I INTRODUCTION

A. Nature of the Problem

1. Automotive Fuel in Perspective[2]*

Automotive vehicles--cars, trucks, and buses--are fueled by petroleum products almost exclusively and constitute the single largest use of petroleum (46 percent) in the United States (Figure 1). It is well known that, until the Arab oil embargo in the winter of 1973, demand for automotive fuels was growing steadily while domestic oil production was beginning to fall. Consequently, interest was renewed in the possible development, production, and use of alternative automotive fuels.

An indication of the level of alternative fuel production that may be required in the future for the automotive market is shown in Figure 2, which is adapted from the Historical Growth scenario of the Ford Foundation Energy Policy Project. This scenario assumes that, in spite of higher energy prices, consumers return to their historical patterns of petroleum use and, thus, that demand for automotive fuel grows steadily. Three domestic oil supply subscenarios (HG 1, 2, 3) are given in the Ford Foundation study. In each, domestic oil supplies would increase temporarily somewhat because the higher prices would stimulate previously unprofitable production; however, this increase could not be sustained and, toward the end of the century, domestic supplies would again fall.

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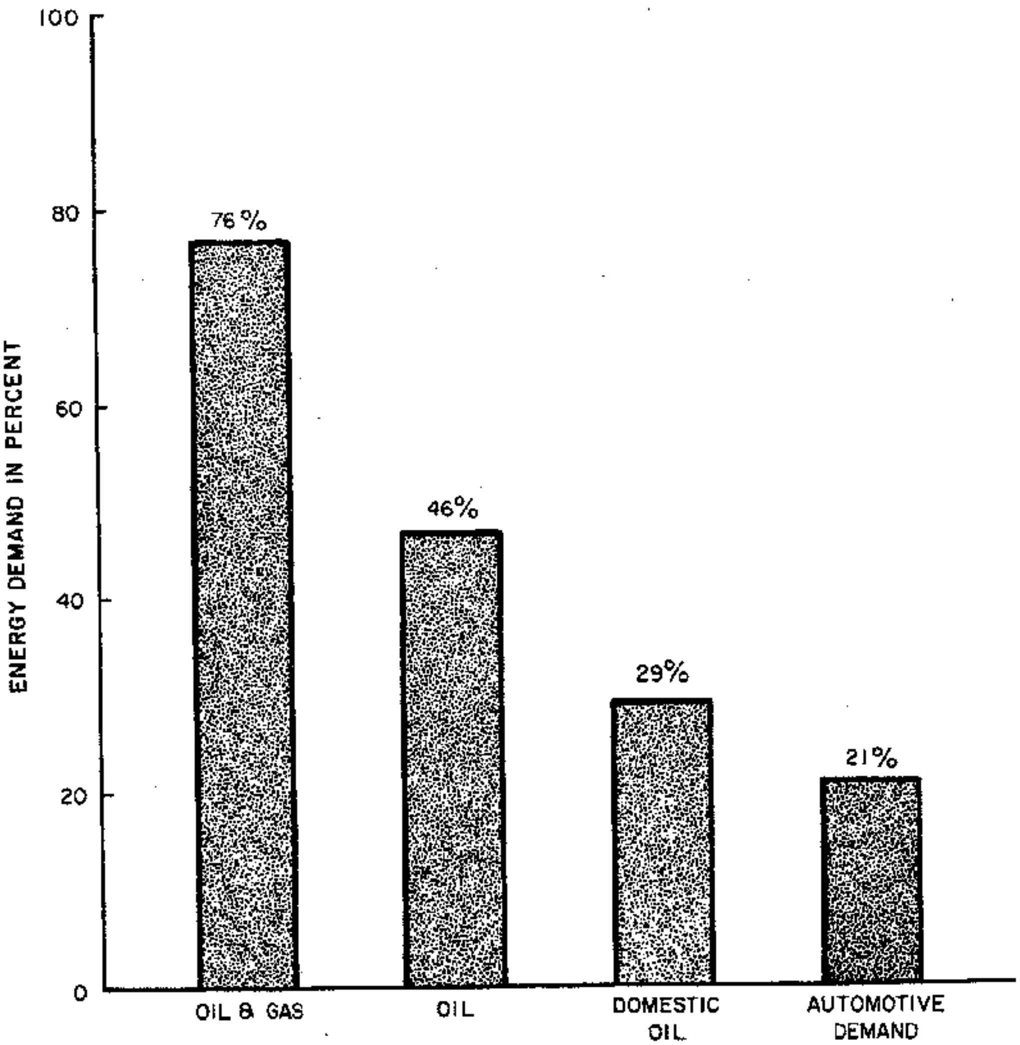
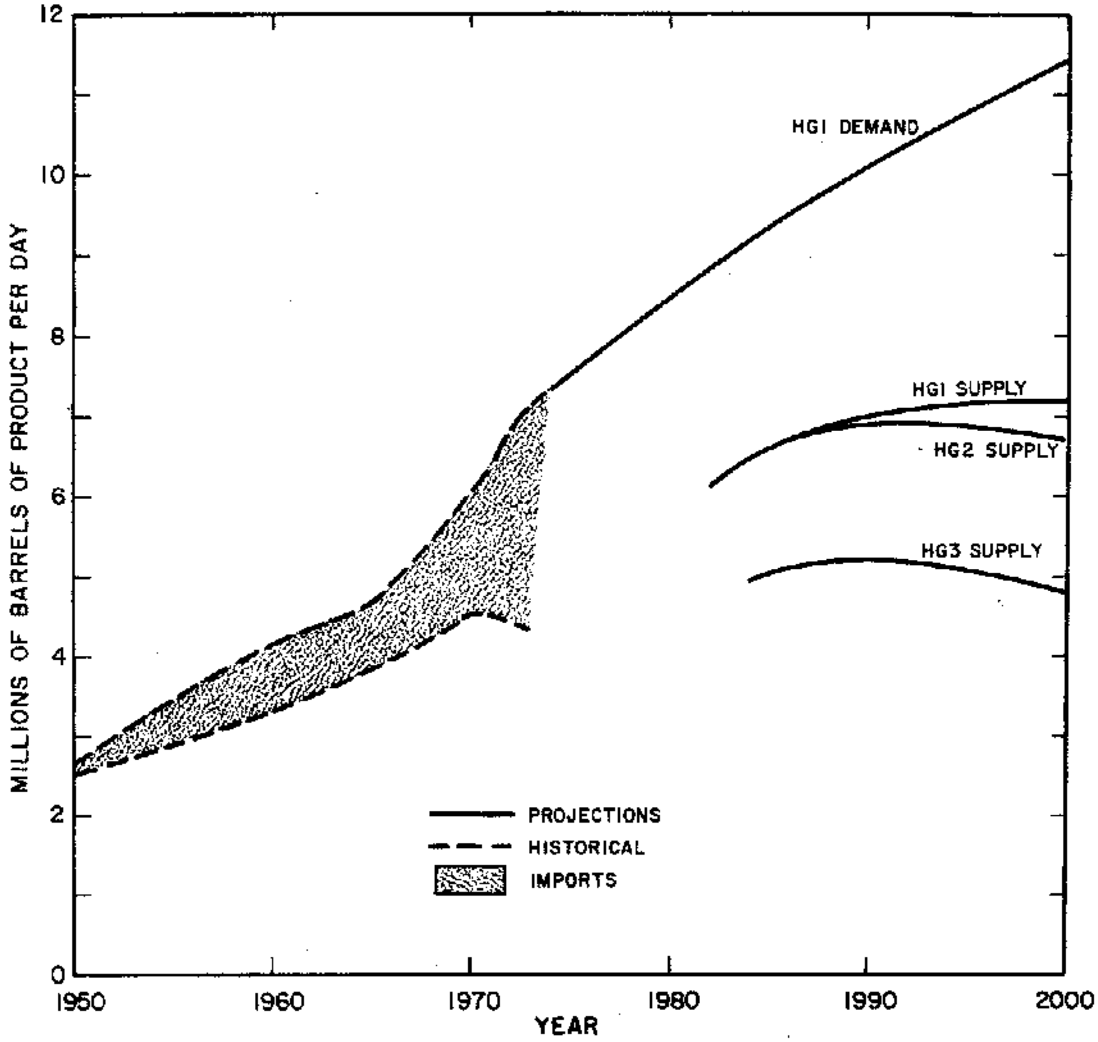
*In this volume, superscripts refer the reader to the chapter in Volumes II and III that discuss the same matter in greater detail.



Source: Figure 2-1

FIGURE 1. AUTOMOTIVE ENERGY DEMAND COMPARED TO 1974 PETROLEUM SUPPLY AND DEMAND



Source: Figure 2-3

FIGURE 2. HISTORICAL GROWTH SCENARIO – AUTOMOTIVE FUEL DEMAND AND DOMESTIC SUPPLY PROJECTIONS

Recent estimates of total U.S. oil resources and reserves made by the U.S. Geological Survey (USGS) strongly suggest that of the three domestic supply curves shown in Figure 2, only the HG3 curve has the barest chance of being realized.[3] Thus, in the year 2000 there could be an automotive fuel shortfall as large as 6 million barrels per day (B/D) (1 million m^3/D). When all other uses of petroleum in the economy are also considered, under the HG3 supply scenario the total petroleum shortfall would be about 18 million B/D (2.9 million m^3/D) in the year 2000.

Consequently, at the end of this century, unless alternative domestic fuel sources are developed or demand is reduced, petroleum imports could be running as high as 18 million B/D (compared to 6 million B/D in 1973). The precision of this estimate is sufficient to provide perspective for the level of alternative fuel production that may be desirable in the future.

2. Future Automotive Fuel Options

There are numerous conceivable options for future automotive energy:

- Reduce demand
  - Through less travel
  - Through improved efficiencies of use
- Change technology (e.g., electric cars)
- Change fuels
  - Develop synthetic gasolines and diesels from coal and oil shale
  - Use methanol derived from coal, wastes, and biomass
  - Use hydrogen produced from coal or by means of nuclear power.

Previous studies performed for the Alternative Automotive Power Systems Division of the Environmental Protection Agency (EPA) examined the technical and economic feasibility of these and other alternative fuels.

The consensus was that until the early part of the next century, the prime candidates for alternative fuels are:

- Gasolines and distillates derived from coal and oil shale
- Methanol derived from coal.

B. Study Objectives

The basic objective of this study was to assess the feasibility of these prime candidate fuels in a much broader sense--their total feasibility when environmental, economic, social, and institutional consequences are taken into account. Moreover, these consequences were to be contrasted to the consequences of an all-out effort to increase production of conventional petroleum--especially in Alaska, offshore, and by advanced (or "tertiary") recovery techniques.

While pursuing this objective, potentially inhibiting factors were to be identified and those that might prove to be critical impediments of the realization of a high level of alternative fuel production were to be singled out for special, expanded analysis.

At the conclusion of the work, a set of criteria were to be developed to rate the various options to help formulators of public policy make difficult choices. In addition, public policy alternatives were to be identified that could increase chances for commercialization of these fuels, ameliorate the most adverse consequences, and strengthen any beneficial consequences.

C. Methods of the Study

The study was conducted as a technology impact assessment by a coordinated interdisciplinary project team. The team took the following steps:

- Devised systems descriptions of the options from the basic resources through the end uses.
- Examined the compatibility of the systems with existing fuel systems to judge the ease of incremental implementation--an important step because new fuel systems must evolve from present ones and must be compatible with existing institutions and infrastructure investments.
- Focused attention on those parts of the new systems that differed the most from present fuel systems--because it would be there that impacts would be most unlike those experienced with the present fuel systems.
- Characterized the new system elements in terms of "natural building blocks" (the normal size to be expected from considerations of economies of scale and scales of physical processes).
- Determined the resource inputs (coal, water, capital, labor, etc.) for a given fuel output.
- Constructed a maximum credible implementation (MCI) scenario to serve as a heuristic device to derive the maximum impact situation and thereby identify the critical inhibiting factors.
- Identified other critical factors that are, in many respects, independent of the level of implementation.
- Analyzed in detail the consequences of implementing the MCI giving special attention to the critical factors.
- Prepared a scenario depicting all-out production of domestic conventional petroleum--to serve as a comparison for the development of synthetic fuels.

D. Organization of the Report

Section II of this synopsis presents the reference case, which is an all-out effort to increase domestic oil supply by conventional means and to supplement the supply with imported oil. The Reference Case can be used as a basis for comparison of the impact of the development of a synthetic fuel industry. Section III treats the technology, economics, and institutional setting for a synfuel industry. Criteria that can be used to compare the various synthetic fuel options are applied in

Section IV. In Section V the maximum credible synthetic liquid fuel implementation scenario is described, and its implications are discussed in Section VI. Some effects of a synfuel industry introduced at less than a maximum rate are treated in Section VII. Finally, in Section VIII, the areas in which public policy actions could influence the development and consequences of a synfuel industry are outlined.

II ALL-OUT CONVENTIONAL PRODUCTION OF DOMESTIC OIL SUPPLEMENTED BY OIL IMPORTS: REFERENCE CASE[3]

As a basis for comparison of essential aspects of a synthetic fuels industry, a reference supply case was developed in which the alternative to a synfuel industry was the all-out conventional production of domestic oil supplemented by oil imports. The Reference Case contains a projection of (1) domestic oil supply and the requirements for imported oil, (2) the resources required to increase domestic oil production without synthetic fuels development, and (3) the environmental impacts that could result from this production and importation.

A. Sources of Domestic Supply

Future domestic oil production will depend heavily on the success achieved in three activities and geographic regimes.

- Alaskan resource development (onshore and offshore)
- Frontier (non-Alaskan) offshore resource development
- Recovery by advanced techniques in all areas.

In the year 2000, about 32 percent of domestic oil will come from Alaska and about 30 percent from offshore (lower 48 states). Table 1 shows the projected supply/demand under HG3 (Figure 2).

With or without an all-out production effort, it appears to be impossible for domestic oil production to satisfy the demand curve shown in Figure 2. The recent USGS estimates indicate that the United States will be hard pressed even to produce oil at a level similar to HG3. Such production would entail producing more oil domestically in the next 25 years than the total amount produced previously--and from resources significantly more difficult to extract. As a consequence, the Reference Case necessarily included an increased level of oil imports.

Table 1

DOMESTIC OIL SUPPLY, IMPORTS, AND TOTAL DEMAND UNDER HG3

(Source: Table 3-2)

Supply/Demand	Quantity 10^6 Barrels per day* (% of Domestic Supply) 1985	2000	Cumulative 1974-2000 (10^9 Barrels) Total	Advanced Recovery
Domestic Supply				
Onshore (lower 48 states)	6.8 (52)	5.0 (38)	63	34
Offshore (lower 48 states)	3.0 (21)	4.0 (30)	28	15
Alaska (onshore and offshore)	3.6 (27)	4.4 (32)	30	16
Total	13.4	13.4	121	65
Imports	11.5	18.4		
Total U.S. demand	24.9	31.8		

*10^6 B/D is about $1.6 \times 10^5 m^3/D$.

B. Resource Requirements

Resource requirements for the HG3 scenario in terms of heavy equipment, labor, steel, and capital investment are shown in Tables 2 and 3.

Table 2

ANNUAL LABOR, DRILL RIG AND STEEL REQUIREMENTS
FOR OIL PRODUCTION UNDER HG3

(Source: Table 3-6)

	Year		
	1977	1985	2000
Exploration Drill Rigs in Use			
Onshore	930	1,250	1,250
Offshore	240	500	500
Alaska			
Onshore	125	150	150
Offshore	26	110	110
Offshore Production Platforms in Use			
Offshore	90	200	200
Alaska-offshore	6	25	25
Labor--Rig and Platform Crewmen Employed			
Onshore	22,000	29,000	29,000
Offshore	24,000	52,000	52,000
Alaska	3,000	8,000	8,000
(Offshore)	(1,600)	(6,500)	(6,500)
Total	49,000	89,000	89,000
Steel--Thousands of Tons* Required			
Onshore	1,400	1,700	1,700
Offshore	1,400	1,400	1,400
Alaska	200	400	400
Total	3,000	3,500	3,500

*One ton is about 907 kg.

Table 3

ANNUAL CAPITAL INVESTMENT IN CONVENTIONAL OIL PRODUCTION FOR HC3 (1973 dollars)

(Source: Table 3-9)

	1977	1985	2000
Onshore Recovery			
Primary and Secondary	1.4	3.9	3.9
Advanced	1.0	1.0	2.6
Subtotal	2.4	4.9	6.5
Offshore Recovery			
Primary and Secondary	0.3	0.9	0.9
Advanced	0.6	0.6	1.3
Subtotal	0.9	1.5	2.2
Alaska			
Primary and Secondary	1.2	1.3	1.3
Advanced	1.0	1.0	2.1
Subtotal	2.2	2.3	3.4
Total	5.5	7.7	12.1

Towards the end of the century over 50 percent of domestic oil recovery should be coming from advanced techniques. That is why the investment split between primary and secondary recovery in Table 3 is weighted heavily on the side of advanced recovery. Some of the production activities involved in oil recovery, especially advanced recovery, are expected to be as costly on a unit basis as the production of synthetic crude oils from coal and oil shale, both of which are still considered uneconomic.

C. Major Impacts of the Reference Case

A summary of the salient impacts of the Reference Case follows.

- Alaskan (onshore)
  - Rapid changes in human populations leading to boom towns with low levels of human amenities and environmental protection.
  - Disruption of established cultures, economies, and values.
  - Damage of fragile ecosystems by petroleum spills, the activity of exploration and production, and establishment of transportation corridors.
  - Damage to the marine environment resulting from ocean transport (and landing) of oil to other states.
- Alaskan (offshore)
  - Same impacts as Alaskan onshore (above).
  - Damage to the marine environment from spills and other accidents.
- Offshore (Continental United States)
  - Impingement on other beneficial uses of coastal zones such as commercial fisheries, recreation, wildlife habitat, aesthetic values.
  - Induced human population in coastal areas owing to increased petroleum-related activity such as port facilities and refineries.
- Advanced recovery
  - Large increase in demand for the chemicals used in tertiary recovery with resulting environmental and health hazards in their manufacture, transport, and use.
  - Increased air pollution from fuel burning for steam generation.
  - Concentration of impacts in heavily populated and polluted Southern California because past recovery techniques for heavy California crude oil has left much oil that is potentially suitable for advanced recovery.

- Imports
  - Economic and political ramifications of economic disruption in the event of another oil embargo.
  - Increased alteration of the coastal zone through increased ship traffic, spills, and construction of single-point offshore moorings and deepwater ports.
  - Increased onshore activity for refining and transport of oil and of induced human population.

Thus, the impacts of the Reference Case will be heavily concentrated in coastal areas--both onshore and offshore and in Alaska. As will be seen later, the nation may have to choose between impacts in the Northern Great Plains and Rocky Mountain states or impacts in the Alaskan and coastal zones unless demand for liquid fuels is significantly reduced through conservation.

III PRODUCTION OF SYNTHETIC LIQUID FUELS FROM COAL AND OIL SHALE

A. The Technology

1. Syncrude from Coal[4]

Coal is abundant and widely distributed throughout the United States. It has been realized for many years that coal could be chemically transformed into liquid hydrocarbons suitable for use as fuel. However, until recently, abundant U.S. petroleum reserves discouraged development and engineering refinement of coal conversion. As a result, the United States has not produced synthetic liquids from coal in commercial quantities. During World War II, however, the Germans manufactured coal liquids for the operation of vehicles and for many years South Africa has produced synthetic gasolines from coal. Coal liquefaction therefore is not a new technology but an old technology ripe for improvement.

Several improved technologies are already nearing commercial readiness.[4] Among these technologies are (by their commonly used name): COED, H-Coal, SRC, and CSF. In all of these, the basic procedure is the production of hydrogen chemically from coal and water followed by the chemical combination of this hydrogen with other coal. At suitable temperatures and pressures, the coal and the hydrogen react to produce a liquid product that is nearly identical to crude oil.*

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*Many of the coal-derived syncrudes are superior to natural crude oils because they are lower in sulfur.

The H-coal process has been selected for analysis in this study because ample data were publicly available, the technology is among the most advanced, and the product is almost entirely a synthetic crude oil with few byproducts.

The H-coal process, like all coal syncrude processes, requires large inputs of natural resources (especially coal, water) and socioeconomic resources (capital, labor). The magnitude of these resources is indicated in Table 4, in which they are compared with other fuel processes considered in the study. The primary residual of the H-coal process is an ash that derives from the foreign mineral matter originally in the coal.

The published literature and discussions with potential syncrude producers make it clear that the natural size of coal liquefaction building blocks will be 25,000 to 30,000 B/D (4,000 to 4,800 m^3/D) during the first stages of commercialization when business risks overshadow the desire to reap full economies of scale. However, in a mature industry, the building block would be about 100,000 B/D (16,000 m^3/D);* plants of this size will have realized nearly all potential economies of scale. In principle, syncrudes could be further transformed by refining to yield consumer products at the same site, but in the early stages of the synfuel industry there is no incentive to do this.

2. Methanol from Coal[4]

The production of methanol from coal is really a wedding of portions of two of the presently more advanced synthetic fuels technologies: synthetic methane derived from coal, and methanol made from

*For comparison, large, modern refineries are often of the 100,000 B/D (16,000 m^3/D) size.

Table 4

RESOURCE REQUIREMENTS FOR 100,000-B/D* (OIL EQUIVALENT)†
SYNTHETIC LIQUID FUELS PLANTS

(Sources: Tables 6-4, 6-5, 6-6)

	H-Coal Process Syncrude	Lurgi Methanol	TOSCO II Oil Shale Syncrude
Construction			
Capital (millions 1973 $)‡	670	1200	750
Labor (10^3 man-yrs)	7.3	15	5.4
Steel (10^3 tons)	110	200	90
Site (10^3 acres)	1	2	0.6
Operation			
Resource (million tons/yr)	18	26	54
Water (10^3 acre-ft/yr)	29	30	16
Electric power (MW)	140	200	170
Labor (10^3 people)	1.4	1.8	1.7

*A 100,000 B/D plant produces 16,000 m^3/D.
†About two barrels of methanol contain the same energy as one barrel of oil.
‡These estimates are taken from the open literature; since 1973 estimates have escalated at a rate that far exceeds the general rate of inflation in the economy.

methane. The latter technology is well developed because it is the process now used to make most methanol (from natural gas). Because shortages of natural gas have been anticipated more commonly than shortages of oil, the processes for the production of synthetic methane from coal are well developed (although not commercially deployed). The gasification options available include Lurgi, Winkler, and Koppers-Totzek, but the synthesis step is most favorably accomplished by an intermediate pressure process such as the ICI process. Lurgi gasification has been adopted in this study because much data for this process are publicly available and it is a likely candidate for first generation plants.

In the production of synthetic methanol from coal, the first step is the generation of synthesis gas, a mixture of carbon monoxide and hydrogen. This is followed by a synthesis step that converts the gas to methanol.* The methanol process directly yields the final product suitable for automotive use in contrast to the coal liquefaction processes which yield a syncrude which must then be refined. The resource requirements for methanol production from coal are shown in Table 4.

The production of methanol from coal is amenable to development of an in situ process in which the coal is transformed underground to synthesis gas without prior conventional extraction (by mining). In this case, the synthesis gas would be pumped to the surface where it would be converted to methanol.* In situ conversion is expected to require less water and cause far less environmental disturbance than above-ground methods. However, in situ processes are quite speculative and data adequate to the needs of this study do not exist; consequently, only above-ground methanol production is considered here.

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*Under different conditions, methane can be produced from this same synthesis gas.

3. Syncrude from Oil Shale[4]

Certain marlstones contain trapped organic material called kerogen; such minerals are called oil shale. When the stone is pulverized and heated, the kerogen is transformed and a very viscous oil-like substance is released. Vast deposits of oil shale rich in kerogen are found in Colorado, Eastern Utah, and Northwestern Wyoming. The richest deposits are found in a two-county area of Colorado called the Piceance Basin.*

Throughout this century there has been sporadic interest in the oil shale hydrocarbon resource. Because it is the consensus in the oil industry that oil derived from oil shale would be less expensive than liquid fuels derived from coal, considerable attention has been given to oil shale technologies--both above ground and in situ conversion.

In all forms of the technology the basic steps are to crush the rock into small lumps or particles (to facilitate heat transfer and release of the kerogen), to heat the crushed shale, and to collect the viscous oil. Some technologies use hot gases to heat the shale, while others use hot solid materials. In both cases, the heat is generated by combustion of some of the kerogen or recovered shale oil. For in situ processes, combustion of the kerogen is the sole source of heat. Among the candidate above-ground conversion processes are Paraho, TOSCO II, and Union Oil.

The TOSCO II process has been selected for this study because much data is publicly available--especially from an environmental impact analysis of the once planned Colony Development Operation oil shale plant. Unfortunately, there are few publicly available data on in situ processes.

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*This is not a drainage basin; the name refers to the basin-like shape of the geological strata.

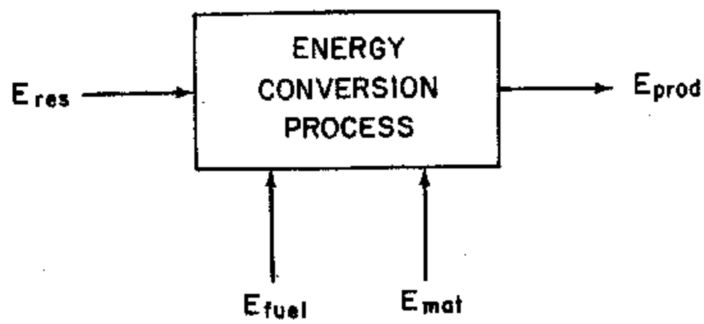
No matter which conversion process is used, the viscous oil must be "upgraded" before it will flow readily as a fluid. Upgrading requires the production of hydrogen and its chemical addition to the raw shale oil. Upgrading also lowers the sulfur and nitrogen content of the raw shale oil.

The mining and retorting of oil shale consume large amounts of natural and socioeconomic resources (shown in Table 4). However, unlike the two coal processes whose only residual is an ash that is 10 to 20 percent by weight of the coal consumed, above-ground oil shale processes produce enormous quantities of "spent" oil shale. Indeed, because of voids, the spent shale actually occupies a volume some 10 to 30 percent (depending on the process) greater than the raw shale. This residue requires disposal--an activity that consumes large amounts of water for compaction, dust control, and revegetation. It also requires large amounts of land.

B. Net Energy Ratio[6]

To extract, transport, and convert coal or oil shale to a form suitable for end-use requires energy--both directly in the form of fuel and electricity and indirectly in the form of energy intensive materials. Systematically accounting for all these energy inputs to compute the energy consumption necessary to deliver the energy present in the product can be accomplished in several ways. For this study the net energy ratio mode of expressing this information has been chosen.

The net energy ratio, as illustrated in Figure 3, is defined as the energy content of the product (E_{prod}) divided by the sum of three terms: the energy that was originally present in the raw fossil resource but thermodynamically lost in processing ($E_{res} - E_{prod}$), the fuel or electrical energy that must be used to run the fuel conversion processes (E_{fuel}), and the energy that has been expended in preparing, assembling and delivering materials used in the process (E_{mat}). Such accounting has been applied to all steps in the sequence from resource extraction to final conversion to products suitable for end use.



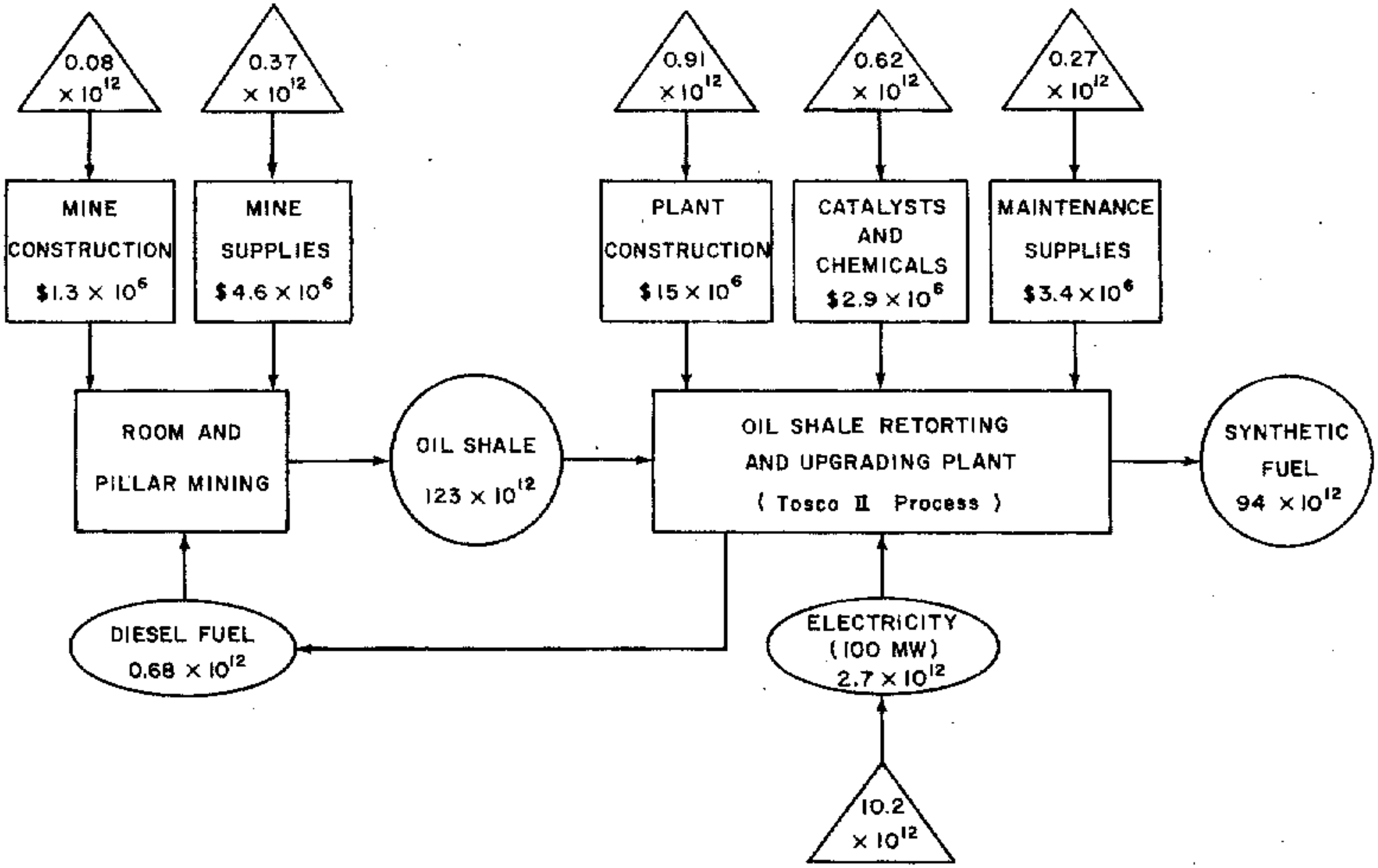
$$\text{NET ENERGY RATIO} = \frac{E_{prod}}{(E_{res} - E_{prod}) + E_{fuel} + E_{mat}}$$

Source: Figure 5-1

FIGURE 3. FLOW DIAGRAM FOR DEFINITION OF NET ENERGY RATIO

Figure 4 shows the application of the concept to an oil shale conversion process. To account for the total use of resource energy in the conversion processes, the energy inputs are reduced to the amounts of original fossil fuel resources required to supply the actual energy forms and materials used. Such resource energy requirements are shown as triangles in Figure 4.

As expressed here, the higher the net energy ratio, the more effectively the process utilizes the nation's energy resources. A ratio of 1.0 simply means that the resource energy consumed in making the fuel



Notes: All resource energy inputs and product outputs are in Btu
All dollar figures are in 1973 dollars per year

Source: Figure 5-5

FIGURE 4. ANNUAL ENERGY INPUTS FOR CONSTRUCTION AND OPERATION A 50,000-B/D OIL SHALE MINING, RETORTING, AND UPGRADING COMPLEX

available is equivalent to the energy contained in the final product fuel; for the three fuel conversion processes considered in this study, a ratio less than 1.0 does not mean that the process, in effect, drains society of energy. For example, a net energy ratio of 0.5 means that of three units of energy initially available, one is delivered to end use while two are used in processing. With our definition, electric generation from coal has a net energy ratio of about 0.36 (counting transmission losses). The case of electricity shows that society sometimes willingly accepts a low net energy ratio as the price of converting energy into a desirable form.

Table 5 shows the net energy ratio for the processes considered in this study. Because there is no intermediate product in methanol production, the net energy ratio for the syncrude alternatives are shown both before and after refining to facilitate comparison with methanol. Several important conclusions can be drawn from Table 5. First the coal resource can be used more effectively if syncrude is made than if methanol is made. Second the oil shale process has the most favorable net energy ratio. However, comparison of ratios is more valid for alternative processes using a single resource than for trans-resource comparison. Perhaps the most important use of net energy ratios is in choosing among alternative processes those which are most conservative of basic resources.

C. Economics of Production

As Table 4 shows, the investment requirements for synthetic liquid fuel plants are very large. The estimates shown in Table 4 are in dollars of 1973 value and the more recent estimates are even larger.*

*The escalation between 1973 and 1976 is larger than the general rate of inflation because plant construction costs have been inflating more rapidly than other costs.

Table 5

NET ENERGY RATIOS FOR SYNTHETIC LIQUID FUELS PROCESSES

(Source: Table 5-8)

	Conversion Step	Resource-to-Fuels System*
Oil shale	2.3	1.6
Coal liquefaction		
Wyoming coal	1.5	1.1
Illinois coal	1.8	1.3
Methanol		
New Mexico coal	0.66	0.65

*Includes refining syncrude and 1000 miles of pipeline shipment of syncrude or methanol.

Recent studies conducted for EPA clearly show that the price of syncrude from coal was about two-thirds determined by the initial plant investment. The next most important determinant of cost was the coal feedstock, while the cost of obtaining water contributed very little to the cost of the final product.

To date, potential operators of commercial synthetic fuel plants have concluded that these synthetic liquid fuels cannot be produced and sold at a reasonable profit at competitive prices (even with the present high cost of imported petroleum).

D. Institutional Setting for a Synfuel Industry[9]

Currently, corporations consider synfuel investments to be fraught with too much risk to undertake without some kind of supportive government intervention. This judgment stems from two basic considerations: First, the fuels produced would cost at least as much as imported oil, even at the high prices set by The Organization of Petroleum Exporting Countries (OPEC); yet OPEC could easily lower the price of imported oil and drive synfuel ventures into bankruptcy. Second, the individual synfuel plant investment requirements are so large and uncertain that it appears to be less of a risk to make smaller individual project investments in exploration for natural crudes; moreover, synfuel plant investments have no exit points that allow capital-saving withdrawal if changing evidence or situations warrant.

The only private institutions likely to undertake synfuel ventures are the oil companies, either singly or in consortia, because they have the most compelling incentive--an existing business with pipelines, refineries, and market facilities that requires a continued supply to remain economically productive. These extant facilities also provide the oil companies with great flexibility to integrate the new fuels smoothly into their existing businesses without establishing new marketing activities. This latter feature also has the property of insulating the consumer from technical change because all such change would be absorbed by the fuel producer. The combined questionable profitability and difficulty of market entry would certainly discourage other potential entrants to the industry (such as the large chemical companies).

This dominating interest by the existing oil companies will inevitably shape the choices of synfuels to be produced. For example, rather than producing directly a final consumer fuel in a single step, the oil industry prefers the production of syncrude because this allows full and flexible use of their existing investments in technology and marketing (including intercompany sales and exchanges).

The study team has concluded, therefore, that the voluntary adoption of the methanol option for automotive fuel is extremely unlikely because, unlike syncrudes, methanol would not fit as readily into the existing system and would require a separate distribution system and modification of marketing facilities.

Nevertheless, the scenarios developed later in this report depict methanol production on a large scale in the expectation that it will be used in large stationary facilities (such as electric utilities). Since such use would release petroleum for possible use in the automotive market, this production of methanol still fits the objective of the study.

E. Working Premises for a Hypothesized Implementation of a Synfuel Industry

The corporations that can be expected to play the dominant roles in commercialization of synfuels do not perceive the technical options as equally ready for deployment. Oil shale conversion is generally thought to be the first synthetic liquid fuel option likely to occur. Thus, the rest of the study is based on the following working premises:

- Syncrude is the most institutionally preferred product and will dominate.
- Oil shale will be the first source of syncrude.
- Methanol technology is closer to being commercially ready than coal syncrude technology and would play an indirect role in the automotive market by releasing petroleum supplies.

IV COMPARISON CRITERIA FOR SYNTHETIC LIQUID FUELS OPTIONS

A. Purpose of Applying Criteria

Besides the obvious comparison of economic cost that will be applied by industrial participants, consumers, and the federal government, several other noneconomic criteria should enter the determination of which synthetic liquid fuels should be produced and the relative rate of industrial development that should accompany production. These criteria are necessary because of the widespread and long-lasting consequences that would result from the deployment of a synfuel industry.

While, in principle, such criteria could be used to rank the candidate fuels and resources, one cannot expect all stakeholders to agree on the rankings. Since each stakeholder will bring different values to the process, each will give different weights to the various factors. Therefore, it is too much to hope that a clear-cut preference for one alternative will be reached by all stakeholders. What can be hoped, however, is that the application of these noneconomic criteria will assist stakeholders to perceive more readily the interactions among the consequences of the several options and the tradeoffs that may be necessary.

B. List of Criteria

The SRI study team believes that the following criteria should be considered in synthetic liquid fuels development:

- Technical
  - Resource use intensity (amounts needed to produce a given amount of fuel) of water, energy minerals, labor, capital, and land.
  - Net energy ratio of fuel systems

- Environmental/social
  - Geographic concentration of development
  - Impacted human populations (number, proximity, culture)
  - Impacted living forms (number, degree affected, reversibility of effect)
- Economic/institutional
  - Feasibility of evolutionary adoption of new fuel into existing systems
  - Opportunity costs (what is foregone by these uses of a resource)

These criteria have evolved from the considerations in this study. The summary application of the criteria presented below is based on the findings synopsized in the remainder of this volume and on their fuller presentation in Volume II.

C. Criteria Application

The criteria are applied below to seven variants of the fuel options:

- Syncrude from oil shale
- Syncrude from coal
  - Western
  - Illinois
  - Appalachian
- Methanol from coal
  - Western
  - Illinois
  - Appalachian.

Table 6 ranks the variants in terms of the criteria set forth above. The degree of impact (resource consumption, net energy ratio, geographic concentration, humans and ecosystems affected, and the potential for evolutionary integration into existing systems) is designated by "Most,"

Table 6

APPLICATION OF CRITERIA TO SYNFUEL OPTIONS: DEGREE OF IMPACT
(Most, Average, Least)*

	Syncrude				Methanol		
	Oil Shale	Coal			Coal		
	Colorado	West	Illinois	Appalachia	West	Illinois	Appalachia
Resource Intensity							
Fossil material used	Most	Average	Least	Least	Most	Most	Most
Energy consumed	Least	Average	Average	Average	Most	Most	Most
Water consumed†	Most	Most	Least	Least	Most	Least	Least
Capital invested	Average	Least	Least	Least	Most	Most	Most
Labor required	Least	Least	Least	Least	Most	Most	Most
Land area mined	Most	Least	Average	Most	Least	Average	Most
Geographic concentration	Most	Least	Least	Least	Least	Least	Least
Humans impacted	Most	Average	Least	Average	Average	Least	Average
Ecosystems impacted	Most	Average	Least	Most	Average	Least	Most
Difficulty of Evolutionary adoption	Least	Least	Least	Least	Most	Most	Most

*With respect, only, to the options shown in this table.
†Relative to availability.

"Average," and "Least." The result is a coarse measure of the favorability of developing each of the variants.

Even though the criteria and the rating systems are coarse indicators of the degree of favorability, it is apparent from Table 6 that no single option is most desirable in every respect. Instead, pursuit of any of the options will necessitate acceptance of social, economic, institutional, and environmental tradeoffs. For example, it is apparent that the methanol option is inferior to the syncrude option and that development in Illinois has generally fewer adverse consequences than development elsewhere. However, Table 10 (Section V) shows that the Illinois area could not itself sustain the industry for long. Therefore, less favorable options would also have to be pursued if the synthetic liquid fuel industry were to become as large as hypothesized in the Maximum Credible Implementation (MCI) scenario presented in the next section (V).

The manner in which these criteria will be weighted depends heavily on who are the decision makers. Pragmatically, one must anticipate that the most economically related criteria will be the first, most heavily weighted ones. Other criteria may ultimately be translated into a form that will allow their inclusion into the economic framework,* but until then criteria such as reversibility of environmental damage will have to be considered separately.

One important additional criterion that is poorly suited to presentation in the form of Table 6 is the "opportunity cost" of using a resource. Opportunity cost is a term used in economics to measure the value of a foregone opportunity. To some extent this cost is included

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*By such measures as pollutant taxes, or the cost of achieving control of air pollutant emissions.

in the economic cost of acquiring the resource, but since much of the coal resource and most of the oil shale resource are on government lands and made accessible by government leasing on a competitive basis, it is highly unlikely that the total opportunity cost to society will be included. Opportunity cost is a concept that is particularly useful in differentiating between coal and oil shale. There is no known "economic" use for oil shale other than oil recovery, while coal can be burned to generate electricity and provide heat, or it can be used to produce synthetic gases that can substitute for natural gas. Therefore, using coal for liquefaction processes may very well entail larger societal opportunity costs than oil shale conversion. It is possible that when all the tradeoffs have been examined, there may be a national consensus that oil shale should be developed up to an "acceptable" level if only to stretch out the more versatile coal resource.