Report Prepared for The Michigan Department
of State Highways and Transportation

THE POTENTIAL FOR USE OF ALTERNATIVE FUELS IN MICHIGAN'S PUBLIC TRANSIT SYSTEMS

July, 1978

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16. Abstract

The availability of various alternative fuels for public transit vehicles is examined, and funding opportunities for demonstration grants are discussed. The only alternative fuels that appear to be likely candidates for a demonstration grant in the near term are alcohol and synthetic fuels. The only likely supporter of a demonstration project is the U.S. Department of Energy, Division of Transportation Energy Conservation, which has tentative plans for supporting some demonstration programs of alcohol/gasoline blends in the near future.

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1. INTRODUCTION

1.1 Background

This is the final report of a study of the availability of alternative motor fuels and their possible use by public transit systems.

Petroleum-derived motor fuels are expected to become more scarce and expensive. As they become more expensive, it is expected that some consumers will shift from private vehicles to use of public transportation. Thus public transit systems will be confronted by increasing motor fuel costs stemming from both increased fuel prices and increased passenger demands. It is important that they position themselves to minimize the effects of cost increases and shortage difficulties that seem likely for petroleum fuels.

The State of Michigan Department of State Highways and Transportation sensed the overall need and asked the Michigan Transportation Research Program to investigate the possibility of obtaining a demonstration grant to support an evaluation of alternative fuels in the public transit environment.

1.2 Study Objectives

The objectives of the study were described in a December 14, 1977 letter from Mr. Charles Uray, Jr., of the Michigan Department of State Highways and Transportation, to Dr. Charles G. Overberger, Michigan Transportation Research Program. The letter requested that "a determination.... be made as to the availability of alternative fuels which may be used in public transportation. Such fuels as the following should be examined:

a. hydrogen (liquid and gaseous)
b. alcohols (methanol, ethanol, and blends)
c. broad-cut fuels
d. gasoline/alcohol blends
e. electricity via storage battery"

The letter requested that the study report list the advantages and disadvantages of each fuel and recommend which fuels appear to be candidates for use in public transit demonstration programs. The problems of cost, availability of resources, applicability to current propulsion technology, and safety and health would be considered.

Because other projects are examining the electrical vehicle demonstration opportunities in more detail, it was subsequently decided to eliminate this type of propulsion system from study consideration. As finally constituted, then, the fuels that were considered in the study are those described in the first four categories listed on the preceding page.

2. OVERVIEW OF ALTERNATIVE FUELS ACTIVITY

It is generally conceded that the transportation energy problem within the United States is serious. The system is almost totally dependent upon petroleum, and the domestic oil resources are being depleted. Failure to implement timely solutions will possibly lead to serious disruptions of the nation's economic, social, and political system.

While several methods exist for reducing the transportation energy shortage potential, one of the major possibilities is to switch to alternative fuels to alleviate the dependence upon petroleum fuels. The federal government is making a major effort to foster the use of alternative fuels by lowering the uncertainty costs associated with their use in highway vehicles. The program, called the Alternative Fuels Utilization Program (AFUP), is being carried out by the Division of Transportation Energy Conversion within the Department of Energy.[1] The AFUP is investigating:

> ...the consequences of the use of synthetic gasoline and/or diesel fuels in current or improved engine types;
>
> ...alcohol fuels, based on an understanding of the production of the fuels and the design of engines optimized for the fuels;
>
> ...advanced and/or less probable alternative fuels such as hydrogen, various hydrogen-nitrogen compounds, and carbonaceous fuels;
>
> ...new hydrocarbon fuels, such as broad-cut or variable composition fuels, based on an understanding of the production of the fuels and the design of engines optimized for the fuels; and
>
> ...ways that nonstandard fuels could be utilized in highway vehicles in emergencies.

In 1973-74 there were two studies performed for the government that examined the various alternatives to petroleum-derived fuel for automotive

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1. Details of the program are contained in the publication, Program Planning Document Alternative Fuels Utilization Program (AFUP), Department of Energy, April, 1978.

application.[2, 3] Based on these projects the AFUP was subsequently developed.

Within the context of examining an alternative fuels solution, it is important to remember that development of a system that can accommodate the alternative fuel is a long-term evolution. In the past, for example, it has taken approximately 60 years for a new fuel type to penetrate the marketplace to such an extent as to become the dominant energy source of the economy.[4] That being the case, it is important to begin work toward the introduction of alternative fuels in the transportation system so that they might be fully developed and demonstrated by the time petroleum peaks and begins to decline. That time point is currently projected to occur about 2000 AD.[5]

For the synthetic fuels the concentration has been on production technology, i.e., developing methods of converting the fuel into a gasoline-like substitute. The major efforts in this regard have been directed toward shale oil recovery programs and toward coal conversion programs. Also, work is underway in developing processes by which methanol is converted to gasoline.

Whatever the synthesis procedure utilized, the major advantage of the synthetic gasoline fuel is that there will be no significant requirements to modify either the engines or the fuel marketing and distribution system.

There have been two major alcohol concepts examined: methanol and ethanol. Most of the present ethanol production in the United States is derived from petroleum and natural gas constituents; however, the product can be obtained by fermentation of grains, fruits, and sulfite liquors.

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2. F.H. Kant et al., "Feasibility Study of Alternative Fuels for Automotive Transportation," Exxon Research & Engineering Co. for the Environmental Protection Agency, EPA-46013-74-990, June, 1974.
3. J. Pangborn & J. Gillis, "Alternative Fuels for Automotive Transportation--A Feasibility Study," Institute of Gas Technology for the Environmental Protection Agency, EPA-460/3/74-012, July, 1974.
4. Program Planning Document, etc., AFUP, Department of Energy, page 2-19.
5. loc cit., page 3-2.

Current prices of producing ethanol are in the range of $13.20-17.10 (1977 dollars) per million BTU. High volume production could possibly reduce this price to an equivalent of $5-7 (1977 dollars) per million BTU. When this is compared with a current price of gasoline of about $3.50 (1977 dollars) per million BTU, it is obvious that there would be a need for high subsidization. Research and development are being conducted to increase crop yields, to reduce processing time, and to improve the economics of the product.[6]

Methanol is presently produced almost totally from natural gas. However, it could easily be produced from coal through gasification and subsequent catalytic conversion. It could also be produced from wood, agricultural residues, and municipal solid waste, using the same general technical approach as for coal. Programs are in progress to more accurately define the production processes. Present production costs for methanol are estimated to be in the $5.28-8.78/(1977 dollars) per million BTU, depending upon such factors as feed stock price, rate of return on investment, and type of financing. High volume production would reduce the cost to $3.75-5.00 (1977 dollars) per million BTU. One of the potential possibilities for methanol would be to have production from high-yield forestry biomass; the costs are projected to be in the same general range as methanol from coal, even though the production facilities would be smaller and more dispersed.[7]

In the hydrogen fuel program, four problem areas are being addressed: (1) production of hydrogen, (2) storage of hydrogen on board the vehicle, (3) development of hydrogen-burning engines, and (4) distribution of hydrogen to the consumer. The pivotal issue seems to be whether the fuel can be produced at a price that will make it economically attractive.[8]

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6. "Department of Energy Position Paper on Alcohol Fuels," U.S. Department of Energy, March, 1978. pp 5. See also, "The Wood Energy Concept--Its Applicability in Michigan," report to the Upper Great Lakes Regional Commission. Submitted by Tom Heck, Energy Administration, Michigan Department of Commerce.

7. Ibid.

8. AFUP Program Planning Document, page 4-3.

As an advanced concept, hydrogen has potential importance as a vital component of the all-electric economy. Hydrogen would be a leading candidate as an energy storage and transmission medium, especially if high-density storage batteries do not materialize.[9]

The development of efficient engines which can burn broad-boiling range fuels can reduce the petroleum requirements needed for transportation. This is because the refinery process can be most efficient if the entire yield from the refinery can be utilized in transportation without regard to octane number or cetane number. The inefficiencies of distribution are also minimized by having to deal with only one fuel type.

Much of the research on broad-cut fuels in the United States has been sponsored by the Department of Defense. Their reasoning has been that the use of such fuels simplifies their logistics problems.

Overall there have been only modest amounts of research in alternative fuels performed in places other than at the Federal level. In the early 1960's the State of Nebraska sponsored a program at Southwest Research Institute to examine the feasibility of using alcohol in gasoline. They were attempting to develop markets that would dispose of the surplus grain crops existing at that time within the state. Other isolated examples exist where that has been state or local support for alternative fuels utilization. But, without doubt, the overwhelming majority of research has been funded by federal programs, especially the Department of Energy (or its predecessor organizations).

The federal programs have been directed mainly toward activities that would precede full-scale trial and preproduction.[10] As seen in Figure 1, the main emphasis is found in the areas of defining the theories and concept formulations, and their verification. As tests and evaluations of the applications are encountered, the Federal participation begins to decline, with industry increasing its share of the funding support.

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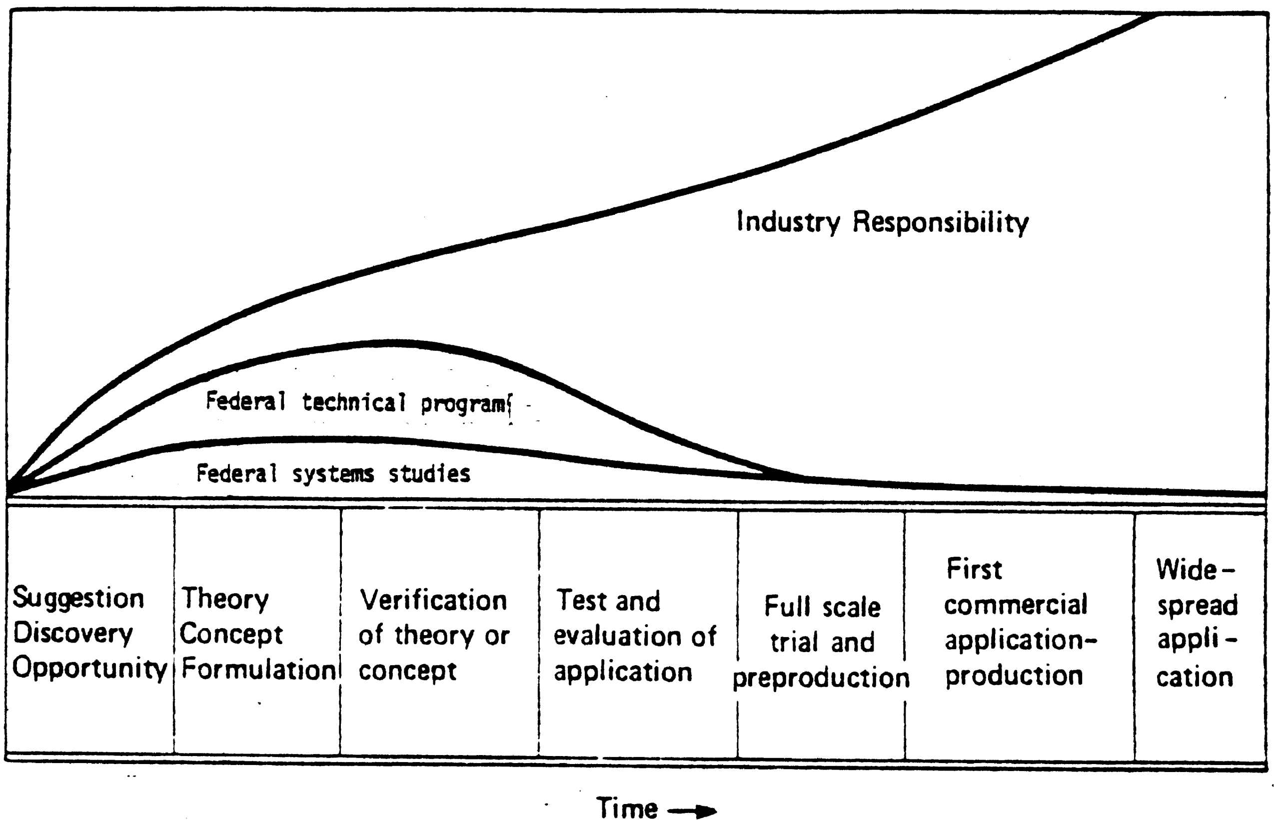
9. Ibid.
10. Op. cit., page 6-3.

In view of the above, the most likely support for any public demonstration project will probably be the federal government. The next chapter will discuss each of the major fuel concepts, and the role of the federal government in this activity.

FIGURE 1

Scope of Federal Alternative Fuels Support Programs Relative to Technology Development



Source: Department of Energy, AFUP.

3. EVALUATION OF SPECIFIC FUELS

This chapter examines the activities that are underway with the following alternate fuel candidates:

...hydrogen

...alcohols

...broad-cut fuels

...gasoline/alcohol blends

Included in this evaluation are summaries of major project activities, indications of future direction, and an estimate of potential configurations of demonstration programs utilizing the fuel.

3.1 Hydrogen Fuel

Table III-1 presents the fundamental characteristics of hydrogen in comparison with those of gasoline and diesel fuel. As seen, hydrogen is an extremely low-temperature (in the liquid form), non-dense fuel. It has a much lower volumetric energy density and a higher gravimetric energy density than the conventional fuels. It also has a very high flame speed. This attribute results in some unique advantages, as well as several unique engine-related design problems.

The principal challenge of using hydrogen for automotive vehicles is the problem of onboard storage. Four approaches have been given some consideration:[11]

...storage as a high pressure gas

...storage as a cryogenic liquid, generally at low pressure

...storage in the form of a metal hydride

...onboard generation from a hydrogen-bearing substance (e.g., reforming a hydrocarbon fuel).

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11. Escher, W., Hydrogen-Fueled Internal Combustion Engine, A Technical Survey of Contemporary U.S. Projects., Escher Technology Associates, ETA Report PR-51. September, 1975. pp. 110.

TABLE III-1

Comparative Technical Characteristics of Hydrogen Fuel

	Gasoline	Diesel Fuel	Hydrogen (Liquid)
Specific Gravity	0.73	0.86	0.071
Boiling Point	38-240C	16-343C	-253C (21K)
Lower Heating Value			
Gravimetric kJ/kg	4.49×10^4	4.30×10^4	12.0×10^4
Volvmetric kJ/m^3	32.7×10^6	36.8×10^6	8.52×10^6
Stoichiometric Mixture	14.8	14.5	34.6
Flammable Limits (Air)	1.4 - 7.6%	0.7 - 5.0%	4 - 74%
Ignition Temperature	257C	254C	574C
Flame Speed (m/sec)	0.34	0.34	2.7

Source: ERDA Report ETA PR-51

Of the four systems, the use of high-pressure gas seems to have been ruled out for general highway vehicle use.[12] It does have potential, however, in applications where the vehicle is traveling a well-defined route, with a limited daily mileage. But the unrefueled range of vehicles operating on high-pressure gas has usually been less than 50 miles, and a transit operation would seldom have this low a mileage accumulation between logical refilling points.

An approach actively being researched by several groups is to provide onboard hydrogen generation. The Jet Propulsion Laboratory (JPL) and International Materials Corporation (IMC) are two organizations that have been examining the concept. The JPL's work involved attempts to lean-out engine operation by use of hydrogen-enriched gasoline. The hydrogen was provided by the use of onboard conversion of a portion of the hydrocarbon fuel to a hydrogen-rich fuel gas, principally consisting of hydrogen, carbon dioxide, and nitrogen. The IMC work was also involved with enriching the gasoline stream with hydrogen produced by an onboard conversion process.[13]

Storage of a cryogenic liquid has been investigated by several organizations, among them UCLA, Los Alamos Scientific Laboratory, and Billings Energy Research Corporation. All systems were essentially the same. A container especially designed to store cryogenic liquid was placed on the vehicle. The vehicle is fueled with hydrogen that has been converted from a liquid into a gas by being passed through a hot water heat exchanger.

The metal hydride hydrogen storage system is probably the system currently receiving the major research concern. In this concept, hydrogen is assimilated into the metallic hydride, where it is held at atmospheric pressure. As the fuel is needed, heat is applied to the metallic hydride, and the hydrogen is released. One project is currently active, and several major investigations have been conducted in the past. The current research, being performed by Solar Division of International Harvester, is concerned with development of a magnesium-base alloy to store hydrogen.[14]

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12. Ibid., pg. 7.
13. Ibid., pg. 7.
14. Highway Vehicle Systems Contractors Coordination Meeting, Thirteenth Summary Report. U.S. Department of Energy Report 771037.

The major issue will be whether hydrogen can be produced with sufficiently high efficiencies to be economically attractive. Hydrogen is not a primary energy source but rather a means of transmitting energy. If the transformations from coal, water, or whatever, are wasteful of energy, then the wide-scale utilization of hydrogen will probably never occur. This issue will possibly be the key to whether significant vehicle system development and demonstration programs will occur.

3.2 Alcohols

There have been ongoing research programs into the use of alcohol fuels for a number of years. The technical advantages and deficiencies of these fuels are well understood, and there appear to be no major technological barriers facing either production or distribution of alcohol fuels. The major remaining uncertainties concerning the fuel are the supply potential, production costs, most appropriate applications, and the best approach to achieving commercialization.

As indicated in the preceding section, the two major alcohol fuels that merit consideration are methanol and ethanol. But in both fuels there is uncertainty of supply. Present manufacture of methanol amounts by volume to about one percent of the fuel used in highway vehicles; this would reduce to about one-half percent of the energy used, since the heating value of methanol is about one-half that of gasoline. It has been forecast that to install methanol capacity to satisfy only five percent of the projected 1990 demand for motor fuel, there would be a need for $5 billion (1977 parity) of investment capital.[15]

Presently most of the ethanol is derived from petroleum and natural gas constituents. However, for ethanol to be beneficial as an alternative fuel, that product would need to be derived from other products, such as the fermentation of grains, fruit, and sulphite liquors. And therein lies the problem. If all practicably available farmland were used for farm crop plantings, in excess of those required for food production, the ethanol

15. DOE Position Paper on Alcohol Fuels, pg. 3.

produced from the crop and crop residues would satisfy no more than eight percent of today's total liquid fuels energy demand.[16] However, production and utilization of ethanol on a regional basis may have merit.

The production costs will be a major uncertainty with the fuels. As indicated in the preceding section, ethanol prices are projected in the $13.20-17.10 per million BTU, and methanol prices are projected at $5.25-8.78 per million BTU. Both estimates are for the fuel at the plant gate, and compare with present gasoline prices of about $3.50 per million BTU. Therefore, it is obvious that both fuels will need to be heavily subsidized, especially ethanol, which is estimated at nearly twice the price of methanol on an equivalent heat content basis.

A recent paper by Patterson[17] examined the problems associated with adapting current internal combustion engines to the use of methanol. (Many of the same comments would also apply to the use of ethanol.) The major conclusions were:

(1) There are no unsolvable technical problems which preclude the use of enhanced methanol or methanol-gasoline blends for spark-ignition vehicles. However, considerable cost and complete retrofitting would be required to assure that existing vehicles perform satisfactorily without incurring continuing repair costs.

(2) Given sufficient lead time of a few years, automobile manufacturers would be able to design and build new vehicles capable of satisfactory operation on methanol.

(3) In view of the limited available supply of methanol and other alcohols, it is readily apparent that considerable lead time and capital investment will be required to introduce alcohol fuels into the general motor fuel supply in large quantities.

Other conclusions of the Patterson study were that methanol would be preferred over the methanol-gasoline blends, that careful and controlled

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16. Ibid, pg. 2.

17. Patterson, D.J., Bolt, J.A., and Cole, D.E., "Engine Modifications for Use of Methanol and Methanol Gasoline Blends.", DOE Highway Vehicle Systems Contractors Coordination Meeting. Troy, Michigan, May, 1978. pp. 14.

blending with hydrocarbon constituents would be required, and special attention will be needed to deal with the problem of phase separation of water in the fuel.

Because of some non-energy issues there has been considerable interest in producing alcohols as a motor fuel. The existence of local grain surpluses has caused interest on a regional basis in using ethanol from grain as a supplement with gasoline. And, the desire to dispose of municipal solid waste and to utilize forest and agricultural residues has resulted in proposals to produce and use both methanol and ethanol on a small-volume localized basis. Continuing studies are underway to "help resolve key technological, economic, environmental, and institutional issues that obstruct or cloud commercialization decisions. Planning for early end-use demonstration is included." (Underlining added for emphasis).[18]

3.3 Fuels (Broad-Cut and/or Synthetic)

Present programs include the testing and evaluation of synthetic gasoline and diesel fuels in current and improved engine types to uncover problems that may occur with the use of these fuels. Additionally, extensive work is being performed on advanced engine types capable of operation on a wide selection of fuel types.

The synthetic fuels are being produced from coal, oil shale, and biomass. Perhaps the major evaluation has been in developing gasoline and diesel fuel from the Western oil shale. The economics of developing a capability to convert the Western oil shale to gasoline/diesel fuel was examined by Stanford Research Institute in 1975. Their study indicated:

- All synthetic liquid fuels production options would have large environmental, social, and institutional impacts - especially in resource development regions.

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18. DOE Position Paper on Alcohol, p. 4.

- No single option is "best" in all aspects, but net energy impact and compatibility analyses generally least favor methanol conversion.
- Institutional and compatibility considerations favor production of a synthetic crude oil rather than direct production of a consumer product.
- Because of compatibility, methanol use is more likely in stationary than mobile applications (but this could "release" petroleum for automotive use).
- The return on investment and business risk climate require improvement before a private-sector effort is likely.[19]

The study indicated that the estimated installed capacity for oil shale refining capability is about $10,500 per barrel/day (in 1977 dollars). The costs would be about $15,000 per barrel/day (1977 dollars) capacity for a coal syncrude refining capability.

Relative to engine development efforts that will provide primemovers capable of operating on wide-boiling-range fuels, the Department of Energy has been providing heavy continuous funding. The Stirling engine program has been underway for several years, and indications are that it will continue for several more years. The Stirling engine (and all external combustion engines) has a major multi-fuel capability.

There is no need to demonstrate the viability of synthetic fuels, provided they have the same specifications as petroleum-derived gasoline and/or diesel fuel. As a result, any demonstration projects relating to broad-cut fuels would probably involve the engine system, rather than the fuel.

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19. Automotive Parnes Systems Contractors Coordination Meeting, Eighth Summary Report, May 6-8, 1975, ERDA. Division of Transportation Energy. pp. 369-385, citing Stanford Research Institute Study.

3.4 Gasoline/Alcohol Blends

One of the major alternative fuel options is to consider alcohol as a gasoline extender. This concept has viability when the limited supply of alcohol is considered. Proponents contend that by using the available alcohol supply as an additive the total fuel available would be effectively increased by the amount of alcohol added into the system.

The technology of blending alcohol with gasoline is reasonably well understood; investigations have been underway in this area since before World War II. The most recent investigations have been concerned with some of the more subtle aspects of utilizing the various fuels, such as providing information to enable reliable prediction of the phase stability of methanol/gasoline mixtures at varied temperatures and water content.[20]

Of all the alternative fuels being considered, the alcohol and gasoline mixtures have attracted the most localized interest. This is the result of alcohol feed-stock surpluses, such as grains, in local areas. In 1971, for example, the State of Nebraska specifically approved the use of a 10 percent ethanol/90 percent gasoline blend as part of their "Gasohol" program.[21] And even more recently, the Southwest Alabama Farmers' Cooperative Association requested the government to approve their proposed formula for denatured alcohol intended for use in a 10 percent ethanol/90 percent gasoline fuel blend to power farm equipment.[22]

The government of Brazil has actively supported the sale of a alcohol/gasoline blend for several years in order to dispose of a surplus supply of local agriculture produce that can be used in the fermentation process.

One of the major problems associated with the gasoline/alcohol blend, however, is the cost for retrofitting the automobile, even when small

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20. Highway Vehicle Systems Contractors Coordination Meeting, 13th Summary Report.

21. Denaturants for Ethanol/Gasoline Blends, Department of Energy, Contract EX 76-C-01-2098, April, 1978. Mueller Associates, Inc.

22. Ibid.

amounts of alcohol are blended into gasoline. Patterson et al.[23] stated:

> While use of both methanol and methanol-gasoline blends introduces problems, it appears more attractive from a cost and time standpoint to concentrate efforts on virtually pure methanol as an alternative fuel rather than as a blending agent in gasoline. By this strategy and with a given amount of methanol introduced, fewer existing vehicles would require retrofitting.

3.5 Summary

Table III-2 summarizes the production processes available for each of the alternative non-petroleum-based automotive fuels. All have, in one way or another, been in commercial production. In almost all instances the main limiting factor is the question of cost in the production processes. This is further verified in Table III-3, "Logistic Factors for Automotive Use of Alternative Non-Petroleum Based Fuels." This table shows estimates of what the costs would be in 1985 at the pump (1973 dollars). These estimates indicated that the synthetic fuels from oil shale have the most attractive economics. The next most attractive is methanol derived from coal. Interestingly, the comparative advantages for synthetic gasoline, a synthetic distillate, and methanol also continue in the other comparisons, as shown in the Table. Storage attributes for the three fuels are either excellent (for the synthetic fuels) or good (for methanol). The fire hazard is no worse than that for regular gasoline. The synthetic fuels and alcohol have good compatibility with petroleum fuels. And in the three cases no major changes are foreseen in the fuel distribution system to the customer.

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23. Patterson, D.J., et al., page 14.

TABLE III-2 Production Processes for Alternative Non-Petroleum-Based Automotive Fuels

FUEL	PROCESS ALTERNATIVES	DEVELOPMENT STATUS	TECHNOLOGY NEEDS
GASOLINE/ DISTILLATE	1. COAL LIQUEFACTION 2. COAL GASIFICATION-SYNTHESIS GAS GASOLINE VIA FISCHER-TRIPSCH PROCESS 3. OIL-SHALE EXTRACTION	1. PILOT PLANT 2. COMMERCIAL PRODUCTION IN SOUTH AFRICA, IN-EFFICIENT, COSTLY 3. READY FOR COMMERCIAL PLANT	1. CATALYST, MATERIAL HANDLING HARDWARE DEVELOPMENT 2. MAKE MORE SELECTIVE, HANDLE CAKING COALS 3. DISPOSAL OF SPENT SHALE AND WATER, DEEP MINING TECHNIQUES
HYDROGEN	1. WATER-ELECTROLYSIS 2. COAL GASIFICATION-SYNTHESIS GAS (CARBON MONOXIDE PLUS HYDROGEN)-SHIFT CONVERTER-CARBON DIOXIDE SCRUBBER 3. THERMOCHEMICAL	1. COMMERCIAL PRODUCTION 2 PILOT PLANT 3. LABORATORY	1. IMPROVE CELL EFFICIENCY 2. EFFICIENT CARBON DIOXIDE REMOVAL, GASIFICATION PROCESS IMPROVEMENTS. 3. SIMPLE, ENERGY EFFICIENT CHEMICAL STEPS. AVOID CORROSIVE, UNSTABLE MATERIALS.
AMMONIA	HYDROGEN PLUS NITROGEN IN PRESENCE OF CATALYST	COMMERCIAL PRODUCTION WITH H_2 FROM NATURAL GAS	SAME AS FOR HYDROGEN ABOVE.
HYDRAZINE	1. RASCHIG PROCESS 2. UREA PROCESS	1. COMMERCIAL PRODUCTION 2. COMMERCIAL PRODUCTION	NEW CHEAPER PROCESS REQUIRED. THERMODYNAMICS LIMITS POSSIBLE SAVINGS.
METHANOL	COAL GASIFICATION-SYNTHESIS GAS (CARBON MONOXIDE & HYDROGEN) IN PRESENCE OF CATALYST	COMMERCIAL PRODUCTION DEMONSTRATED	GASIFICATION PROCESS IMPROVEMENT
ETHANOL	FERMENTATION OF AGRICULTURAL PRODUCTS (SUGAR, STARCH, CELLULOSE)	COMMERCIAL PRODUCTION	PRESENT FERMENTATION TECHNOLOGY TOO EXPENSIVE, NEED NEW RAPID FERMENTATION PROCESS
METHANE	COAL GASIFICATION-SYNTHESIS GAS (CARBON MONOXIDE PLUS HYDROGEN)-CATALYTIC METHANATION	COMMERCIAL PRODUCTION WITH METHANATION STEP NOW BEING DEMONSTRATED	GASIFICATION PROCESS IMPROVEMENT
PROPANE	BY-PRODUCT IN COAL GASIFICATION OR LIQUEFACTION	SAME AS COAL LIQUEFACTION AND/OR GASIFICATION	DEVELOP EFFICIENT BY-PRODUCT EXTRACTION FROM COAL PROCESSING

SOURCE: Mueller and Associates.

TABLE III-3 Logistic Factors for Automotive Use of Alternative Non-Petroleum-Based Fuels

FUEL	EST. COST (1973 DOLLARS) AT PUMP (TAXES EXCLUDED) $/10⁹ JOULES [a]	VEHICLE STORAGE	TOXICITY	SAFETY	COMPATIBILITY WITH PETROLEUM FUELS	STATUS OF DISTRIBUTION TO CONSUMER
GASOLINE[b]	2.99 (FROM COAL) 2.46 (FROM SHALE)	EXCELLENT	MEDIUM	HIGH FIRE HAZARD	--	EXISTING
DISTILLATE[b]	2.37 (FROM COAL) 1.90 (FROM SHALE)	EXCELLENT	LOW	LOW FIRE HAZARD	HIGH	EXISTING
LIQUID HYDROGEN	6.64 (FROM NUCLEAR ELECTROLYSIS) 4.46 (FROM COAL)	POOR	LOW	HIGH FIRE AND EXPLOSION HAZARD	LOW	MAJOR DEVELOPMENT AND INVESTMENT REQUIRED.
AMMONIA	7.25 (USING HYDROGEN FROM ELECTROLYSIS)	FAIR	HIGH	MODERATE FIRE HAZARD	LOW	SOME EXPERIENCE IN FARM DISTRIBUTION. MAJOR EXPANSION REQUIRED WITH EMPHASIS ON SAFETY.
HYDRAZINE	OVER 19	GOOD	HIGH	HIGH FIRE AND EXPLOSION HAZARD	LOW	MAJOR MODIFICATIONS TO EXISTING GASOLINE SYSTEM IN AREAS OF MATERIALS COMPATABILITY AND SAFETY.
METHANOL	3.22 (FROM COAL)	GOOD	MEDIUM	MODERATE FIRE HAZARD	HIGH IF WATER CONTAMINATION CONTROLLED	EXISTING GASOLINE SYSTEM COULD BE USED WITH MODIFICATIONS TO PREVENT WATER CONTAMINATION AND CORROSION.
ETHANOL	7.40 (FROM ORGANIC WASTE)	GOOD	LOW	MODERATE FIRE HAZARD	HIGH IF WATER CONTAMINATION CONTROLLED	SAME AS METHANOL.
METHANE	3.60	POOR	LOW	HIGH FIRE AND EXPLOSION HAZARD	LOW	ABOUT THE SAME PROBLEMS AS FOR HYDROGEN.
PROPANE	> 3.60 (FROM COAL LIQUEFACTION)	FAIR	LOW	MODERATE FIRE HAZARD	LOW	LIMITED AVAILABILITY AT PRESENT. REQUIRES EXTENSION.

[a] $/10⁹ JOULES - DOLLARS PER BILLION JOULES FOR THE POST 1985 PERIOD.

[b] CURRENTLY, AT THE PUMP, GASOLINE FROM PETROLEUM AT 10.04 CENTS PER LITER IS EQUIVALENT TO $3.08/10⁹ JOULES AND DISTILLATE FROM PETROLEUM AT 9.77 CENTS PER LITER IS EQUIVALENT TO $2.65/10⁹ JOULES (TAXES EXCLUDED).

SOURCE: Mueller and Associates.

4. IDENTIFICATION OF TRANSIT DEMONSTRATION OPPORTUNITIES

All federal activities dealing with alternative fuels have been assigned to the Alternative Fuels Branch, Division of Transportation Energy Conservation.

The Division of Transportation Energy Conservation (TEC) is under the Assistant Secretary for Conservation and Solar Applications. The TEC program is recognized as a high-priority program, and is presently the largest single program in Conservation.[24] The funds appropriated by Congress for this program were about $30,000,000 in FY78. Funding estimates for FY79 indicate a one-hundred percent increase.[25] About 90 percent of this budget will go into industry for the conduct of the program. While most of the funds are directed toward advanced engine development, a significant portion is directed toward alternative fuels research. This effort is directed by the Alternative Fuels Branch, which coordinates all activities in the fuels utilization effort into the Alternative Fuels Utilization Program (AFUP).

The specific objectives and strategies of the AFUP are to:[26]

> ...achieve and evaluate multifuel operation in research engines of the continuous combustion types and experimental IC types in order to uncover problems with the use of different fuels in these engines. This is a near-term goal.
>
> ...In the long term, for hydrocarbon and for alcohol fuels, achieve and evaluate new systems to optimize the resource/fuel/engine systems for efficiency, emissions, performance, manufacturability and marketability.
>
> ...Test and evaluate alcohol gasoline blends in commercial or government fleets to discover and solve problems and ultimately prove the feasibility and reliability of blends
>
> ...Test and evaluate synthetic gasoline and diesel fuels in current and improved current engine types to uncover problems that may occur with the use of these fuels.

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24. Highway Vehicles Coordination Meeting, 13th Summary Report, Pg. 3.
25. The Budget of the U.S. Government, Fiscal Year 1979, Appendix, Pg. 359.
26. Highway Vehicles Coordination Meeting, 13th Summary Report, Pg. 308.

It is significant that in the above-listed objectives the AFUP program specifically indicates that a demonstration program will be carried out in the near term with alcohol/gasoline fuels. Interviews[27] with the chief of the Alternative Fuels Branch confirmed that this is the only area where a demonstration program is being considered. It was further indicated that the federal government's position is that a demonstration program is not to be undertaken until a concept is shown to be reasonable, and the production technology and distribution economics indicate the fuel might be competitive. Of all the alternate fuels that are candidates, only alcohol and alcohol/gasoline blends meet this requirement. It is believed the AFUP team would look favorably upon a demonstration being conducted in a public transit operation.

In spite of the AFUP's apparent preference for alcohol as the only candidate for demonstration, others have indicated that the preferred fuel for demonstration would be synthetic gasoline and/or diesel fuel. In separate studies conducted in 1974 by the Institute of Gas Technology[28] and Exxon Research[29], it was concluded that the following alternative fuels would be the closest to having commercialization potential (and hence would be the most likely candidates for a demonstration project):

Near Term (1975-1985)

gasoline from coal and water or oil shale and water
distillate (diesel) oils from coal and water or oil shale and water

Mid-Term (1985-2000)

gasoline from coal and water or oil shale and water
distillate (diesel) oils from coal and water or oil shale and water
methanol from coal and water

Long-Term (Beyond 2000)

gasoline from coal and water or oil shale and water
distillate (diesel) oils from coal and water or oil shale and water
nuclear-based hydrogen (from water)
methanol from coal and water

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27. Personal interview with the Chief, Alternative Fuels Branch, Transportation Energy Conservation, DOE, April, 1978, in Ann Arbor, Michigan.

28. Pangborn and Gillis, IGT.

29. Kant, et al, Exxon Research.

Since the IGT and Exxon studies were conducted there has been further work indicating that methanol derived from coal does not have some of the economic advantages that were assumed by IGT and by Exxon. But there has not been any serious disagreement with the contention that synthetic fuels are in the forefront of the likely candidates during all future periods. It would appear, therefore, that a demonstration program could be developed around a program utilizing synthetic fuel. But the program would probably be a demonstration of a synthetic fuel production process, rather than a demonstration of a specific fuel. The fuel, after all, would be a replicate of currently available supplies.

The only other candidate that has been mentioned as a possibility for a demonstration project is hydrogen. It does not appear that this fuel would be a serious contender for an automotive evaluation anytime in the near future. The AFUP plan does not even mention the fuel as meriting demonstration consideration. The IGT and Exxon studies mention the fuel as having possible attractiveness only after the year 2000.

5. CONCLUSIONS AND RECOMMENDATIONS

The first conclusion of the study is that the only alternative fuels that appear to be likely candidates for a demonstration in the near term are alcohol and synthetic fuels. But if synthetic fuels are used in a demonstration, the main demonstration criteria will be an evaluation of the production process, not the merit of the fuel itself. Alcohol, however, would benefit from a demonstration that would include either the production process <u>or</u> the actual use of the fuel in the field. The major demonstration fuel contender therefore, is alcohol, either straight or in a gasoline blend. Ideally, the demonstration should include an evaluation of the production process and the field application.

The only likely supporter of a demonstration project is the U.S. Department of Energy, Division of Transportation Energy Conservation. There are tentative plans for supporting some demonstration programs of alcohol/gasoline blends in the near future.[30] The most likely funding dates will be during FY1980, with the possibility that the funding would not occur until FY1981 or FY1982. The presentation by a serious commercial or governmental entity of a demonstration concept to the Department of Energy would accelerate the funding date. This would be especially true if the organization indicated a willingness to perform the demonstration on a shared-cost basis.

It is recommended that there be a plan for a public transit demonstration project using alcohol. The preferred alcohol would be methanol. The demonstration, hopefully, would include the construction and operation of a methanol pilot plant utilizing:

...forest products biomass, available in large quantities in the upper peninsula, or

...solid waste, available in Southeastern Michigan.

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30. Personal interview with Chief, Alternative Fuels Branch, DOE, April, 1978.

Both concepts have appeal, but for different reasons. A project developed on the utilization of forest products biomass also has the benefits of being operated in an isolated areas (the upper peninsula). The effects (costs and benefits) could therefore be more easily measured. A project using solid waste biomass from Southeastern Michigan has the benefit of being a demonstration that would have results more potentially extrapolatable to heavily urban areas.

In developing the demonstration proposal the following concepts should be used as a guide:

> ...The production of new technology regarding the characteristics of a technology in a real-world setting. This new information is aimed at potential adopters and manufacturers to stimulate the use of the technology, and at regulatory agencies to provide the basis for decisions that might require use of the technology.
>
> ...The exemplification of a technology, by dissiminating existing information; to provide potential adopters with opportunities for first-hand assessment of its usefulness and applicability.
>
> ...The encouragement of institutional and organizational changes in an industry and related organizations to facilitate adoption of the technological change.
>
> ...The fulfillment of high-level national policy goals, such as reducing the U.S. dependency on imported foreign oil.[31]

The proposed demonstration should contribute to achieving all four categories of goals. A demonstration that would accomplish this would consist of the following:

1) ...construction and operation of a methanol pilot plant, utilizing local materials input. Such a plant should be totally self-contained, and should supply all of the demonstration fuel utilized by the transit property. Any extra methanol produced would be sold in the open market to help defray pilot plant operating costs.

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31. Foster, R.W., "Alternative Fuels and Intercity Trucking, University of Miami and Escher Technology Associates, ETA Report PR-82. April, 1978. Pp. 302 plus Appendicies.

2) ...a transit property that would have both alternative-fuels demonstration vehicles and regular-fueled vehicles in operation. The demonstration fleet would then be evaluated against the regular-fueled "base" fleet.

3) ...the project should operate for <u>at least</u> three full seasons, hopefully for at least five years. In this way, the aberrations caused by operator and mechanic training would be neutralized.

4) ...the State of Michigan and/or the local transit property should agree to participate in the project on a shared-cost basis.

In describing a demonstration project on intercity trucking utilizing alternative fuels, Foster[32] discussed the critical role of information in the demonstration. His comments should be used as a guide in developing a plan for a demonstration project of a public transit property utilizing alternative fuels:

> Figure...(5-1)...illustrates the inter-relationships between participating organizations and agencies, the program objectives, the two basic processes of the program planning and program operation, and the information product resulting from the program operation.
>
> In the program under discussion here, our final objective, given that the results of the demonstration program are positive and encouraging, is to provide effective dissemination of these position findings to the target audiences...Effective information dissemination is essential if diffusion success is to be achieved. The key to achieving a good program and effective information dissemination is good project planning....
>
> ....Planning for an operation of the demonstration project would include explicitly the target audiences who are expected to make use of the demonstration results. The following guidelines are proposed....
>
> 1. Potential adopters and other target audiences should help plan the demonstration through advisory panels or preferable, as direct participants.

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32. <u>Ibid</u>, pp. A-6 to A-8.

2. Where substantial technological uncertainty exists, planning for the demonstration should include organizations that have conducted R&D or field tests in the technology.

3. Where resolution of externality uncertainties (such as health, safety, and environmental quality standards) is important, the relevant federal, state, and local regulatory agencies should be directly involved in planning for the demonstration.

4. Concrete planning should be done at the local operating level with federal review, and not by the federal agency.

5. The demonstration should include private sector firms with strong incentives to become manufacturers or suppliers of the technology.

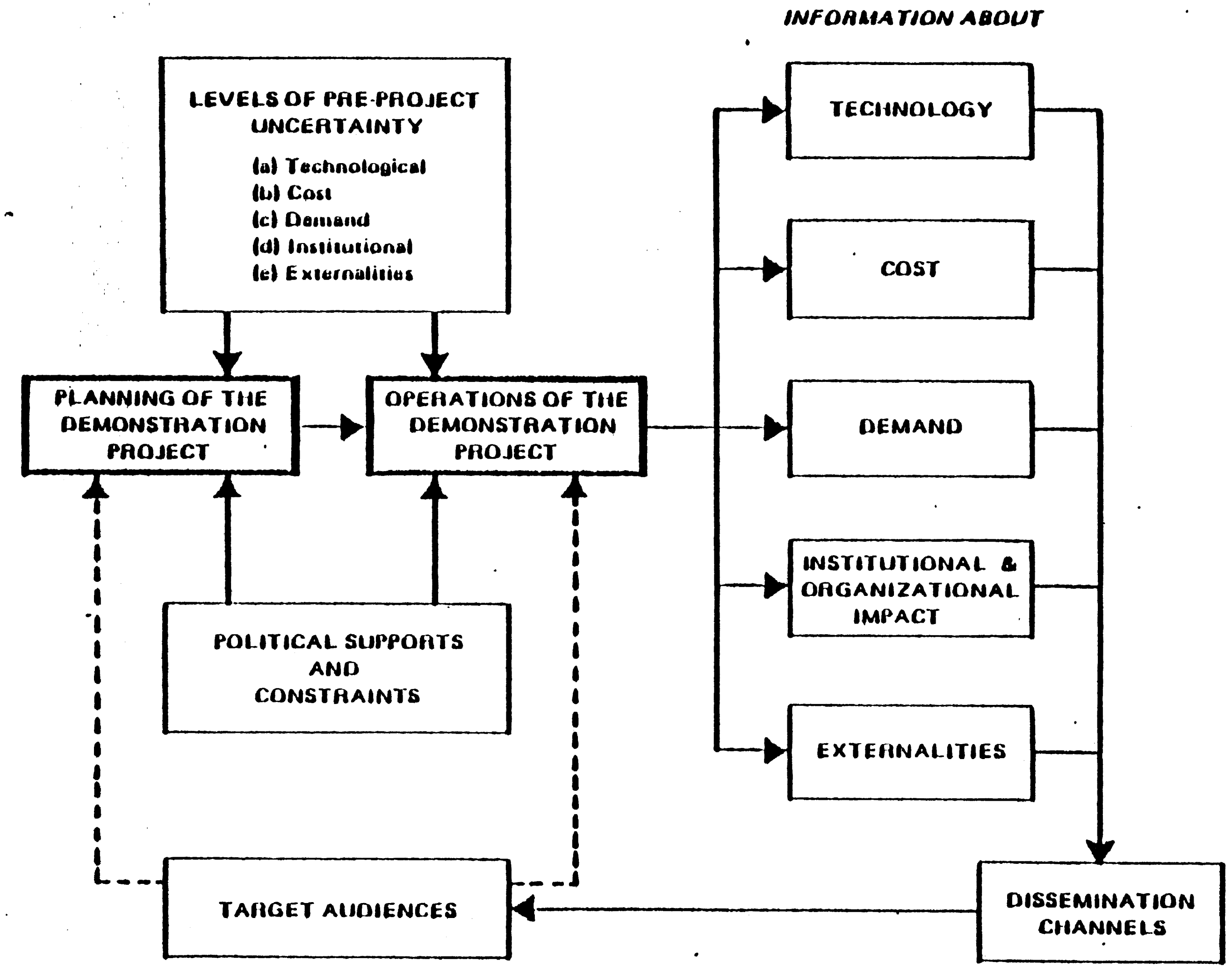

Figure 5-1 Information Flow in a Typical Demonstration Project

Source: Reference A-1

6. BIBLIOGRAPHY

1. Adt, Jr., R.R. and Rhee, K.T., "Effects of Blending Alcohol with Gasoline on Automotive Engine Steady State Performance and Regulated Emissions Characteristics", (DOE Contract EY-76-5-05-5216.)

2. Adt, Jr., Robert R., Swain, Michael R., Pappas, John M., "Hydrogen Engine Performance Analysis Project". DOE Contract E(04-3) - 1212.

3. Affens, Wilbur A., Boss, Bruce D., Hazlett, Robert N., and Schuldiner, Sigmund, Hydrogen as a Navy Fuel, A study prepared by the NRL Hydrogen Panel, June 12, 1974.

4. "Alternative Fuels Utilization Report", No. 2., August 1977. U.S. Energy Research and Development Administration.

5. "Alternative Fuels Utilization Report", U.S. Department of Energy, March, April and October, 1978.

6. Automotive Hydrogen Storage with Magnesium Hydride, Contract EY-76-C-04-3684.

7. Automotive Power Systems Contractors Coordination Meeting, Eighth Summary Report, Ann Arbor, Michigan, May 6-8, 1975. U.S. Energy Research and Development Administration.

8. Automotive Stirling Engine Development Program, Contractors Coordination Meeting Report, May 1978, Abstract. Ford Motor Company, Engineering and Research Staff, Dearborn, Michigan.

9. Bade, Nicholas E., "The Greyhound/DOE Turbine-Powered Intercity Bus Demonstration Program." (Director of Marketing Greyhound Lines, Inc.)

10. Beremand, Donald G., and Ragsdale, Robert G., National Aeronautics and Space Administration, "Stirling Engine Project Status". Prepared for U.S. Department of Energy.

11. Bernard, Martin J. III, "The Tec Environmental Development Plan," Argonne National Laboratory, University of Chicago.

12. Bolt, J.A., Cole, D.E., Patterson, D.J., Department of Mechanical Engineering, The University of Michigan. DOE Contract #E(29-2)-3682, "Engine Modifications for Use of Methanol and Methanol Gasoline Blends."

13. CSAD-Controlled Speed Accessory Drive Demonstration Program, presented by Jet Propulsion Laboratory, California Institute of Technology.

14. Chesnes, Albert A., and Campbell, James F., "Demonstration and Evaluation of Gas Trubine Engines in Urban Transit Coaches."

15. Denaturants for Ethanol/Gasoline Blends, Department of Energy, Contract EX-76-C-01-2098, April 1978. Mueller Associates, Inc.

16. Department of Energy Position Paper on Alcohol Fuels, U.S. Department of Energy, March 1978.

17. Department of Energy Position Paper on Alcohol Fuels, DOE paper on Alcohol Fuels, April 1978.

18. Energy, 1978 Special Annual Issue, A Look Back-A Look Forward.

19. Energy Topics, A Periodic Supplement to IGT Highlights, October 10, 1977.

20. "Engine and Environment Improvement Possibilities with Alcohol", The University of Santa Clara, California Mechanical Engineering Department.

21. "Engine Lubricants for Use in Alcohol Fueled Highway Vehicles", Contract No. E(49-28)-1021. By U.S. Army Fuels and Lubricants Research Laboratory in San Antonio, Texas, for U.S. Department of Energy.

22. Escher, Wm. J.D., Hydrogen-Fueled Internal Combustion Engine, A Technical Survey of Contemporary U.S. Projects. Escher Technology Associates, ETA Report PR-51. September 1975.

23. Escher, Wm. J.D., Prospects for Liquid Hydrogen Fueled Commercial Aircraft, Escher Technology Associates, Report PR-37. September 1973.

24. Escher, Wm. J.D., and Foster, R.W., "Direct Solar Energy Conversion at Sea (DSECAS): Characteristics of a Baseline Concept."

25. Escher, Wm. J.D. and Hanson, Joe A., Ocean Based Solar-to-Hydrogen Energy Conversion Macro System, November 1973.

26. Foster, R.W., Alternative Fuels and Intercity Trucking, ETA Report No. PR-82, April 1978. Ryder Program in Transportation and Escher Technology Associates.

27. Foster, R.W. and Escher, Wm. J.D., Hydrogen-Fueled Railroad Motive Power Systems, A Feasibility Study. Escher Technology Associates, ETA Report PR-70. September 1970.

28. "The Wood Energy Concept--It's Applicability in Michigan" report to the Upper Great Lakes Regional Commission, submitted by Tom Heck, Energy Administration, Michigan Department of Commerce.

29. "An Evaluation of the Safety and Handling Properties of the Cab-Under Truck-Tractor Vehicle", by Highway Safety Research Institute, The University of Michigan, March 1, 1978.

30. Highway Vehicle Systems Contractors Coordination Meeting, Ninth Summary Report, Ann Arbor, Michigan. November 17-18, 1975.

31. Highway Vehicle Systems Contractors Coordination Meeting, Tenth Summary Report, Ann Arbor, Michigan. May 4-6, 1976. Division of Transportation Energy Conservation.

32. Highway Vehicle Systems Contractors Coordination Meeting, 13th Summary Report.

33. "Identification of Probable Automotive Fuels Compositions: 1985-2000", DOE presented by Southwest Research Institute, Contract EY-76-C-04-3684.

34. "In-Vehicle Stirling Engine Operational Experience", presented by KB United Stirling (Sweden) AB & Company, sponsored by U.S. Department of Energy Highway Vehicle Systems Contractors' Coordination Meeting.

35. Jones, L.W., "Perspectives on the Evolution into a Hydrogen Economy", The University of Michigan.

36. Keller, James L., Union Oil Company of California, Research Center, Brea, California. "Solving Alcohol Fuel Problems by Fuel Modification", DOE Contract EY-76-C-04-3683.

37. MTI Stirling Engine Powertrain Development, by Mechanical Technology Incorporated, Latham, New York, presented at Department of Energy Highway Vehicle Systems Contractor's Coordination Meeting, May 9-12, 1978.

38. Moses, C.A., "Hybrid Fuels", Southwest Research Institute, San Antonio, Texas.

39. Phoebe, C.H., Gulf Research and Development Company, Pittsburgh, Pennsylvania, Passenger Car Fuel Economy in Short Trip Operation.

40. Prestamo, Prof. Felip, and Foster, Richard W., "A Study of the Applicability of Near, Mid and Far Term Alternative Fuels to Intercity Trucking Systems."

41. Program Planning Document Highway Vehicle Alternative Fuels Utilization Program (AFUP), Department of Energy.

42. Ragsdale, Robert G., and Beremand, Donald G., "Stirling Engine Project Status", prepared for DOE, Agreement EC-77-A-31-1040.

43. Review of Automotive Technology Status and Projections Projects, DOE Contractor's Coordination Meeting. Jet Propulsion Laboratory, California Institute of Technology.

44. Schiferlie, J.W., "The Present Philips Program on the 4-215 DA Stirling Engine", presented at DOE Highway Vehicle Systems Contractor's Coordination Meeting, May 9-12, 1978.

45. Second Symposium on Low Pollution Power Systems Development, the U.S. LPPSD Technical Information Exchange Document No. 3.

46. Correspondence to Mr. William D. Eberle, President of Motor Vehicle Manufacturers Association, Detroit, Michigan from Mr. Leonard Segel, Head, Physical Factors Group, The University of Michigan.

47. Report to "Japan Society for the Promotion of Science", June 4, 1975, reported by Professor Leonard Segel.

48. "Status Report on Diesel Organic-Rankine Compound Engine for Long-Haul Trucks", Thermo Electron Corporation.

49. "Etherified Fuels - A Transitional Approach to Straight Oxygenated Hydrocarbons?", by SUNTECH, Inc., Marcus Hook, PA, for the U.S. Department of Energy, Alternative Fuels Branch. Contract #EM-78-C-04-4045.

50. Survey of Liquid Hydrogen Container Technology for Highway Vehicle Fuel System Applications, Escher Technology Associates.

51. "World Energy Outlook", Exxon Corporation, April 1978.