8.58	7.71	9.15
	B. Long Haul Transport	.65	.65	.65	.65	.33	.33	.33	.33
	C. Local Distribution[b/]	3.41	3.41	3.41	3.41	[illegible].29	2.29	2.29	2.29
	D. Excise Taxes	1.29	1.29	1.29	1.29	[illegible].03	1.03	1.03	1.03
	E. Total	14.29	12.37	12.45	11.51	1[illegible].80	12.23	11.36	12.80
2.	MMBtu Per Mile	.0045	.0045	.0045	.0045	.0056	.0056	.0056	.0056
3.	Fuel Cost Per Mile (Line 1x2)	.0643	.0557	.0560	.0518	.0717	.0685	.0636	.0717
4.	Fuel Cost Per Year	772	668	672	622	860	822	763	860
5.	Annual Capital Costs ($)	0	0	0	0	0	0	0	0
6.	Total Cost Per Year (Line 4+5)	772	668	672	622	860	822	763	860

a/ Costs include total annual fuel costs plus, as seen in line 5, the increase in investment cost associated with a methanol-powered car.

b/ Local Distribution costs for non-fleet cars are higher than for fleet cars because a retailing cost is included.

TABLE 7-12

SUMMARY OF NON-FLEET COST COMPARISONS
IN 1990 FOR BOTH SMALL AND LARGE
SCALE DISTRIBUTIONS TO NEW YORK
AND WITH LOW RETAIL COSTS[a/]
(Dollar Differences in Annual Cost)

	Direct Liquefaction Estimate						Mobil-M Gasoline	
	SRC-II		EDS		H-Coal			
Methanol Estimate	Small Scale	Large Scale	Small Scale	Large Scale	Small Scale	Large Scale	Small Scale	Large Scale
Badger	(20)	192	(58)	154	(116)	95	(20)	192
Texaco	(25)	188	(63)	150	(121)	91	(25)	188
BGC/LURGI	30	238	(8)	200	(66)	141	30	238
Average	(5)	206	(43)	168	(101)	109	(5)	206

a/ Differences are determined by subtracting total costs of synthetic gasoline from that of methanol. A bracketed figure means methanol was more expensive. This is a summary of the two previous tables.

TABLE 7-13

FLEET AUTO COST COMPARISON IN 2000
FOR SMALL SCALE SYNFUEL DISTRIBUTION TO CHICAGO[a/]

	Koppers Totzek Methanol Estimate	Badger Methanol Estimate	Texaco Methanol Estimate	BGC/LURGI Methanol Estimate	SRC-II Gasoline Estimate	EDS Gasoline Estimate	H-Coal Gasoline Estimate	Badger Mobil-M Estimate
1. Delivered Fuel Cost (in $1980 per MMBTU)								
A. Plantgate Cost	10.36	8.09	8.19	7.10	11.12	10.26	9.16	10.54
B. Long Haul Transport	.57	.57	.57	.57	.28	.28	.28	.28
C. Local Distribution	1.43	1.43	1.43	1.43	.71	.71	.71	.71
D. Excise Taxes	0	0	0	0	0	0	0	0
E. Total	12.36	10.09	10.19	9.10	12.11	11.25	10.15	11.53
2. MMBtu Per Mile	.0049	.0049	.0049	.0049	.0056	.0056	.0056	.0056
3. Fuel Cost Per Mile (Line 1x2)	.0606	.0494	.0499	.0446	.0678	.0630	.0568	.0646
4. Fuel Cost Per Year	1,383	1,137	1,148	1,026	1,560	1,499	1,307	1,485
5. Annual Capital Costs ($)	117	117	117	117	0	0	0	0
6. Total Cost Per Year (Line 4+5)	1,510	1,254	1,265	1,143	1,560	1,499	1,307	1,485

a/ Costs include total annual fuel costs plus, as seen in line 5, the increase in investment costs associated with a methanol-powered car.

TABLE 7-14

FLEET AUTO COST COMPARISON IN 2000
FOR LARGE SCALE SYNFUEL DISTRIBUTION TO CHICAGO[a/]

		Koppers Totzek Methanol Estimate	Badger Methanol Estimate	Texaco Methanol Estimate	BGC/LURGI Methanol Estimate	SRC-II Gasoline Estimate	EDS Gasoline Estimate	H-Coal Gasoline Estimate	Badger Mobil-M Estimate
1.	Delivered Fuel Cost (in $1980 per MMBTU)								
	A. Plantgate Cost	10.36	8.09	8.19	7.10	11.12	10.26	9.16	10.54
	B. Long Haul Transport	.15	.15	.15	.15	.08	.08	.08	.08
	C. Local Distribution	1.43	1.43	1.43	1.43	.71	.71	.71	.71
	D. Excise Taxes	0	0	0	0	0	0	0	0
	E. Total	11.94	9.67	9.77	8.68	11.91	11.05	9.95	11.33
2.	MMBtu Per Mile	.0045	.0045	.0045	.0045	.0056	.0056	.0056	.0056
3.	Fuel Cost Per Mile (Line 1x2)	.0537	.0435	.0440	.0391	.0667	.0619	.0557	.0634
4.	Fuel Cost Per Year	1,236	1,001	1,011	898	1,534	1,423	1,282	1,459
5.	Annual Capital Costs ($)	0	0	0	0	0	0	0	0
6.	Total Cost Per Year (Line 4+5)	1,236	1,001	1,011	899	1,534	1,423	1,282	1,459

a/ Costs include total annual fuel costs plus, as seen in line 5, the increase in investment costs associated with a methanol-powered car.

TABLE 7-15

SUMMARY OF FLEET COST COMPARISONS
IN 2000 FOR BOTH SMALL AND LARGE
SCALE DISTRIBUTIONS TO CHICAGO[a/]
(Dollar Differences in Annual Cost)

	Direct Liquefaction Estimate							
	SRC-II		EDS		H-Coal		Mobil-M Gasoline	
Methanol Estimate	Small Scale	Large Scale	Small Scale	Large Scale	Small Scale	Large Scale	Small Scale	Large Scale
Badger	306	533	195	422	53	281	231	458
Texaco	295	523	184	412	42	271	220	448
BGC/LURGI	417	635	306	524	164	383	342	560
Average	339	564	228	453	86	312	264	489

a/ Differences are determined by subtracting total costs of synthetic gasoline from that of methanol. A bracketed figure means methanol was more expensive. This is a summary of the two previous tables.

increase by two percent per year. Second, coal prices rise over time. The effects of these assumptions are shown by presenting cost comparisons for the year 2000. Tables 7-13 and 7-14 display the small scale and large scale examples for fleet cars; the summary table is 7-15.

There is a noticeable increase in methanol's cost advantage in fleet cars. For 1990, methanol won in ten of twelve small cases with a cost advantage of $84 to $269; by 2000 methanol had an advantage in all twelve cases that ranged from $42 to $417. For large scale distribution, methanol had a cost advantage in 1990 in all twelve cases that ranged from $197 to $479; by 2000 that advantage had increased to $271 to $635.

For non-fleet cars, Table 7-16 and 7-17 present the results for both small and large scale: Table 7-18 presents a summary of the comparisons.

As with fleet cars, methanol's cost advantage grows by the year 2000. In the small scale case in 1990 with low retail costs methanol had a cost advantage in only seven of twelve cases and that advantage ranged from $33 to $84. By 2000, methanol had an advantage in ten cases which ranged from $29 to $161. In the large scale examples, methanol had from a $102 to a $249 advantage in all twelve cases; by 2000 that range of advantage ranged from $140 to $331.

The lesson from these comparisons is that methanol's cost advantage grows over time in absolute terms; that is the dollar advantage grows. This increase is primarily the result of the assumed increases in real construction and coal costs. All synfuel production cost will increase by about the same percentage and therefore, the cost advantage between methanol and the other fuels should increase comparably. This is not as interesting a finding as it may seem at first glance since the growing advantage is dictated by the arithmetic of the assumed production cost increases.

TABLE 7-16

NON-FLEET AUTO COST COMPARISON IN 2000
FOR SMALL SCALE SYNFUEL DISTRIBUTION TO CHICAGO
WITH LOW RETAIL COSTS[a]

	Koppers Totzek Methanol Estimate	Badger Methanol Estimate	Texaco Methanol Estimate	BGC/LURGI Methanol Estimate	SRC-II Gasoline Estimate	EDS Gasoline Estimate	H-Coal Gasoline Estimate	Badger Mobil-M Estimate
1. Delivered Fuel Cost (in $1980 per MMBTU)								
A. Plantgate Cost	10.36	8.09	8.19	7.10	11.12	10.26	9.16	10.54
B. Long Haul Transport	.57	.57	.57	.57	.28	.28	.28	.28
C. Local Distribution[b]	3.24	3.24	3.24	3.24	2.[illegible]9	2.29	2.29	2.29
D. Excise Taxes	1.18	1.18	1.18	1.18	1.[illegible]3	1.03	1.03	1.03
E. Total	15.35	13.08	13.18	12.09	14.[illegible]2	13.86	12.76	14.14
2. MMBtu Per Mile	.0049	.0049	.0049	.0049	.[illegible]056	.0056	.0056	.0056
3. Fuel Cost Per Mile (Line 1x2)	.0752	.0641	.0646	.0592	.0824	.0776	.0715	.0792
4. Fuel Cost Per Year	903	769	775	711	989	931	857	950
5. Annual Capital Costs ($)	117	117	117	117	0	0	0	0
6. Total Cost Per Year (Line 4+5)	1,020	886	892	828	989	931	857	950

a/ Costs include total annual fuel costs plus, as seen in line 5, the increase in investment cost associated with a methanol-powered car.

b/ Local Distribution costs for non-fleet cars are higher than for fleet cars because a retailing cost is included.

TABLE 7-17

NON-FLEET AUTO COST COMPARISON IN 2000
FOR LARGE SCALE SYNFUEL DISTRIBUTION TO CHICAGO
WITH LOW RETAIL COSTS[a/]

		Koppers Totzek Methanol Estimate	Badger Methanol Estimate	Texaco Methanol Estimate	BGC/LURGI Methanol Estimate	SRC-II Gasoline Estimate	EDS Gasoline Estimate	H-Coal Gasoline Estimate	Badger Mobil-M Estimate
1.	Delivered Fuel Cost (in $1980 per MMBTU)								
	A. Plantgate Cost	10.36	8.09	8.19	7.10	11.12	10.26	9.16	10.54
	B. Long Haul Transport	.15	.15	.15	.15	.08	.08	.08	.08
	C. Local Distribution[b/]	3.41	3.41	3.41	3.41	2.29	2.29	2.29	2.29
	D. Excise Taxes	1.29	1.29	1.29	1.29	1.03	1.03	1.03	1.03
	E. Total	15.21	12.94	13.04	11.95	14.52	13.66	12.56	13.94
2.	MMBtu Per Mile	.0045	.0045	.0045	.0045	.0056	.0056	.0056	.0056
3.	Fuel Cost Per Mile (Line 1x2)	.0684	.0582	.0587	.0538	.0813	.0756	.0703	.0781
4.	Fuel Cost Per Year	821	699	704	645	976	918	844	937
5.	Annual Capital Costs ($)	0	0	0	0	0	0	0	0
6.	Total Cost Per Year (Line 4+5)	821	699	704	645	976	918	844	937

a/ Costs include total annual fuel costs plus, as seen in line 5, the increase in investment cost associated with a methanol-powered car.

b/ Local Distribution costs for non-fleet cars are higher than for fleet cars because a retailing cost is included.

TABLE 7-18

SUMMARY OF NON-FLEET COST COMPARISONS
IN 2000 FOR BOTH SMALL AND LARGE
SCALE DISTRIBUTIONS TO CHICAGO
WITH LOW RETAIL COSTS[a/]
(Dollar Differences in Annual Cost)

	Direct Liquefaction Estimate						Mobil-M Gasoline	
	SRC-II		EDS		H-Coal			
Methanol Estimate	Small Scale	Large Scale	Small Scale	Large Scale	Small Scale	Large Scale	Small Scale	Large Scale
Badger	103	277	45	219	(29)	145	64	238
Texaco	97	272	39	214	(35)	140	58	233
BGC/LURGI	161	331	103	273	29	199	122	292
Average	120	293	62	235	(12)	161	81	254

a/ Differences are determined by subtracting total costs of synthetic gasolines from that of methanol. A bracketed figure means methanol was more expensive. This is a summary of the two previous tables.

CHAPTER 8

AUTOMOTIVE FLEETS AND FUEL USE

It is likely that methanol will first be used as a fuel by automotive fleets. As illustrated in the previous chapter, methanol use can be cheaper for this class of operators because they can avoid the cost of retail distribution and excise taxes. But more important is the possibility that some fleets will not be concerned with methanol's limited availability. That-is, some fleet cars will be used in a narrow geographic area and can return for refueling to the fleet's central methanol storage area. Methanol use would not be precluded, as it might be for nonfleet or "family" cars, by the fact that it cannot be found in several service stations in most cities.

However, even for fleets which find an operating cost savings with methanol and, in addition, are not bothered by limited availability, there is at least one more disincentive for methanol use in the early stages of its development. The disincentive concerns the fact that many fleets consider resale value to be a primary criterion for an auto purchase[1/] and further, fleet cars are most often resold to used car dealers who in turn sell to the general public.[2/] If methanol is not available widely and non-fleet use is thereby precluded, resale value will fall to zero for many fleets when methanol-powered cars are used. Inability to resell is an obvious and a very important disincentive to methanol use in automotive fleets.

Despite this important disincentive, automotive fleets are still the most likely first-round market for methanol. But, they are also a likely target for many other new auto fuels or technologies. For example, the federal government already has programs encouraging through subsidies the use of methane in cars as well as the introduction of electric vehicles. The purpose of this chapter is to study available information on fleet car energy use and thereby, to identify the possible demand for methanol by automotive fleets. The first section displays some relevant characteristics of fleet cars while a second section presents a forecast of fleet car fuel use.

1/ Based on a survey reported in Joseph R. Wagner, Fleet Operator Data Book, p. 16 prepared for the U.S. Department of Energy, September 1979.

2/ AUTOMOTIVE FLEET, April 1980, p. 36.

FLEET CAR CHARACTERISTICS

The term fleet car is applied in a wide range of circumstances. For example, fleets include the cars rented by Avis and Hertz as well as the cars used by taxi services and by police departments. Since such varied uses are included, wide variations are found in terms of annual mileage, fleet size, and the like. This section begins with a broad characterization of auto fleets and then turns to a more detailed description in an attempt to identify the portion most likely to be suitable for methanol use at the early stage of the industry's development.

Cars in fleets of ten or more account for 6 to 7 percent of all cars operated in the United States. If cars in smaller fleets--four to nine cars--are added, then fleets account for 10 to 11 percent of the total stock of cars.1/

The significance of fleets increases when the focus is on new car sales because fleet cars are replaced more quickly than other automobiles. New cars bought for fleets of ten or more have accounted for 10 to 13 percent of new car sales in recent years.2/ Table 8-1 displays the level of new car sales for these large fleets in each year between 1970 and 1979. In each of the last two years sales have been around 1.3 to 1.4 million cars.

TABLE 8-1

NEW CAR SALES FOR
FLEETS OF TEN OR MORE
(in thousands of cars)

Year	Fleet Vehicles Registered
1970	939
1971	1,048
1972	1,016
1973	1,229
1974	1,036
1975	950
1976	1,104
1977	1,265
1978	1,432
1979	1,330

Source: Automotive Fleet, Bobit Publishing Co., Redondo Beach, Calif., April 1980 issue, p.24.

1/ D.B. Shonka, Characteristics of Automotive Fleets in the United States, 1966-1977, September 1978, p.12.

2/ Shonka, p.11.

As stated above, fleet cars are used for a variety of purposes. Table 8-2 shows cars by type of use in fleets of ten or more. Some of the classes need further definition.

- Business Fleets - include cars which are company or salesperson owned or leased.
- Individually leased - purchased in mass and then leased to individuals for unspecified use.
- Government - state and local only.
- Daily Rental - includes firms such as Hertz, Avis, etc. who lease for periods of less than one year.

The data show that business fleets contain almost half of the cars in fleets of ten or more; about 35 percent of the cars are in business fleets which have 25 or more cars.

TABLE 8-2
CARS BY TYPE OF USE
IN FLEETS OF TEN OR MORE
(in thousands of cars)

	1970		1979	
	No.	Percent	No.	Percent
BUSINESS FLEETS				
25 or more	1,852	37	2,448	35
10 to 24	652	13	726	10
INDIVIDUALLY LEASED	803	16	1,690	24
OTHER FLEETS				
Government	601	12	645	9
Utilities	416	8	529	8
Police	207	4	291	4
Taxi	171	3	207	3
Daily Rental	314	6	462	7
Driver School	25	1	21	-
Total	5,041	100	7,019	100

Source: Automotive Fleet, p. 30.

Another 24 percent of the fleet cars in 1979 were covered under individual leases. Seventeen percent of the cars were in government or utility fleets.

Each of these categories of fleet use differ in terms of miles driven and average size of fleets. Table 8-3 displays such information. As can be seen, annual miles driven varies from 12,000 miles per car for utility fleets to 57,000 miles per car for taxicabs. With respect to number of cars per fleet, the number varies from 31 cars in taxi fleets to 1,428 cars in government fleets. Business fleets were found to have 205 cars on average.

TABLE 8-3

ANNUAL MILES DRIVEN AND
AVERAGE SIZE OF FLEETS BY TYPE OF USE

Sector	Annual Miles	Average Size of Fleet
Police	33,000	506
Government	17,000	1,428
Utilities	12,000	137
Taxi	57,000	31
Auto Rental	18,000	1,040
Business 25+	27,000	205
Business 4-24	26,000	205
All Sectors	24,000	230

Source: D. B. Shonka, CHARACTERISTICS OF AUTOMOTIVE FLEETS IN THE UNITED STATES 1966-1977 for U.S. DOE, September 1978, p.31.

With respect to methanol demand there is an especially important characteristic for which data is especially hard to find. That characteristic is the geographic range of use. As noted before, when it is not widely available, methanol can be use only in cars which operate in a narrow geographic range and can return for fuel to a central site.

A recent survey of fleet operators by the DOE and the publishers of the magazine AUTOMOTIVE FLEET provides some perspective. The first relevant survey question concerned driving range capability. Fleet operators were asked how far their vehicles must be capable of driving on any given day. The responses by type of use are shown in Table 8-4.

TABLE 8-4

NEEDED DRIVING RANGE CAPABILITY
(in percent)

Fleet Use	0 to 100 Miles	100 to 150 Miles	Over 150 Miles
Police	1	2	97
Government	26	6	68
Utility	35	22	43
Taxi	4	35	61
Rental	33	7	60
Business	7	11	82
Total	16	10	74

Source: Joseph Wagner, Fleet Operator Data Book, September 1979, p.26.

The reason for looking at these responses is to see whether daily driving ranges could easily be covered by one fueling. For example, a gasoline-powered car getting 22.5 miles per gallon could travel 150 miles on 6.6 gallons of fuel; a methanol-powered car getting 25 percent better fuel efficiency would need 10.6 gallons. Clearly, most cars would have this capability. A considerable portion of utility, rental, taxi, and government fleets needed driving range is 150 miles or less according to this data.

Unfortunately, the survey data goes not give useful detail beyond 150 miles. With fuel tanks of 22 gallons the assumed methanol-powered cars would have a round trip driving range of about 300 miles. Further, even if the needed range was higher it does not mean methanol is precluded; the key is whether it is feasible for those vehicles to return to a central refueling station.

One other question in the survey is relevant. Fleet operators were asked what percentage of the cars sit idle for eight hours per day at a central location. Table 8-5 displays the responses.

TABLE 8-5

GARAGING INFORMATION

Fleet Use	Percent of All Cars
Police	20
Government	49
Utility	51
Taxi	25
Rental	18
Business	20
Total	28

Source: Joseph Wagner, Fleet Operator Data Book, September 1979, p.26.

The reason for looking at this data is to see which cars typically return to a central location. Considerable portions of utility and government vehicles were said to be garaged at a central location for eight hours. Unfortunately, the data does not give a definitive answer to the question at hand. Vehicles could still return to a central location for shorter periods of time and therefore methanol use cannot be said to be precluded for the cars not sitting idle for eight hours.

The data in Tables 8-4 and 8-5 only give some rough idea of the minimum market target in the early stages of methanol use. Twenty six percent of fleet cars need only a 150 mile driving range so they are likely candidates as are the 28 percent of fleet cars which return each day to a central garage for eight hours or more. Based on this data, it could be argued that utility, government, and taxi fleets may be more likely users of methanol during the infancy of the methanol industry.

Finally, it is important to look at the geographic distribution of fleet cars. Table 8-6 displays some very rough estimates of the distribution of fleet cars by the nine Census Regions, these regions are defined in Figure 1.

It appears that 40 percent of the fleet cars were found in the Middle Atlantic and East North Central States. Those regions include populous areas such as New York, Pennsylvania, Illinois, and Indiana. Other Census Regions each accounting for 12 or 13 percent of the fleet cars are the West South Central, Pacific, and West North Central.

More specific information on the location of fleet cars would be useful. It may be appropriate to focus the initial methanol marketing on a narrow geographical area. In this way, the economies of scale for methanol transport and distribution might be realized quickly. Moreover, intense use of methanol by fleets in one area may be a sufficient foundation on which non-fleet use could begin.

FLEET CAR FUEL USE

While fleets account for about 10 or 11 percent of the total stock of automobiles, they account for a much larger share, perhaps 20 percent, of auto fuel use. This is because each fleet car when compared to non-fleet cars tends to be driven almost twice as many miles each year. According to projections from the Argonne National Lab, fleet cars will become an even more important part of the U.S. auto stock. Table 8-7 displays their projection of the number of fleet cars in 1985, 1990, and 2000. That projection is shown for two fleet sizes--fleets of ten or more cars and fleets which include four to nine cars.

TABLE 8-6

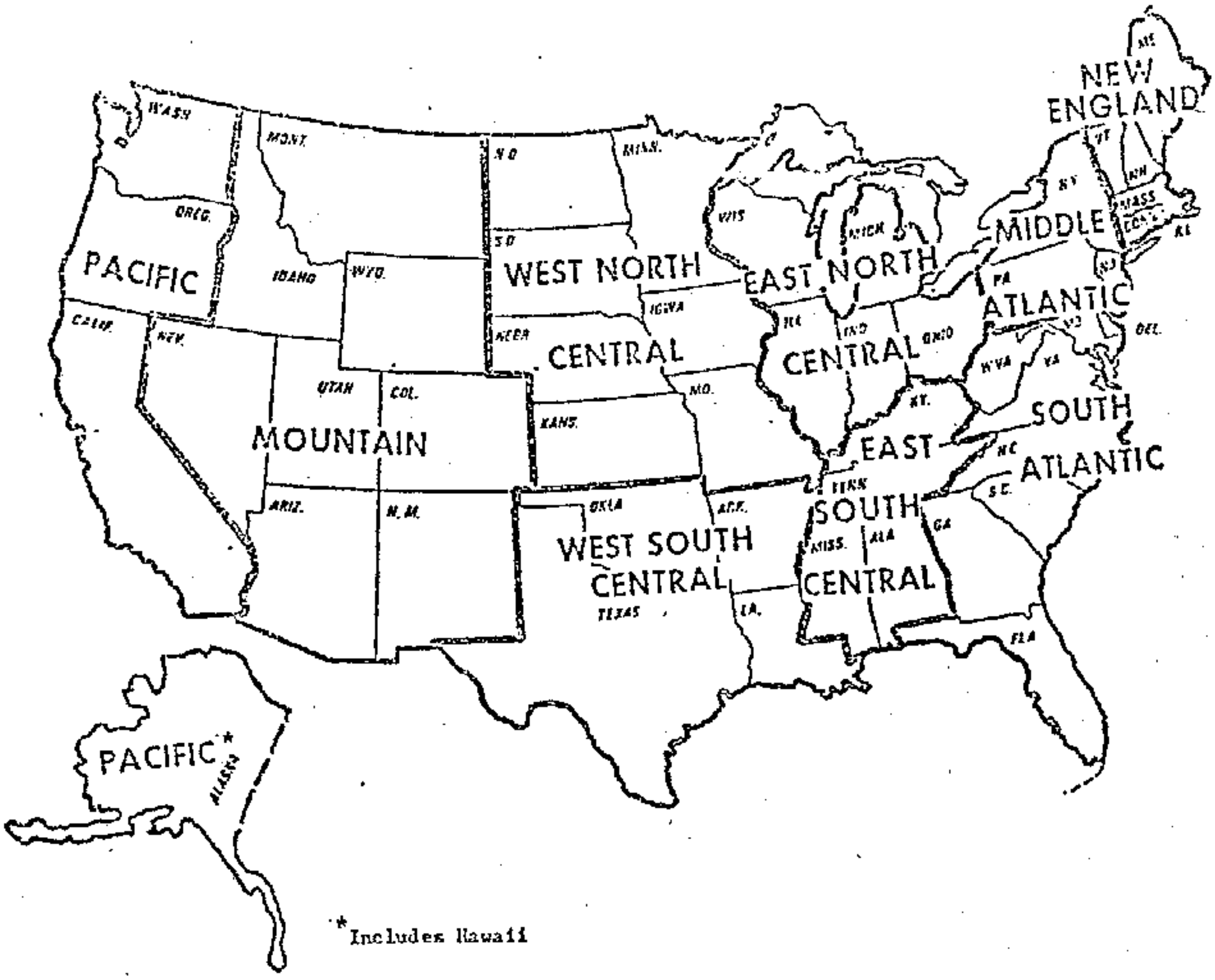
GEOGRAPHIC DISTRIBUTION
OF FLEET CARS
(in percent)

	Percent of Cars									
	New England	Middle Atlantic	East North Central	West North Central	South Atlantic	East South Central	West South Central	Mountain	Pacific	Total
Police	0.18	38.51	8.21	8.52	11.89	3.57	8.62	3.26	17.24	100.00
Government	6.69	31.05	18.17	2.34	13.55	0.0	6.86	3.87	17.47	100.00
Utility	6.95	30.44	14.45	8.06	8.53	3.35	7.44	5.28	15.51	100.00
Taxi	5.84	29.12	21.63	4.15	20.96	0.0	9.80	0.72	7.77	100.00
Rental	1.01	2.62	12.69	39.80	4.43	0.53	33.83	0.83	4.26	100.00
Business	9.94	18.56	29.51	5.64	10.95	1.46	10.63	3.51	9.79	100.00
All Sectors	5.24	24.22	17.46	12.08	10.13	1.78	13.07	3.34	12.68	100.00

Source: Joseph Wagner, Fleet Operator Data Book, September 1979, p.13

FIGURE 8-1

MAP OF CENSUS REGIONS



*Includes Hawaii

TABLE 8-7

PROJECTED STOCK OF
FLEET CARS
(in millions of cars)

Year	Fleets of 10 or More	Fleets of 4 to 9	Total
1975	6.0	4.4	10.4
1985	9.3	4.1	13.4
1990	10.3	3.8	14.1
2000	12.8	3.8	16.6

Source: Rita E. Knorr and Ma[illegible] Millar, Projections of Direct Energy Consumption by Mode: 1975-2000 Baseline Argonne National Laboratory, August, 1979, p.36, Figure 3.6.

As seen in the Table, cars in the larger fleets are projected to more than double over the twenty-five year period between 1975 and 2000. In contrast, the number of cars in the smaller fleets are expected gradually to decline.

As the number of cars in fleets grows, their fuel use could also be expected to increase. Fuel use, however, should grow more slowly since significant improvements in fuel efficiency are likely to be achieved. This point is illustrated by the projections of fleet car fuel use in Table 8-8.

TABLE 8-8

PROJECTED GASOLINE USE
BY FLEET CARS
(in trillion Btu of gasoline)

Year	Fleets of 10 or More	Fleets of 4 to 9	Total
1975	1,339	982	2,321
1985	1,198	528	1,726
1990	1,327	489	1,816
2000	1,649	489	2,138

Source: ICF Incorporated

In Table 8-8 it is seen that total fuel use does not increase over the period. This finding can be traced to one assumption--in 1975 the average fuel economy was 13 miles per gallon while in all other years it is assumed to be 22.5 mpg. Note that in all years its assumed each fleet car travels 23,000 miles.

Note also in Table 8-8, that fuel use is expressed in terms of trillion Btu of gasoline. As explained before, methanol powered cars are expected to be more fuel efficient so fewer Btu of methanol would be required. Assuming 15 percent superior fuel efficiency, about a 13 percent drop in total fuel consumption should be expected. Table 8-9 shows fleet car fuel use in terms of trillion Btu of methanol.

TABLE 8-9

PROJECTED FUEL USE BY FLEET CARS
IN TERMS OF METHANOL CONSUMPTION
(trillion Btu of methanol)

Year	Fleets of 10 or More	Fleets of 4 to 9	Total
1985	1,048	462	1,510
1990	1,161	428	1,589
2000	1,443	428	1,871

Source: ICF Incorporated

Note that in these tables on-the-road fuel efficiencies are used as opposed to EPA estimates which are considerably higher. The 22.5 mpg is the on-the-road equivalent of the 27.5 mpg mandated for all new cars in 1985 by the Energy Production and Conservation Act. There is strong evidence that in the 1990's cars will get much higher mpg either because of stronger legislation or higher oil prices. Table 8-10 shows the effect of improved fuel efficiency on the market potential for methanol. Shown are estimates of market potential when assumed on-the-road mpg is raised to 35 for gasoline cars. Again, methanol powered cars are assumed to be 15 percent more fuel efficient.

TABLE 8-10

PROJECTED FUEL USE
WITH HIGHER FUEL EFFICIENCY
(trillion Btu of methanol)

Year	Fleets of 10 or More	Fleets of 4 to 9	Total
1985	663	292	955
1990	734	271	1,005
2000	913	271	1,184

Source: ICF Incorporated

In Table 8-10 it is seen that the higher fuel efficiency cuts potential methanol use by about 37 percent.

Finally, it is of interest to identify the new car sales implicit in the projections of the number of fleet cars. Table 8-11 lists an estimate of new car sales for the larger fleets in 1985, 1990, and 2000.

TABLE 8-11

NEW CAR SALES FOR
FLEETS OF TEN OR MORE

Year	Millions of Cars
1979 (Actual)	1.3
1985	2.1
1990	2.6
2000	3.3

Source: ICF Incorporated

It is clear that the Argonne projections embody a large increase in new car sales. Those sales are shown to grow at a compound annual rate of 4.5 percent over the 1979 to 2000 period. This steady, rapid growth contrasts sharply with the experience in the 1970's as displayed in back in Table 8-1. During that decade the recession in 1974-75 cut sales back to their 1970 level and over the 1970-79 period the compound annual rate of increase in sales was 3.5 percent.