Alternative Fuels for Buses: Current Assessment and Future Perspectives

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ABSTRACT

The issue of alternative fuels for transit buses is examined from the perspective of the 1980s and beyond. At a time when federal involvement in alternative fuel development is of lesser significance and marketplace actions appear to be of greater value than government intervention or investment, it is relevant to examine the objectives of developing diesel fuel alternatives for public transportation vehicle use. Four fuel groups are evaluated: alcohols, vegetable oils, methane (or natural gas), and hydrogen. An assessment is made of current development status and conclusions are presented regarding future research efforts.

The issue of alternatives to petroleum-based fuels has been around as long as the internal-combustion engine. However, in the 1970s a renewed and intensive effort was made to explore, develop, and test alternative fuels. The reason for this sudden surge of interest in nonpetroleum-based fuels is obvious: the tremendous uncertainty over oil price and supply due to the emergence of the Organization of Petroleum Exporting Countries (OPEC) as a powerful force. Before the 1970s, the only oil supply problems ever faced by the United States were related to military allocation of fuel during World Wars I and II. During the 1970s, the United States faced two supply disruptions, predicated by OPEC as a means of limiting worldwide oil production and thereby obtaining higher prices (as well as prolonging their own supply). Prices rose, not only because of these two disruptions but also because of a decade-long effort to maintain OPEC production quotas. U.S. oil prices had risen by only 7 percent for the entire 80-year period from 1890 to 1970 (in 1972 dollars). From 1970 to 1980, domestically produced crude oil, which was still subject to government price controls, rose by 250 percent (in constant 1972 dollars). The issue had clearly become one of U.S. vulnerability to a price and supply mechanism that it could no longer adequately control.

ALTERNATIVE FUELS IN THE 1980s AND BEYOND

Large segments of the alternative fuel research and development movement lost considerable financial and political support in the 1980s as a result of an altered oil supply and demand picture. Spurred by the major increases in worldwide oil prices in 1979 to 1980 and the deregulation of U.S. oil prices in 1981, worldwide production soared while consumption dropped. The result was an oil glut, beginning in the spring of 1981 and extending to this day, accompanied by lower oil prices and the diminished pricing and production influence of OPEC. U.S. oil production in 1982 was at its highest level in years. Suddenly, the urgency of alternative fuel development appeared to diminish and the boundary of economic competition appeared further away. Interest in synthetic fuels on the part of the federal government in particular decreased.

After 1985 the world is expected to increase oil consumption, and OPEC is simultaneously expected to regain significance as a determinator of oil prices and supply. This would once again create a situation ripe for oil price increases and supply disruptions. However, the United States and other nations appear better, although differently, prepared to handle future disruptions by using major petroleum storage reserves, international fuel sharing, and, at least in the United States, marketplace mechanisms. All these actions are intended to reduce the magnitude and duration of future disruptions, and to return to normal modes of international fuel trading as quickly as possible. Energy independence is therefore a lesser national and international goal of the 1980s and beyond, although reduced vulnerability and uncertainty remain important objectives.

Where does this leave alternative fuel development, particularly for transit buses? Basically, it can be assumed that federal involvement in alternative fuel research and development beyond 1985 will not reach the levels once expected. Furthermore, if the United States and developed countries are successful in reducing the disruptive influence of OPEC, then there clearly will be little need for any such involvement. On the other hand, the objectives of bus fuel research are still relevant because

- Contingencies may still occur and although the market mechanism may work well for private or individual oil consumers, government-sponsored transit services will face the double-bind of (a) being expected to continue to provide basic public services while (b) not having the financial means to do so;
- Environmental concerns persist and extend beyond the concerns of energy use;
- Transit systems face a further federal financial constriction, that of diminished operating subsidies, so there is greater pressure to improve productivity both from the services standpoint (e.g., articulated buses) and the maintenance standpoint--the coordination of improved productivity with more economical fuel is a natural link; and
- Finally, although the short-term payoffs may not be apparent, in an era of diminishing energy resources there are long-term benefits to serving public transportation needs with an appropriate and adequate level of energy.

POSSIBLE ALTERNATIVE FUELS FOR BUSES

Those fuels most often suggested as alternatives to bus fuels can generally be classified as liquid and

gaseous. Liquid fuels include alcohols (namely methanol and ethanol) and vegetable oils. Gaseous fuels include methane, hydrogen, and other miscellaneous gases (e.g., ammonia and producer gas). Liquid fuels can be viewed as either diesel fuel extenders or diesel fuel substitutes. Gas fuels can be viewed only as diesel fuel substitutes. Some fuels require minor adjustments to current diesel-fuel bus engines, whereas others require major modifications or complete engine redesign.

LIQUID FUELS

Alcohols

Effectiveness

There is probably more published research on alcohol fuels than any other alternative fuel type. The most notable and accessible examples include general discussions of alcohols as transportation fuels (1-3); specific evaluations of alcohols as diesel fuel substitutes (4-7); and the economic and policy issues related to alcohol fuel development (7,8). Alcohols comprise carbon, hydrogen, and oxygen, whereas gasoline and diesel fuel are simply hydrocarbon fuels. Alcohols can be operated in diesel as well as spark-ignition engines, but the following serious problems must be considered:

- Energy content of alcohols versus diesel fuel;
- Cetane quality of alcohols versus diesel fuel;
- Compatibility of alcohols with diesel engine materials; and
- Alcohol fuel emissions.

Energy Content

The net heating values (by volume) reveal that the Btu contents of ethanol and methanol are 60 and 45 percent of that of diesel fuel, respectively. Therefore, the typical 100-gal fuel tank in buses would either have to be expanded or supplemented with an additional tank, or fueling procedures would have to be changed (i.e., multiple fuel fill-ups during the day).

Cetane Quality

Cetane quality is a key concern and requires one of many possible engine modifications. For diesel engines, where the fuel must ignite on compression, the ignition quality of a particular fuel is measured by the cetane number of the fuel. Simply put, the cetane number is a measure of ignition delay, or the time between fuel injection into the combustion chamber and fuel ignition. Current diesel fuels range from 40 to 60. A cetane rating of 15 is generally classified as a minimum baseline number, signifying poor ignition quality. Alcohols, in particular ethanol and methanol, have cetane numbers ranging from 0 to 8.

There are many possible solutions to the issue of poor cetane quality. Some involve fuel additives such as castor oil and nitrated compounds. Others recommend that alcohols only be blended with diesel fuel, although anything greater than a 10 percent blend of alcohol is likely to reduce the cetane level below manufacturers' specifications (1). Finally, others recommend engine modifications. In a recent report, the following five options to adapt U.S. diesel bus engines for methanol operation were analyzed (4):

1. Convert to Otto cycle engine,
2. Convert to Otto cycle engine and vaporized methanol,
3. Add spark ignition,
4. Add surface ignition, and
5. Add indirect, prechamber ignition.

The most promising option was surface ignition, which would involve the use of glow plugs in the combustion chamber to provide a hot surface to vaporize and ignite methanol shortly after injection. The use of these glow plugs may be conserved for cold starts and during the warm-up period.

Compatibility with Diesel Engine and Vehicle Materials

Diesel engines and diesel fuels are naturally compatible. Alcohols, on the other hand, could cause accelerated wear of diesel fuel systems and engine components (9). This is especially true if fuel additives are used. All nitrate compounds are particularly corrosive and prolonged use of castor oil can clog fuel injector tips (1,4). In European experiences, methanol rapidly diluted crankcase oil, requiring more frequent oil changes. Furthermore, methanol corrodes some materials contained in onboard fuel tanks, damaging the tanks and causing downstream deposits (ethanol will do the same for any diesel fuel-related deposits in fuel tanks). Both methanol and ethanol adversely affect most elastomeric (rubber) parts such as fuel-pump diaphragms and fuel hoses.

Alcohol Fuel Emissions

When a Volvo diesel engine operated under transit bus test conditions (although in a laboratory setting) was used, hydrocarbon and carbon monoxide emission levels were higher, and nitrous oxide and particulates were lower for both ethanol and methanol (10). However, a more recent report indicates that, for methanol at least, hydrocarbon emissions are less volatile than diesel-fuel emissions and less likely to cause smog, whereas carbon monoxide emissions vary considerably from test to test because of the relative leanness or richness of the fuel-air mixture (4).

Besides these emissions, which are regulated by the federal government, other relevant emissions include smoke (essentially nonexistent for alcohol fuels) and aldehydes. These emissions (particularly formaldehyde from methanol) are considerably higher for alcohols than for diesel fuel (4).

Development Potential

Economics of Fuel Production and Marketing

Diesel fuel prices currently average around $1.00 per gallon (especially for relatively large users such as transit systems). Ethanol prices range from 50 to 70 percent higher than that, whereas methanol is about 30 percent lower than the price of diesel fuel (11). Methanol is clearly the more cost-effective alcohol option, strictly on the basis of the price of fuel. Methanol costs even show signs of declining to a level nearly half that of diesel fuel.

Market Demand

Alcohols, particularly ethanol, have established a minor foothold in the U.S. transportation sector, primarily as a blend with gasoline. Nearly 10 per-

cent of all the gasoline currently in the United States contains either ethanol or methanol (mostly ethanol) (12). Both, however, are used primarily for industrial purposes. Methanol, for example, is produced at a rate of more than 1 billion gal a year. In 1980 (the most recent year for which data are available), 95 percent of methanol was used as a chemical precursor for industry, 3 percent as a gasoline octane booster, and 2 percent as a direct fuel (13).

Other Interest in Development

Alcohol fuel development was pushed in the late 1970s by the federal government and a number of agricultural states, all of which were looking for alternative uses for various products (e.g., corn grain). Although federal involvement declined, state interest remains strong, particularly in agricultural states and some states with significant alternative energy programs and concerns such as California. Petroleum companies have shown growing interest in ethanol as a gasoline octane booster, but nearly all (except ARCO) reject the use of methanol for similar purposes.

Vegetable Oils

Effectiveness

Vegetable oils particularly lend themselves to applications in diesel engines. As early as 1931, researchers noted that the hydrocarbon structure of vegetable oils had a capacity for compression ignition in diesel engines. A wide range of vegetable oils are possible diesel fuel substitutes or blending agents, including corn, cottonseed, peanut, soybean, and sunflower oils. Most experimental research conducted in the last few years to determine the fuel potential of vegetable oil has centered on cottonseed and sunflower oils (in part because of the availability and market development potential of these oils) and has been confined to laboratory settings. Some of the concerns raised about alcohols do not pertain to vegetable oils, whereas others do.

Energy Content

Unlike alcohols, the Btu content of vegetable oils is relatively close to that of diesel fuel; sunflower and cottonseed oils, for instance, have approximately 90 percent of the Btu content of diesel fuel (14,15). As a result, the fuel volume and associated fuel tank requirements are not much greater than those of diesel fuel.

Cetane Quality

Also, unlike alcohols, vegetable oils have cetane levels much closer to those of diesel fuel. Indeed, cottonseed oil produced by the transesterification process (i.e., lowering the viscosity of the oil) exceeds diesel fuel cetane quality.

Cold Weather Performance

The cloud and pour points of vegetable oils are such that they create potential difficulties with cold weather operation (i.e., fuel flow will be irregular and slow). Significant cold-start problems arose in test temperatures of -1°C (30°F) and -7°C (20°F) when only a 50 percent blend of sunflower oil was used with diesel fuel (14).

Engine Compatibility

Engine durability is a key issue in the use of vegetable oil-based fuels in diesel engines. Vegetable oils have a greater propensity to leave behind carbon deposits after only short periods of operation. As considerable and fast-growing as these deposits can be, they do tend to be blown off to some extent during engine operation. Deposits in the piston and the cylinder liner are more stubborn, however, (and much greater than the amount produced by either diesel or alcohol fuels) because of the oiliness of the blend and the large droplet size of vegetable oils. Research reports point out, however, that deposits would vary among diesel engine designs (no transit-type engines have been tested) and that processes that lower oil viscosity can reduce, but not eliminate, the deposit problem.

Emissions

Relatively sparse data on cottonseed oil and diesel fuel blends and 100 percent, low-viscosity cottonseed oil indicate little difference between the carbon monoxide, hydrocarbon, nitrous oxide, and smoke emissions of these fuels and straight diesel fuel (15). The differences that do exist are insignificant.

Development Potential

Economics of Fuel Production and Marketing

Vegetable oils are considerably more expensive than diesel fuel; the price of cottonseed oil, for example, was approximately $2.25 per gallon in early 1984 (16). Other oils are similarly priced, although prices vary considerably depending on the annual availability of feedstock agricultural products. Peanut oil, for example, sold in early 1984 at a price 52 percent higher than cottonseed oil, primarily because of poor peanut crops.

Market Demand

Vegetable oils are not currently used as fuels in the United States. They are used primarily as food preparations, such as baking or frying fats, margarine, and salad or cooking oil. In 1983, nearly 2 billion lb (or approximately 257 million gal) of oil were used for food preparation (17). There are also other industrial uses. Some oils are exported in substantial amounts, including cottonseed and peanut oils.

Other Interest in Development

The U.S. Department of Energy (DOE) stated that the "availability of [vegetable oils] in quantities to satisfy even emergency [vehicle] fleet appetites is questionable" (18). DOE does point out, however, that such oils may be available, but on a highly localized basis. It is clear that for other than food preparation and a few established industrial purposes, there is no significant interest in developing vegetable oils for fuel-related purposes.

GASEOUS FUELS

Methane

Effectiveness

Methane, or CH_4, is the prime ingredient of natural gas. Typically, 95 percent of natural gas is composed of methane; natural gas is therefore interchangeable with methane in any discussion of methane as a transportation fuel. When used as a transportation fuel, methane is neither stored on board the vehicle nor delivered to the engine in its natural gaseous state. Instead, it is used either in a highly compressed form (at 2,500-3,000 psi) or as a cryogenic liquid (cooled to -260°F). The issues related to methane use as a specific diesel engine fuel are energy content, cetane quality, and safety.

Energy Content

In a pound-for-pound comparison, methane has slightly more energy content, measured in Btu's, than diesel fuel. However, when stored on board a vehicle as a cryogenic liquid, the fuel volume and associated fuel tank requirements are greater than those of diesel fuel (6).

Cetane Quality

Methane has an extremely low cetane number, which corresponds to the fact that the octane quality of methane is among the highest of transportation fuels. For this reason, methane is unsuited for direct use in diesel engines. Various alternatives, as with the alcohol fuels, are to (a) use methane with diesel fuel (via fumigation) with the latter serving essentially as a pilot light, (b) use methane with other fuel additives, or (c) adapt the engine via the use of glow plugs, which provide a hot internal cylinder chamber capable of igniting the methane shortly after injection.

Safety

The safety issues related to methane vehicle use are significant and remain unresolved. The major safety concerns are fuel leakage, boil-off of liquid methane, corrosive failure of compressed methane gas cylinders due to excess hydrogen sulfide in natural gas, and the crashworthiness of both liquid and compressed methane gas cylinders. Crashworthiness is accompanied by other related hazards, including fuel release upon impact and tank rupture due to fire. There are currently no industry-wide standards regarding the design, manufacture, installation, and performance of compressed methane gas fuel systems (19).

Also related to safety concerns are environmental hazards. Tested only in spark-ignition engines, significant reductions in carbon monoxide, nitrogen oxides, and most hydrocarbon emissions were recorded (20). The one hydrocarbon that greatly increased in emissions was, naturally enough, methane, which is nonreactive. Methane also significantly reduces diesel fuel-related smoke emissions.

Development Potential

Economics of Fuel Production and Marketing

Methane gas currently sells for between $3.50 (for electric utility purchases) and $6.00 (for residential purchasers) per thousand cubic feet. Its cost is directly related to federal natural gas regulation. By 1985, the price of natural gas will begin to be deregulated, at which point its price will be uncertain. That uncertainty is based on worldwide trends in natural gas demand and supply as well as similar trends in closely aligned fuels (oil and coal).

Other sources besides natural gas can be exploited for methane, including coal and biomass. However, the price impact of these sources is uncertain because alternative methane production techniques and sources have been neither marketed nor tested.

Market Demand

Methane is mainly used for two purposes: (a) as a natural gas component, it is used for its heating value by the residential and industrial electric utility commercial sectors, and (b) as a chemical feedstock, methane is used to produce methanol and ammonia. The demand of these markets is expected to remain strong, although tied to methane price trends.

Other Interest in Development

In 1980, the Methane Transportation Research, Development, and Demonstration Act was signed into law by the President. Congress is interested in methane as a vehicular fuel because of (a) its ability to reduce oil imports, (b) its ability to reduce vehicle emissions, and (c) development of alternative market uses for methane from natural gas and other sources. This act, however, has not been funded by Congress. Nevertheless, DOE has performed a state-of-the-art assessment of methane-fueled vehicles and is likely to conduct further research in the following three areas:

1. Engine testing is needed to clearly define the limits of efficiency, emissions, and performance of natural gas vehicles, and the development of practical conversion systems for diesel-engine vehicles. In addition, fundamental work on high-energy-density gas storage systems should be encouraged.
2. A test program to determine the crashworthiness and fire safety of state-of-the-art natural gas vehicles is needed, and various compressed natural gas tank designs should be evaluated for resistance to internal corrosion potentially caused by impurities.
3. Assessments need to be made of institutional barriers to natural gas use in vehicles and of the means to overcome those barriers (19).

Hydrogen

Effectiveness

Hydrogen has already become the staple fuel of space transportation and has been called the fuel of the future. It is described as such for three main reasons: it provides the highest energy conversion efficiency obtainable; it burns relatively cleanly, with no emissions of carbon monoxide, hydrocarbons, smoke, or odors; and it can be produced from water. Hydrogen has to date been used in a limited manner, both as a transportation fuel and an overall fuel (its primary use is as an industrial feedstock). It has had a few significant applications in transit systems; in particular, the testing of a hydrogen-powered bus in Riverside, California, in 1980. That bus, however, was not a typical transit vehicle; it was a 21-passenger Winnebago Minbus, originally

equipped with a heavy-duty truck gasoline engine. (21). (Hydrogen's high octane value makes it a good gasoline substitute.) The gasoline carburetor was removed and replaced with a gaseous fuel carburation device. Although the Riverside test does not directly apply to most current transit operations, the interesting aspects and results of the operation are worth reporting.

First, the hydrogen fuel was stored on board the vehicle as a metal hydride. Although this methodology had its problems (i.e., in order to release the hydrogen, the metal hydride was heated, which required considerable water and fan cooling), it is often considered the most promising means of hydrogen fuel storage. The other alternatives for hydrogen storage include hydrogen stored as a high-pressure gas, chemical fuels synthesized from hydrogen (e.g., ammonia and hydrazine), and hydrogen stored as a cryogenic liquid (22). Metal hydrides are considered the best option because of fewer handling problems and safety concerns (23). However, because of the significant weight of metal hydrides, a vehicle fueled in this manner must either use an extremely heavy fuel tank or limit its mileage range. In the Riverside test, for example, the latter choice was made and most test runs were no longer than 60 mi before refueling was necessary (24). Major advances in metal hydride storage clearly need to be made before widespread vehicular use can be envisioned.

Second, a number of problems were encountered in the Riverside test. In nearly 20 percent of the test runs, vehicle cold-starting was very difficult. Unusually high amounts of dirt and iron were found in the crankcase oil. Finally, carburetor flashback occurred often, damaging the carburetor diaphragm and causing a loud backfire-type sound. Altogether, these problems suggested that further improvements in hydrogen-fueled buses must be made before further tests in transit revenue service are made.

The other significant ongoing research effort in hydrogen-fueled vehicles concerns diesel applications, although primarily in the railroad sector (25). That effort is investigating the use of high-pressure hydrogen gas and cryogenic hydrogen in converted diesel engines. Hydrogen's low cetane value, for example, requires some type of fuel or engine ignition assistance.

There are still many issues that need to be investigated in terms of hydrogen use in vehicles in general and diesel-powered vehicles in particular. Safety is a major concern, as are all aspects of fuel handling and distribution. Because of the current status of hydrogen fuel research, at least two recent studies rank the possible use of hydrogen fuel as a diesel fuel substitute before the 21st century extremely unlikely (6,9).

Development Potential

Economics of Fuel Production and Marketing

The iron titanium used in the Riverside bus test sells for approximately $13 per pound. The less heavy magnesium hydride sells for twice that amount (23). Liquid hydrogen costs considerably less; depending on the source of production, the cost is between $0.65 per pound ($2.88 per cubic foot) for hydrogen made from methane to $1.44 per pound ($6.38 per cubic foot) for hydrogen made from water via electrolysis (9). Hydrogen is currently produced from two main sources: methane (i.e., natural gas) and petroleum (in about a 73/27 percent split) (26). Electrolysis from water produces less than 1 percent of the hydrogen currently needed.

Market Demand

About half the hydrogen produced in the United States is used by the petroleum and chemical industries; a third is used to make ammonia for fertilizer and other uses; and the rest is used to make methanol and for other miscellaneous purposes, including liquid hydrogen for the National Aeronautics and Space Administration (26). Metal hydrides are primarily used by the petroleum industry in the refinery process (27).

Other Interest in Development

In 1980, Congress identified the following potential uses for hydrogen:

- Mixing hydrogen with natural gas to expand natural gas resources;
- Transportation, including rail and air transportation and such special uses as forklift trucks, mining and agricultural equipment, buses, fleet vehicles, and other multipassenger vehicles designed for short-distance travel;
- Hydrogen fuel cells for electricity generation and other uses; and
- Greater use in ammonia production (28).

NEAR-TERM VERSUS LONG-TERM DEVELOPMENT POTENTIAL OF ALTERNATIVE FUELS

Five fuels were identified as possible alternative fuels for bus transit systems: methanol, ethanol, vegetable oils, methane, and hydrogen. All are currently in production, although it should be noted that only vegetable oils are being produced from renewable resources in any significant quantity in the United States. A small portion of ethanol, that which is used for such automotive fuels as gasohol, is produced from agricultural products. Methanol, ethanol, methane, and hydrogen are principally derived from petroleum or natural gas resources. The technologies for producing these fuels from these resources are well developed, as are the economics. Neither the alternative technologies nor the economics for producing these fuels from alternative resources (e.g., agricultural products, coal, water, and waste products) are fully developed. Thus, only vegetable oils can be considered an immediate alternative fuel for transit systems from the production point of view. In the near-term future, however, ethanol is a likely candidate (the facilities for producing and marketing grain, corn, and sugar alcohol are well established), although not one of major significance. Ethanol production could be expanded to serve the needs of transit systems without any major problems. Long-term candidates from the point of view of fuel production and availability (from nonpetroleum and non-natural-gas resources) include methanol, methane, and hydrogen.

In terms of their use in current bus vehicles, vegetable oils once again are the only fuels with immediate applications. All other fuels would require significant changes to (a) engine design (primarily through the use of glow or spark mechanisms), (b) fuel storage and delivery (both from the vehicle storage tank to the engine and from the facility storage area to the vehicle), and (c) engine parts (particularly elastomers). In addition, further testing is needed to establish appropriate blending percentages with diesel fuel (if that is the procedure chosen), necessary fuel additives, emissions, and so forth, none of which has been well explored in transit-type operations. (Vegetable oils would

also have to undergo some of these tests as well.) Among these fuels, both methanol and ethanol are likely near-term candidates for the development of appropriate engine and fuel components, whereas methane is a long-term candidate. Hydrogen's potential goes far beyond the year 2000.

In summary, vegetable oils are the only fuel with immediate development potential. Ethanol has near-term potential; methanol has near-term potential from the end-user point of view (i.e., transit systems) but only long-term potential from the production point of view; methane has long-term potential; and hydrogen has potential as a bus fuel through the 21st century.

EVALUATION OF ALTERNATIVE FUELS

An evaluation was conducted to determine the ability of alternative fuels to

1. Protect the fuel supply during future oil shortages;
2. Reduce the air quality impacts of diesel fuel;
3. Reduce transit system operating costs; and
4. Serve as more energy-efficient fuels.

The results of this evaluation revealed the following:

1. There is no alternative fuel that could serve on any widespread basis as a transit contingency fuel in the event of an imminent oil shortage. However, governments can ensure that transit systems receive an adequate supply of diesel fuel. On a limited basis, vegetable oils could serve as an adequate contingency supplement to diesel fuel during a disruption. Alcohols could serve as adequate supplementary fuels if oil shortages occurred in the near- or long-term future.
2. Alcohols emit far more carbon monoxide and hydrocarbon pollutants than diesel fuel. However, they emit less nitrogen oxides and soot or smoke pollutants; the latter are the major diesel engine pollutants. Other alternative fuels do not have a sufficient test history in transit bus settings for a substantive evaluation of their environmental impacts; however, indications are that vegetable oils, methane, and hydrogen are cleaner-burning fuels. Two problems associated with these latter fuels, methane emissions and nitrogen oxide emissions from hydrogen, are likely to be resolved by engine adjustments.
3. Methanol is clearly the alternative fuel that provides the lowest operating costs for transit systems. However, despite the lower fuel cost of methanol compared with diesel fuel, the overall operating and maintenance costs are higher than those for diesel fuel.
4. Hydrogen is considered the most efficient fuel, but various aspects of its storage properties (either cryogenic or metallic) make it an unsuitable near- or long-term fuel for any extensive use by transit systems. Methane has similar limitations, although those could be solved within a long-term framework. Vegetable oils are excellent fuels from the point of view of Btu's and cetane; however, their cold-start problems and overall availability restrict their immediate applications with transit vehicles except on a limited basis. Alcohols are the most likely near-term candidates for transit use despite necessary engine modifications because of their availability potential, their relative similarity to diesel fuel in storage handling and suitability to withstand urban vehicular accidents, and their ability to reduce nitrogen oxides and soot and smoke emissions. Because of methanol's even greater potential for availability and cost savings, this particular alcohol is considered the likeliest candidate for near-term exploitation in bus transit systems.

FUTURE DEVELOPMENTS

Alternative fuel research and development continue even though the federal government and private industry are less interested than they were in the 1978 to 1981 period. Indeed, expressed federal interest in alcohols, methane, and hydrogen ensure their continued study. However, only alcohols are seriously being considered and tested as transit fuels. In Florida, the Department of Transportation is converting a small number of revenue-making buses for methanol use, utilizing glow plug and other engine modifications. In California, two buses (with modified engines) in the San Francisco region are running on methanol. Elsewhere in the world similar tests are ongoing. No current interest has been generated for vegetable oil research among U.S. transit systems, and methane and hydrogen applications are being studied in nontransit areas.

Should current research and development of alternative fuels for transit buses be expanded? Or is the current level of research adequate? There are factors that support both positions. Three major factors work in favor of maintaining current levels of research:

1. Objectives do not warrant further support,
2. Market demand is too small, and
3. Current economics are unfavorable.

Among the factors that support research expansion are

1. Objectives still hold some significance,
2. There is new competition in the bus manufacturing industry,
3. Future economics are likely to be favorable, and
4. Transit systems could serve as lead developers.

Each factor is discussed in the following paragraphs.

Factors Favoring Maintenance of Research Levels

Objectives

- Governments and transit systems can take other actions besides developing alternative fuels to protect the supply of diesel fuel or fuel budgets or both during oil supply disruptions. These actions include the allocation of necessary supplies to transit systems (via federal or state intervention), the creation of contingency diesel fuel reserves by transit systems, subsidies from the federal government, and so forth. These actions fit within the current fuel procurement and subsidy channels and do not reflect the kind of changes in procurement, fueling, and maintenance that alternative fuel use would require.
- The key urban vehicular pollutants are carbon monoxide, hydrocarbons, and nitrous oxides. Transit buses simply are not major contributors of these pollutants.
- Diesel fuel operating and maintenance costs remain cheaper than all other alternative fuel and engine combinations.
- Years of tandem diesel fuel-diesel engine development have established diesel fuel as the most efficient and best-suited bus transit fuel, considering current bus vehicles.

In summary, when viewed within a larger spectrum, the objectives of transit bus alternative fuel development have not essentially been met.

Market Demand

Transit systems consume only around 3 percent of the on-highway diesel fuel used in this nation and less than 1 percent of all diesel fuel (29). At the same time, there are about 60,000 transit buses in the United States, whereas diesel trucks number at least six times that number (30). There are similar engine manufacturers for both industries. It is difficult to envision an economic environment in which manufacturers will make substantial changes in engine and vehicle design for a relatively small segment of their consumer population. Therefore, unless other alternative fuel development concepts consider the needs of diesel trucks as well as transit systems, they may not receive widespread attention by relevant manufacturers.

Current Economics

An unfavorable economic climate relates to a number of relevant factors: steady diesel fuel prices, high prices of alternative fuels (except for methanol), and fiscally restrained transit systems unwilling to invest heavily in necessary modifications to vehicles and facilities (including those related to methanol).

Factors Favoring Expanded Research

Objectives

Some of the following aspects of development objectives are validated by alternative fuel research.

- Transit systems are operating in a deregulated energy environment along with other oil product consumers. Despite their public standing, it behooves transit systems to act as responsible consumers by mitigating the risks of fuel loss or price changes without relying on government bailout as a first resort. Alternative fuels, particularly methanol in the near term, are a responsible way to guard against possible disruptions. Despite the necessary adjustments in fuel procurement, the move toward alternative fuels is one that recognizes the hazards of letting other governmental bodies solve the problems of transit systems. It is also one that recognizes the need for transit systems to provide important services during fuel disruptions to the best of their ability.
- Although not as crucial as other pollutants, soot and smoke emissions are a visible and uncomfortable intrusion into everyday urban life, one that alternative fuels can help reduce.
- The increase in total operating costs of alternative fuels should be viewed as a possible short-term occurrence; manufacturing and facility processes are likely to be refined and less costly.
- Finally, the current fuel-engine coupling can be uncoupled quickly if other fuels and proper engine modifications occur in a smooth and relatively inexpensive manner.

New Competition

Since 1980 at least four new bus manufacturers have entered the U.S. market for transit buses. Others may also join as a result of prototype tests. Competition will stiffen and manufacturers will search for production and marketing strategies. Although it was stated that there are no major empty product niches (30), manufacturers might view dual-fueled or alternative-fueled buses as a possible product area to exploit. This could be especially true for the large number of foreign entrants into the market [e.g., Volvo, and Maschinenfabrik Augsberg-Nürnberg (MAN)] that have considerably more experience in alternative fuel development and operations than most domestic companies.

Future Economics

Diesel fuel prices will not remain steady; rather, they will most likely rise as oil production demand resumes on a worldwide basis. At that time, the economic potential of alternative fuels will once again become attractive. Furthermore, transit systems, although likely to be in constant need of subsidization, will eventually emerge from the massive rehabilitative phase they are currently in and will have more capital and operating funds available for alternative fuel ventures.

Transit as a Lead Developer

This is turning the market share issue around. Truckers, who use most of the diesel engines and fuel on the highway, are in a constant and fiercely competitive struggle for freight haulage. This competition has only been enhanced by the deregulation of the trucking industry, and it has been characterized largely by significant price competition. This has two implications: (a) trucking firms have less funds available to engage in alternative fuel R&D programs and (b) whatever cost advantages alternative fuels could offer to truckers (during periods of constant fuel shortages) would be of great benefit. Therefore, the transit industry is the proper sector for alternative fuel development. First, such systems are not strictly cost-competitive, although costs must be carefully scrutinized because of the pervasive deficit operations throughout the industry. Second, any cost savings that result are likely to be picked up by the private trucking industry, which in turn will aid transit systems by spurring manufacturer interest.

New Directions in Research and Development

In light of the factors that either support or oppose an expanded alternative fuel R&D effort, what directions should be pursued? This study recommends the following in terms of program initiatives and R&D participants and roles.

Program Initiatives

Current U.S. transit methanol tests and the considerable wealth of foreign expertise suggest that vehicle testing should not be expanded to any large extent. The following actions are recommended instead:

- A joint study between UMTA and the U.S. Departments of Energy and Agriculture would identify the potential role of vegetable oils as contingency fuels. This study would address the key aspects of (a) price and availability issues, (b) identification of regions, markets, and conditions where availability of vegetable oils is ensured, (c) which transit

systems (by size, location, etc.) will be the most likely users, and (d) what the benefits and costs are compared with other, nonalternative means of providing assistance to transit systems during fuel disruptions.

• A cooperative effort should be made between one or more bus manufacturers, an alternative fuel producer, and at least one transit system to test the costs and benefits of developing alternative fuels. The costs and responsibilities of this cooperative effort should be divided according to where they properly belong: engine modifications to the manufacturer; fuel quality characteristics and assurance and delivery methods to the fuel supplier; and maintenance and facility redesign and readjustment to the transit system.

Participants and Roles

The relevant participants in future R&D efforts are

• The federal government, including UMTA, U.S. Department of Energy, U.S. Department of Agriculture, and U.S. Department of Transportation, Office of the Secretary;
• Transit systems;
• Fuel suppliers;
• Bus manufacturers; and
• State and local governments.

Their roles should be as follows:

• The federal government should actively pursue the vegetable oil contingency study and relay any positive results to transit systems.
• The federal or state governments should not play an active role in forming the cooperative fuel development program.
• Interested transit systems should contact bus manufacturers and together they should seek out fuel providers to form a cooperative development effort. Any results should be publicized, but the individual profitability of manufacturers and fuel suppliers should not be restricted by federal or state guidelines or mandates.

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