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FEASIBILITY STUDY OF ALTERNATIVE FUELS FOR AUTOMOTIVE TRANSPORTATION

VOLUME I - EXECUTIVE SUMMARY

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Mobile Source Air Pollution Control
Alternative Automotive Power Systems Division
Ann Arbor, Michigan 48105

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Prepared by

F. H. Kant, R. P. Cahn, A. R. Cunningham,
M. H. Farmer, W. Herbst, and E. H. Manny

Exxon Research and Engineering Co.
P. O. Box 45
Linden, New Jersey 07036

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EPA Project Officer:

C. E. Pax

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FOREWORD

For convenience, the material covered in this report is divided into three volumes. Volume I is an executive summary comprising the report summary, highlights of the various sections and a list of conclusions. Volume II is the technical section, which is a complete description of the work carried out under this contract. It includes the sections bound separately in Volume I. Volume III includes the appendices, which deal with supplementary material for some of the topics discussed in Volume II.

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SUMMARY

This study identifies feasible and practical alternatives to automotive fuels derived from petroleum for the 1975-2000 time period. The alternative fuels are liquids derived from domestic coal and oil shale -- specifically, gasolines, distillates, and methanol. While many uncertainties remain, initial production of the new fuels is likely within the next five to seven years.

The United States has vast resources of coal and oil shale, sufficient to permit large scale production of synthetic fuels. However, other factors such as the availability of skilled manpower and water are expected to constrain the rate at which the resources can be developed. Complete replacement of petroleum with synthetic fuels is therefore improbable until after the turn of the century. Rather, it appears that the alternative fuels will begin to be used in conjunction with petroleum, that usage will expand as availability increases, and that the approach to complete replacement will be evolutionary.

The study shows that there is an excellent chance of developing alternative automotive fuels, or blending components, that can take advantage of the existing distribution and marketing system for automotive fuels. Additionally, the new products may satisfy the fuel requirements of conventional vehicles as well as the anticipated needs of several types of automotive power plants now under development. Not surprisingly, fuels similar to petroleum, derivable from both coal and oil shale, present the least difficulty and uncertainty.

While differing in estimated cost, the individual fuels examined in detail may all be producible at a cost level or range projected for petroleum fuels. Indeed, the shale fuels may be significantly lower in cost. Nevertheless, the estimates of cost are sensitive to more than technological uncertainties. For example, costs are sensitive to assumptions that concern inherently unpredictable matters such as surface mining legislation, leasing policy, and required level of investment return.

Early in 1974 consumption of automotive fuel was just over six million barrels/day (MMB/D) or 12 x 10^{15} BTU/year, and this may be taken as a lower bound of future consumption. Upper limits are estimated to be about 9.5 MMB/D or 19 x 10^{15} BTU/year in 1985 and 12.5 MMB/D or 25 x 10^{15} BTU/year in the year 2000. The total output of synthetic fuels, for all purposes, including automotive fuels, could reach 25 x 10^{15} BTU/year by the year 2000, but will only be about 4 x 10^{15} BTU/year in 1985, which is about a third of the minimum projected automotive fuel demand.

Fuels were screened on the basis of economic, technical, and performance criteria, with consideration given to the way in which each new fuel could be brought into general use. Consideration was also given to the environmental impact of producing and using the fuels. From a fairly comprehensive list of initial candidates, feasible and practical alternative automotive fuels were identified:

- gasoline-type and distillate-type fuels from oil shale

- gasoline-type, distillate-type, and methanol fuels from coal.

Each of these five fuels was then evaluated in detail.

For the shale-derived fuels, the analysis began with mining, crushing and retorting of the oil shale. The raw shale oil was upgraded, and then transported by pipeline to a plant capable of converting the shale syncrude into automotive fuels. The latter were then fed into a distribution and marketing system, ending at a fuel pump in a service station. Investment and operating costs were estimated for the entire system for three points in time: 1982, 1990 and 2000.

The same procedure was applied to the petroleum-type fuels derivable from coal, except that mining was followed by liquefaction rather than retorting. Methanol from coal was made by gasification, followed by methanol synthesis. In this case, the methanol product entered the distribution and marketing system without additional processing steps other than keeping the fuel dry throughout the system.

Based on 1973 constant dollars, the costs per million BTU estimated for the five fuels were*: (including a 10% discounted cash flow return on investment)

		1982		1990	2000
		$/MMBTU	¢/Gal.	— $/MMBTU —	
Shale:	gasoline	2.65	31.5	2.60	2.15
	distillate	2.05	26.5	2.00	1.65
Coal:	gasoline	3.35	39.5	3.15	2.65
	distillate	2.75	36.5	2.50	2.10
	methanol	3.85	22.	3.40	2.95

1973 $, ex tax at pump

Because internally consistent assumptions were used, the cost estimates are more reliable on a relative rather than on an absolute basis. However, the differential between the gasoline-type and distillate-type fuels depends on a "prudent" refining scheme in which the ratio of gasoline

* It must be stressed that these are 1973 costs. As of May 1974, costs for capital projects have escalated substantially in excess of general inflation.

to distillate is not less than about 2:1. The shale-derived fuels are projected to be cheaper than coal-derived fuels over the entire time-frame of the study. However, the quantitative development of shale oil will probably be limited environmentally and by other resources, such as manpower and water, rather than by economics and potential demand.

The ranking of fuels was not changed by consideration of user economics, i.e., the total cost of vehicle operation as opposed to fuel cost alone.

Potential product quality problems, related to the aromaticity of coal-derived fuels on the one hand and the paraffinicity of shale-derived fuels on the other, can most easily be dealt with by blending with petroleum fractions, or with each other. Product quality considerations with methanol depend on whether it will be used alone or in gasoline blends. In the former case, significant efficiency improvements in a spark-ignition engine seem possible if the engine is modified. However, such a modified engine would not be compatible with gasoline fuel.

Methanol appears to be an excellent gas turbine fuel. In particular, it could find growing application in stationary turbines where bulk deliveries minimize the relatively high distribution costs of methanol vs. hydrocarbon fuels. Methanol is also a leading candidate for fuel cells, used either directly or via reforming to hydrogen.

The use of methanol/gasoline blends in spark-ignition engines could lead to performance problems due to water sensitivity, vapor lock, and excessive leaning out of the engine. On the other hand, use of these blends would result in improved octane quality and could lead to significant fuel economy savings, in miles/BTU.

The uncertainties about the performance of methanol have to be resolved before its merits relative to hydrocarbons can be established. On balance, however, the compatibility of shale and coal hydrocarbons with petroleum is a key point in favor of these fuels.

There is a critical need for product quality and performance data on fuels from coal and shale, alone and in blends. This is one of the research data gaps identified in a separate phase of the study. Other data or technology gaps include:

- New or improved technology for:
  - in-situ recovery of shale oil
  - hydrogen production for coal liquefaction
  - selective removal of S, N, and O from coal and shale
  - coal gasification plus methanol synthesis

- Large-scale demonstration of environmentally acceptable disposal of spent shale and reclamation of surface-mined coal areas.

- General studies dealing with:

    - alternative automotive fuels in the context of the entire economy, based on utilizing all resources including petroleum

    - water availability in the Western states

The future availability of capital will have a strong influence on investment priorities. This is an argument in favor of alternative fuels, such as shale and coal gasolines and distillates, which are compatible with the existing petroleum-based system. Major investments are beginning to be made in these synthetic fuels. For example, about $450 million was bid on the first four shale tracts recently leased by the government. Research and development programs on coal liquefaction by industry and government, including construction of various demonstration units, will probably total over one billion dollars in the next five years. Some products of such shale and coal conversion plants will surely find their way into the automotive fuel market. There is therefore beginning to be a commercial underpinning of the technological and economic feasibility conclusions drawn in this study.

HIGHLIGHTS

The highlights that follow reflect the contractor's judgment of what are the most important points in each of the detailed sections of the report.

Objectives (2.1)

- Identify feasible and practical automotive fuels that are producible from non-petroleum sources.
- Define the alternative automotive fuels in terms of: when? how much? at what cost?
- Consider safety, toxicity, reliability, compatibility with different engines, and convenience of use.
- Identify R&D and other information gaps.

Approach (2.2)

- Select alternative fuels with a reasonable chance of being feasible and practical within the 1982-2000 time-frame which is the most important with regard to potentially new fuels.
- Use preliminary screening to permit concentration of effort on a small number of the most promising fuels to get maximum information on cost, availability, and performance.

Relationship to Energy Supply/Demand in General (3.2)

- Automotive fuel questions should not be divorced from energy matters in general.
- Detailed analysis of "externalities" is beyond the scope of the study, but identification and rough quantification of the most important externalities is possible.
- With some modification, the Department of Interior's energy forecast of December 1972 may be used quantitatively as an energy context for alternative automotive fuels.

Automotive Fuel Demand (3.3)

- The goals of "Project Independence" probably set <u>upper</u> limits on automotive fuel consumption of about 9.5 MM B/D in 1985 and 12.5 MM B/D in the year 2000. Consumption of just over 6 MM B/D, early in 1974, may be taken as a <u>lower</u> limit.

Domestic Resource Base (3.4)

- The principal domestic fossil fuel resources are petroleum, coal and oil shale. Nuclear energy may facilitate the utilization of these resources.

- Other energy resources can lessen the industrial or stationary demand for the principal fossil fuel resources, thereby increasing their potential availability for automotive purposes.

U.S. Coal Resources (3.4.1)

- The domestic coal resource base is very large and, per se, will not be the factor that limits the production of synthetic fuels for several decades.

- Western coal resources, recoverable by surface mining, appear best suited economically to the production of alternative fuels.

- The Federal government controls the mineral rights to much of the Western coal. This important part of the resource base cannot be utilized until the coal lands are leased.

U.S. Oil Shale Resources (3.4.2)

- The oil shale resource is very large and very important. However, environmental considerations and other factors such as water availability are likely to limit the rate at which shale oil can be produced.

- Possible production levels during the next several decades are more important than the ultimate "reserves" of shale oil.

- Government leasing policy will be very important since the government holds the mineral rights to about 80% of the richer oil shale properties.

U.S. Petroleum Resources (3.4.3)

- Conventional petroleum supplies for the production of motor fuel are likely to be available from domestic resources beyond the year 2000.

- Production of domestic petroleum is likely to be higher in the 1980's than it is today. Even so, synthetic fuels from other domestic resources will be needed.

U.S. Natural Gas Resources (3.4.4)

- Production of domestic natural gas is also likely to increase, thereby freeing liquid fuels, such as distillate, from stationary uses.

U.S. Nuclear Resources (3.4.5)

- Nuclear electricity capability is behind schedule, and available capacity will be fully required for satisfaction of conventional demands for electricity until about 1985.

- Eventually, nuclear energy may be applied to the production of synthetic fuels and, possibly, in the long run to the production of hydrogen fuel.

Capacity Build-Up (3.5)

- The rate at which resources can be brought into production must be considered as well as the size of the resource base.

- Various constraints on the building of synthetic fuels plants are expected to limit production in 1985 to products containing the energy equivalent of about 3.7×10^{15} BTU/yr. This estimate is for the total of all types of synthetic fuels including what may be used as automotive fuels. By the year 2000, total output could reach 25×10^{15} BTU/yr. These estimates of synthetic fuel supplied are equivalent to 4.2% and 18% respectively of the total U.S. energy demand by final consuming sectors as forecast by the Department of the Interior in 1972.

Criteria for Fuel Selection (3.6)

- Economic criteria include the ex. tax cost of fuel at the pump, the operating cost of the vehicle that would use a particular fuel, and the implied capital requirements of given fuel/vehicle systems.

- Technical criteria include fuel availability, prudence in resource utilization and associated environmental impacts.

- Performance criteria include compatibility (i.e., the suitability of a given fuel for use in a given vehicle), toxicity and safety, efficiency of fuel use, environmental impact in use, and the convenience and acceptability of a given system as perceived by the user (driver).

- Consideration must also be given to the way in which a new fuel could be brought into general use, to interactions with the existing vehicle population and fuel delivery system, and the impact on availability of resources.

Initial List of Fuels (4.1)

- A list of fuels was prepared containing all candidates which could conceivably become viable automotive fuels by 2000.

- The list included (1) coal-derived fuels: gasoline, middle distillate, methanol, higher oxygenated compounds, and hydrogen; (2) shale-derived fuels: gasoline and middle distillate; (3) ethanol by fermentation; (4) hydrogen from water; (5) ammonia from coal or water-based hydrogen, and (6) hydrazine.

Physical and Chemical Properties (4.2)

- A detailed literature search yielded information on the properties of the above fuel candidates, but indicated that many data gaps exist. These gaps reflect the fact that the fuels either have not been available (coal and shale derived hydrocarbons) or have not been completely evaluated in internal combustion engines (methanol, hydrogen, ammonia).

- The physical property data were analyzed in terms of their relation to combustion, storage and handling, automotive maintenance, and "driveability".

Cost of Manufacture and Distribution (4.3)

- The technology for fuel manufacture was reviewed in order to choose a basis for estimating manufacturing economics.

- Published information allowed such estimates to be made. Distribution costs were based on analyzing similarities to, and differences from, the system presently used for petroleum products.

- The following first generation costs (ex. tax, at the pump) were estimated in terms of 1973 $/MMBTU (including a 10% DCF return):

Fuel	Cost
Gasoline from Shale	2.65
Middle Distillate from Shale	2.05
Gasoline from Coal	3.35
Middle Distillate from Coal	2.75
Methanol from Coal	3.85
Methane from Coal	5.65
Oxygenated Compounds from Coal	4.60
Ethanol by Fermentation	7.10
Hydrogen from Coal	9.90
Hydrogen from Water	10.20
Ammonia	7.65
Hydrazine	20+

Fuel-Vehicle Compatibility (4.4)

- A brief assessment was made of the compatibility of the above fuels with various engine types including the conventional Otto cycle, stratified charge, diesel, gas turbine, Stirling, Rankine, and fuel cell.

- The compatibilities range from high (e.g., for coal and shale hydrocarbons in all of the engines) to moderate (e.g., alcohols and methane in Otto cycle engines) to low (e.g., hydrogen in all engines or ammonia in Otto cycle engines).

Environmental Impact (4.5)

- Coal and shale mining will have substantial environmental impacts. In order to keep these to a manageable level, it will be necessary to (1) permanently revegetate spent shale dispersal areas with a minimum amount of water, (2) reclaim surface-mined Western coal lands, (3) plan effectively for the influx of a large number of people into sparsely populated areas.

- Information is very limited on exhaust emissions for the alternate fuels. Coal and shale-derived hydrocarbons are expected to result in emissions similar to petroleum fuels.

Toxicity and Safety (4.6)

- Hydrazine and ammonia are the most toxic of the fuels examined, considering skin penetration, inhalation, and ingestion. Methane and hydrogen are the least toxic. Shale and coal hydrocarbons and alcohols are intermediate.

- Consideration of safety in manufacture, handling, and use indicate that hydrogen, methane, ammonia, and hydrazine present the most serious problems. Shale and coal gasolines, as well as methanol, are safer to handle. Shale and coal distillates and ethanol are the safest of the fuels considered.

Ranking of Fuels (4.7)

- The fuels were ranked using the criteria described in Section 3.5.

- The following five fuels were judged most promising and were examined in detail:

  (1) gasoline from shale
  (2) distillate from shale (as coproduct with gasoline)
  (3) gasoline from coal
  (4) distillate from coal (as coproduct with gasoline)
  (5) methanol from coal

Cost of Automotive Fuels From Shale Oil (5.1)

- Economic estimates were prepared for manufacturing gasoline and distillates from shale using the following sequence:

  (1) mining and crushing.

  (2) retorting, using the TOSCO design based on recycled hot solids.

  (3) upgrading of raw shale oil to high quality syncrude by hydrogenation and coking at the mining site.

  (4) pipelining of syncrude to a refinery.

  (5) refining of syncrude to gasoline and distillates by conventional processes, such as catalytic cracking and reforming.

  (6) distribution of products the same as for petroleum.

- The economics for steps (1), (2), and (3) were adapted from those prepared by the National Petroleum Council (NPC), adjusted to the bases used in this study.

- The following costs in 1973 \$, were estimated for the period 1982/1985 (including a 10% DCF return):

  Shale Syncrude: ca. \$5.50/Bbl (includes value of lease bonus payment). The sensitivity of syncrude cost to investment level, rate of return, and oil content of shale was calculated, e.g., with a 15% DCF return the syncrude would cost \$7.05/Bbl and would result in proportionate increases in gasoline and distillate costs.

  Shale Gasoline: \$2.70/MMBTU ex. tax at pump.

  Shale Distillate: \$2.10/MMBTU ex. tax at pump.

- The distillate cost is applicable only to a case where distillate and gasoline are co-products in the ratio of ca. 1:2.

- Cost projections were made for the 1982-2000 period allowing for effects of new technology (see Section 5.4).

Cost of Hydrocarbon Fuels From Coal (5.2)

- The cost of gasoline and distillate from coal was based on the following sequence:

  (1) Surface-mining of Western coal.

(2) Hydrogenation at the mine to syncrude using the HRI "H-Coal" process; other processes were considered but were rejected on the basis of insufficient available information; hydrogen was supplied via gasification (Lurgi process).

(3) Pipelining of syncrude to a refinery.

(4) Refining of syncrude to gasoline and distillate by conventional processes, such as hydrocracking and catalytic reforming.

(5) Distribution of products same as for petroleum.

- The following costs were estimated for the period 1982/1985 (1973 $):

  Coal Syncrude: ca. $8.00/Bbl, based on $3/ton coal. The sensitivity of this cost to changes in coal price, investment, and return level was calculated, e.g., with a 15% DCF return and $5/ton coal the syncrude would cost $11.40/Bbl.

  Coal Gasoline: $3.35/MMBTU ex. tax at pump.

  Coal Distillate: $2.75/MMBTU ex. tax at pump.

- As with the shale fuel economics, the distillate/gasoline ratio was ca. 1:2.

- Cost projections for the 1982-2000 period reflected changes in coal price as well as new technology (see Section 5.4).

Cost of Methanol From Coal (5.3)

- The cost of methanol from coal was based on coal gasification with the Lurgi process followed by methanol-synthesis from CO + H_2. This scheme produces methanol and methane (SNG) as co-products. Other gasification processes seem to be less efficient for this application, but information on these alternates was very limited.

- Methanol distribution is significantly different from distributing petroleum products for two reasons:

  (1) if used in a 10-15% gasoline blend, blended at the pump, methanol must be distributed dry to avoid phase instability.

  (2) methanol has about 50% of the energy content of hydrocarbon fuels, which results in higher distribution costs, on a BTU basis.

- The methanol cost at the pump, for the 1982-1985 period, was estimated at $3.85/MMBTU.

- As with the other fuels, cost projections were made for the 1982-2000 period.

Comparison of Costs (5.4)

- From the cost information developed in Sections 5.1-5.3, the following projections were made:

		1982		1990	2000
		$/MMBTU	¢/Gal.	— $/MMBTU —	
Shale:	gasoline	2.65	31.5	2.60	2.15
	distillate	2.05	26.5	2.00	1.65
Coal:	gasoline	3.35	39.5	3.15	2.65
	distillate	2.75	36.5	2.50	2.10
	methanol	3.85	22.0	3.40	2.95

1973 $, ex tax at pump

Due to the many uncertainties in these estimates, ±10% limits on the costs seem reasonable. Nevertheless, relative costs are felt to be fairly reliable.

- Shale-derived fuels are projected to be cheaper than coal-derived fuels over the entire time-frame of the study. The development of shale fuels, however, will not be governed solely by these economics. It will probably be controlled by environmental, manpower, and resource limitations.

- Methanol is slightly more expensive than coal liquids, reflecting the greater contribution of distribution costs for methanol. Methanol would therefore be more attractive in applications such as transportation fleet accounts, or, more generally, in fuel uses other than transportation.

- Distillates are cheaper than gasolines, as long as a prudent refining scheme is used, in which the two are co-products with roughly 30-40% distillate.

- A comparison among these fuels on the basis of capital intensity gives the following:

	$/Barrel/Day		
	Production of Syncrude	Refining	Total
Shale			
Gasoline	6,700	2,000	8,700
Distillate**	6,500	400	6,900
Coal			
Gasoline	11,600	2,600	14,200
Distillate**	12,200	1,300	12,500
Methanol	—— 5,900 (11,800)* ——		5,900 (11,800)*

* On equivalent BTU basis.
** As co-product with gasoline.

- The relative capital intensities parallel the relative costs at the plant gate.

- Another comparison was made of the relative efficiencies of manufacturing these fuels:

	Energy in Total Product/Total Input Energy	
Auto. Fuel Product:	Gasoline	Gasoline + Distillate
Shale	0.55	0.65
Coal Hydrocarbons	0.65	0.70
Methanol	—— 0.65 (0.55)* ——	

* If Lurgi process by-products cannot be used as process fuel.

- Efficiencies for producing shale fuels are a little lower than for coal fuels, reflecting losses in shale retorting. Methanol production is less efficient than coal liquefaction unless the gasification by-products can be used as a source of process heat.

User Economics (5.5)

- An attempt was made to compare the cost of owning and operating a vehicle over its life as a function of fuel type. This was done by estimating the effect on vehicle weight and cost due to fuel-connected factors related to compatibility, environmental effects, toxicity and safety.

- Based on reference data for cost and weight of a 1973 model, 3500 lb. vehicle, the following comparison was made for the relative cost of fuel vs. other operating and fixed costs:

10 Year Life, 100,000 Miles

Engine	Fuel	Relative Cost*			
		Fuel	O,M,R,T†	Fixed**	Total
Otto Cycle	Shale Gasoline	[1.0]	1.2	2.9	5.1
	Coal Gasoline	1.3	1.2	2.9	5.4
	Methanol	1.5	1.2	2.9	5.6
Diesel	Shale Distillate	[1.0]	2.6	6.5	10.0
	Coal Distillate	1.3	2.7	6.7	10.7
Gas Turbine	Shale Distillate	[1.0]	1.7	4.1	6.8
	Coal Distillate	1.3	1.7	4.2	7.2
	Methanol	2.0	1.7	4.2	7.9

* Reference point for each engine designated by [1.0]; comparison among engines not valid.
† Oil, mainenance, repairs, tires.
** Depreciation, insurance, license, and registration.

- The data indicate that, for a given engine type, changes in relative fuel cost are dampened by other costs unrelated to fuel, so that total vehicle operating cost is not changed much.

- Another comparison of relative fuel cost per mile for the three time periods and engine types indicates that these costs parallel the relative ex. tax pump costs. This reflects the assumption that, for the fuels examined, engine efficiency is not a significant function of fuel.

Performance of Gasolines and Distillates From Shale and Coal (6.1)

- High Research octane gasoline fractions based on catalytically reformed coal and shale syncrude fractions will be quite aromatic but no more so than petroleum fractions reformed to the same Research octane level. Comparable data on Motor octanes are generally not available for these synthetic fuels.

- Due to the aromatic nature of coal vs. shale syncrude, naphtha (unreformed) and distillates based mainly on coal will have a higher aromatics content. If, however, the coal-derived fuels are blended either with shale or petroleum fractions, as is likely to be the case, the aromaticities of the blends will be similar to those in current use.

- If gasolines rich in coal-based fractions are used, consideration must be given to factors such as:

  (1) front-end volatility adjustment.

  (2) maximum safe benzene concentration.

  (3) materials of construction of the fuel system.

- It should be possible to make a good quality diesel fuel from shale syncrude. However, more information is needed on cloud point to determine if it should be reduced -- e.g., by the use of additives.

- There are almost no product quality data on distillates from coal. Based on their composition, however, it is likely that such fractions will be deficient in cetane number. If this is confirmed, the options available for correcting the deficiency are: (1) blending with shale or petroleum fractions (the best alternative), (2) use of cetane improvers, or (3) more severe hydrogenation.

- The suitability of coal distillates as a gas turbine fuel has to be determined. High aromaticity could lead to excessive flame luminosity and smoking.

Performance of Methanol and Methanol/Gasoline Blends (6.2)

- Pure methanol could be an attractive motor fuel for an Otto cycle engine, based on its high octane number (106 Research and 92 Motor unleaded). It should be possible to operate at increased compression ratio, leading to improvements in thermal efficiency. However, the vehicle and engine have to be modified to take account of the low volatility, high heat of vaporization, and low heat of combustion of methanol. Methanol should be a very good fuel for continuous combustion engines.

- The use of methanol/gasoline blends brings up a number of potential problem areas:

  (1) Water sensitivity: Methanol/gasoline blends are susceptible to phase separation in the presence of small amounts of water. Unless a cost-effective solution is demonstrated for this problem, it will be necessary to insure that the customer receives a dry blend. The only realistic chance for doing this depends on distributing dry methanol and gasoline separately, and blending at the pump.

  (2) The non-ideality of methanol/hydrocarbon systems results in excessive gasoline vapor pressure in the presence of

5-10% methanol. Unless the automotive fuel system is modified to handle a more volatile blend, methanol addition requires displacing butanes from gasoline, which is economically undesirable.

(3) The use of methanol/gasoline blends results in operation at a higher air equivalence ratio. It is important to determine if such a change causes any driveability problems.

- The use of methanol/gasoline blends could also lead to some practical benefits:

  (1) Very limited data suggest some improvement in fuel economy, measured in miles/BTU, by blending 15% methanol into gasoline. More information is required to define fully the extent of such improvements.

  (2) Exhaust emissions can be reduced. The emissions data can be rationalized by considering changes in air/fuel ratio. Whether CO, hydrocarbons, or NO_x in the exhaust increase or decrease depends on whether the initial operation is leaner or richer than stoichiometric.

  (3) Methanol is expected to have good octane blending characteristics, but more data are needed on blending octanes as a function of gasoline pool octane level.

<u>Evolutionary Considerations (7)</u>

- It is necessary to see an approach path from the present to a new condition in the future.

- Although a given path may be technically possible, it is not likely to be followed if easier or better paths are available.

<u>New Engine/New Fuel Dilemma (7.1)</u>

- Highway vehicles must be able to obtain suitable fuel wherever they are driven. The general public will not purchase a vehicle for which fuel is not readily available. This poses a special problem in the hypothetical case of introduction of new engine and fuel products that are not compatible with existing engines and fuels.

<u>The Compatibility Scenario (7.2)</u>

- Full compatibility of new fuels with existing fuels and engines has numerous advantages. Nationwide distribution of new fuels can evolve as availability increases, and the transition from 100% petroleum to 100% alternative fuels can be accomplished without any discontinuity.

Automotive Fuel Blends (7.3)

- The most likely way that automotive fuels from coal and oil shale will be marketed will be as blends with petroleum fuels and, perhaps, with each other, until the early part of the 21st century.

Automotive Distillate Fuels (7.4)

- There may be both physical limitations and economic penalties associated with increasing the ratio of distillate-type to gasoline-type automotive fuels. This will be examined in an amendment to the contract, and will be covered in a separate report.

- There will be some difficulty in introducing automotive distillate fuels other than automotive diesel. Although an introductory strategy is available, the incentive for using it will depend on the capacity of the new fuels to improve upon the cost and performance of diesel fuel.

Fleet Account Stratagem (7.5)

- New fuels may be introduced to operators of fleets of commercial vehicles. This builds operating experience and defers the problem of how to introduce a new fuel to the general public. The maximum potential of the fleet market is about 5% of total automotive fuel demand.

Automotive Hydrogen (7.6)

- It is very unlikely that the automotive transportation system will evolve of its own accord in the direction of using hydrogen as a fuel for private vehicles before the year 2000.

Labor Force Requirements and Implications (7.7)

- Through 1985, it seems likely that the manpower needed to design and construct synthetic fuel plants will be a limiting factor.

- Longer range, beyond 1990, the balance of natural resources in the Mountain states may be the limitation. Richness in mineral resources may not be adequately matched by water availability for all of the demands, direct and indirect, of a rapidly growing synthetic fuels industry.

Capital Availability and Investment Implications (7.8)

- Capital availability will set investment priorities; unnecessary investments will be avoided. One implication is that the existing distribution and marketing system will not be duplicated to permit the introduction of fuels not compatible with the existing system -- since new compatible fuels can accomplish the same objective at lower cost.

Research Data Gaps (8.1)

- Research data gaps were classified according to fuel type.

Fuels From Shale Oil (8.1.1)

- The disposal of spent shale in an environmentally acceptable way has to be demonstrated for a commercial-scale operation.

- In situ retorting of shale is very important to large scale growth of shale oil production beyond the 1985-1990 period. An efficient, environmentally acceptable process has to be developed.

- Alternatives should be developed to severe mine-mouth upgrading of raw shale oil to syncrude. One possibility involves mild treatment with heat and/or hydrogen to make it pumpable to a remote refining site.

- A complete spectrum of product quality and engine/vehicle performance data is required, for shale oil gasoline and distillate fractions alone and in blends with petroleum or coal-derived materials.

Hydrocarbon Fuels From Coal (8.1.2)

- The permanent reclamation of surface-mined land has to be demonstrated on a large scale.

- Long range, there is a need for an underground coal liquefaction process, as an alternate to underground mining.

- More efficient methods are needed to generate hydrogen from coal for use in hydrogenation processes.

- Liquefaccion processes must be improved to give more selective molecular weight reduction with the minimum hydrogen consumption -- e.g., by developing better catalysts.

- Coal syncrude refining has to be demonstrated with feedstocks from a variety of different coals to give fuel products with acceptable sulfur, nitrogen, and oxygen content.

- The Fischer/Tropsch process could be an interesting candidate for coal liquids if the selectivity and thermal efficiency of the process were substantially improved.

- Complete product quality and performance data are required for coal gasoline and distillate fractions alone or in blends with petroleum or shale-derived materials.

Methanol From Coal (8.1.3)

- Improved coal gasification technology is needed to produce the $CO + H_2$ for methanol synthesis.

- The methanol synthesis reaction could be improved by a more active catalyst (lower temperature and/or pressure) and by the development of selective techniques for separating methanol from unreacted $CO + H_2$.

- With regard to methanol/gasoline blends, complete information is needed on water sensitivity, volatility, corrosion, exhaust emissions, fuel economy and driveability.

- With pure methanol fuel, data are needed on the maximum efficiency improvement possible with various engines, making use of the desirable combustion properties of methanol.

- Methanol is potentially an important fuel cell fuel. Impurity effects have to be defined both for direct fuel cell use and as a feedstock to a reformer for fuel cell hydrogen.

Other Information Gaps (8.2)

- Automotive fuel alternatives must be considered in the context of the economy as a whole.

- The future availability of water in the coal and shale regions of the West requires a careful study. This study should be part of a broader assessment of the the impact of coal and shale mining and conversion industries in sparsely populated areas.

- On-going studies should address the proper utilization of all domestic resources including petroleum.

9. CONCLUSIONS

The conclusions of this study can be classified into four types:

(a) Virtual certainty: Where the evidence and logic are so persuasive that it may be concluded that something will happen.

(b) Dependent on assumptions used: The conclusion is valid only if the assumptions are valid, e.g., that surface mining will be permitted or that the cost of automotive fuels may be adequately compared on an ex-tax basis.

(c) Dependent on contractor's judgment: Many factors affecting long range projections are not forecastable in a rigorous way and must be dealt with by judgment.

(d) Information gaps: One objective of the study is to identify uncertainties that can be resolved by additional work. In effect, such conclusions are recommendations that the necessary work be done.

The conclusions that follow are identified by (a), (b), (c), or (d) to indicate the type of uncertainty associated with it. Unless otherwise noted, the conclusions apply to the 1982-2000 time-frame.

(1) It is feasible and practical to make petroleum-type fuels from coal and oil shale. They are the most attractive alternates to petroleum over the time frame of the study. (a),(c)

(2) Initial production of these petroleum-type fuels is likely within the next 5-7 years. (a)

(3) Automotive fuel components from coal and oil-shale will be blended with petroleum fractions. (c)

(4) For practical purposes, if petroleum-type products from coal and oil shale are blended with petroleum, no product quality problems will be experienced by customers. However, at present, there are many data gaps which will have to be filled. (c),(d)

(5) The potential for product quality problems is greater if unblended coal or shale gasoline distillate is marketed: (c)

- early determination of product quality and other performance data would be essential, but - (d)

- the scenario of unblended fuels is unrealistic (c)

(6) Methanol from coal:

- is a feasible automotive fuel for spark-ignition engines, gas turbines, and fuel cells. (a)

- in spark-ignition engines will require engine and vehicle modification for optimum performance. (a)

- is an excellent gas turbine fuel, particularly suited for stationary turbine applications. (c)

- if used widely as an automotive fuel, in the near and mid-term future, would have to enter the market as a blend with gasoline but, eventually, would be used unblended. (c)

- if used in a modified spark-ignition engine could lead to improved efficiency relative to hydrocarbon fuels. (c)

- used in blends with gasoline could lead to driveability problems unless the system is kept dry, the gasoline is debutanized and the fuel system is modified. (c)

- is a sufficiently probable product that vehicle performance data should be obtained using both methanol/gasoline blends and neat methanols. (d)

(7) Synthetic fuel production from coal and oil shale:

- will not be limited by the size of domestic coal and oil shale resources. (a)

- will be limited initially by the availability of skilled manpower and eventually by water availability and environmental/ecological considerations. (c)

- will make only a minor contribution to automotive fuel supplies in 1985, but has the potential for becoming a major factor by the year 2000. Realization of this potential is critically dependent on a satisfactory resolution of the previous item. (c)

(8) Estimates of fuel costs:

- In the 1982/85 time-frame the cost of shale and coal syncrudes, including a 10% DCF return, will be about \$5.50/bbl and \$8.00/bbl respectively in 1973 constant dollars. (b)

- At the pump, on an ex-tax basis, the potential alternative automotive fuels are estimated to cost:

		1982		1990	2000
		$MMBTU	¢/gal	-------$MMBTU-------	
Shale	- gasoline	2.65	31.5	2.60	2.15
	- distillate	2.05	26.5	2.00	1.65
Coal	- gasoline	3.35	39.5	3.15	2.65
	- distillate	2.75	36.5	2.50	2.10
	- methanol	3.85	22.0	3.40	2.95

1973 $, ex tax at pump

- The absolute values projected are sensitive to the underlying assumptions. (b)

- The lower cost projected for distillate than for gasoline depends on a gasoline/distillate ratio of about 2:1. (c)

- The present average level of Federal plus state gasoline taxes (about $0.90 per MM BTU) is comparable to the cost differences projected above. Therefore, future taxation of automotive fuels, particularly if different fuels are taxed differently, could have a major impact on what the customer decides to purchase. (b),(c)

(9) The total cost of operating a vehicle of a given size and type throughout its useful life depends on fuel cost. However, differential taxation of vehicles and fuels could result in a different ranking than that obtained from cost calculations that exclude this factor. (b),(c)

(10) Trends in fuel costs:

- after an initial period of high cost, synthetic fuels from coal and shale are expected to decline in cost on a constant dollar basis, reflecting new and improved technology. (c)

- eventually, the more economic synthetic fuel resources will be depleted and costs will rise again. (c)

- the long-term trend in the cost of domestic petroleum is upward. (c)

(11) Petroleum from domestic resources will be available at least through the year 2000 and probably, although to a declining extent, through the year 2025. (c)

(12) Other supplies and forms of energy, such as nuclear power, have the potential for displacing liquid fuels from non-transportation uses. (a)

(13) When such displacement occurs, particularly after 1985, liquid fuels will be released for transportation use. (c)

(14) Automotive fuel questions should not be divorced from energy supply/demand in general. the future demand for aviation fuels is particularly pertinent. (c),(d)

(15) On-going studies should address the optimum utilization of all domestic resources, including petroleum. It is impossible to properly evaluate the impact of alternative fuels without considering petroleum as an integral part of domestic energy supplies. (a)

(16) Many research data gaps were identified. The most important of these point up the need for: (d)

- product quality and performance data on shale and coal-derived fuels, alone or in blends with petroleum, in various types of engines and vehicles.

- an improved process for producing hydrogen from coal.

- a more selective coal hydrogenation process.

- an improved coal gasification process, operating at elevated pressure, which maximizes $CO+H_2$.

- commercial demonstration of spent shale disposal.

- longer-range, an underground shale retorting process, which minimizes environmental problems.

(17) The relative overall attractiveness of coal and shale-derived fuels requires more than the technical feasibility analysis presented in this study. However, this issue will be addressed in an EPA sponsored alternate fuels impact study. (a)

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16. ABSTRACT

This study identifies feasible and practical alternatives to automotive fuels derived from petroleum for the 1975-2000 time period. The alternative fuels are liquids derived from domestic coal and oil shale -- specifically, gasolines, distillates, and methanol. While many uncertainties remain, initial production of the new fuels is likely within the next five to seven years.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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