

National Methanol Fuel Systems: A Transportation Fuel Pathway

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One set of opportunities for decreasing the transportation sector's dependence on petroleum is the substitution of methanol for gasoline. The potential for implementing the transition is investigated within the context of a development path. Elsewhere, the feasibility of methanol has been studied mostly from either a production or an end-use perspective. Here, a systems perspective is used to integrate methanol production, distribution, and end-use activities into a staged development path. The path chosen is one designed to simulate a rapid and large production buildup. The choice of a high-growth path accentuates future conflicts and therefore sets the framework for pursuing the two purposes of the paper: (a) to highlight the critical factors that affect the expansion of methanol fuel activities and (b) to identify key opportunities for hastening the transition to methanol fuels. A set of market penetration strategies is devised that best responds to constraints and opportunities, and specific government and industry actions are proposed to support these strategies. It is shown that technical, economic, and institutional barriers to efficient distribution and rapid market penetration may be overcome with a moderate amount of government support. That support depends, however, on the formation of a national consensus to support methanol as an alternative fuel. The implementability of a high-growth methanol path is addressed. The major concerns are examined in order to give policymakers and others an understanding of the costs and responsibilities government would have to assume in order to promote a rapid transition to methanol fuel use.

The three principal challenges facing the introduction of alcohol fuels are (a) establishment of a producing industry, (b) penetration of traditional petroleum markets, and (c) development of an efficient distribution system. These challenges must be addressed in concert, for action taken with regard to one problem area may severely affect the feasibility of options in another area. The structure that has been used to investigate these challenges is a development path.

This paper focuses on one methanol development path. The chosen path is one designed to simulate a rapid and large production buildup that would reach 1.5 million bbl/day of methanol in the mid to late 1990s. It represents the upper limit of opportunities for introducing methanol fuel to this country. The choice of this high-growth scenario is intentional. It accentuates future conflicts and therefore sets the framework for pursuing the two purposes of this paper: (a) to highlight the critical factors affecting the expansion of methanol fuel activities and (b) to identify key opportunities for hastening the transition to methanol fuels.

The problem of introducing methanol fuels into the transportation sector is of more than passing interest. Methanol may prove to be the most attractive replacement for gasoline in motor vehicles. Recent cost estimates indicate that methanol from coal (if available) would probably already be price competitive with gasoline and less expensive than any other available fuel, especially when one considers the higher quality and energy efficiency provided by methanol (1-3).

The paper is organized to focus on the three challenges cited earlier. First, to set the stage, the general characteristics and attributes of the chosen path are presented. Then the supply component is specified for this high-growth development path. Financial risk and its impact on plant investment are the main concerns here. The most attractive end-use markets for methanol are also identified and quantified. The supply industry and end-use markets are then compared. The resulting disequilibrium between supply and demand serves as

an input to the subsequent analysis of fuel distribution needs. Next, the major components of the development path having been examined, a set of market penetration strategies is devised. Finally, the major constraints and uncertainties facing the introduction of methanol fuels are summarized within the context of the three challenges cited earlier. Where precise policy opportunities exist to solve or mitigate constraints and uncertainties, they are presented. Where obvious answers do not exist, more general approaches are suggested.

INTRODUCTION TO DEVELOPMENT PATH

The opportunity for producing the most alcohol in the shortest time frame at the lowest cost comes from the indirect liquefaction of coal into methanol. (Other important feedstocks might be "remote" natural gas, which is now flared or left undisturbed, and cellulosic biomass, such as wood. These secondary sources could not, however, be diverted to methanol production in as large quantities, or as inexpensively, as coal in the next 20-30 years or so.) The development path is therefore based on the construction of coal-to-methanol processing plants. It will be shown how a large coal-to-methanol industry leads to the deployment and use of systems and activities that are national in scope. A salient feature of the development path, and one that influences the evaluation of many other path activities, is the large size of individual plants.

Economies of scale will dictate that individual plants be very large in size, at capacities of 40 000 bbl/day or more, costing more than \$2 billion (1). Two important implications of large plant size are that (a) each plant will constitute a significant increment to the supply base and (b) large amounts of capital will be concentrated in relatively few coal-to-methanol projects.

The concentration of investments in only a few projects and the need to manage large units of methanol output create situations that favor the participation of large economic units in this path. The large processing plants must be matched with similarly large distribution systems and massive modification or production of end-use technologies. Thus, this path requires investment in pipelines to transport the large quantities of methanol and large production runs of methanol vehicles by major automobile makers to provide the end-use technology. The diversion of investments to a new industry and new activities is risky, however. To achieve rapid production increases and market penetration would require the participation of large firms that can use their market power and resources to reduce uncertainty and risk.

Uncertainty comes about in two ways. First, it comes from the unpredictability of petroleum prices. Methanol is a substitute for petroleum products, mostly gasoline; the market price of methanol will therefore be determined by the price of gasoline. This uncertainty is beyond the influence of producers, yet it directly affects their rate of return on investment. The second source of uncertainty is the virtual absence of methanol markets. Prospective plant owners are called on to invest

substantial sums of money in projects that require a lead time for construction of 5-10 years. It is difficult to forecast markets, especially in these early years of the path, and even more difficult for producers to procure sales contracts for methanol so far in advance of actual plant operation.

Risk is based in part on these uncertainties of price and market and in part on the construction and operation of the physical plant itself. Although the indirect liquefaction technologies to be used for methanol production have been successfully demonstrated, there are always engineering problems in upsizing demonstration plants and putting together old technologies in new combinations. Unexpected problems are often expensive to resolve and may also lead to costly construction delays. Susceptibility to disruptions, such as natural disasters or strikes by coal miners or rail workers, is another source of risk.

The high degree of uncertainty and risk is a major impediment to the implementation of an ambitious methanol development path. If it is determined that such an effort is in the nation's interest, then it may be necessary for the public sector to reduce price and market uncertainty for producers and to encourage intraindustry and interindustry coordination by easing antitrust rules. The rapid-growth path presented in this paper would only come about as the result of coordinated and concerted efforts by key actors in the public and private sectors. These efforts would recognize and build on the interdependencies between and among producers, shippers, and users. Intentional and structured systems would have to be established to promote the production, distribution, and use of large volumes of methanol. Smooth and successful implementation of methanol-serving systems would require the blessing and support of government. Public policy therefore plays a key role in the emergence of a high-growth methanol development path.

PATH SPECIFICATION

Supply Industry

The predominant production sequences in this path are conversion of coal to methanol and, secondarily, remote natural gas to methanol. In both cases, processing plants are large and expensive--generally \$2-4 billion/plant for coal conversion and somewhat less for gas conversion--and are generally owned by large energy companies.

Natural gas is the current feedstock for production of industrial methanol; the conversion processes are well established. Remote gas will be converted by those same processes. The first and second generations of coal-to-methanol plants, at least through 1995, would use exclusively the indirect liquefaction processes, where coal is gasified into a synthetic gas that in turn is processed into methanol. Some processes are already commercialized, and others are near commercialization. The newer and more efficient processes are less proven and carry some risk. A key factor in gas conversion and most indirect liquefaction processes is that methanol is the only important output (although some coal-to-methanol processes could also produce significant amounts of synthetic natural gas). This inflexibility makes producers more vulnerable to price and market shifts.

The supply components for the hypothesized development path are drawn from surveys of actual proposed coal-to-synfuel projects. Most of the proposed plants were identified from applications for financial assistance to the federally sponsored U.S. Synthetic Fuels Corporation. The plants in most

Table 1. Proposed coal synfuel plants.

State	No. of Plants	State	No. of Plants
Alaska	1	North Dakota	3
Alabama	1	Pennsylvania	2
California	1	Tennessee	2
Colorado	3	Texas	1
Illinois	2	Utah	2
Kentucky	2	Virginia	1
Louisiana	1	Washington	1
Montana	4	West Virginia	1
New Mexico	2	Wyoming	2
North Carolina	1		

Note: Data based on surveys prepared for the National Alcohol Fuel Commission (5) and applications to the U.S. Synthetic Fuels Corporation (6).

cases were proposed to begin operations generally by 1993 (in most cases, conditioned on some form of financial support by the U.S. government). Proposed plant capacities are mostly between 10 000 and 50 000 bbl/day. Full-sized commercial coal-to-methanol plants are expected to be somewhat larger, however--typically 50 000 bbl/day or more (4).

Table 1 lists 33 plants identified in the surveys. They are hypothesized to constitute the mid-term supply component of the high-growth methanol development path, for the period 1995-2000. Average plant output is assumed to be 50 000 bbl/day, which sets industry capacity at 1.65 million bbl/day (25 billion gal/year). This production level is ambitious; although it is compatible with the lofty goals established by the Energy Security Act of 1980, it would satisfy only about 15 percent of 1980 gasoline energy demand. The 33 plants would consume 120 million tons of coal annually, about 5-10 percent of projected 1995 coal production (7).

The precise plants identified in the surveys will not be the ones finally constructed as coal-to-methanol plants, but they do provide a good indication of where future plants might locate. The apparent preference for western sites is in large part due to the lower cost of western coal and its suitability for the first generation of indirect liquefaction processes used to produce methanol. Other preferred feedstocks are lignite in Texas and Montana and peat in North Carolina and Minnesota.

The major risks perceived by prospective coal-to-methanol producers are due to large market and price uncertainties; methanol markets are uncertain because they do not yet exist, and methanol prices are uncertain because they are mostly determined by oil prices, which in turn are mostly determined in the unpredictable political arena. These uncertainties could be significantly reduced by government price and purchase guarantees, similar to those currently proposed for the federally sponsored U.S. Synthetic Fuel Corporation.

The second source of risk perceived by coal-to-methanol producers is associated with the costs and reliability of the processing plant. This risk, though substantial, is less critical than price and market uncertainty for two reasons:

1. The plants will be based on existing technology or at least evolutionary improvements on it (4).
2. Prospective plant operators and owners have considerable experience with other industrial projects of similar size and the normal problems associated with them: construction delays, start-up and operating troubles, and unknown inflation rates of equipment and construction costs.

Given these conditions, it is anticipated that the coal-methanol industry will evolve like other

capital-intensive industries, such as petroleum refining; that is, a successive stream of technical process improvements will be made. [If the reported experience of the chemical methanol industry holds, cost reductions of 15-20 percent will be achieved over the first five years of operation (8).] Changes of the spectacular discontinuity variety will not be made, and therefore associated risks will also not be spectacular.

Potential Markets

Methanol is a high-quality fuel and a useful chemical. Methanol is currently used mostly in the chemical industries. In late 1979, a methanol derivative, MBTE, began to be used as an octane-boosting gasoline additive, replacing other traditional additives that were being restricted by the U.S. Environmental Protection Agency. By late 1980, almost 10 percent of total methanol production, equivalent to an annual rate of about 100 million gal, was being diverted to the MBTE additive (3).

The chemical market for methanol is projected to grow steadily in the foreseeable future but, generally, traditional natural gas feedstock sources will be retained (3). The chemical industry is not considered a significant near-term market for a new coal-to-methanol industry.

The greatest potential application for methanol is as a gasoline substitute, although it is an attractive fuel in other applications as well. Its attractiveness is based on technical, economic, and environmental criteria. Methanol is a high-quality (octane) fuel that potentially provides greater engine efficiency than any conventional petroleum products. Methanol also burns more cleanly than petroleum fuels, since it has no particulate or sulfur oxide emissions and greatly reduced nitrogen oxide emissions. Because methanol is a fairly expensive fuel, it is competitive only with the most expensive hydrocarbon fuels, such as gasoline and light distillates, and, of course, it is most competitive in areas where air pollution is a problem. Because the gasoline market is many magnitudes greater than any other potential end-use market, the focus of this paper is on the use of methanol as a gasoline substitute in the transportation sector.

An important qualifier applies here. The advantages of methanol, particularly its greater efficiency, are captured by redesigning an engine to take advantage of the different combustion characteristics of methanol. The use of methanol-gasoline blends in an unchanged (or slightly modified) gasoline engine will provide few or none of the potential efficiency benefits of methanol.

Other much smaller markets would also arise during the remainder of this century if large price-competitive methanol supplies became available. Principal secondary applications would be gasoline engines in nontransportation uses (e.g., agriculture and construction applications) and diesel engines in both transportation and industrial uses. Diesel engines are not a primary market because major retrofits and/or engineering advances need to be made before methanol can be used. Methanol can be used as a blend with both gasoline and diesel engines, but, again, the opportunities are more limited with diesels.

MATCHING SUPPLY WITH MARKETS: IMPLICATIONS FOR A DISTRIBUTION SYSTEM

Spatial Disequilibrium

The implementation of the high-growth development path quickly leads to spatial disequilibrium between

Figure 1. Hypothesized methanol supply compared with 1980 gasoline fuel demand on energy-equivalent basis.

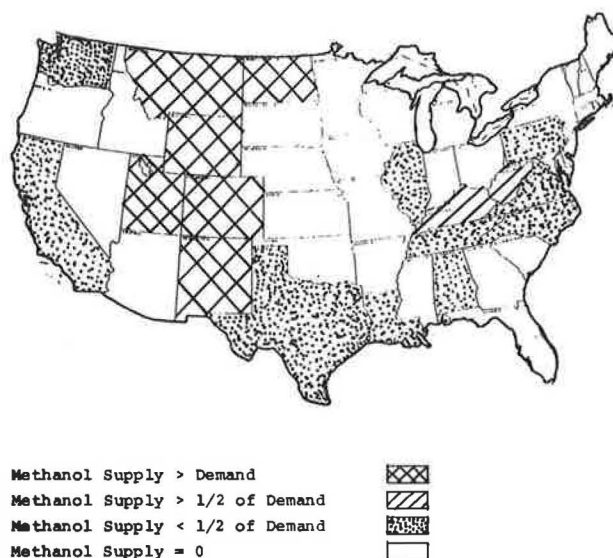
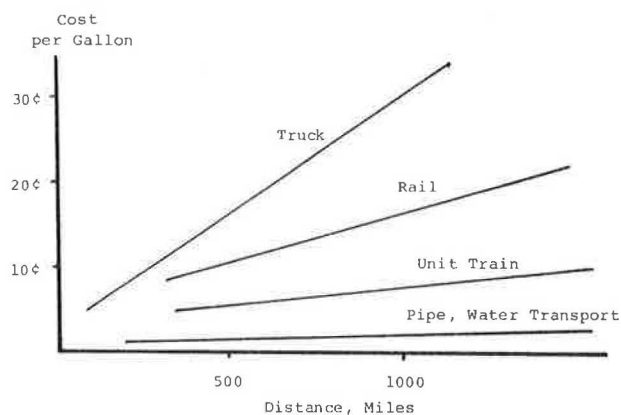


Figure 2. Liquid commodity freight rates: 1981.



demand and supply. The output of a single coal-to-methanol plant is greater than total gasoline consumption in some states. It would provide enough fuel for about 1 million automobiles.

Figure 1 shows that in the late 1990s, when total production would have surpassed the targeted 1.5 million bbl/day, six contiguous states in the Rocky Mountain and Great Plains areas would be producing a tremendous excess of methanol. Those six states, which contain 3 percent of the nation's population, would produce one-half of the methanol. Even if all six states converted all their vehicles and electric-generating gas turbines to methanol, they could consume only about one-third of the methanol they produced. The excess in the area would be truly enormous when one considers that actual market penetration in any given area is unlikely to exceed 10 percent of the potential market for at least several years after methanol sales begin. Market penetration is limited by the rate at which new vehicles are purchased. The adaptation of end-use technologies (especially motor vehicles) to methanol takes many years. Instantaneous markets do not become available for methanol when a new plant begins operations.

Methanol plants in the Rocky Mountain area, almost from the inception of the industry, will be as

far as 1000-2000 miles away from their principal markets. Plants located in Illinois and the Appalachian area will be closer to possible markets. With aggressive marketing of methanol as a transportation fuel, markets in Appalachia and nearby regions may be able to absorb locally produced methanol output as it becomes available.

Pipelines as Key to National Distribution

The movement of large volumes of methanol becomes feasible on one condition: inexpensive transportation services. Figure 2 illustrates the superiority of pipeline over rail and truck. The cost functions are intended only to be representative; actual rates vary considerably. With this caveat in mind, a rough estimate for the cost of a 1000-mile shipment of 1 gal of fuel would be as follows:

Mode	Cost (¢)
Truck	30
Rail	17
Unit train	8
Pipe	2

Because about 2 gal of methanol replace 1 gal of gasoline, the difference in transportation costs between pipe and truck would be 56¢ per gasoline-equivalent gallon and between unit train and pipe, 12¢/gal.

Long-distance methanol shipments generally are feasible only by pipe. (The costs of water transportation are similar to those of pipeline, but most coal conversion plants would not be located near waterways. Where water transportation is available, it is an attractive alternative.) Even for trips as short as 100 miles, pipe is the preferred mode if sufficient volume exists. Pipeline transportation is therefore essential to path development because of spatial disequilibrium between supply and demand.

As a rule of thumb, a minimum volume of about 10 000 bbl/day is required to justify a pipeline. Coal conversion plants will produce on the order of 50 000 bbl/day. So, even accounting for local use and diverse destinations, most plants, especially those in the Rocky Mountain and Great Plains areas, will depend on pipelines to decrease their distribution costs.

There are two obstacles to methanol distribution by pipeline: the large initial investment and the incompatibility of methanol with existing pipelines. Pipeline investment costs are large but not overwhelming. The cost of building a 1000-mile pipe to carry 50 000 bbl/day (which requires a 10-in-diameter pipe) would add about \$150 million (9) to the initial \$2 billion plant investment. The pipeline in this case adds 8 percent to the total investment.

The 8 percent pipeline cost covers only the first link in the trip to the final delivery point. Once fuel reaches the first terminal, it is often transshipped to other local terminals, where it is delivered locally by truck. Economies of scale exist all along the line. It is therefore in the interest of shippers to consolidate. The highest level of consolidation is complete integration of methanol into the existing petroleum product distribution system, where average distribution (transportation and storage) costs have hovered around 5¢/gal until recently (10).

Integrating methanol into the existing pipeline network, as an alternative to constructing new pipelines, presents difficulties (11). Product pipeline operators are generally hostile to alcohol, partly because it may strip away corrosion inhibitors but more importantly because the alcohol, especially

methanol, may corrode and shorten the lives of pipelines, their major asset. Further testing is required but, if corrosion is a problem, pipes could be coated with special materials, although with some disruption and, according to industry sources, at some undetermined but probably large cost.

Methanol Blends in Distribution System

The use of methanol-gasoline blends requires some modifications in the existing distribution system but not because of the physical blending process. Blending could take place at oil refineries, bulk storage terminals, or in blending pumps at service stations; blending pumps are already widely used in some areas for gasoline, and blending at refineries and storage terminals presents no critical barriers. Some cost may be incurred by the logistics of blending, possibly more and longer transshipments, but it should not be too great (11). A more important drawback to blending is the need to deter water intrusion into the storage and transportation vessels of the distribution system.

The "wet" characteristics of the petroleum product distribution system may be a major barrier to the use of methanol-gasoline blends. Currently, water is allowed to intrude into storage tanks, pipelines, and other tank vessels. If methanol is used straight, water is not a problem. It is a problem, however, if methanol is blended with gasoline; even the presence of 0.1 percent water may cause the liquids to separate (12). Technically speaking, the petroleum distribution system could be easily dehydrated (it would require new valves, fixed roofs on storage tanks, and generally tighter operational controls), but the disruption and cost would be significant. No single major change would be required, but many small modifications would. Exxon data (updated and inflated to 1981 dollars) suggest that the cost for dehydrating the distribution system would be about 3-5¢/gal of methanol for a large methanol industry (13).

In terms of the distribution system, the disadvantages of methanol blending are not onerous. Already alcohol blending is occurring: In 1980, 135 million gal of ethanol and almost 100 million gal of methanol-based additives were blended with gasoline (3). The ethanol was blended in storage terminals in a 10/90 proportion with gasoline, and the methanol-based additives were blended at refineries.

MARKET PENETRATION STRATEGIES AND OPPORTUNITIES

Fuel prices are not explicitly treated in developing this ambitious nationally oriented path and in analyzing market penetration strategies. Petroleum products are the fuels against which methanol will compete for market share. Oil and gas will dominate those markets into the foreseeable future and will therefore determine fuel market value. To a large extent, however, oil and gas prices are set in the political arena and not in the market place, which creates great uncertainty over future price trends. Even if methanol production costs were precisely known, it would be difficult to predict specific prices and times when methanol could penetrate traditional oil and gas end-use markets.

Methanol offers advantages over other fuels, including presumably greater security of supply and cleaner burning qualities, which attract it to certain market segments even when it is not competitive on a price basis. Earlier in this paper, penetrable markets were identified. In this section, some credible penetration strategies are devised for marketing the methanol outputs of the development path's ambitious production schedule. Emphasis is

placed on the timing and matching of production, distribution, and marketing activities.

Transportation Sector

Methanol can be used as a fuel additive, as a component in a fuel blend, or straight. Each type of use has a role to play in the penetration of gasoline markets.

In the first stage of market penetration, methanol is used as a gasoline additive ("additive" is defined here as a liquid constituting up to 5 percent of fuel volume). It is highly attractive in that role because it boosts the octane rating of the gasoline fuel and requires no vehicle modification. The use of methanol additives saves energy and extends gasoline supplies by significantly easing the severe energy-intensive refinery processing otherwise required to obtain gasoline's premium octane rating; one estimate is that approximately 2 gal of oil are replaced by each gallon of methanol (or methanol-based) additives (14). As noted earlier, by late 1980 a methanol-based additive was already being used at the rate of about 100 million gal/year.

The potential market for methanol as an additive is limited, however. In view of the difficulties and cost in distributing methanol from the remote and rural regions where methanol plants would locate, an average market penetration of 2 percent is about the maximum that would be feasible and likely. Two percent of the market represents about 2 billion gal, the output of only 2-3 typical coal-to-methanol plants. The additive option is best regarded as an initial market for smaller methanol plants using biomass or remote natural gas as feedstocks and as a small "guaranteed" market (to the extent that long-term supply contracts could be secured with oil refineries) for the first few coal-to-methanol plants.

Greater market opportunities are presented by the use of methanol as a blend component. This second option, blending, is fraught with difficulties and burdensome costs, however. The first concern is inaccessibility to the existing gasoline distribution system. Pipeline owners would be hesitant to handle methanol; this hesitance may be overcome only after years of researching, testing, and corrosion-proofing of the pipes. Another distribution obstacle is the problem of water intrusion; it would be solved only by building a parallel distribution system, at great cost because of missing economies of scale, or by dehydrating major parts of the existing gasoline distribution system, again at great cost. From a distribution perspective, blending is unattractive.

Blending is also unattractive from an end-use perspective. First of all, fuel intake components of vehicles must be redesigned; second, certain materials in the engine and fuel lines must be replaced; and third, dramatically increased evaporative emissions would have to be controlled. Possibly the greatest end-use disadvantage, however, is the foregone efficiency benefit. The use of straight methanol in appropriately designed vehicles should provide efficiency improvements of about 30 percent [estimates generally range from 15 to 40 percent, depending mostly on the extent of engine and power-train redesign (2)]. This efficiency gain is not realized in conventional gasoline vehicles that are modified only to be compatible with methanol, as would be the case when blends are marketed.

The preferable strategy for marketing large volumes of methanol is as a straight fuel. The water contamination problem disappears in this case, and vehicles can be designed to capture fully the efficiency and clean-burning benefits of methanol.

Unfortunately, market conditions and the timing of supply availability preclude moving directly from the additive stage to the straight methanol stage. Market conditions dictate that a secure and widely dispersed methanol fuel supply be available before consumers are called on to switch; they must be assured that fuel supplies are available not only in their own neighborhood and region but elsewhere as well. However, the gradual buildup of production capacity precludes the possibility of establishing a prominent and widespread retail market in a brief period of time. It would take many years to provide such an extensive network of retail outlets with adequate fuel supply.

The marketing of methanol blends is therefore a necessary but not fully attractive transition strategy. Even though a transitional period with blends is probably necessary, its duration and dimension can be abbreviated. This is accomplished by developing other smaller, specialized methanol markets during the additive marketing stage. Methanol production capacity could be built up and general marketing in the transportation sector restricted to additives only as long as possible. Meanwhile a retail infrastructure could be established and greater experience with fuel methanol gained. When production capacity begins to accelerate, the new output would be diverted to straight methanol use as quickly as possible.

The most prominent of the small, specialized markets referred to above are vehicle fleets, the gas turbines of electric utilities, and self-contained regional fuel markets. Vehicle fleet markets are examined in the following section. Electric utilities and self-contained regional markets such as California and possibly the Rocky Mountain area are not addressed further in this paper.

Corresponding to the fuel marketing strategies must be vehicle production strategies. Vehicle production strategies can be devised to ease the risk and cost burden to automobile makers. Transitional vehicle strategies that match the fuel marketing strategies have already been hinted at but are addressed more explicitly here.

Before any methanol fuel is consumed, in a >5 percent blend proportion, engines and vehicles must be modified. Current production models can be retrofitted for methanol, but the cost ranges up to \$2000/vehicle (15). To capture completely the benefits of methanol, the entire engine, drive train, and fuel system should be redesigned. This redesign is now taking place in Brazil for ethanol fuels. A transitional strategy is simply to make a vehicle methanol compatible and not methanol efficient. The cost is much less: The inner coating of the fuel tank must be replaced, the sensor-controlled fuel intake system must be modified (generally for blends with more than 10-15 percent methanol), and certain noncompatible materials must be replaced (2).

Thus, the cost burden and the risk to automobile makers would be softened by a gradual transition to true for-methanol vehicles. The first step is conversion of one or more models to methanol-compatible status. The extra development and production costs would be small. Large fleets could convert their methanol-compatible vehicles to methanol-efficient status if the economics were justified. Several years later, after the first large coal conversion plants come on line and more experience has been gained with methanol fuel, automobile makers could begin production runs of efficient for-methanol vehicles. Ford and Volkswagen already have mounted major research and development programs to build methanol vehicles, so these suggested production strategies should be reasonable.

Vehicle Fleets

An early and key methanol market is vehicle fleets. Fleets are ideal initial markets because vehicles are fueled and maintained in a few centralized locations. Fuel distribution and availability problems are simplified. By themselves, fleets constitute a substantial market, but just as important is their function as a test market for the general vehicle market.

Until distribution becomes widespread, fleet operators will be the primary users of methanol fuel. The early use of alcohol fuel by several large fleet operators may be the key to stimulating large production runs of alcohol vehicles by automobile makers. Early and important markets are government fleets. Government fleets account for about 12 percent (about 1 million vehicles) of all fleet vehicles and 1 percent of total U.S. gasoline vehicles (16,17). They consume about 1.5 billion gal of gasoline per year, which represents 1.5 percent of annual gasoline sales.

The conversion of business fleets to alcohol may be more important not only because it opens up a large market but also because it sends a signal that alcohol is a viable competitor in the marketplace. This may be the key development that convinces automobile makers to initiate on-line production runs of alcohol vehicles.

The Bank of America is the first business to convert a major part of its large fleet to methanol. The Bank's objective in converting to methanol use is to establish a secure fuel supply so that Bank operations are not threatened by fuel shortages such as those of 1979. The program has been so successful that, in addition to the initial group of 146 converted vehicles, the Bank has ordered 100 more and is seriously considering eventually converting its entire fleet of 2000 vehicles to methanol (15). The Bank's enthusiasm stems from the unexpectedly efficient and relatively trouble-free performance of the methanol vehicles, which comes as a bonus to their primary objective of fuel security. The vehicle conversion costs (15) incurred by the Bank of America represented about 15 percent of vehicle life-cycle costs; additional costs of about \$5000 for modifying a fuel station are minor when amortized over the station life.

If rapid market penetration is to occur, a number of large institutions, such as the Bank of America, must decide that the objective of long-term fuel security is important enough to justify making a major and early commitment to methanol. One could imagine that a large number of large business fleets would consider justifiable the extra 15 percent or so in transportation costs, particularly where transportation costs are a small percentage of a firm's annual expenses.

An impediment to converting early fleets to methanol may be the absence of a used-car market. Fleet operators may be reluctant to risk foregoing revenues that they would otherwise receive from vehicle resale. A 1977 survey indicates that resale value as a criterion of vehicle purchase is very important for rental fleets, fairly important for business fleets, and a minor consideration for utility, taxi, and police fleets (16). Survey responses regarding time of resale suggest that resale value is large for rental fleets, negligible for taxi fleets, and somewhere in between for other fleets. The survey results are averages, however, and do not signify that fleet operators in each sector behave identically. One concludes from this evidence that, although vehicle resale may be an important barrier to methanol market penetration in some cases, signifi-

Table 2. Sequence and timing of path activities.

Year	Activity
1980	Methanol and a methanol derivative, MBTE, gain use as octane-enhancing gasoline additives
1984	Barge-borne methanol plants begin operation offshore of United States; methanol from remote gas may also be produced in Canada, Alaska, and elsewhere
1985	Production runs of methanol-compatible vehicles; some fleets, especially government, start converting to methanol
1987	Methanol-from-coal (including peat and lignite) plants begin operation; electric utilities in southern California and other smog-prone areas begin using methanol; many large fleets (government and private) begin switching to methanol
1989	Methanol blended with gasoline for use as transportation fuel; parts of petroleum product distribution system are dehydrated
1990	Production runs of methanol-efficient vehicles by major automobile makers
1994	Blending mostly eliminated and methanol used as a straight fuel; methanol completely integrated into liquid fuel distribution system
1997	Total methanol production reaches 1.5 million bbl/day

cant numbers of fleets would consider it a minor consideration.

One response to uncertainty over vehicle resale is to guarantee vehicle repurchase. Car dealers, associations of car dealers, or the government could assume this responsibility. The firm that converts Bank of America vehicles already provides such a guarantee.

RECOMMENDATIONS FOR PATH IMPLEMENTATION

The previous sections outlined the development of activities that contribute to an accelerated and large-scale introduction of methanol fuels. Presented below is a summary of important activities. Dates are assigned to suggest the earlier plausible or necessary occurrence of that activity or event, given the production target of 1.5 million bbl/day by 1995-2000. Table 2 summarizes the sequence and timing of path activities.

In this accelerated development path, coal conversion would be the major supply source and motor vehicles the major market. But during the initial stages, the indivisibilities, long lead times, and remote rural locations of production facilities would not match well with the dispersed, urbanized location of vehicles and their demand for stable and widely available fuel supplies.

The challenge is to stimulate production in a way that matches the timing of developing markets while not overwhelming the capabilities of the distribution infrastructure. The public sector is called on to provide incentives and remove barriers so that each of the three major activities may proceed. Key private-sector participants would have to coordinate their efforts to mitigate mismatches of demand and supply and to ensure efficient deployment of resources. They must also assure the automobile-buying public that methanol fuel is an attractive alternative and will be widely available.

A program of actions to support the timetable is suggested below. The actions are grouped according to the three challenges identified at the beginning of this paper. The focus is on the public sector, but industry actions are also included.

Establishment of a Producing Industry

The major barriers to coal-to-methanol investments are uncertainties of market and price. Government responses to reduce uncertainty and risk, in order of effectiveness, might be (a) price guarantees, (b) purchase guarantees, and (c) tax incentives. Government programs should attempt to create stable

market environments. Reducing the cost of capital (for instance, through loan guarantees) is a secondary concern because market risk appears to be significantly greater than technological risk for large-scale methanol producers.

Penetration of Traditional Petroleum Markets

Methanol is a replacement for petroleum, a fuel that has dominated the transportation market and other markets for many decades. The challenge is to reduce market barriers and exploit opportunities where appropriate so as to ensure the growth of reliable and stable markets for methanol as it becomes available. The first step is to overcome barriers to the use of methanol. The second step is to encourage the establishment of diverse and stable markets as methanol becomes available. Some specific proposals for creating such conditions are as follows:

1. Modification of national fuel and vehicle (emission) certification procedures;
2. Government purchase of methanol fleet vehicles;
3. Imposition of the requirement that some percentage of vehicle production be methanol compatible by 1985 and methanol efficient by 1990, or three years after the first large methanol plants come on line (the requirement should be put into law now so as to reduce market uncertainty);
4. Tax incentives to automobile makers for producing methanol vehicles;
5. Temporary removal of excise tax on methanol fuel;
6. Government or dealer guarantees to repurchase methanol fleet vehicles;
7. Automobile industry guarantees to supply fuel for methanol vehicles (one option would be establishment of methanol stations in key locations);
8. Tax credits to large methanol users (e.g., vehicle fleets and electric utilities); and
9. A workshop to disseminate information to vehicle fleet operators.

Development of an Efficient Distribution System

The key strategies for timely and efficient provision of distribution services are, first, integration of methanol shipments into the existing petroleum product distribution system and, second, coordination of new investments, principally pipelines. The public sector traditionally has not played a strong or prominent role in fuel distribution activities and probably has few opportunities to promote these strategies. Its principal role may be of a passive nature in promoting coordination: to relax competition requirements on pipeline owners and encourage coordination in deploying methanol pipelines. This coordination may lead to clustering of plants to reduce the proliferation of methanol pipelines and to achieve economies of scale in pipeline use—a promising trend from the perspective of distribution cost, especially in the Rocky Mountain and Great Plains areas where local markets are sparse anyway.

Because the public sector plays a small role in meeting the distribution challenge and because most specific actions will be a result of coordinated planning, the following proposals are general in nature:

1. Supportive Federal Energy Regulatory Commission policies to encourage coordinated planning and deployment of pipelines;
2. Clustering of plants, especially in remote western coal regions, to establish a more concentrated pipeline network;

3. Immediate establishment of research and development programs and testing programs to determine opportunities for integrating methanol into the existing petroleum pipeline network;

4. Coordinated planning among shippers, pipeline owners, and storage tank owners to selectively and efficiently dehydrate a distribution network that permits fuel blending.

CONCLUSIONS

The methanol development path formulated in this paper presents one set of opportunities for making the transition from petroleum to alcohol fuels. It is a path that leads to the greatest use of alcohol fuel in the shortest time frame. But rapid expansion of the new methanol industry will not proceed unless aid is forthcoming. The new industry is rife with risk and uncertainty. Start-up costs are formidable. Implementation of the high-growth path within such a short period would require considerable public-sector support. Government support is forthcoming, however, only if a national consensus coalesces to promote alternative fuels.

Consensus formation must survive the scrutiny of many interest groups. A national methanol path will be judged as to its environmental, economic, political, and social implications. If the national objective of fuel security is strong enough and the adverse impacts of the path are not too unpalatable, then government support will materialize and the high-growth methanol development path will become reality. Lack of a strong national consensus will probably not mean abandonment of methanol as an alternative fuel, however. Enough special market niches and favorable production situations exist to elicit at least some methanol investments in the near future.

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Motor-Vehicle Fuel Economy: Estimated Cost and Benefits from 1980 to 2020

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Results of an analysis of motor-vehicle fuel economy performed by Purdue University as part of an ongoing analysis of the costs, benefits, and effects of various energy options are discussed. The analysis is presented in three sections: (a) automobiles, (b) light trucks, and (c) combined results and sensitivities. Three scenarios are studied in the automobile and light-truck sections. In the third section, automobile and light-truck scenarios are combined.

About 70 percent of the petroleum consumed in transportation is used by passenger automobiles and light trucks. Obviously, improvements in these vehicles or in their use could pay large dividends in reduced fuel consumption. However, unless domestic automobile makers can meet the demand for fuel-efficient automobiles, the United States may be simply substituting one import, automobiles, for another, oil. Congress passed legislation in 1975 that required a corporate average fuel economy for new cars of 27.5 miles/gal by 1985. Should more be done beyond 1985? If so, how much?

Purdue University is performing an analysis for the U.S. Department of Transportation (DOT) to determine the benefits, costs, institutional and environmental impacts, distributional equity effects, and technology mobilization for various energy options, including oil from shale, coal liquefaction, biomass liquids, freight movement, and automobile fuel economy. This analysis is called transition path analysis. This paper reports the work done to date, primarily in the development of nationwide costs and benefits for the passenger car and light-duty truck. All benefits are measured in terms of oil saved.

The discussion of the results is divided into three parts: automobiles, light trucks, and combined results and sensitivity.

AUTOMOBILES

Sales Forecast

The sales forecast was based on a relatively mature market. The forecast is based on an average increase in sales of about 0.33 percent each year,

which would cause the total fleet to grow from 106 million cars in 1980 to 122 million in 2020 (1). Past sales cycles seem to correlate with gross national product, and the length of the cycles reflects the average life span of cars. If this average age stays relatively fixed, we can expect six-year cycles in the future. Figure 1 shows the Purdue sales estimate and also indicates the reference low and high sales estimates from DOT (2) and the Mellon Institute (3) for comparison.

Baseline

Whereas other studies have used a baseline of 27.5 miles/gal for new cars in 1985 and later, this study instead assumes that no investments are made solely to improve fuel efficiency after 1985 and that some improvement will occur with normal replacement of worn-out plants and obsolete tools. More specifically, it is assumed that the industry will spend no more than \$2 billion/year (after 1982) and that consumers will continue to demand improved fuel efficiency. The timing of line changeover will slow from the present replacement schedule of every 10-12 years to every 15-17 years. New models will be introduced much less frequently than at present.

This baseline is very different from that used by other studies, since fuel economy continues to improve over time. This means that future investments over the baseline achieve lower fuel savings with the moving baseline used here than would be achieved with a static baseline.

Scenarios

Meeting the 1985 standards will not be a severe technological problem. The standards will be met by the implementation of downsizing, front-wheel drive, limited material substitution, and less powerful engines. Although the scenarios predict large increases in fuel economy, this is not unrealistic in light of existing technological developments. According to a June 1980 news release, General Motors is predicting a corporate average fuel economy of more than 32 miles/gal in 1985.