ALTERNATIVE FUELS FOR BUS
CURRENT ASSESSMENT AND
FUTURE PERSPECTIVES

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DEPARTMENT OF TRANSPORTATION
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16. Abstract

This report summarizes the limited research that has been conducted regarding alternative fuels for buses, matching results with relevant objectives, and recommending further research and policy directions. This report examines the issue of alternative fuels for transit buses from the perspective of the 1980s and beyond. This report points out that in a time when Federal involvement in alternative fuel development is of lessened significance and market place actions seem 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. Five fuels have been named as possible alternative fuels for bus transit systems: methanol; ethanol; vegetable oils; methane; and hydrogen. All are in production at the current time, although the authors feel it should be noted that only vegetable oils are being produced in any significant quantity in the United States from renewable resources. Four fuel groups are evaluated in this report: alcohols; vegetable oils; methane (or natural gas); and hydrogen. An assessment of current developmental status is provided and conclusions regarding future research efforts are presented.

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EXECUTIVE SUMMARY

Introduction

The issue of alternatives to petroleum-based fuels has been around as long as the internal combustion machine. But in the 1970s, there was a renewed and intensified effort to explore, develop and test alternative fuel options. The reasons for this sudden surge in interest in non-petroleum based fuels is obvious: the tremendous uncertainty created over oil price and supply due to the emergence of the Organization of Petroleum Exporting Countries (OPEC) as a powerful force.

Alternative fuels loomed as a partial solution to the nation's oil vulnerability. After all, if a fuel could be developed from an American-based resource, then the U.S. would be energy independent, free from the economic and political perils which international fuel trading posed.

The main thrust in the development of alternative fuels in the 1970s was directed toward transportation fuels in general, and automotive fuels in particular. Other modes of transportation spurred interest in alternative fuel development. Alcohols for tractor, truck and train utilization have been studied and tested. These three modes dominate U.S. transportation consumption of diesel fuels. Buses, on the other hand, are relatively small consumers of U.S. diesel fuel supplies (currently, for example, transit buses consume approximately one-thirtieth the amount of fuel that heavy trucks use annually). As a consequence, alternative fuel development interests in the bus and, in particular, the transit bus mode were not of major significance in the U.S. In other nations, however (especially India and Brazil), where transit plays a larger role in personal transport, bus fuel alternatives have been researched to a larger extent.

This report summarizes the limited research that has been conducted on alternative fuels for buses, matching results with relevant objectives, and recommends further research and policy directions.

Technical Potential for Using Alternative Fuels in Buses

Five fuels have been identified as possible alternative fuels for bus transit systems: namely methanol, ethanol, vegetable oils, methane and hydrogen. All are in production at the current time, although it should be noted that only vegetable oils are being produced in any significant quantity in the United States from renewable resources (a small portion of ethanol, that which is used for 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. Alternative technologies for producing these fuels from alternative resources (e.g., agricultural products, coal, water, waste products, etc.) are not fully developed, nor are the economics. Thus, only vegetable oils can be considered an immediate alternative fuel for transit systems from the point of view of production. In the near-term however, ethanol would be a likely candidate (the facilities, production and marketing capabilities of grain, corn and sugar alcohol production are well established) although not of major significance. Its production could be expanded without major problems to serve the needs of transit systems. Long-term candidates, from the point of view of fuel production and availability (from non-petroleum and non-natural gas resources), include methanol, methane and hydrogen.

From the point of view of usability in current bus vehicles, vegetable oils once again are the only fuel with immediate applications. All others would require significant changes to a) engine design (primarily through the use of glow or spark mechanisms), b) fuel storage and delivery (both from vehicle storage tank to the engine and from facility storage area to the vehicle), c) engine parts (particularly elastomers). In addition, further testing would have to be applied to establish appropriate blending percentages with diesel fuel (if that is the route chosen), necessary fuel additives, emissions, etc.; none of which have 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 would be considered likely near-term candidates for development of appropriate engine and fuel components, while methane would be a long-term candidate. Hydrogen's potential is far beyond the year 2000.

In summary, vegetable oils are the only fuel with immediate development potential; ethanol has near-term potential, while methanol has near-term potential of the end user point of view (i.e., transit systems) but only long-term potential from the production point of view; methane is a long-term potential fuel, while hydrogen is a post-20th century potential bus fuel.

Alternative Fuels for Buses and Energy Contingencies

The role of alternative fuels as oil supply disruption contingency fuels is the following:

- Alternative fuels would never be relied upon to substitute completely for diesel fuel, only supplement those supplies due either to shortages or high prices.

- Vegetable oils provide the only immediate contingency protection potential but only on a limited spot basis; there are too few supplies to supplement the needs of all transit systems.

- o Ethanol would be an adequate contingency fuel in a near-term disruption.

- o Methanol might be an adequate contingency fuel in a near-term disruption (if oil prices rose but supply was constant) but would definitely provide assistance in the long-term.

- o Government actions could alter the importance of alternative fuels as contingency measures vs. simple allocation of diesel fuel supplies to transit systems.

- o Methane and hydrogen should not be considered contingency fuels.

Alternative Fuels for Buses and Their Environmental Effects

Findings regarding air quality impacts of alternative fuels are derived from a) laboratory settings and b) engines not always similar to typical transit bus diesel engines. Still, the data do suggest overall trends in the relative quality of fuels and diesel engines as contributors to urban pollution. The relevant pollutants of interest are carbon monoxide, hydrocarbons, nitrogen oxides and soot/smoke emissions.

Carbon Monoxide (CO)

Alcohols were shown in some tests to emit significantly larger amounts of carbon monoxide (CO) than diesel fuel -- on the order of four to five times as much. (However, an oxidation catalyst can be used to reduce CO emissions.) In any event, emissions are considerably less than produced from gasoline. Vegetable oil emission data is sketchy, but that which exists suggests little difference from diesel fuel in CO emissions. Methane use drastically reduced CO emissions, while limited hydrogen tests show virtually no CO associated pollution.

Hydrocarbons (HC)

The findings with regards to hydrocarbons (HC) is similar to that of carbon monoxides: higher HC emissions among alcohol fuels (50 to 120 percent greater than diesel fuel); negligible changes among limited vegetable oil tests; lower HC emissions in methane use (except for actual methane emissions); virtually no emissions due to hydrogen use. In addition, methanol is a significant polluting source of unregulated hydrocarbons, particularly aldehydes (including formaldehyde).

Nitrogen Oxides (NO_x)

Here, alcohol fuels are significantly better than diesel fuel, on the order of one-third lower. Again, vegetable oil emissions data are limited and not significantly different than diesel fuel. Methane use produces lower emissions, while hydrogen has questionable indications that NO_x emissions could rise above those of diesel fuel, although engine redesign could improve the situation.

Soot/Smoke

Here, all alternatives fuels produce significantly lower emissions levels than diesel fueled vehicles.

In conclusion, methane is the only fuel consistently shown to have lower emissions in all important pollutants than does diesel fuel (except for the currently unregulated methane pollutant itself). Otherwise, methanol and ethanol are lower polluters of NO_x and soot (i.e., particulates)/smoke but greater polluters of HC and CO. Vegetable oil emissions are not really known, but preliminary indications suggest little difference from diesel fuel. Hydrogen is expected to be a relatively clean burning fuel, except for possible problems in NO_x emissions.

Alternative Fuels for Buses and Transit Operating Costs

On a per-gallon basis, methanol, cryogenic (i.e., liquid) methane and cryogenic hydrogen are all cheaper than diesel fuel. On an energy content basis, however, almost nothing is cheaper than diesel fuel, except methane sold at utilities' purchase prices. In addition, metal hydrides become prohibitively expensive under this analysis, due to the relatively low weight of hydrogen in terms of the total metal compound. Energy content becomes particularly important when using alternative fuels in a non-blend manner; when viewed as blends (particularly smaller blends of the 90% diesel/10% other type), the energy content differences between diesel fuel and other fuels is less meaningful and relevant.

Direct fuel costs are not the only aspect of operating costs related to alternative fuels. There are also the costs related to maintenance of a) the engine, b) the vehicle (due to additional parts replacement), and c) facility maintenance (i.e., the fueling facilities). The only significant attempt to identify these costs for alternative fuels was done in a recent UMTA report. That information clearly indicates that alcohols cause significantly fewer maintenance costs than either methane or hydrogen. Vegetable oils were not part of this evaluation, but would likely be more similar to alcohol costs than methane or hydrogen costs.

In conclusion, utilizing the assumption that the average transit bus uses 1,258 million BTU per year, diesel fuel remains the least expensive fuel type to buy (and use on a 100% fuel basis) and to maintain. After that, methanol is clearly the most economically sound alternative fuel from the point of view of both fuel and maintenance costs. All other fuels are closely bunched well behind methanol, except for metal hydrides, which are clearly economically inferior.

Research and Policy Initiatives

Current United States bus transit methanol tests and the considerable wealth of foreign expertise suggest that expanded vehicle testing efforts not be pursued to any large extent. What is recommended is the following:

1. A joint study between UMTA, the United States Departments of Energy and Agriculture that would identify the potential role of vegetable oils as contingency fuels. The key aspect is to address a) price and availability issues, b) identifying regions, markets and conditions where availability of vegetable oils is assured, c) which transit systems (by size, location, etc.) are the likeliest users, and d) what are the benefits and costs compared to other, non-alternative fuel means of providing assistance to transit systems during disruptions.

2. A cooperative effort between one or more bus manufacturers, an alternative fuel provider and at least one transit system to test the costs and benefits of developing alternative fuels. Within this cooperative effort, costs and responsibilities should be split and identified where they appropriately belong: engine modifications to the manufacturer; fuel quality characteristics and assurance, and delivery methods to the fuel supplier; and maintenance and facility redesign and readjusting to the transit system. Such an effort could be supported by a federal demonstration project.

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CHAPTER I

INTRODUCTION, PURPOSE AND ORGANIZATION OF THIS REPORT

Why Alternative Fuels?

The issue of alternatives to petroleum-based fuels has been around as long as the internal combustion machine. But in the 1970s, there was a renewed and intensified effort to explore, develop and test alternative fuel options. The reasons for this sudden surge in interest in non-petroleum based fuels is obvious: the tremendous uncertainty created over oil price and supply due to the emergence of the Organization of Petroleum Exporting Countries (OPEC) as a powerful force. Prior to the 1970s, the only oil supply problems ever faced by the U.S. were related to military allocation of the fuel during World Wars I and II. During the 1970s, the U.S. faced two supply disruptions, predicated by OPEC as a means of limiting world-wide oil production and thereby obtaining higher prices (as well as prolonging their own supply). And prices did rise, not only due to these two disruptions but also due to a decade-long effort to maintain OPEC production quotas. In the U.S. oil prices had risen by only 7 percent for the entire 80 year period spanning 1890-1970 (using 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/supply mechanism which it could no longer adequately control.

Alternative fuels loomed as a partial solution to the nation's oil vulnerability. After all, if a fuel could be developed from an American-based resource, then the U.S. would be energy independent, free from the economic and political perils which international fuel trading posed. And there were the other benefits:

1. The environmental consequences of oil-based fuels, in particular lead from gasoline (as well as other noxious fumes from incomplete combustion of the petroleum hydrocarbon fuels) were severe and actually produced an environmental crisis (or awareness) which preceded the energy crisis by some 5-10 years. Surely a different fuel could be developed which was less detrimental to air quality.

2. As oil prices rose (and indicated a trend toward steady price increases throughout the 20th century) other fuels became more economically attractive. When oil was cheap, these fuels were not economically viable due to necessary reformulation of extraction, production, distribution and consumption practices. But as oil prices soared, the boundary between unaffordability and marketability of alternative fuels seemed to be approachable.

3. Finally, alternative fuels were attractive on a strict conservationist basis: joining the least amount of the most efficient fuel to the appropriate purpose. Methanol, for example, had long been championed as a more efficient internal combustion engine fuel than gasoline.

The movement toward alternative fuel development reached a climax at the end of the 1970s, when the federal government's interest in alcohol and other synthetic fuels was spurred by the Iranian fuel crisis of 1978-79 and the grain embargo against the U.S.S.R. in late 1979.

Why Alternative Fuels for Buses?

The main thrust in the development of alternative fuels in the 1970s was directed toward transportation fuels in general, and automotive fuels in particular. States, corporations and even the federal government sponsored automotive tests and marketing aids (e.g., fuel tax abatements) for ethanol and methanol blends. Brazil pledged itself in the late 1970s to convert its automotive fleet to 100 percent alcohol by the 21st century. This policy gave U.S. researchers, fuel developers and government energy policy officials alike an enthusiasm and optimism about the likelihood of developing a major alternative fuel industry in the U.S. to meet automotive needs. The reasons for this emphasis were obvious: automobiles dominate all other forms of U.S. transportation, while transportation is the single largest consuming sector of energy (re: oil) products in the nation.

At the same time, however, other modes of transportation spurred interest in alternative fuel development. Alcohols for tractor, truck and train utilization have been studied and tested. These three modes dominate U.S. transportation consumption of diesel fuels, and throughout the 1970s all three experienced dramatic fuel cost increases and interim supply problems of extremely serious nature.

Buses, on the other hand, are relatively small consumers of U.S. diesel fuel supplies (currently, for example, transit buses consume approximately one-thirtieth the amount of fuel that heavy trucks use annually). As a consequence, alternative fuel development interests in the bus and, in particular, the transit bus mode were not of major significance in the U.S. In other nations, however (especially India and Brazil), where transit plays a larger role in personal transport, bus fuel alternatives have been researched to a larger extent.

Despite the lack of emphasis placed on alternative fuel development for transit buses in the U.S., the objectives of such research compared to overall alternative fuel development efforts are very similar. That is:

1. Can a fuel be developed to serve as a permanent or emergency diesel replacement fuel in the event of shortages brought on by oil supply disruptions?* The issue is particularly crucial for transit, since public transportation would be expected to at least maintain and possibly expand services during a disruption, in order to provide basic urban mobility needs at a time when automobile use may be severely restricted. Service maintenance or expansion can only be achieved, however, if the fuel is readily available.

2. Is there a more environmentally sound fuel than diesel fuel which, although not a significant producer of carbon monoxide, is a highly visible source of particulates and sulfur dioxide emissions? (To such an extent that many transit systems resist switching from diesel fuel #1 to cheaper, yet higher polluting diesel fuel #2.

3. Is there a more economical fuel, especially in terms of the effects upon engine wear and maintenance?

4. Finally, is there a more efficient fuel for transit-type operations (i.e., stop and go travel; continual use throughout the day; variable loads)?

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/demand picture. Spurred by the major increases in worldwide oil prices in 1979-80 and the deregulation of U.S. oil prices in 1981, worldwide production soared while consumption dropped. The result was an oil glut, beginning in Spring 1981 and extending to this day, which has brought with it a lowering in oil prices and a diminishing of the pricing and production influence of OPEC. U.S. oil production in 1982 was at its highest level in years. Suddenly, the urgency in alternative fuel development seemed to diminish and the boundary of economic competitiveness seemed further away. Interest in synthetic fuels by the federal government, in particular, decreased.

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*Another objective which has been proposed at times is to develop a non-petroleum based substitute fuel in the event of eventual depletion of oil supplies. Such an objective is not pertinent to transit systems, however, for two reasons. First, the time of any possible worldwide oil depletion is removed from any near- or long-term consideration [i.e., one source indicates that proven oil resources, which are only 33 to 50 percent of recoverable oil resources, are available at least through the early 21st century (1)]. Second, the issue of oil depletion is such a large, encompassing one that dwarfs investigation of alternative fuel development for such a negligible user of petroleum products as transit systems.

Beyond 1985, the world is expected to increase oil consumption, and, at the same time, OPEC is expected to regain significance as a determinator of oil prices and supply. That would once again set up a situation ripe for oil price increases and supply disruptions. However, U.S. and other nations appear better and differently prepared to handle future disruptions, utilizing major petroleum storage reserves, international fuel sharing and, at least in the U.S., marketplace mechanisms. All are intended to reduce the magnitude and duration of future disruptions, and return normal modes of international fuel trading as quickly as possible. Thus, energy independence is a lesser national and international goal of the 1980s and beyond, although reduced vulnerability and reduced uncertainty remain as important objectives.

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

- Contingencies may still occur and while 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 its basic public services, while b) not having the financial means available to afford to do so;

- Environmental concerns persist and extend beyond the concerns of energy utilization;

- Transit systems face a further federal financial constriction, that of diminished operating subsidies. Therefore, there is greater pressure for improved productivity both from the services standpoint (e.g., articulated buses) and maintenance standpoint. The coordination of improved productivity with an overall more economic 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 bus alternatives can generally be classified as liquid and gaseous fuels. Liquid fuels include alcohols (namely methanol and ethanol) and vegetable oils. Gaseous fuels include methane, hydrogen and other miscellaneous gases (e.g., ammonia, producer gas). Liquids can be viewed as either diesel fuel extenders or diesel fuel substitutes. Gases can be viewed only as diesel fuel substitutes. Some fuels require minor adjustments to current bus diesel fuel engines while others require major modifications or else complete engine redesign.

Objectives of this Research

This study of alternative fuels for buses utilizes existing research findings found in the literature to answer three general question areas, which are discussed below:

1. Likelihood of near-term development - Are there alternative fuels available for near-term (within the 1980s) development which are likely to:

   a. provide transit system fuel security in light of future oil disruptions;

   b. improve air quality;

   c. result in lower operating costs; and/or

   d. be a more efficient/powerful urban transit fuel?

   If near-term development is unlikely, what about long-term (by the year 2000) development?

2. Key development factors - How important are these factors in achieving near-term or long-term developments:

   a. economies of fuel/engine production;

   b. size of the transit market; and

   c. transit vehicle replacement costs and schedule?

3. Lead development role - If near-term or long-term development is feasible, who should take the lead role in development:

   a. federal government;

   b. state government;

   c. transit systems;

   d. fuel producers; or

   e. engine/bus producers?

The literature consulted includes research not only in the area of bus-related developments but other diesel engine developments as well.

Organization of the Report

Chapter II summarizes state-of-the-art knowledge about various alternative fuels. This information includes a) a description of the fuels, b) a description of necessary engine/bus changes, c) present and potential market for the fuels, d) environmental consequences, and e) economics of production and marketing. The conclusion of the chapter judges near-term and long-term development feasibility.

Chapter III draws upon the near-term/long-term development evaluation and specifically addresses it to a) transit fuel security objectives, b) urban air quality concerns, c) transit operating costs and d) better transit efficiency.

Chapter IV then asks whether developments should indeed be pushed and if so what are the consequential factors involved: a) economics of development, b) market size, c) transit replacement and d) lead agency.

Notes to Chapter I

1. International Energy Agency, World Energy Outlook, Paris, 1982, p. 203.

CHAPTER II

ALTERNATIVE FUELS FOR TRANSIT BUSES: STATE-OF THE-ART REVIEW

Introduction

When Rudolph Diesel patented the diesel cycle in 1892, he presumed that any fuel would be suitable for an engine operating in the manner he detailed (1). Indeed, high-speed diesel engines of the current type used to power transit buses impose only a few minimum requirements on the fuel. Over the years, however, diesel engines have been fueled most effectively with the liquid petroleum fuel known as diesel fuel.

In determining the possible effectiveness of diesel fuel alternatives, the following considerations are addressed:

1. Does the alternative fuel meet minimum diesel engine requirements?

2. If not, what engine or fuel changes are necessary?

3. What are the environmental consequences of utilizing the alternative fuel and its possible engine/fuel adaptations?

4. Are there other impacts of alternative fuel/engine adapted utilization?

Following a determination of effectiveness is an evaluation of the near-term or long-term developmental feasibility of the alternative fuel. This evaluation includes these following points:

1. Economics of fuel production/marketing;

2. Market demand for fuel/engine adaptation;

3. Other interest in development potential.

The determination of effectiveness and developmental feasibility is done for two subsets of alternative fuels: liquid and gaseous fuels.

Liquid Fuels: Alcohols

A. Effectiveness

There is probably more published research on alcohol fuels than any other alternative fuel type. Among the most notable and accessible examples include generalized discussions of alcohols as transportation fuels (1, 2, 3); specific evaluations of alcohols as diesel fuel substitutes (4, 5, 6, 7); and the economic and policy issues related to alcohol fuel development (8, 9). Alcohols are comprised of 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 there are serious problems to consider. They are the following.

1. Energy content of alcohols vs. diesel fuel;

2. Cetane quality of alcohols vs. diesel fuel;

3. Compatibility of alcohols with diesel engine materials;

4. Alcohol fuel emissions.

These are discussed below.

1. Energy Content. Table II.1 lists many of the characteristics of diesel fuels and two of the most important alcohol fuels: ethanol and methanol. The net heating values (by volume) reveal that the BTU content of ethanol and methanol are 60 and 45 percent of that of diesel fuel, respectively. This means that a) buses equipped with equal amounts of diesel fuel vs. alcohols will be able to operate for greater periods of use, or to put it another way, b) buses equipped with alcohol fuels will need to carry larger amounts of fuel in order to operate for a comparable period of use as diesel powered buses. The typical 100 gallon fuel tank in buses would either have to be expended or supplemented with an additional tank, or else fueling procedures changed (i.e., multiple fuel fill-ups during the day). Assuming, for example, that tank expansion would be the plan followed, then the size of that increase is shown in Table II.2.

2. Cetane Quality. This is the key concern, requiring one of many possible engine modifications. For diesel engines, where the fuel must ignite on compression, ignition quality of a particular fuel is measured by the cetane number of the fuel. Simply put, cetane number is a measure of ignition delay, or the time between fuel injection into the combustion chamber and the fuel's ignition. The minimum cetane number established by many of the world's diesel engine manufacturers is 40. Present day diesel fuels range from 40 to 60 and are primarily found within the tighter range of 45-50. 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 zero to eight.

There are many proposed solutions to the poor cetane quality issue. Some involve fuel additives: castor oil, nitrated compounds, etc. Figure II.1 shows what happens to alcohol cetane level when cyclohexyl nitrate is added in varying amounts. Others recommend operation of alcohols only as a blend with diesel fuel, although any-

TABLE II.1

PROPERTIES OF ALCOHOLS AND OTHER FUELS

CHARACTERISTIC	GASOLINE	NO. 1 DIESEL FUEL	NO. 2 DIESEL FUEL	ETHANOL	METHANOL	GASOHOL
CHEMISTRY	MIXTURE OF HYDROCARBONS	MIXTURE OF HYDROCARBONS	MIXTURE OF HYDROCARBONS	C_2H_5OH	CH_3OH	90% UNLEADED GASOLINE 10% ETHANOL
Approx. Specific Gravity @ 60°F	.72 - .75	.82	.85	.79	.79	.73 - .76
Boiling Point						
°F	85 - 437	360 - 530	375 - 630	173	149	77 - 410
°C	30 - 225	190 - 280	210 - 325	78.3	65	25 - 210
Net Heating Value (Mass)						
BTU/lb	18,700	18,500	18,400	11,600	8,600	18,000
MJ/kg	43.5	43	43	27	20.1	41.9
Net Heating Value (Volume)						
BTU/gal	117,000	126,000	130,000	76,000	57,000	112,900
MJ/1	32	35.3	36.6	21.3	15.9	30.9
Heat of Vaporization	170	250	250	390	500	200
kJ/kg	400	600	600	900	1,110	465
Vapor Pressure @ 100°F						
psi	9 - 13	.05	.04	2.5	4.6	8 - 16
kPa	62 - 90	.34	.27	17	32	55 - 110
Octane Number						
Research	91 - 100	Note 1	Note 1	111	112	Note 2
Motor	82 - 92			92	91	
Cetane Number	Below 15	40 - 60	40 - 60	Below 15	Below 15	Below 15
Stoichiometric A/F Ratio	14.6	14.6	14.6	9	6.4	14
Vapor Flammability Limits, % by Volume	.6 - 8	.6 - 6.5	.6 - 6.5	3.5 - 15	5.5 - 26	Note 3
Viscosity @ 40°C						
Centipoise	.5	1.45	2.41	.83	.46	.5
Centistokes	.6	1.75	2.79	1.1	.58	.6
Appearance	Colorless to light amber color	Colorless to light amber color	Light amber color	Colorless	Colorless	Colorless to light amber color
Vapor Toxicity	Moderate irritant. Extreme concentration causes narcosis.			Irritant toxic only in large doses.	Irritant cumulative toxicant. Causes narcosis.	Moderate irritant. Extreme concentration causes narcosis.

Note 1. Not applicable.
Note 2. May be the same as gasoline, or add 1.5 or 2 numbers depending on blending practice.
Note 3. Values not published.

Source: Alternative Fuels Committee of the Engine Manufacturers Association, "A Technical Assessment of Alcohol Fuels," SAE Technical Paper 820261, February 22-26, 1982.

TABLE II.2

FUEL AND TANK REQUIREMENTS

IF SUBSTITUTING DIESEL FUEL OPERATION

WITH AN ENERGY EQUIVALENT AMOUNT OF ALCOHOL FUELS

AND ASSUMING SINGLE TANK

	% Increase in Diesel Fuel Characteristics Due to the Use of the Following Alcohols:	
	Ethanol	Methanol
Fuel Weight	+57%	+102%
Tank Volume	+60%	+107%
Tank Spherical Diameter	+19%	+31%
Estimated Tank Weight	+46%	+92%
Fuel Plus Tank Weight	+57%	+101%

Source: Data from University of Miami and Escher Technology Associates, Alternative Fuels and Intercity Trucking, prepared for USDOE, Miami, June 1978.

thing greater than a 10 percent blend of alcohol is likely to reduce cetane level below manufacturers' specification (see Figure II.2). Finally, others recommend engine modifications. In a recent report, five options to adapt U.S. bus diesel engines for methanol operation were analyzed (10). These included the following:

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

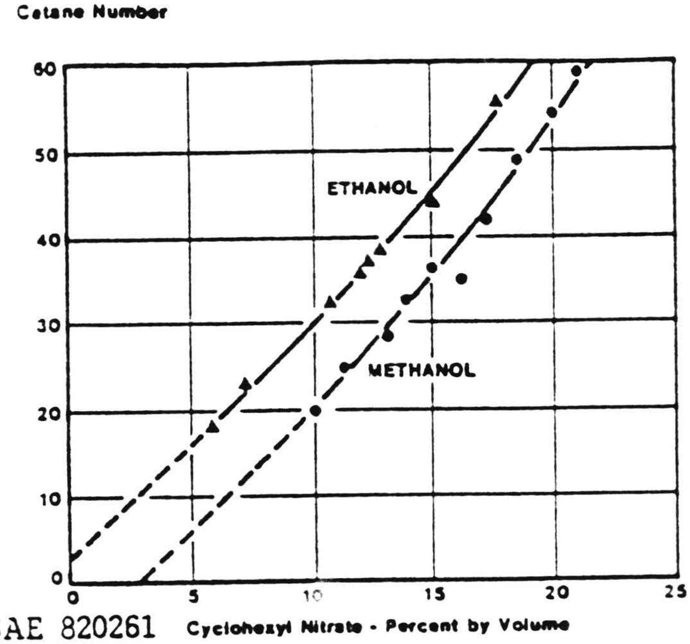
The option chosen as most promising was the surface ignition option: use of glow plugs in the combustion chamber provide a hot surface, vaporizing and igniting methanol shortly after injection. The use of these glow plugs may be conserved for cold starts and during the warm-up period.

3. Compatibility with Diesel Engine and Vehicle Materials. Diesel engines and diesel fuel are naturally compatible. Alcohols, on the other hands, could cause accelerated wear of diesel fuel systems and engine components (11). This is especially true if fuel additives are used: all nitrate compounds are particularly corrosive and, prolonged castor oil use can clog fuel injector tips (12). In European experiences, methanol rapidly diluated crankcase oil, requiring more frequent oil changes (13). Furthermore, methanol corrodes some materials contained in on-board 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.

In summary, as one source puts it:

> "Using alcohol fuels in vehicles designed for gasoline or diesel fuel will result in small and usually manageable materials compatibility problems. However, in some cases the effects could be drastic enough to cause massive failure of major parts. Each particular conversion will have its own specific problems and solutions (14).

4. Alcohol Fuel Emissions. Using a Volvo constructed diesel engine operated under transit bus test conditions (although in a laboratory setting), hydrocarbon and carbon monoxide emission levels were higher, while nitrous oxide and particulates were lower for both ethanol and methanol, as Table II.3 shows. 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

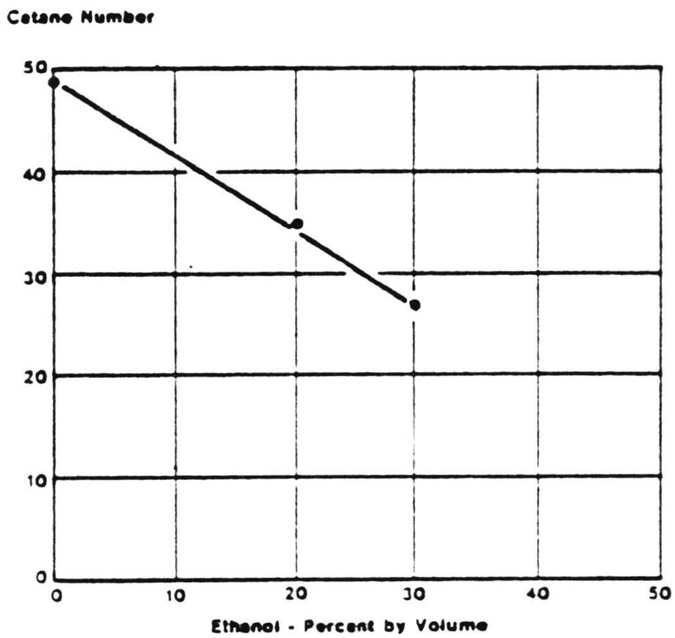


Source: SAE 820261

Figure II.1

EFFECT OF FUEL ADDITIVE CYCLOHEXYL NITRATE

ON ALCOHOL CETANE LEVEL



Source SAE 820261

Figure II.2

EFFECT OF ETHANOL/DIESEL FUEL BLEND

ON CETANE LEVEL

TABLE II.3

EMISSIONS FROM VOLVO DIESEL ENGINE

OPERATED IN TEST BUS OPERATIONS

Pollutant	Diesel Fuel Emissions*	% Change in Emissions When Fueled By: Ethanol Fuel	Methanol Fuel**
Hydrocarbon	1.00	+119%	+46%
Carbon Monoxide	3.42	+428%	+457%
Nitrogen Oxides	9.28	-35%	-32%
Patriculates	0.62	-27%	-27%

*Grams per horsepower-hour
**As the text explains, other tests show less dramatic carbon monoxide increases for methanol use, even suggesting that decreases may occur.

Source: Terry Ullman and Charles Hare, Emission Characterization of an Alcohol/Diesel Pilot Fueled Compression-Ignition Engine and its Heavy Duty Diesel Counterpart, prepared for U.S. EPA, San Antonio, August 1981.

smog, while carbon monoxide emissions vary considerably from test to test, due to the relative leanness or richness of the fuel-air mixture (15).

Besides these emissions (which are regulated by the Federal government), other relevant emissions include smoke (essentially non-existent for alcohol fuels) and aldehydes. These emissions (particularly formaldehyde from methanol) are considerably higher for alcohols than for diesel fuel (16).

B. Developmental Potential

1. Economics of Fuel Production/Marketing. Currently, diesel fuel prices 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, while methanol is about 30 percent less than the diesel fuel price (17). Clearly, methanol is the more cost-effective alcohol option, based strictly on price of fuel. Methanol costs even show signs of declining to a level nearly half that of diesel fuel.

2. Market Demand. Alcohols, in particular ethanol, have established a minor foothold in the U.S. transportation sector, primarily as a blend with gasoline, Currently nearly 10 percent of all the gasoline is the U.S. contains either ethanol or methanol (primarily the former) (18). Both, however, are primarily used for industrial purposes. Methanol, for example, is produced at a rate of over 1 billion gallons annually; in 1980 (the most recent year for which data is available), 95 percent was used as a chemical precursor for industry; 3 percent as a gasoline octane booster; and 2 percent as a direct fuel (19).

There is considerable interest among diverse transportation providers in a) alcohol fuels as diesel fuel substitutes and blending agents and b) appropriately matched diesel engines to accomodate the special characteristics of alcohols, in particular the low cetane number. These providers include the intercity trucking industry, the railroad industry, the farming community and, of course, the public transportation sector. The following excerpts from recent reports reflect the concern, however, that while potentially attractive, alcohols may not be likely diesel fuel substitutes:

> "If ethyl alcohol (ethanol) is blended with diesel fuel [in diesel-powered farm tractors], it will reduce engine power output, increase fuel consumption per unit of work, delay combustion, and increase engine delay (20)."

> "A representative of the Association of American Railroads told us that methanol can be used as an extender mixed with diesel fuel, but it introduced technical problems for locomotives (21)." (In particular, methanol use would require either a considerably larger locomotive fuel tank or more frequent refueling.)

On the other hand:

> "Ethanol must be considered a valid contender as an alternative fuel for intercity trucking. ... [Methanol] might thus also be considered a candidate for a given 'minority' transportation sector such as intercity trucking (22)."

3. Other Interest in Development. As Chapter I stated, 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). Whereas federal involvement has declined, state interest remains strong, particularly in agricultural states and some states with significant alternative energy programs and concerns (e.g., 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.

Liquid Fuels: Vegetable Oils

A. Effectiveness

Vegetable oils lend themselves particularly 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
- Sunflower

as well as others. Most experimental research conducted in the last few years to determine the fuel opportunities 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, while others are important for these fuels too. The following sections discuss:

1. Energy content of vegetable oils vs. diesel fuel
2. Cetane quality of vegetable oils vs. diesel fuel
3. Cold weather performance of vegetable oils
4. Engine compatibility
5. Emissions

1. 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 the BTU content of diesel fuel (23, 24). As a result, the fuel volume and associated fuel tank requirements are not much greater than those of diesel fuel, as Table II.4 indicates.

2. Cetane Quality. Also unlike alcohols, cetane levels of vegetable oils are much closer to those of diesel fuel, as Table II.5 indicates. In fact, cottonseed oil exceeds diesel fuel cetane quality produced via the transesterification process (i.e., lowering the viscosity of the oil).

3. Cold Weather Performance. Vegetable oils have relatively high cloud and pour points, indicating potential difficulties with cold weather operations (i.e., fuel flow will be irregular and slow). In fact, 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, as Table II.6 indicates.

As one source puts it:

> "Cold temperature operation is a very critical issue related to sunflower oil and blends thereof. High viscosity can cause fuel system problems, failed starting, unacceptable emission level, injection pump failures due to lack of lubrication (25)."

4. Engine Compatibility. Engine durability is a key issue in the use of vegetable oil-based fuels in diesel engines. There is an increased propensity for oils to leave behind carbon deposits after only short periods of operations. As considerable and fast growing as these deposits can be, they do tend to be blown off to some extent during engine operation (26). Deposits in the piston and the cylinder liner area are more stubborn, however, (and considerably more than either diesel or alcohol fuels produce) due to a) the oiliness of the fuel and b) the large droplet size characterizing vegetable oils (27). Research reports do point out, however, that deposits would vary among diesel engine designs (no transit-type engines have been tested) and that processes which lower oil viscosity can reduce (but not eliminate the deposit problem.

5. Emissions. Relatively sparse data on cottonseed/diesel fuel blends and 100 percent, low viscosity cottonseed oil indicate little difference between carbon monoxide, hydrocarbon, nitrous oxide and smoke emissions of these fuels and straight diesel fuel (28). What differences exist are not significant.

TABLE II.4
FUEL AND TANK REQUIREMENTS IF SUBSTITUTING DIESEL FUEL OPERATION WITH AN ENERGY EQUIVALENT AMOUNT OF COTTONSEED OIL AND ASSUMING SINGLE TANK

	% Increase Over Diesel Fuel Characteristics Due to the Use of Cottonseed Oil
Fuel Weight	+12%
Tank Volume	+ 9%
Tank Spherical Diameter	+ 3%
Estimated Tank Weight	0%
Fuel Plus Tank Weight	+11%

Source: Data From University of Miami and Escher Technology Associates, Alternative Fuels and Intercity Trucking, prepared for USDOE, Miami, June 1978 and E.F. Fort, et. al, "Evaluation of Cottonseed Oils as Diesel Fuel," SAE Technical Paper 820317, February 1982.

TABLE II.5

CETANE NUMBERS FOR VARIOUS VEGETABLE OILS

OIL	CETANE NUMBER
Corn	34
Cottonseed	52
Peanut	39
Soybean	42
Sunflower	31

Source: Southwest Research Institute, Emergency Fuels Utilization Guidebook, prepared for USDOE, San Antonio, August 1980 and E.F. Fort, et. al., "Evaulation of Cottonseed oils as Diesel Fuel," SAE Technical Paper 820317, February 1982.

TABLE II.6

COLD START FINDINGS FOR SUNFLOWER OIL/DIESEL FUEL BLEND VS. DIESEL FUEL

AMBIENT TEMP. °C		TIME TO FIRST FIRING, sec	TOTAL CRANKING TIME, sec	TOTAL ACCEL. TIME TO 2000 rpm, sec
-1°C	#2D fuel	1	3	4
	50/50 blend	10	43	47
-7°C	#2D fuel	6	14	18
	50/50 blend	29	50	52

Source: Rodica A. Baranescu and Joseph J. Lusco, "Sunflower Oil as a Fuel Extender in Direct Injection Turbo Charged Diesel Engines," SAE Technical Paper 820260, February 1982.

B. Developmental Potential

1. Economices of Fuel Production/Marketing. Vegetable oils are considerably more expensive than diesel fuel, with cottonseed oil, for example, costing approximately $2.25 per gallon in early 1984 (29). Other oils are similarly priced, although prices do vary considerably depending on the annual availability of feedstock agricultural products. Peanut oil, for example, sold in early 1984 at a price which is 52 percent higher than cottonseed oil, due primarily to recent poor peanut crops.

2. Market Demand. Vegetable oils are not used for fuels in the United States at the current time. They are used primarily for edible purposes: baking or frying fats, margarine, and salad or cooking oil. In 1983, nearly 2 billion pounds (or approximately 257 million gallons) of oils were used for edible purposes (30). There are also other uses in industry. Some oils are exported in substantial amounts, including cottonseed and peanut oils.

3. Other Interest in Development. The United States Department of Energy had stated that:

> "availability of [vegetable oils] in quantities to satisfy even emergency [vehicle] fleet appetites is questionable (31)."

It does point out though that such oils may be available, however, on a highly localized basis. But is is clear that other than for edible and a few established industrial purposes, there is no significant interest in developing vegetable oils for fuel related purposes.

Gaseous Fuels: Methane

A. Effectiveness

Methane, or CH_4, is the prime ingredient of natural gas. Typically, 95 percent of natural gas is made up of methane (and thus in any discussion of methane as a transportation fuel, natural gas can be considered interchangeable). When used as a transportation fuel, methane is not 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 2500-3000 psi) or as a cryogenic liquid (cooled to -260° Farenheit). The issues related to methane use as a specific diesel engine fuel are:

1. Energy content
2. Cetane quality
3. Safety

1. Energy Content. On a pound for pound comparison, methane has slightly more energy content, measured in BTU, than diesel fuel (32). However, when stored on board a vehicle as a cryogenic liquid, the fuel volume and associated fuel tank requirement are larger than those of diesel fuel, as Table II.7 shows.

2. Cetane Quality. Methane has an extremely low cetane number, corresponding to the fact that the octane quality of methane is among the highest among 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. Testing has been preliminary and only in laboratory settings (and rarely on transit type diesel engines), but results have shown methane performance to be more than adequate, with one source calling the diesel fuel/methane fumingation option the most suitable alternative fuel (including, in its comparison, alcohol fuels) and another referring to glow plugs (and other options) as workable conversions of high-speed diesel engines (33). Indeed, in testing various ignition aides on a Detroit Diesel-Allison (DDA) 71 diesel engine, the same engine used in most transit buses today, it was found that methane use in engines produced easy starts, good idling and smooth runs through the full power and speed ranges (34).

3. Fueling. Methane fueling of vehicles (in its compressed gaseous form) is a complex process, accomplished by either of two methods: a) Fast Fill, where filling is done within five minutes, but at very high pressures and utilizing elaborate (and expensive) facilities, or b) Time Fill, where filling generally takes half a day, but at lower pressures and with far less ancillary equipment needed (34a).

4. Safety. The safety issues related to methane vehicle use are significant and remain unresolved. United States vehicular use of methane is too limited to reveal safety problems and concerns and the successful automotive use of compressed methane gas in Italy is not directly transferrable because of differences in storage cylinder designs, safety devices and administrative procedures (35). 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. [Liquid methane is generally stored at between 5 to 60 psig (per square inch/gram) while compressed methane is stored at 2400 psi (per square inch).] Crashworthiness has other related hazards, including fuel release upon impact and tank rupture due to fire. There are currently no industry-wide standards regarding design, manufacture, installation and performance of compressed methane gas fuel systems (36).

TABLE II.7

FUEL AND TANK REQUIREMENTS IF SUBSTITUTING DIESEL FUEL OPERATION WITH ENERGY EQUIVALENT AMOUNT OF CRYOGENIC METHANE AND ASSUMING SINGLE TANK

	% Increase Over Diesel Fuel Characteristics Due to the Use of Cryogenic Methane
Fuel weight	-14%
Tank volume	+66%
Tank spherical diameter	+31%
Estimated tank weight	+76%
Fuel plus tank weight	+14%

Source: Data from University of Miami and Escher Technology Associates, Alternative Fuels and Intercity Trucking, June 1978.

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 (37). The one hydrocarbon which greatly increased in emissions was, naturally enough, methane, which is non-reactive (38). Methane will also reduce significantly diesel fuel-related smoke emissions.

B. Developmental Potential

1. Economics of Fuel Production/Marketing. Methane gas currently sells for between \$3.50 (for electric utility purchases) and \$6.00 (for residential purchasers) per thousand cubic feet (39). 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 world-wide 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 impacts of these sources is uncertain since alternative methane production techniques and sources have neither been marketed or tested.

2. Market Demand. Methane is used for two main purposes: a) as a natural gas component, it is used for its heating value by the residental, 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.

3. 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 a) of its ability to reduce oil imports, b) of its ability to reduce vehicle emissions and c) to develop alternative market uses for methane from natural gas and other sources. This Act, however, has not been funded by Congress. Nevertheless, the United States Department of Energy has performed a state-of-the-art assessment of methane-fueled vehicles and is likely to conduct further research in these three areas:

a. Engine testing is needed to clearly define the limits of efficiency, emissions, and performance of natural gas vehicles, and development of practical conversion systems for diesel engine vehicles. In addition, fundamental work on high-energy-density gas storage systems should be encouraged.

b. A test program to determine 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.

c. Assessments need to be made of institutional barriers to natural gas use in vehicles and of the means to overcome those barriers (39a).

Gaseous Fuels: Hydrogen

A. 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: 1) it provides the highest energy conversion efficiency obtainable, 2) it burns relatively clean, with no emissions of carbon monoxide, hydrocarbons, smoke or odors, and 3) it can be produced from water. Currently, hydrogen has been used in a very limited manner, both as a transportation and an overall fuel (its primary use is as an industrial feedstock.) It has had a few significant applications in the area of transit systems; in particular, the testing of a hydrogen-powered bus in Riverside, California in 1980 (see Figure II.3). That bus however, was not a typical transit vehicle. It was a 21-passenger Winnebago Minibus, originally equipped with a heavy duty truck gasoline engine (40). (Hydrogen's high octane value makes it a good gasoline substitute.) The gasoline carburetor was removed and replaced by a gaseous fuel carburation device. Although the Riverside test is not directly applicable to most current transit operation, there were interesting aspects and results of the operation are worth reporting. First of all, the hydrogen fuel was stored on board the vehicle as a metal hydride. While this methodology had its problems, (i.e., in order to release the hydrogen the metal hydride was heated; that process then required considerable water and fan cooling) it is often considered the most promising means of hydrogen fuel storage. The other choices for hydrogen storage include a) hydrogen stored as a high-pressure gas, b) chemical fuels synthesized from hydrogen (e.g., ammonia and hydrazine) and c) hydrogen stored as a cryogenic liquid (41). Metal hydrides are considered the best option because of fewer handling problems and lesser safety concerns (42). Currently, however, because of the significant weight of metal hydrides, a vehicle fueled in this manner has either of two choices: use of extremely heavy fuel tank or limited mileage range. In the Riverside test, for example, the latter choice was made and most test runs were no longer than 60 miles before refueling was necessary (43). Table II.8 indicates the different fuel tank requirements of current metal hydrides, cryogenic hydrogen, ammonia and hydrazine. Clearly major advances in metal hydride storage need to be made before widespread vehicular use can be envisioned.

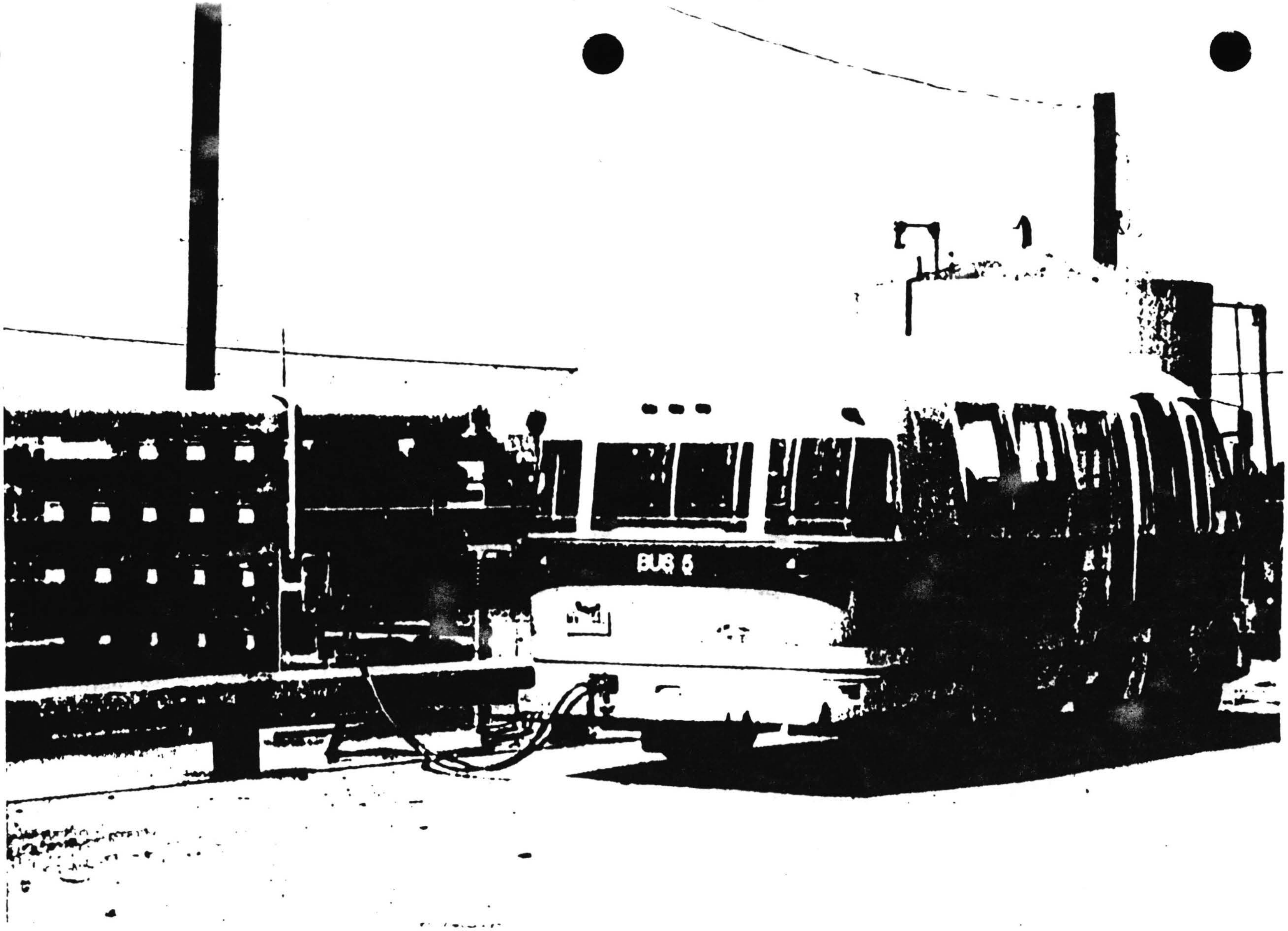


FIGURE II.3

HYDROGEN POWERED TRANSIT BUS IN RIVERSIDE, CALIFORNIA (in 1980)

TABLE II.8

FUEL AND TANK REQUIREMENTS IF SUBSTITUTING DIESEL FUEL OPERATION WITH AN ENERGY EQUIVALENT AMOUNT OF HYDROGEN (AND HYDROGEN DERIVATIVES) AND ASSUMING SINGLE TANK

	% Increase Over Diesel Fuel Characteristics Due to the Use of:			
	Metal Hydride*	Cryogenic Hydrogen	Hydrazine	Ammonia
Fuel Weight	-64%**	-64%	+349%	+131%
Tank Volume	+32%	+33%	+258%	+141%
Tank Spherical Diameter	+14%	+64%	+58%	+36%
Estimated Tank Weight	+6208%**	+439%	+500%	+285%
Fuel Plus Tank Weight	+4905%	-20%	+363%	+145%

* Magnesium Hydride used

** Hydrogen is only 6% by weight of magnesium hydride.

Source: University of Miami, and Escher Technology Associates, Alternative Fuels and Intercity Trucking, June, 1978.

Secondly, a number of problems were encountered with the Riverside test. In nearly 20 percent of the test runs, vehicle cold starting was very difficult (43a). Unusually high amounts of dirt and iron were found in the crankcase oil (44). Finally, carburetor flashback occurred often, damaging the carburetor diaphragm and causing a loud backfire-type sound (45). Altogether, these problems suggested that further improvements in hydrogen-fueled buses must be made before further testing in transit revenue service is carried out (46).

The other significant ongoing research effort in hydrogen fueled vehicles does concern diesel applications, although primarily in the railroad sector (47). (See Figure II.4.) 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, would require some type of fuel or engine ignition assistance.

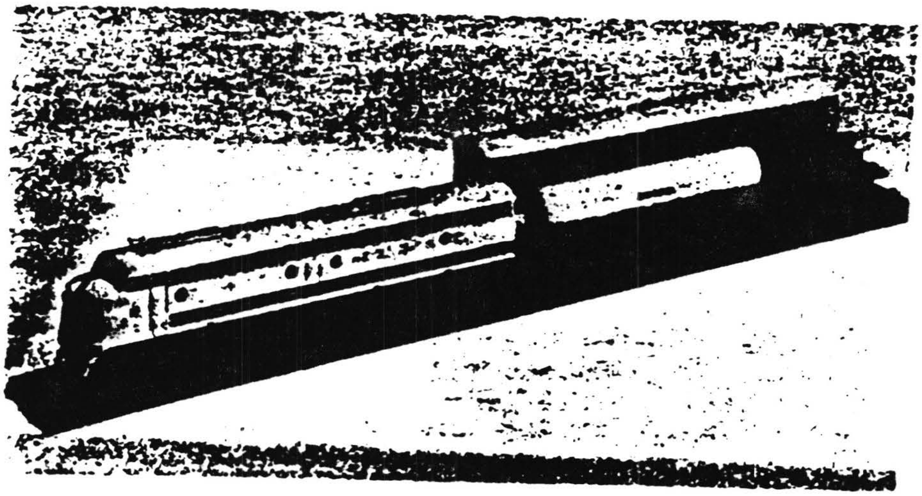
There are still many issues which need to be investigated in terms of hydrogen use in vehicles in general, and diesel-powered vehicles in particular. Safety is of major concern as are all aspects of fuel handling and distribution. Because of the current status of hydrogen fuel research, at least two recent studies rank the possible use of hydrogen fuel as a diesel fuel substitute before the 21st century as extremely unlikely (48).

B. Development Potential

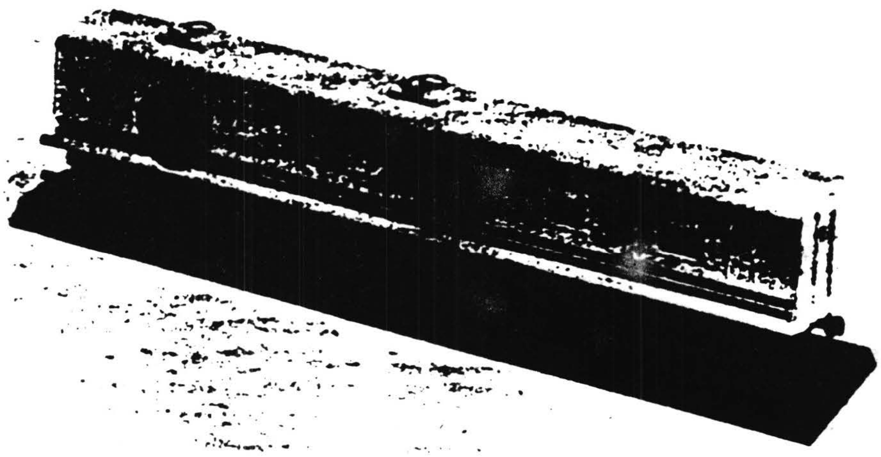
1. Economics of Fuel Production/Marketing. The iron titanium used in the Riverside bus test sells for approximately $13 per pound (49). The less heavy magnesium hydride sells for twice that amount, $26 per pound (50). Liquid hydrogen would cost considerably less: depending on the source of production, 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) made from water via electrolysis (51). Currently, hydrogen is produced from two main sources: methane (i.e., natural gas) and petroleum (in about a 73%/27% split) (52). Electrolysis from water currently produces less than one percent of current hydrogen needs.

2. Market Demand. About half the hydrogen produced in the United States is used by the petroleum and chemical industries; another 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 NASA's needs) (53). Metal hydrides are primarily used by the petroleum industry in the refinery process (54).

3. Other Interest in Development. In 1980, Congress identified the following potential uses for hydrogen in the future:



HYDROGEN RAILROAD DEMONSTRATION CONFIGURATION



DEMONSTRATION CAR (TOP OFF)

FIGURE II.4

EXPERIMENTAL DESIGN OF HYDROGEN FUELED LOCOMOTIVES

a. Mixing hydrogen with natural gas to expand natural gas resources;

b. 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;

c. Hydrogen fuel cells for electricity generation (and other uses as well); and

d. Greater use in ammonia production (55).

Despite finding that the prospects for near-term adoption of hydrogen as a fuel are low, the National Research Council recommended the need for a well conceived R & D program, guided by the following principles:

a. Basic exploratory research should be pursued on innovative concepts for hydrogen production, transmission, storage, and utilization through the laboratory demonstration stages. Such research should be pursued even if near-term market needs cannot be identified.

b. The federal program should include R & D elements designed to create a national data base of sufficient depth and quality that sound evaluations can be made of program alternatives in the future selection of coherent and timely development and demonstration programs.

c. The federal program should defer large-scale system development and demonstration activities aimed at hydrogen production until a market need of significant magnitude is clearly identified and it is established that the timing or risks make it unlikely that the private sector will undertake these R & D phases.

d. The architects of hydrogen R & D programs should remain alert to developments in application areas that might enhance the need for hydrogen, and thus accelerate consideration of development and demonstration programs for production, transmission, and storage systems.

e. Program priority should be given to exploratory research on concepts that hold promise of significantly reducing hydrogen production costs, particularly for coal/hydrogen systems where the cost reductions could also benefit synthetic fuel costs.

f. Research should be initiated on hydrogen/air fuel-cells suitable for transportation applications to provide an alternative to battery powered automobiles in the event that future hydrocarbon fuel limitations are encountered.

g. In addition to work on hydrogen production concepts, appropriate R & D should also be conducted on potential problems associated with the transmission and storage of hydrogen as a consumer fuel. Particular attention should be given to the identification and resolution of potential safety problems for all phases of the hydrogen chain from production to consumption. Such studies should be conducted in a timely fashion so as to contribute to the overall evaluation of the feasibility of proposed hydrogen systems (56).

Conclusions: Near-Term vs. Long-Term Development Potential

Five fuels have been identified as possible alternative fuels for bus transit systems: namely methanol, ethanol, vegetable oils, methane and hydrogen. All are in production at the current time, although it should be noted that only vegetable oils are being produced in any significant quantity in the United States from renewable resources (a small portion of ethanol, that which is used for 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. Alternative technologies for producing these fuels from alternative resources (e.g., agricultural products, coal, water, waste products, etc.) are not fully developed, nor are the economics. Thus, only vegetable oils can be considered an immediate alternative fuel for transit systems from the point of view of production. In the near-term however, ethanol would be a likely candidate, (the facilities, production and marketing capabilities of grain, corn and sugar alcohol production are well established) although not of major significance. Its production could be expanded without major problems to serve the needs of transit systems. Long-term candidates, from the point of view of fuel production and availability (from non-petroleum and non-natural gas resources), include methanol, methane and hydrogen.

From the point of view of usability in current bus vehicles, vegetable oils once again are the only fuel with immediate applications. All others would require significant changes to a) engine design (primarily through the use of glow or spark mechanisms), b) fuel storage and delivery (both from vehicle storage tank to the engine and from facility storage area to the vehicle), c) engine parts (particularly elastomers). In addition, further testing would have to be applied to establish appropriate blending percentages with diesel fuel (if that is the route chosen), necessary fuel additives, emissions, etc.; none of which have 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 would be considered likely near-term candidates for development of appropriate engine and fuel components, while methane would be a long-term candidate. Hydrogen's potential is far beyond the year 2000.

In summary, vegetable oils are the only fuel with immediate development potential; ethanol has near-term potential, while methanol has near-term potential of the end user point of view (i.e., transit systems) but only long-term potential from the production point of view; methane is a long-term potential fuel, while hydrogen is a post-20th century potential bus fuel.

Notes to Chapter II

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16. Ibid., II-12.

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CHAPTER III

EVALUATING ALTERNATIVE FUELS FOR TRANSIT BUSES FROM THE PERSPECTIVE OF FUEL RESEARCH OBJECTIVES

Four objectives for conducting alternative fuel research for transit buses were identified in Chapter I. They are as follows:

1. To provide protection of fuel supply during future oil supply disruptions.

2. To reduce the air quality impacts of diesel fuel.

3. To reduce transit system operating costs.

4. To utilize a more energy efficient fuel.

The fuels identified and evaluated in Chapter II are now evaluated against these objectives.

Alternative Fuels as Contingency Protection

Future oil supply disruptions are uncertain and unpredictable events. Will they occur and if so, when? How large will a disruption be and how long will it last? Will the United States Government attempt to intervene in a future disruption or will it let market conditions dominate? Will a disruption produce diesel fuel shortages for transit systems? Will the price of diesel fuel (and other relevant petroleum-based fuels) rise precipitously during a disruption?

These are only a subset of the questions related to disruptions. There are no set answers. There are only scenarios and policy positions. Scenarios say that the United States could face minor, moderate or major oil supply disruptions in the coming years. Minor scenarios would mean the loss of less than 7 percent of the free world's oil production (which, it should be pointed out, is considerably more than was lost during the 1978-1979 Iranian crisis). Moderate scenarios involve the loss of over 7 but no more than around 15 percent of the free world's oil production (the 1973 Arab Embargo crisis removed around 10 percent of the world's oil). Major scenarios involve over a 15 percent loss in free world production. Whereas the first two types of disruptions can legitimately be initiated by OPEC production quotas (given the proper demand/supply environment; i.e. not the current market), the major disruption is generally seen as a war scenario (most likely a major Middle East war involving Saudi Arabia). Scenarios further say that disruptions can last up to a year in length, although given the current oil supply and demand market (which is likely to endure for a few more years at least) shorter disruptions are far more likely. Finally, scenarios say something very important about the supply and price of petroleum products during a disruption. Either of two extreme conditions could occur given the current (and continued) absence of federal regulatory control over oil price and supply:

a. Prices could rise precipitously during a disruption to new equilibrium levels. [Some scenarists predict rises of around 80 percent, 180 percent and 370 percent during minor, moderate and major disruptions, respectively (1).] Given these price rises, though, shortages of petroleum products to consumers should not occur; i.e. those consumers who can afford the new prices should be able to purchase however much fuel they desire.

b. Prices will rise slowly and to low levels during a disruption because of contractural reasons as well as relatively conservative business practices on the part of the United States oil industry. Demand will not decline to any great extent, and as a result supply shortages will occur. Consumers, including transit systems, may face supplier-induced allocation of products (replacing the mandatory allocation system set up by the federal government in the 1970s).

Policy positions involve the role of the United States Government during future oil supply disruptions. At its current disposal, the federal government could a) release emergency crude oil supplies from the Strategic Petroleum Reserve (SPR), b) share fuel with other nations and c) respond to economic calamities caused by disruptions through such mechanisms as reductions in income tax withholding rates. Furthermore, the United States Government could respond to future disruptions with a host of actions which it currently does not have the authority to implement, including a) product rationing, b) import tax levies, c) price and supply controls, and d) block grants to states, etc. Currently most observors feel that likely policy positions in light of disruption scenarios are the following:

a. Minor disruption - The federal government will attempt to not intervene with any significant action. In the event of high prices, it may reduce income tax withholding rates. In the event of supply shortages, it may encourage states to allocate a very small portion of supplies to essential users or hardship cases.

b. Moderate disruption - The federal government will likely (though not certainly) use the SPR to lessen the effects of a disruption. It may participate in international fuel lending agreements, which may require some small level of domestic crude oil allocation or restraints on consumer product demand (e.g., weekend gasoline station closings). It will likely reduce tax withholding and/or initiate block grants to states.

c. <u>Major disruption</u> - The federal government will likely take <u>drastic actions</u>, including use of the SPR, international fuel trading, economic assistance to individuals and/or states, <u>and</u> other actions which reduce demand, control prices and <u>allocate</u> shortages.

How do alternative fuels fit into this setting of disruption scenarios and policy positions? <u>First of all, there are no reasonable combinations of scenarios and policy positions under which transit systems would face a full cutoff of diesel fuel supplies.</u> At worst, transit systems would face an allocated fuel supply, roughly equivalent to the size of the disruption (e.g., for a 10 percent loss in free world oil production, transit systems would receive 90 percent of their current diesel fuel requirements). Thus alternative fuels would serve here as blending agents, with diesel fuel still providing the bulk of the need. Vegetable oils would work in this role, but their utility is severely hampered by their availability. Using the earlier example, if all transit systems needed to supplement their diesel fuel supply by 10 percent, this would require nearly one fifth of the current amount of available vegetable oil, by all reckonings a significant amount. Therefore, vegetable oils could only serve as a contingency supply supplement on a limited, spot basis. Ethanol and methanol could also work as supplementary contingency fuels, but only if disruptions occurred in the near-term and long-term, respectively. Prior to that, diesel engine compatibility could be a problem, but more importantly, ethanol and methanol would still be tied to petroleum resources and therefore subject to similar shortages as diesel fuel. Methane and hydrogen could not serve as likely contingency supplement fuels because of the inability of instituting blending operations.

Secondly, if there were no shortages but instead there were significant price increases, a somewhat similar evaluation occurs. In this setting, transit systems would not need vegetable oil supplies but might find them financially desirable during moderate or major disruptions, when the price of diesel fuel would likely exceed that of vegetable oils. But under such scenarios, vegetable oils would not be available to any great extent as to make any significant economic difference (once again, their availability on a limited, spot basis might prove worthwhile for some transit systems). Ethanol and methanol would be likely contingency fuel candidates but only in the near-term: ethanol, because only in the near-term would sufficient supplies be available from non-petroleum supplies (otherwise ethanol prices will rise in line with other oil products, maintaining their price margin above diesel fuel) and methanol because only in the near-term would end-user systems be available (since methanol is less expensive than diesel fuel it could serve as a near-term contingency fuel despite its petroleum basis because the price differential would likely remain the same). Once again, methane and hydrogen would not be adequate contingency fuels in the high-price/constant supply scenario.

Since price and supply conditions during a disruption would not operate in a vacuum from policy positions, the feasibility of alternative fuels would be subject to the following events:

- o If state governments allocate fuels to essential users (via a system commonly known as the set-aside program), transit sytems will likely get all required diesel fuel supplies. In this case, alternative fuels would not play a role. However, if prices rise and supply stays constant, state set-aside will not be relevant and alternative fuels would have a role.

- o If the SPR is used, supply would be enhanced, but shortages or major price increases would only be lessened, not eliminated. There would still be a role for alternative fuels.

- o If the United States participates in international fuel sharing agreements, there would be even fewer supplies of conventional oil products available in the United States. The role of alternative fuels would increase in this event.

- o If a major disruption occurs, the range of possible United States Government reaction and intervention is unlimited. Alternative fuels might play a role, but they could just as easily not, since the federal government would likely allocate supply requirements to essential users and otherwise freeze fuel supply relationships, meaning that the availability of alcohols could be an institutionally created problem.

In summary, the role of alternative fuels as oil supply disruption contingency fuels is the following:

- o Alternative fuels would never be relied upon to substitute completely for diesel fuel, only supplement those supplies due either to shortages or high prices.

- o Vegetable oils provide the only immediate contingency protection potential but only on a limited spot basis; there are too few supplies to supplement the needs of all transit systems.

- o Ethanol would be an adequate contingency fuel in a near-term disruption.

- o Methanol might be an adequate contingency fuel in a near-term disruption (if oil prices rose but supply was constant) but would definitely provide assistance in the long-term.

- o Government actions could alter the importance of alternative fuels as contingency measures vs. simple allocation of diesel fuel supplies to transit systems.

- o Methane and hydrogen should not be considered contingency fuels.

Alternative Fuels and Their Environmental Effects

Chapter II indicated that many of the findings regarding air quality impacts of alternative fuels are derived from a) laboratory settings and b) engines not always similar to typical transit bus diesel engines. Still, the data do suggest overall trends in the relative quality of fuels and diesel engines as contributors to urban pollution. The relevant pollutants of interest are carbon monoxide, hydrocarbons, nitrogen oxides and soot/smoke emissions.

Carbon Monoxide (CO)

Alcohols were shown in some tests to emit significantly larger amounts of carbon monoxide (CO) than diesel fuel -- on the order of four to five times as much. (However, an oxidation catalyst can be used to reduce CO emissions.) In any event, emissions are considerably less than those produced from gasoline. Vegetable oil emission data is sketchy, but that which exists suggests little difference from diesel fuel in CO emissions. Methane use drastically reduced CO emissions, while limited hydrogen tests show virtually no CO associated pollution.

Hydrocarbons (HC)

The findings with regards to hydrocarbons (HC) is similar to that of carbon monoxides: higher HC emissions among alcohol fuels (50 to 120 percent greater than diesel fuel); negligible changes among limited vegetable oil tests; lower HC emissions in methane use (except for actual methane emissions); virtually no emissions due to hydrogen use. In addition, methanol is a significant polluting source of unregulated hydrocarbons, particularly aldehydes (including formaldehyde).

Nitrogen Oxides (NO_x)

Here, alcohol fuels are significantly better than diesel fuel, on the order of one-third lower. Again, vegetable oil emissions data are limited and not significantly different than diesel fuel. Methane use produces lower emissions, while hydrogen has questionable indications that NO_x emissions could rise above those of diesel fuel, although engine redesign could improve the situation (2).

Soot/Smoke

Here, all alternatives fuels produce significantly lower emissions levels than diesel fueled vehicles.

In conclusion, methane is the only fuel consistently shown to have lower emissions in all important pollutants than does diesel fuel (except for the currently unregulated methane pollutant itself). Otherwise, methanol and ethanol are lower polluters of NO_x and soot (i.e., particulates)/smoke but greater polluters of HC and CO. Vegetable oil emissions are not really known, but preliminary indications suggest little difference from diesel fuel. Hydrogen is expected to be a relatively clean burning fuel, except for possible problems in NO_x emissions.

Alternative Fuels and Transit Operating Costs

Table III.1 shows the cost of diesel fuel and the alternative fuels under study on a volumetric or weight basis and on an energy content basis. On a per-gallon basis, methanol, cryogenic methane and cryogenic hydrogen are all cheaper than diesel fuel. On an energy content basis, however, almost nothing is cheaper than diesel fuel, except methane sold at utilities' purchase prices. In addition, metal hydrides become prohibitively expensive under this analysis, due to the relatively low weight of hydrogen in terms of the total metal compound. Energy content becomes particularly important when using alternative fuels in a non-blend manner; when viewed as blends (particularly smaller blends of the 90% diesel/10% other type), the energy content differences between diesel fuel and other fuels is less meaningful and relevant.

Direct fuel costs are not the only aspect of operating costs related to alternative fuels. There are also the costs related to maintenance of a) the engine, b) the vehicle (due to additional parts replacement), and c) facility maintenance (i.e., the fueling facilities). The only significant attempt to identify these costs for alternative fuels was done in a recent UMTA report (3). That information, shown in Table III.2, clearly indicates that alcohols cause significantly fewer maintenance costs than either methane or hydrogen. Vegetable oils were not part of this evaluation, but would likely be more similar to alcohol costs than methane or hydrogen costs.

In conclusion, utilizing the assumption that the average transit bus uses 1,258 million BTU per year (4), diesel fuel remains the least expensive fuel type to buy (and use on a 100% fuel basis) and to maintain. After that, methanol is clearly the most economically sound alternative fuel from the point of view of both fuel and maintenance costs. All other fuels are closely bunched well behind methanol, except for metal hydrides, which are clearly economically inferior.

Alternative Fuels and Energy Efficiency

There is no more efficient fuel for diesel engines than diesel fuel. The fuel and engine have developed simultaneously since the early twentieth century in an effort to produce an efficient and inexpensive form of surface transit propulsion. But the diesel engine continues

TABLE III.1

CURRENT COST OF DIESEL FUEL
AND VARIOUS ALTERNATIVE FUELS

	Cost (in $) per:	
Fuel	Volumetric Unit	Million BTU
Diesel Fuel #2	$1.00 per gallon	$7.17
Ethanol	$1.50 - $1.70 per gallon	$17.41 - $19.72
Methanol	$0.70 per gallon	$10.27
Cottonseed Oil	$2.25 per gallon	$17.12
Natural Gas (Methane)	$0.47 - $0.80 per gallon	$5.53 - $9.48
Hydrogen:		
o Magnesium Hydride	$26.00 per pound	$8511.00
o Cryogenic Hydrogen	$0.39 - $ 0.85 per gallon	$10.64 - $23.57

Sources: Chapter II referenced sources, and University of Miami and Escher Technology Associates, Alternative Fuels and Intercity Trucking, June 1978.

TABLE III.2

INCREASES IN MAINTENANCE COSTS PER BUS
(in 1981 DOLLARS) DUE TO ALTERNATIVE FUELS*

	Increased Maintenance Costs for:			
Fuel**	Engine	Vehicle	Facilities	Total
Methanol	$3,000	$ 200	$ 100	$ 3,300
Ethanol	3,000	200	100	3,300
Methane (Cryogenic)	7,000	10,000	748	17,748
Hydrogen				
(Hydride)	3,000	10,000	748	$13,748
(Cryogenic)	7,000	10,000	748	$17,748

* Represents an increase over diesel fuel maintenance costs.

** Vegetable oils not evaluated.

Source: Booz Allen & Hamilton, Inc., Evaluation of Alternative Fuels for Urban Mass Transit Buses, Bethesda, February 1983.

to be modified and some of those changes make alternative fuels more likely. One such experimental modification is the adiabatic turbo-compound engine, with research conducted by Cummins Diesel Engines for the United States Army (5). This research is intended to produce a non-watercooled turbocharged diesel engine. While the main advantage of this change is improved thermal efficiency, it would also make room for use by alternate fuels (6).

But beyond the issue of diesel engines themselves are two questions. First, is there a more efficient fuel and engine type to use for bus transit operations? The answer to this question is clearly yes. Alcohol fuels, methane and hydrogen are all capable of being combusted in a more efficient manner than diesel fuel (or any other complex hydrocarbon for that manner) in the properly constructed engine. Secondly, can alternate fuels withstand the loads and other problems associated with transit service (i.e., potholes, minor accidents, continual stop and go, etc.)? To this question, alcohols, vegetable oil and metal hydrides qualify as capable candidates, with cryogenic and compressed gas options (for methane and hydrogen) not currently proven as crashworthy and accident resistant fuels.

Conclusion

In light of the objectives of developing alternative fuels for transit vehicles, the following can be said about the relevant group of alternative fuels under study in this effort.

1. There is no alternative fuel which can currently serve as a transit contingency fuel on any widespread basis. However, governments have at their disposal the ability to assure transit systems receive an adequate supply of diesel fuel. On a limited, spot basis, vegetable oils can serve as an adequate contingency supplement to diesel fuel during a disruption. In disruptions which occur in the near- or long-term, alcohols could serve as adequate supplementary fuels.

2. Alcohols are far worse polluters of carbon monoxide and hydrocarbons than is diesel fuel. However they emit less nitrogen oxides and soot/smoke pollutants, with the latter two being the major concerns of diesel engine pollution. Other alternative fuels do not have a sufficient test history within transit bus settings to make 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 (i.e., methane emissions, and nitrogen oxides emissions from hydrogen) are likely to be handled by engine adjustments. Only nitrogen oxides are a major diesel engine problem (the other two pollutants are gasoline engine problems primarily).

3. Methanol is clearly the alternative fuel which provides the lowest operating costs for transit systems. Still, despite the lower fuel cost when compared to diesel fuel, the overall operating and maintenance costs are higher than for diesel fuel.

4. Hydrogen is considered to be the most efficient fuel, but various aspects of its storage (either cryogenic or metallic) properties 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 a BTU and cetane point of view; however, their cold start problems and overall availability restrict their immediate applications in transit vehicles except on a limited, spot basis. Alcohols are the most likely near-term candidates for transit use despite necessary engine modifications because of a) their availability potential, b) their relative similarity to diesel fuel in storage handling and suitability to withstand urban vehicular accidents, and c) their ability to reduce nitrogen oxides and soot/smoke emissions. Because of the even greater potential for availability and cost savings of methanol, this particular alcohol is considered the likeliest candidate for near-term exploitation in bus transit systems.

Notes for Chapter III

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CHAPTER IV

CONCLUSIONS: THE FUTURE OF BUS ALTERNATIVE FUEL RESEARCH AND DEVELOPMENT

Future Developments

Alternative fuel research and development continue despite a lesser interest by the federal government and private industry than existed in the 1978-1981 period. Indeed, expressed federal interest in alcohols, methane and hydrogen assure their continued study. However, only alcohols are being seriously considered and tested as transit fuels. In Florida, UMTA is sponsoring conversion of three in-revenue buses for methanol use, utilizing glow plug (and other) engine modifications (1). In California, two buses (with modified engines) in the San Francisco area are running on methanol (2). Else where in the world similar tests are ongoing. At the current time no interest has been generated for vegetable oil research among United States transit systems, while methane and hydrogen applications are being studied in non-transit areas.

Should there be an expansion of the current R & D efforts in transit bus alternative fuels? Or is the current level of research adequate? There are factors which support both positions. As far as maintaining current levels of research, three major factors work in favor of this position.

1. Objectives don't warrant further support.

2. Market demand too small.

3. Current economics unfavorable.

Among the factors which support an expansion of research are:

1. Objectives still hold some significance.

2. New competition in the bus manufacturing industry.

3. Future economics likely to be favorable.

4. Transit as a lead developer.

These factors are all discussed below.

Factors Favoring Maintenance of Research Levels

Objectives

Chapter III related development potential to the four key objectives of alternative fuel research. But these objectives cannot be viewed in a vacuum apart from other policies and actions. Thus the following can be noted:

a. Governments and transit systems can take other actions besides alternative fuels to protect diesel fuel supply and/or fuel budgets during oil supply disruptions. These actions include allocation of necessary supplies to transit systems (via federal or state intervention), contingency diesel fuel supplies held by transit systems, subsidies by the federal government, etc. 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.

b. The key urban area pollutants emanating from mobile (i.e., vehicular) sources are carbon monoxide, hydrocarbon and nitrous oxides. Transit buses simply are not major contributors to these pollutant levels.

c. Diesel fuel costs (operating and maintenance) remain cheaper than all other alternative fuel/engine combinations.

d. 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 are essentially unmet.

Market Demand

Transit systems consume only around three percent of on-highway diesel fuel used in this nation and less than one percent of all diesel fuel utilized (3). At the same time, there are about 60,000 transit buses in the United States, whereas diesel trucks amount to at least six times that amount (4). There are similar engine manufacturers for both industries. It is difficult to envision an economic environment where manufacturers make substantial changes in engine and vehicle design for a relatively small segment of their consumers. Thus any further alternative fuel development concepts that do not consider the needs of diesel trucks as well as transit systems may not receive widespread attention by relevant manufacturing parties.

Current Economics

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

Factors Favoring Expanded Research Efforts

Objectives

Some aspects of development objectives are validated by alternative fuel research, namely:

a. Transit systems are operating in an energy deregulated environment along with other oil product consumers. Despite their public standing, it behooves them to act as responsible consumers by mitigating against risks of fuel loss or price changes without relying on government bailout as the source of first resort. Alternative fuels, particularly methanol in the near-term, are a responsible way to secure against possible disruptions. Despite the necessary adjustments in fuel procurement, the move can be seen as one which recognizes the fragility and inefficiencies of letting other government bodies solve problems for transit systems, and at the same time recognizes the need for transit systems to provide important mobility services during disruptions to the best of their ability.

b. Soot and smoke emissions are visible and uncomfortable intrusions into everyday urban life which alternative fuels can help reduce.

c. Increased total operating costs of alternative fuels should be viewed as possible short-term occurrences, with manufacturing and facility processes likely to be refined and less costly.

d. Finally, the current fuel/engine coupling can be uncoupled quickly if other fuels and proper engine modifications can occur in a smooth and relatively inexpensive manner.

New Competition

Since 1980 at least four new bus manufacturers have entered the United States market for transit buses (see Table IV.1a). Others may also join as a result of prototype tests (see Table IV.1b). Competition

TABLE IV.1

NEW BUS MANUFACTURERS IN THE UNITED STATES

COMPANY	ORIGIN	TRANSIT PRODUCT
GILLIG	CALIFORNIA SCHOOL BUS BUILDER	STANDARD-SIZE UTILITY TRANSIT BUS
CROWN COACH	CALIFORNIA INTERCITY BUS, SCHOOL BUS AND FIRETRUCK BUILDER	ARTICULATED BUS PURCHASED FROM IKARUS (HUNGARY)
NEOPLAN	W. GERMAN BUS BUILDER	STANDARD-SIZE AND ARTICULATED BUSES
M.A.N.	W. GERMAN ENGINEERING COMPANY AND TRUCK AND BUS BUILDER	ARTICULATED BUSES

(a) New Entrants

POTENTIAL NEW MANUFACTURERS	PROTOTYPE TESTS
HINO (JAPAN)	NEW YORK
RENAULT (FRANCE)	NEW YORK, MONTREAL
SCANIA (SWEDEN)	NORWALK, CONN.
VOLVO (SWEDEN)	NEW JERSEY

(b) Potential Entrants

Source: B. Weiers and M. Rossetti, Entry and Competition in the United States Transit Bus Manufacturing Industry, Transportation Systems Center, Cambridge, March 1982.

will become stiffer and manufacturers will search for production and marketing strategies. Although it has been stated that there are no major, empty product niches (5), 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, M.A.N.) which have considerably more experience in alternative fuel development and operations than do most domestic companies.

Future Economics

Diesel fuel prices will not remain steady; rather, most likely they will rise in price as oil produce demand picks up again on a worldwide basis. At that time, alternative fuels will once again resume their potential economic attractiveness. Further, transit systems, while likely to be in constant need of subsidization, will eventually pass out of the massive rehabilitative phase which they are in at present and have more capital and operating funds available for alternative fuel ventures.

Transit as a Lead Developer

This is turning around the market share issue. Truckers, while representing the lion's share of highway diesel engines and diesel fuel use, are in a constant and fierce competitive struggle for freight haulage. This competition has only been enhanced by the deregulation of the trucking industry, and it has been characterized largely through significant price competition. That has two implications: 1) trucking firms have less funds available to engage in alternative fuel R & D programs and 2) whatever cost advantages alternative fuels could offer to truckers (during periods of constant and disrupted fuel supply) would be of great benefit. Therefore, the transit industry can be seen as the proper sector for alternative fuel development. First, such systems are not in a strict cost competitive situation, although costs must be carefully scrutinized because of the pervasive deficit operations throughout the industry. Secondly, advantageous results that also result in cost savings are likely to be picked up by the private trucking industry, which in turn aides transit through more manufacturer interest.

New Directions in Research and Development

In light of the factors in support of and opposing an expanded alternative fuel R & D effort, what directions should be pursued? The following are the recommendations of this study in terms of a) program initiatives and b) R & D participants and roles.

Program Initiatives

Current United States transit methanol tests and the considerable wealth of foreign expertise suggest that expanded vehicle testing efforts not be pursued to any large extent. What is recommended is the following:

1. A joint study between UMTA, the United States Departments of Energy and Agriculture that would identify the potential role of vegetable oils as contingency fuels. The key aspect is to address a) price and availability issues, b) identifying regions, markets and conditions where availability of vegetable oils is assured, c) which transit systems (by size, location, etc.) are the likeliest users, and d) what are the benefits and costs compared to other, non-alternative fuel means of providing assistance to transit systems during disruptions.

2. A cooperative effort between one or more bus manufacturers, an alternative fuel provider and at least one transit system to test the costs and benefits of developing alternative fuels. Within this cooperative effort, costs and responsibilities should be split and identified where they appropriately belong: engine modifications to the manufacturer; fuel quality characteristics and assurance, and delivery methods to the fuel supplier; and maintenance and facility redesign and readjusting to the transit system. Such an effort could be supported by a federal demonstration project.

Participants and Roles

The relevant participants in future R & D efforts are:

1. The Federal Government
    a. UMTA
    b. United States Department of Energy
    c. United States Department of Agriculture
    d. United States DOT/Office of the Secretary
2. Transit Systems
3. Fuel Suppliers
4. Bus Manufacturers
5. State and Local Governments

Their roles should be as follows:

a. The federal government should actively pursue the vegetable oil contingency study and disperse any positive results to transit systems.

b. The federal or state government could play an active role in forming the cooperative fuel development program by bringing together interested transit systems, bus manufacturers and fuel providers. Any results should be publicized, but the individual profitability of manufacturers and fuel suppliers should not be restricted by strict federal or state guidelines or mandates. This does not imply that the federal government should not pursue regulatory control over safety and environmental hazards of alternative fuels.

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