CHAPTER 1: INTRODUCTION

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1.1 Role of Synthetic Fuels

Energy consumption in the U.S. has become increasingly dependent upon foreign sources, especially in the liquid fuels area. Transportation energy usage is a dominant user of foreign petroleum. Motor gasoline alone accounts for over 35% of all petroleum products consumed in the Us. (Reference No. 1) ; petroleum itself accounting for over 43% of all the energy consumed in the U.S. (Reference No. 2).

Unfortunately, over the past 35 years, the ratio of U.S. oil reserves to total U.S. oil consumption has declined, even with Alaskan North Slope oil discoveries. On the other hand, oil imports have been increasingly filling the gap in petroleum supply-demand imbalances. From 1950 to 1977, domestic petroleum production fell from an average 85% of total domestic petroleum consumption to 47% in 1977 (Reference No. 3)* This trend has been somewhat slowed down recently by increased energy conservation measures--especially in the transportation sector--but it has not stopped. The impacts of this increasing dependence on foreign crude oil and refined products have been staggering. In addition to the increased and continual exposure to supply interruptions, and subsequent national security vulnerability, the direct costs of these imports have increased enormously (Reference No. 4). From a modest plateu of 1-2 billion/year in the 1958-68 time period, the direct costs have mushroomed to 25 billion in the embargo period (1973-74) , and are heading for 90-100 billion in 1980 (Reference No. 5). The impacts of this capital drain in domestic investments, subsequent jobs, and consumer inflation has been notable. In the third quarter of 1979 alone, domestic prices for energy, housing; food, and medical care rose at an annual 17.6% rate--with energy prices escalating at a 50.1% annual rate. Adverse impacts have not been confined to the U.S. domestic economy. Oil bills, being raised by OPEC faster than inflation--not only account for 25-50% of total inflation rates around the world, but also pose a global inflationary problem, apparently without end--unless alternate or substitute fuel supplies are found\developed in sufficient quantities and at competitive prices to put the lid on world crude price escalation in a timely fashion.

Alternate Synthetic Fuels

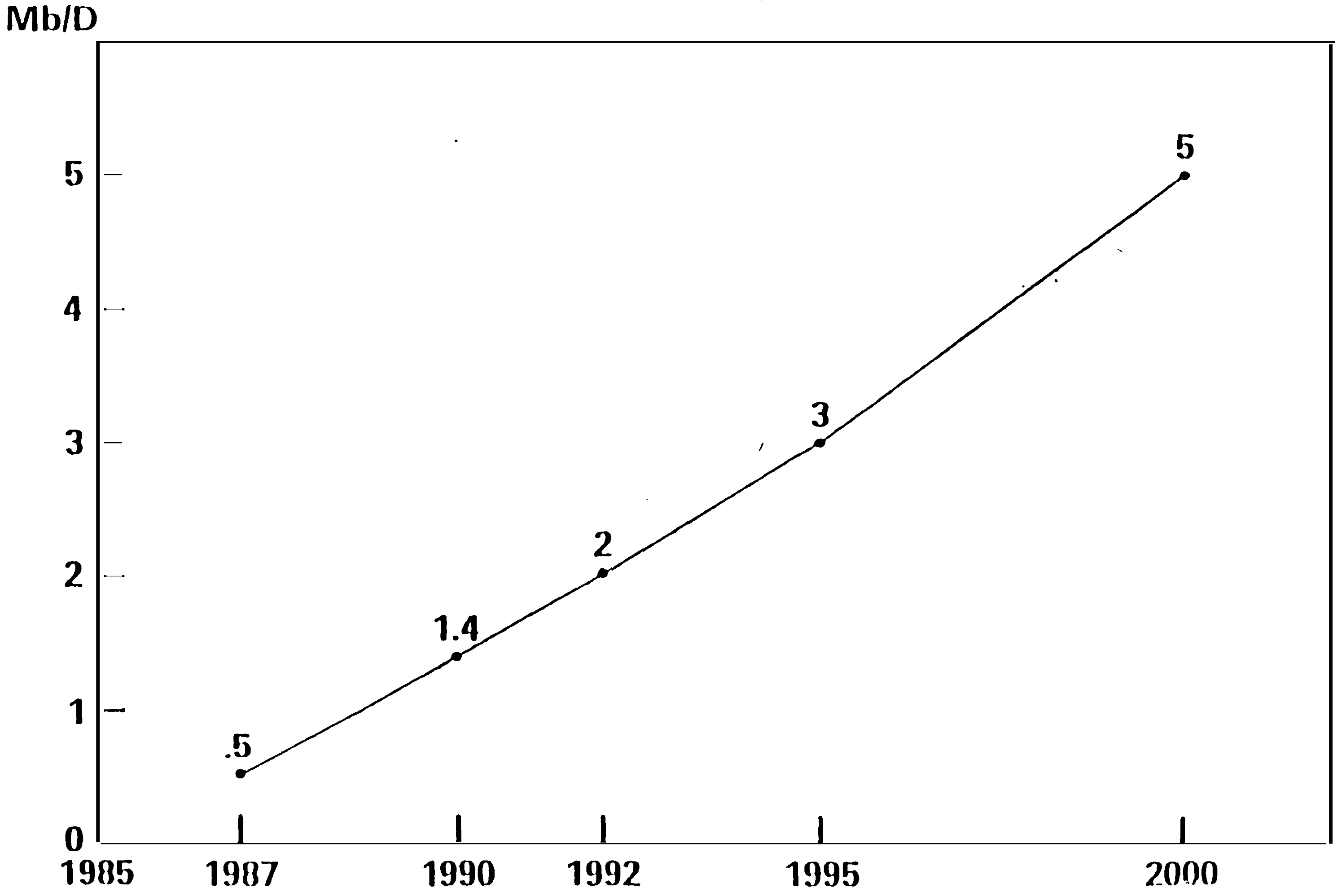
Many recent studies (Reference No. 6) have estimated the domestic energy and petroleum supply-demand imbalances. Most have credited conservation with decreasing petroleum demand from its historical rates of growth, and most have nonetheless projected a need for alternate domestic liquid fuels to fill the increasing domestic petroleum supply-demand imbalances.

Although most studies have agreed on the need for/and future role-of alternate domestic-fuels, they have differed in projecting their rate of growth in the marketplace, date of introduction, prospective cost, ease of usage, and "raw" resource availability--as well as their potential environmental, health, and safety impacts. The U.S. Department of Energy has recently targeted synthetic production goals to reach 5 million barrels/day of crude oil equivalent from all synthetic sources by the year 2000 (Figure 1.1), and the recently passed Energy Security Act (6/30/80) has targeted goals of .5 MMBD by 1987 and 2.0 MMBD by 2000. Although current forecasts vary, synthetics have generally been forecast to provide between 12-13% of total domestic energy by the year 2000, and even up to 30% of primary liquid fuel supplies. Although composition of those synthetic fuel targets and projections are varied (shale, unconventional gas, biomass, solar,. ..) , coal--as both a feedstock for synthetic fuels and as a direct combustion boiler fuel--generally has been projected to play a large and growing role. In many ways, this is a natural reflection of the abundant and regionally diverse U.S. coal resources and reserves. This is similarly true for shale as described in Chapter 2.

1.2 Scope of Study

The study design of this effort is, in a broad fashion, to provide for a technical and economic comparison of various selected synfuel technologies. As outlined in the contract study Scope of Work, the study team was directed to use existing published (and referenced) information and data. OTA staff and the Synfuels Advisory Group assisted in the acquisition of published data, as well as providing guidance and review. The study team was further directed to look solely at technical and economic aspects of selected synfuel technologies and specifically not at policy implications, interpretations, and concerns. These very

FIGURE 1.1: **U.S. Synthetic Fuels Production Goals 1985-2000**



Source: DoE, 1980

real policy considerations are the stated prerogative of the OTA itself and its existing well-defined review procedures.

In consultation with the OTA staff, generic technology choices have been made (Chapters 3 and 4), and supply deployment scenarios developed (Chapter 5). Each chapter, and sub-section, specifically identifies the respective referenced sources and assumptions used. Where available in the literature, comparative estimates have been provided. Scope, timing, and budget greatly limited the degree of first-hand data verification. The recent ESCOE coal conversion study, as referenced in Chapter 4, was the scope directed starting point for the comparative economic analysis, with specific cost basis and assumptions provided in the addendum to Chapter 4.

The outline of the report is as follows:

Introduction to Role of Synthetic Fuels and
Study Effort: chapter 1

Background on synthetic Fuel Processes
Chapter 2

Discussion of Selected Synthetic Fuel
Technologies: Chapter 3

Discussion and Comparison of Selected
Synthetic Fuel Technologies Cost
and Product Economics: Chapter 4

Supply Deployment Scenarios for
Synthetic Fuels: Chapter 5

Appendices

Glossary

Bibliography

Potential Next Steps

Potential next steps to the broad-based study effort could include site-specific, technology-specific detailed technical, economic, and socioeconomic evaluations. Site-specific supply transportation and product distribution needs and costs; assessments of facility-specific integration of synfuel facilities with existing refinery capacity; and site and region-specific socioeconomic and labor/skill mix needs. Case study assessment are sub-examples.

On the policy side, the OTA using this study, as well as other component study efforts, will be developing policy interpretations.

CHAPTER 2: BACKGROUND

Section No. Page

(I) Dascription of the Coal Conversion and Oil Shale Retorting Fuel Cycles

(II) Characteristic Synfuel Technologies Parroters

Chapter 2: BACKGROUND

(I) Description of the coal Conversion and Oil Shale Retorting Fuel Cycles

2.1 Overview of the Coal and Oil Shale Fuel Cycles

In order to estimate investments from mine to end user (excluding automobiles) , or to assess the rates of potential development of the synthetic fuels industry, it is necessary to consider all phases of the fuel cycles involved in the development. They include exploration for the resources, their mining, local transportation, beneficiation, transportation to conversion plants, conversion of the energy resources to fuels, and finally, their distribution to end users. Figures 2.1 and 2.2 (modified from Reference No. 7) describe in a schematic manner the energy systems involved in the case of coal conversion and of oil shale retorting.

2.2 Coal and Oil Shale Resources

Coal and oil shale resources are defined as those deposits "that can be extracted and processed to yield products that can be marketed at a profit" (Reference No. 8). Estimates of resources are not limited by whether or not the deposits have been demonstrated, or whether they are extractable by existing technologies at competitive economic costs. If the resource has been demonstrated (i.e. its location, quality, and quantity have been determined by evidence supported by measuements) and its extraction is economically feasible, then it is classified as a reserve. Resources may become reserves as a result of changes in technical or economic development. The major coal and oil shale resources of the coterminous United States are shown in Figure 2.3 (Reference No. 9) and 2.4 (Reference No. 8) . The United States reserves and resources of coal are estimated as 178 and 1,285 billion metric tons (Reference No. 10) . Other estimates vary widely, depending on economic and technical assumptions. For example a recent estimate of recoverable reserves of coal (Reference No. 11) places them at 38,000 quads[2] or equivalent to 150 billion metric tons of coal.

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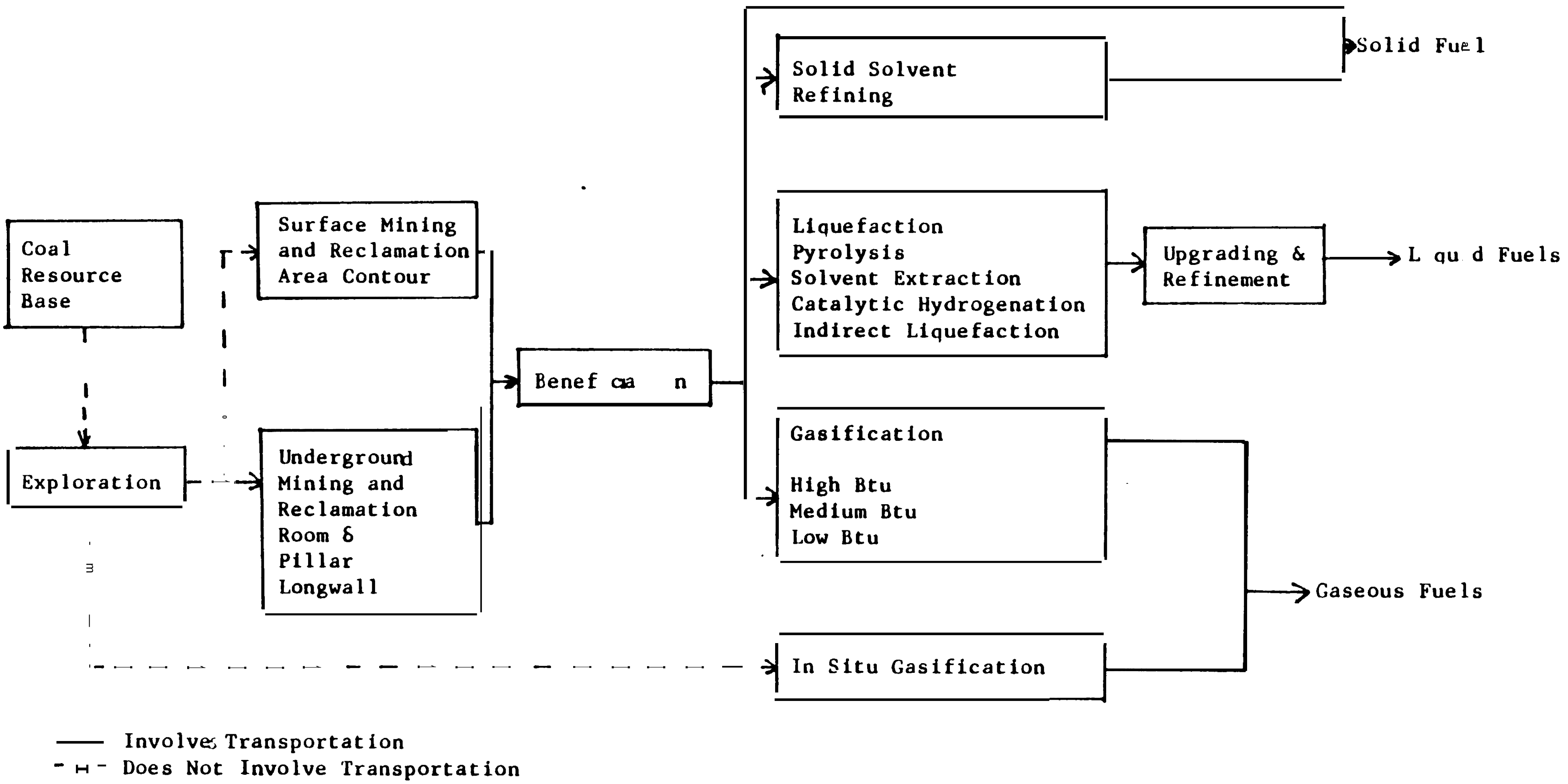
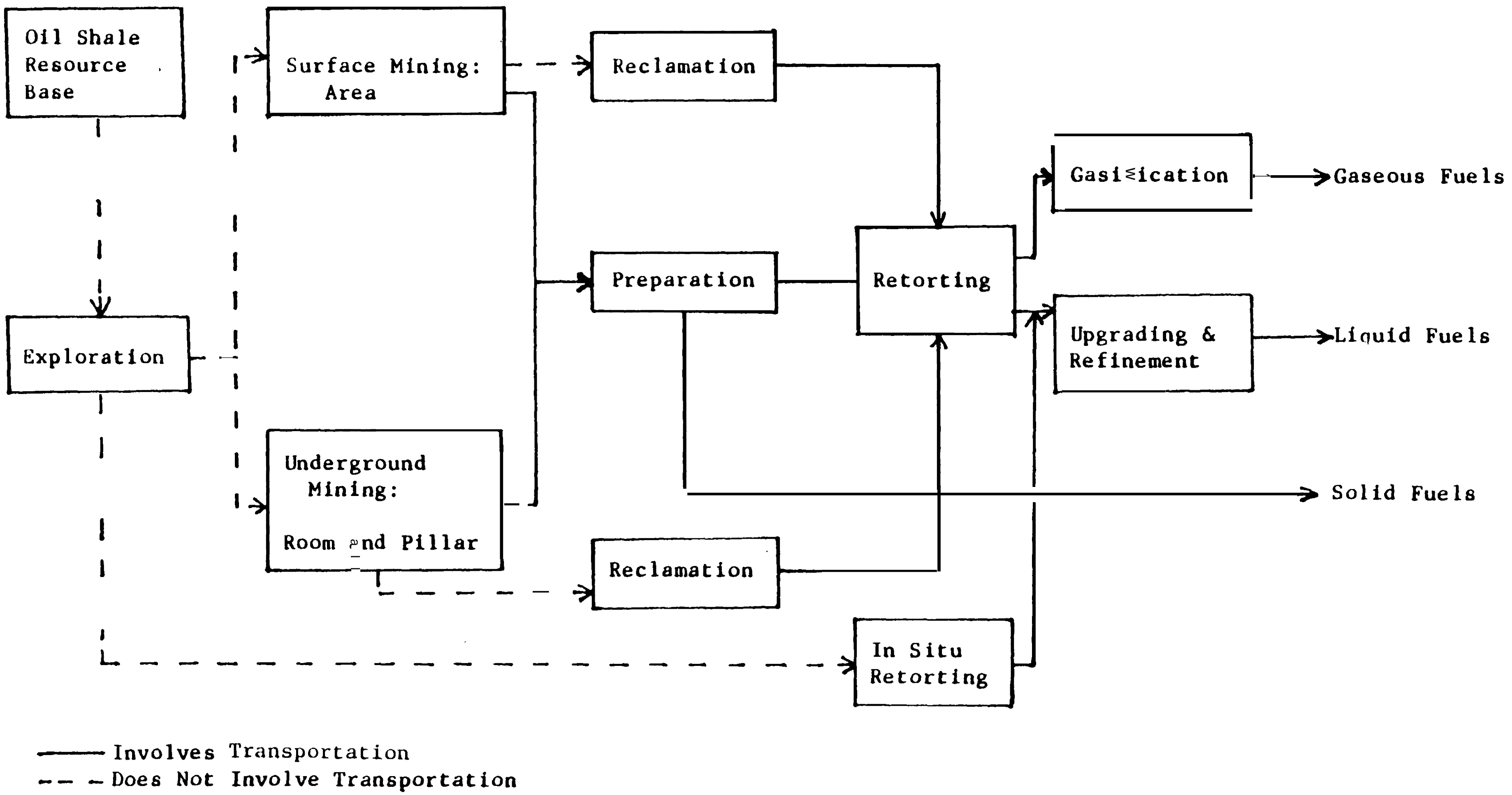
[1] A recoverability factor of 50 percent is assumed for resources.

[2] Quad is a unit of energy equivalent to 10^{15} (quadrillion) Btu. It is approximately equivalent to 180 million barrels of oil or to 40 million metric tons of bitumious coal. On the average, one quad is enough to supply all the present energy requirements of about 3 million Americans for one year.



SOURCE: E. J. Bentz & Associates

FIGURE 2.1 Coal Conversion System



SOURCE: E. J. Bentz & Associates

FIGURE 2.2: Oil Shale Retorting System

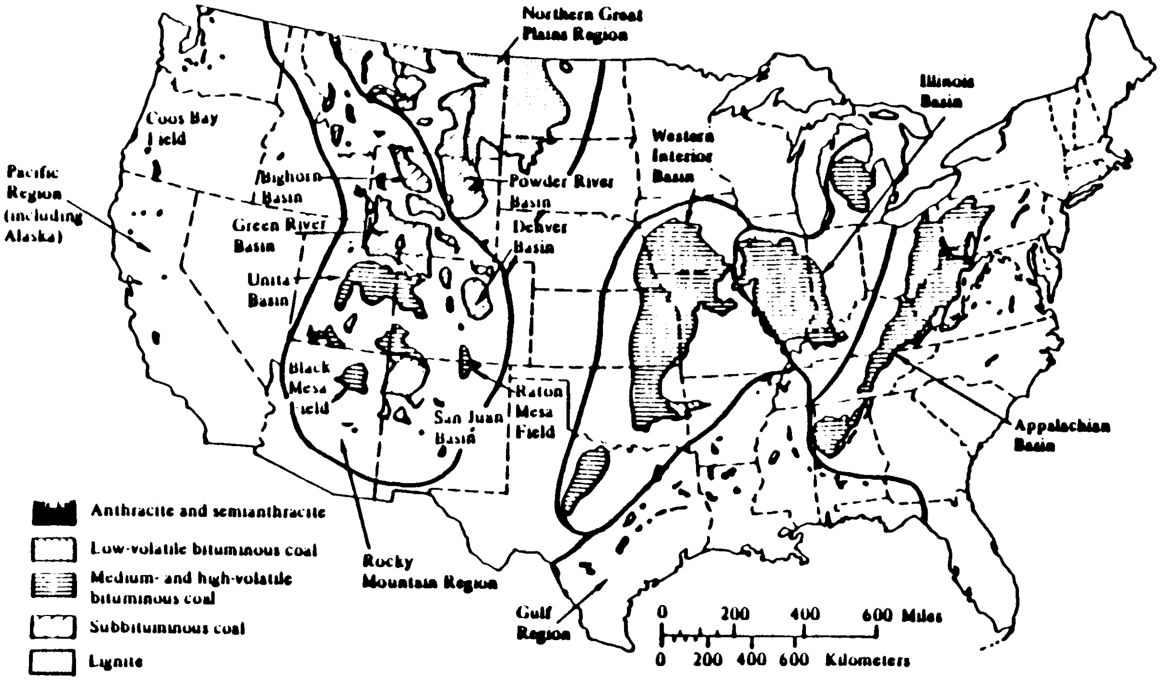
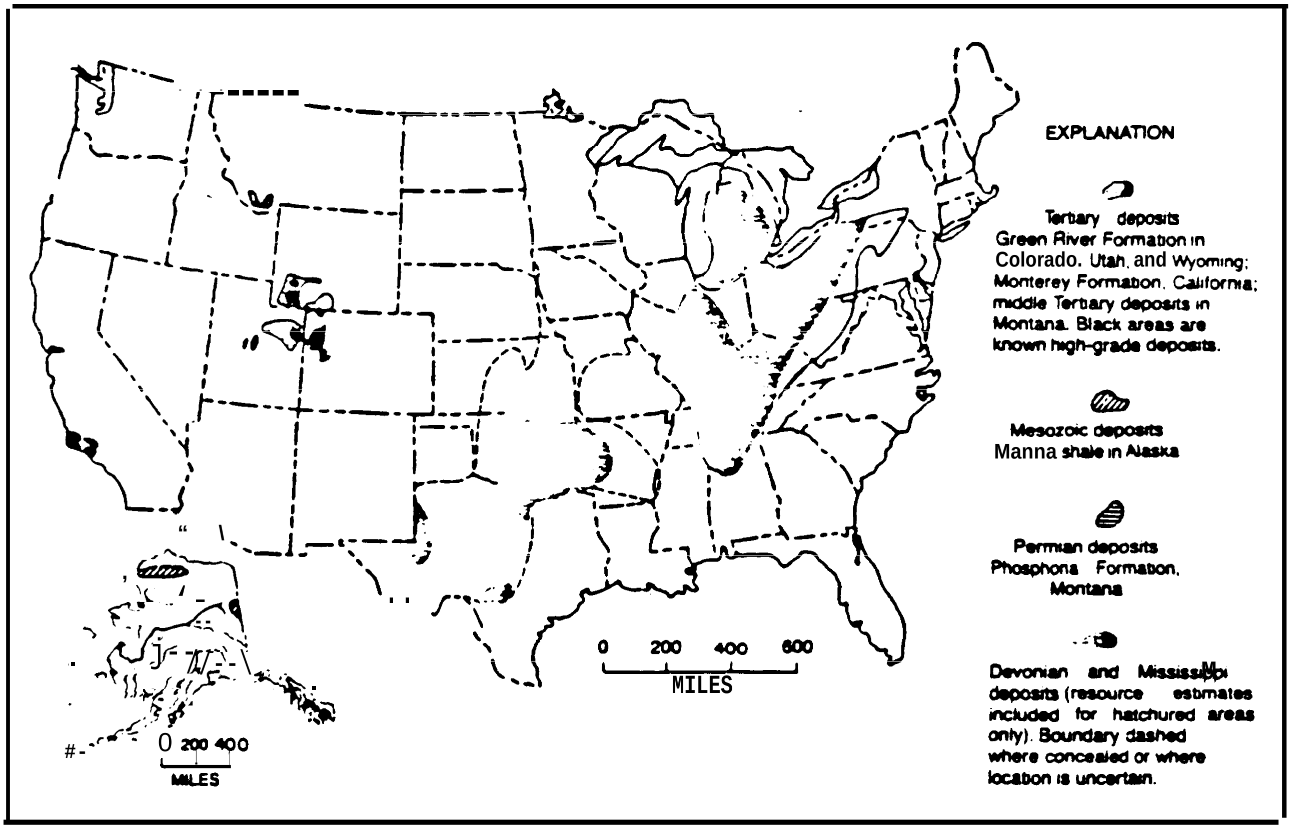


FIGURE 2.3 Coal fields of the coterminous United States. Source: Adapted from Paul Averitt, *Coal Resources of the United States, January 1, 1974*, U.S. Department of the Interior, Geological Survey Bulletin 1412 (Washington, D.C.: U.S. Government Printing Office (Stock No. 024-001-02703), 1975), p. 5; and U.S. Department of Energy, Energy Information Administration, *Coal Data* (Washington, D.C.: U.S. Government Printing Office (DOE/EIA-0064), 1978), p. 1.

ejb &a

Figuro24: Oil Shale Deposits of the United States



SOURCE D C Duncan and V E. Swanson, *Organic-Rich Shales of the United States* and *World Land Areas*. U.S Geological Survey Circular S23. 1965.

Estimates of recoverable reserves and resources of oil shale vary even more broadly than those of coal because of the poor existing state of knowledge. An estimate by the Committee on Nuclear and Alternative Energy Systems of the National Academy of Sciences places them at 3660 quads of recoverable oil at $21.50 -$27.50 in 1978 dollars (Reference No. 9) which is equivalent to about 1.50 billion metric tons of real. Schurr's estimates of shale oil reserves are only 1100 quads which is equivalent to 44 billion metric tons of coal (Reference No. 11) . Oil shale resources have been estimated by OTA (1980) as equivalent to between 2,000 and 140,000 billion barrels of oil equivalent, or 440 to 3,090 billion tons of Coal.

The distribution of the coal and oil shale resources are given in Tables 2.1 (Reference No. 12) and 2.2 (Reference No. 8) . There are large variations among the characteristics of coal and oil shale resources, as well as the characteristics of sites at which they are found. These characteristics affect the processes, economic rests and resource requirements of the development of a synthetic fuels industry. The important variables are the quantity and quality of the coal and oil shale in each site or province, ownership, relationships to markets and processing facilities, bed depth, seam thickness, availability of water resources, and competition for surface area usage. These are discussed at greater length in Appendices A and B (Reference No. 7) .

2.3 Exploration and Mining

Knowledge about coal and oil shale resources is usually obtained in stages. The steps begin with the assessment of geological and geophysical data and are followed by surface and areal photographic surveys and magnetic measurements. Finally, mapping and appraisal of regional deposits are done, based on seismic surveys and drilling. The steps are explained in greater detail in references below.

There are two basic methods of coal and oil shale mining, namely surface mining and underground mining. The choice between them depends mainly on the depth of burial and thickness of the seam. In the case of coal seams that are relatively close to the surface (i.e. less than 180 feet) surface mining is employed (Reference No. 13) . In the case of oil shale, where the deposit is within a few hundred feet (200 to 300 feet) from the surface, it can be surface mined (Reference No. 14) . However, higher quality oil shale is commonly located at depths of over 600 feet, so that it may be more efficient to apply underground processes of retorting rather than mine the shale (Reference No. 8) .

A qualitative description of the mining methods and their impact are given references 7 and 8. Appendix A to Chapter 2 summarizes the the major components, resource requirements, costs and pollutants

TABLE 2.1

U.S. BY STATES
RESOURCES-RESERVE BASE-PRODUCTION
BITUMINOUS-SUBBITUMINOUS-LIGNITE COAL

(**Millions** of Tons)

State	USGS Remaining Identified Resources January 1, 1974	Yearly Production 1977	Estimated Remaining Reserve Base January 1, 1978
Alabama	15,262	21	1,823
Alaska	130,079	<1	11,642
Arizona	21,234	11	308
Arkansas	4,938	<1	668
Colorado	148,850	12	14,815
Georgia	1+	<1	1+
Illinois	146,001	54	65,286
Indiana	32,868	28	10,495
Iowa	6,505	<1	**2,882**
Kansas	18,668	<1	1,385
East Kentucky	22,226	92	12,360
West Kentucky	36,120	51	35,788
Louisiana	1,000	0	800
Maryland	1,152	3	1,027
Michigan	205	0	118
Missouri	31,184	7	9,457
Montana	291,639	29	108,282
New Mexico	61,387	11	4,344
North Carolina	110	0	32
North Dakota	350,602	12	15,954
Ohio	41,116	46	20,736
Oklahoma	7,117	5	1,276
Oregon	334	0	57
Pennsylvania	63,940	83	23,335
South Dakota	2,185	0	428
Tennessee	2,530	10	932
Texas	139,000	17	3,210
Utah	23,359	9	3,982
Virginia	9,216	38	29,225
Washington	6,194	5	1,932
West Virginia	100,150	95	38,822
Wyoming	136,891	44	53,182
Other States (Calif., Idaho, Nebr., Nevada)	688	0	447

Table From: **Solid Fuels for** U.S. Industry, Cameron Engineers, **1979**

TABLE 2.2

POTENTIAL SHALE OIL IN PLACE IN THE OIL SHALE DEPOSITS OF THE UNITED STATES (billions of barrels)

Location	Range of shale oil yields, gallons per ton		
	5 - 10[a]	10 - 25[a]	25 - 100[a]
Colorado, Utah, and Wyoming (the Green River formation)	4,000	2,800	1,200
Central and Eastern States (includes Antrim, Chattanooga, Devonian, and other shales)	2,000	1,000	(?)
Alaska	Large	200	250
Other deposits	134,000	22,500	(?)
Total	140,000+	26,000	2,000(?)

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[a] Order of magnitude estimate includes known deposits, extrapolation and interpolation of known deposits, and anticipated deposits.

Data from: D.C. Duncan and V.E. Swanson, Organic-Rich Shales of the United States and World Land Areas, U.S. Geological Survey Circular 523, 1965.

associated with generic surface and underground coal and oil shale mining in East and West.

The following conclusions can be drawn about coal and oil shale, namely:

1. The Northern Great Plains and Rocky Mountain Provinces contain approximately 70 percent of the coal resources in the United States and most of the nations low-sulfur coal (References No. 7 and 14a) .
2. Much of the coal likely to be developed in the near future can be surface mined. This estimate is based on existing trends of continued shift from underground to surface mined coal (References No. l& and 14c) , and on the abundant quantities of coal that can be mined by existing surface mining technologies (References 7 and 14a) .
3. Competition for surface area usage is relatively low in those areas of coal mining (Reference No. 7) .
4. The federal government controls the majority of the coal and oil shale lands (References No. 7, 8, and 14a) .
5. Water resources can become a constraint on coal development in the Rocky Mountain and Northern Great Plains Provinces (References No. 7, 9, and 14d) .
6. The development of oil from oil shale resources involves tremendous quantities of materials that need to be mined and disposed. The production of 1 million bbl oil per day from oil shale would require the mining and disposal of about 1.3 million metric tons of shale per day (Refer-e No. 15) .
7. Most oil shale extraction is expected to be by underground mining, with only about 1.5 to 20 percent being extractable by surface methods (Reference No. 16) . This proportion may change with technological developments.

2.4 Beneficiation

Coal and oil shale feedstocks require some preparation, called beneficiation,prior to their feeding into the conversion process.

The nature of the preparation depends on the characteristics of the feedstocks, and on the type of conversion process adopted. In some cases, mechanical upgrading is sufficient, and consists of any or all of the following processes:

1. Crushing and screening
2. Cleaning
3. Drying

In some cases of coal feedstocks, further processing is required. A portion of the ash and sulfur can be removed from the coal by simple procedures such as water washing, or magnetic separation of iron pyrites. Further upgrading of the coal can involve chemical processes, such as reacting the coal with various chemicals, or converting it to more desirable products. A further discussion of coal beneficiation is included in Reference No. 7 and Reference No. 13.

Appendix Table 8 (Reference No. 17), summarizes the major components and resource requirements of coal beneficiation. Appendix A to Chapter 2 compares the costs of various chemical coal cleaning processes.

Oil shale beneficiation consists mainly of crushing and sizing. The process is further discussed in Reference No. 8.

2.5 Transportation

Local transportation is mainly limited to the transfer of the coal or Shale between different parts of the mining area. Truck, belt conveyor, or rail transport are the most used means.

Coal also needs to be transported beneficiation plants, and in large quantities and over large distances to coal conversion plants. There are a number of alternatives for transporting the coal, namely, railroads (both unit and conventional trains), slurry pipelines, and to a lesser extent, barges and trucks. The transportation of coal is further discussed in Reference 7. Appendix to Chapter 2, References 7 and 18, summarize the major components and resource requirements of transportation.

In the case of oil shale, siting of the conversion plan is near the mining area is envisaged. This is because of the tremendous quantities of shale involved.

2.6 Conversion

The Conversion of coal and oil shale to other energy products is

covered in detail in Chapter 3 of this report.

2.7 Upgrading and Refining

Raw synfuels may be used directly in the market for same applications without further upgrading; or they may require modifications before they can become substitutes for existing products. The need for different variations of upgrading will be detemined by the characteristics of the synfuels, and their uses. Liquid synfuels can be utilized in many end uses, the most important of which are the transportation, space heating, raising of steam in boilers and as chemical feedstocks. Substitution of coal or oil shale derived liquids for petroleum based fuels particularly in transportation, will create problems because of the differences between them. They differ mainly in the types and quantities of hydrocarbon species involved in the overall ratio of hydrogen to carbon atoms in the mixture, and to a lesser extent, an increased presence of ash, trace metals, and nitrogen compounds.[3] While the ratio of hydrogen to carbon is approximately 2 for petroleum, it drops in general to 1.9 for shale oil and in general 0.75 for coal derived liquids (Reference No. 19) , although this depends on the specific product slate and operating conditions. The addition of substantial amounts of coal or shale derived fuels will mainly decease the hydrogen to carbon ratio, and increase the aromatic, nitrogen, and trace metal content of the refinery products.

The concerns and costs associated with selective upgrading are discussed in Chapter 4. The key concern is to match anticipated product demand slate specifications and tolerances with variable feedstock inputs (from West Texas crude to shale oil) at least cost. The factors that affect the cost are the kind of strategies that have to be developed to meet the challenge, and the decision whether to upgrade the synfuel at the conversion plant or at the refinery.

There are several strategies that can be used to adopt synfuels to product demand. One is to modify the engines using at present petroleum derived fuels to match the characteristics of synthetic fuels; another is to modify the synthetic fuels; a third is to develop an optimum combination of changes in both the supply and end use sections. Still, it should be pointed out, that many variations of upgrading can be conceived, not necessarily requiring conversion of the total raw synfuel streams to refined products Rather, some Synergistic effects can be used to incorporate synfuels upgrading into a variety of refining schemes, with significant improvement in *economics* .

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[3] Raw ***coal*** *distillates* contains 100 *times* the nitrogen of **conventional** petroleum (Reference No. 19) .

Early analysis (Reference No. 19) suggested that in the short run, selective synthetic fuel upgrading can alleviate fuel distribution concerns. More recent analyses (Reference No. 20) suggest that transition solutions will probably entail synthetic fuel finished products — such as methanol in modified automotive fleet engines. These matching concerns reflect the sensitivity of combustion engines to the hydrocarbon makeup of the fuel. Experience has * that the combustion of fuels low in hydrogen content and rich in aromatics results in an increased formation of soot, in addition to various other in-field maintenance problems.

Existing and anticipated petroleum refining technology can upgrade synthetic oils to meet current engine and turbine specification. This is primarily done by the hydrogeneration of crudes. For most existing refineries, the development of such upgrading capabilities would require costly changes in the reactor vessels to withstand high pressures, and a further supply of hydrogen. Therefore, an economic evaluation needs to be carried out for each specific situation. It would determine whether product upgrading is more cost effective when conducted together with the primary coal hydroliquefaction step, thus forcing the conversion process to produce finished, more premium hydrocarbon liquids; or whether upgrading should be combined with refining.

Oil from shale with hydrogen to carbon ratio of 1.9 (vs 2 for petroleum) can be substituted for present fuels with some relative ease. Oil from coal conversion with hydrogen to carbon ratio of 0.75 requires more upgrading.

Preliminary studies indicate that the upgrading of the H/C ratio and reducing the aromatic and organic nitrogen contents of synthetic crudes is feasible but expensive in terms of costs and energy losses. chapter 4 discusses these cost comparisons[4]. Various estimates have been prepared for upgrading. Among them are references for coal conversion and shale . Estimates have been prepared by Chevron, U.S.A.

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[4] - uncertain still. surrounds the costs of alternate fuels for heat engines since absolute costs will not be established until fuel production plants are built and operated. However, for the purpose of initial screening of alternate fuels, relative rests can be established from published studies . Comparing these studies on a consistent basis in terms of total delivered costs and engine efficiencies is more important than the assesment of absolute product costs shown by such studies.

[5] Other authors (Reference Nos. 21, 22, 23, 24 and 25) indicate and describe processes for upgrading shale oil but no comparable cost and energy estimates are given.

putting the cost of upgrading crude shale oil for a 100,000 bbl/d facility at $6.50, in first quarter 1978 dollars, equivalent to about $7.80 in 1980 dollars (Reference No. 8) . Total cost of upgrading and refining crude synthetic fuels vary according to the capacity and location of the refinery, the nature of the crudes involved and the available facilities and options at the refinery. Estimates of the refining costs for crude shale oil ranged from $8.00 to $12. 00/bbl (Reference No. 8) . In the case of refineries modified for crude shale oil, estimates as low as $0.25 to $2. 00/bbl are reported (Reference No. 8) . Upgrading of these crudes may also result in energy losses as large as 25 to 50 percent of the original energy in the coal (Reference No. 19) .

There are several studies underway to define capabilities of state-of-the-art petroleum refineries for syncrude upgrading and development of new refining methods specifically tailored towards syncrudes (Reference Nos. 22, 23, 26, 24 and 21) . The preliminary conclusions that can be drawn are:

1. Syncrudes can be refined by conventional methods.

2. Products are interchangeable with petroleum derived products.

3. There are serious economic and energy penalties in upgrading (Reference No. 19) , but research leading to improved refining processes to @@- the syncrudes and engine development to use then are expected to reduce the penalties.

4. Direct coal liquids may require more severe upgrading than shale oil (Reference No. 19) .

The processing details of upgrading of various coal conversion and oil shale derived crudes as well as their properties relative to petroleum males are given in references 22, 23, 26a and 26b.

Crude synthetic fuels can be upgraded either at the synfuel plant or at a refinery[6]. The upgrading process is similar in many respects to the refining of crude petroleum. Therefore, there may be economic and technical incentives to combine the two operations in one plant. Utilization of existing facilities, and the available options of existing refineries to mix syncrudes and petroleum crudes to ease the upgrading process are other advantages. Furthermore, upgrading requires water, so that the location of many potential synfuel conversion plants in dry areas may dictate the separation of the two. However,

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[6] Most existing refineries will need to be modified before they can handle syncrudes.

a decision on whether to upgrade synfuels at the conversion plant or in the refinery should be based on a detailed analysis with consideration given to location and marketing factors.

2.8 Distribution to End Users

There is similarity between syncrudes and petroleum crude oil. It is therefore most likely that the mode of distribution will. be through the presently existing crude oil pipelines shown in Figure 2.5 (Reference No. 27) . Some new pipeline additions or extensions will undoubtedly be built, depending on the location of the syncrude plants However, it is likely that the location of crude oil pipelines, as well as the availability of coal, water, etc. , will be taken into account in siting the plants. Once the syncrude has entered the pipeline distribution system, it will probably be treated as another source of crude, as is presently done with syncrude from Canadian tar sands, and districted to refineries as a supplement to natural crude supplies (Reference No. 27) .

(III) Synfuel Technologies Parameters

2.9 Common Elements

There are about one hundred different processes for converting coal or oil shale to gaseous, liquid or solid fuels. Still there are important similarities among then. They relate to the physical size of the plants, their complexity costs, conversion efficiencies, and the requirements for resources such as manpower, feedstocks, land, water, and equipment. These factors are important for the understanding of the various conversion processes; the situation of constraints and time tables of implementation; and for understanding the uncertainties involved in projections.

2.10 Physical. Size

Larger sizes of synfuel plants do not cost propotionately more than smaller sizes. As a result there is an incentive to minimize costs by designing large capacity plants of the order of 50,000 to 100,000 barrels per day oil equivalent production. Such large plants can provide the equivalent energy requirements of a city of about a quarter to half a million people. The investment required for a 50,000 barrels per day synfuel plant is estimated between \$2 and \$4 billion (Reference No. 28) . The constuction of the plant will be a major engineering endeavor and require about five to eight years. The size of the plant is measured in square miles[7]. The amounts of material that have to be handled by

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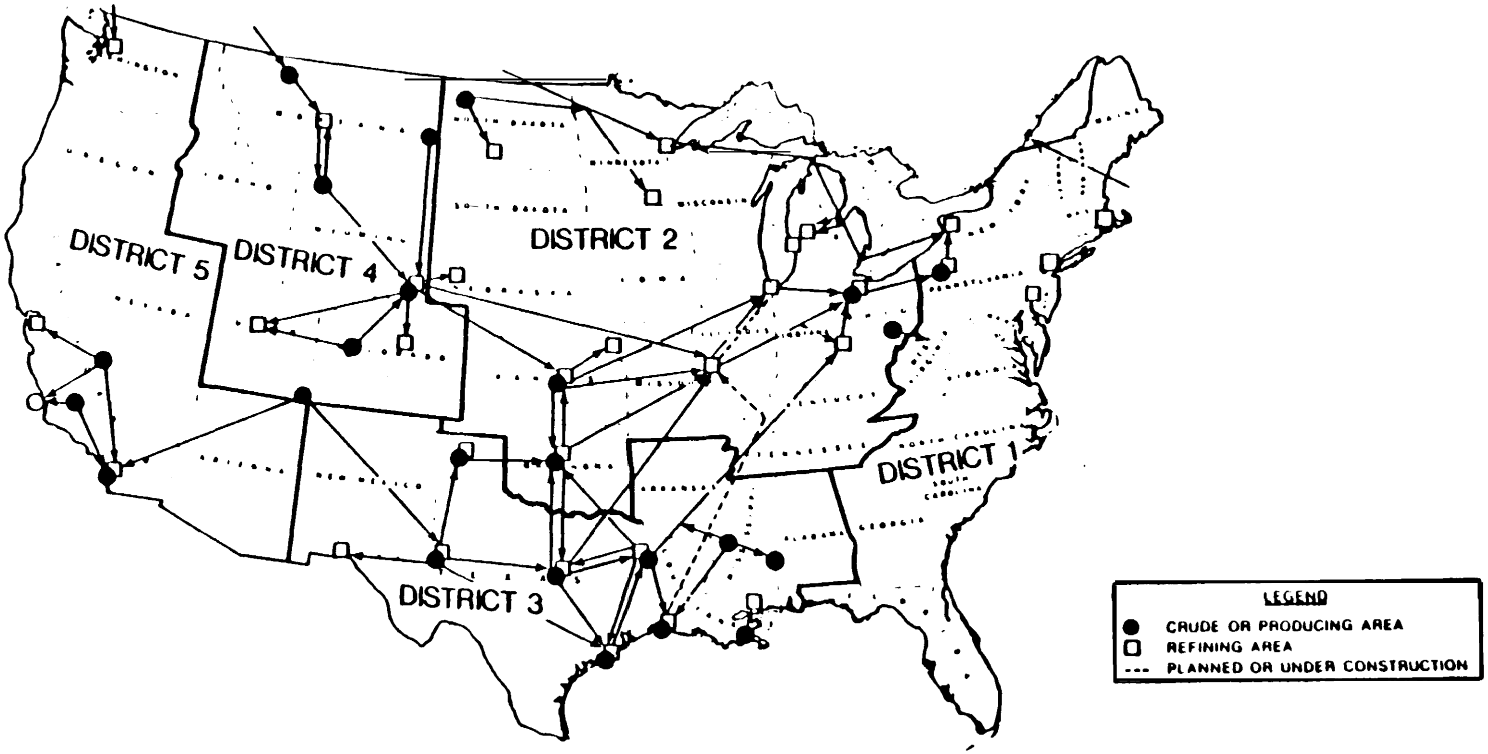
[7] Two squares miles of land are required for a 125 million CFD gasification plant producing the equivalent of 22,000 barrels of oil per day (Reference No. 28) .



SOURCE IONAL PETROLEUM COUNCIL

FIGURE 2.5: CRUDE OIL PIPELINE NETWORK

the conversion plants are also very large. In the case of a 50,000 barrel per day SRC II coal liquefaction plant, coal feed is estimated at 32,000 tons per day and solid wastes at 36,000 tons per day on a dry basis (Reference No. 25) . This is equivalent to one railroad car every three minutes . In the case of a similar capacity oil shale retorting plant, the quantities are double those for the coal liquefaction plant (Reference No. 28) .

2.11 Complexity

All of the synfuel processes reviewed in this paper have varying degrees of overall complexity[8] (Reference NOS. 28, 29, and 30) . This is because many individual steps are required. However, although some complexity is unavoidable, redundant complexity is costly in terms of such factors as investment and operation costs, efficiency, lag time between initiation and finalization of projects, and reliability of operation. Rogers (1979) divided complexity into the following categories, which can apply to all coal and oil shale conversion processes, and comments on their implications:

- "Reaction complexity. A process which requires several consecutive reactions is less desirable than a process involving fewer reactions . The sensitivity of any one reaction to changes in any of the important variables, such as temperature, concentration, etc., may have strong effect on quality control and reliability. Coal is a heterogenous material and imposition from a given mine often varies with time. This further aggravates the reaction blem.

- Operational complexity. A process with many steps which entails multiple handling of solids and fluid streams will be prone to more equipment failures and consequently greater downtime . As detailed in the section on reactor complexity, the methods used for gas/solid contacting and catalytic conversion can also greatly increase process complexity. As a general rule, solids cause more problems than fluids, and liquids are more troublesome than gases.

- Operating regime. The chemistry of coal conversion processes normally involves high operating temperatures and pressures. Very high pressures or temperatures involve more difficulties. Special materials and equipment such as high pressure solids feeders and non-standard items must be built and maintained

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[8] Shale oil retorting and upgrading systems may not be as complex as some coal. conversion systems.

with much higher standards than required for simpler conditions.

- Auxiliary facilities. The number of *required support* facilities such as catalyst reclaiming, by-product recovery plants and special utility services will make the process complex. Each auxiliary service brinqs with it its own complexity factor with an influence on cost and reliability."

Comprehensive tables comparing the process complexity of various coal conversion processes have been published (Reference No. 29) . It should be noted that many of the coal conversion and oil shale retorting processes share many common unit operations. These include such steps as grinding, drying, preheating, reaction, ash separation, flashing, hydrotreating, distillation, storage, and many auxiliary operations such as hydrogen generation, removal of sulfur and nitrogen compounds, waste processing, electric power production and plant maintenance. Many of these unit operations are familiar and can be designed with confidence. There are, however, a few steps which are either difficult or impossible to accomplish with known technology. They are the ones that add Uncertainty to synfuel technology with respect to costs and time tables.

2.12 costs

Synfuel plants are capital intensive. As discussed in Chapter 4, capital cost ranged significantly as a function of product cost over the technologies. This makes the plant cost estimate very important in any economic study. However, existing cost estimates of synfuel processes have many uncertainties. They are primarily due to uncertainties associated with unproven technologies, changing inflation rates, and wide fluctuations of primary energy prices. There are therefore wide fluctuations among economists, particularly with respect to feedstock rests, price of products, the capital investment needed to build the facilities, and the rates of return on investment.

one can expect that capital investment in first-of-a-kind (pioneer) plants is going to be higher, in equivalent dollars, than later plants designed and built with the benefit of operating experience for the process involved.[9]

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[9] Learning experience cost reductions can be very significant. An example applying to a rapidly emerging industry is the chemical and allied products industry, where real non-energy rests declined by nearly 3% yearly for more than two decades.

Larger size plants cost less per unit of product than smaller , plants . The relationships between capital cost and plant size is given (Reference No. 28) by the equation:

$$\text{Capital Cost} = ks^{x}$$ [10]

where: k is a constant

S is a plant production rate

The exponent, x, is generally somewhere between 0.4 and 0.9, although usually between 0.6 and 0.8. The exponential rule" only applies for process plants which are similar in all respects except size. It is generally not applicable for situations where sizes differ by more than a factor of ten.

There are no quantitative estimates of anticipated cost reductions due to experience in building synfuel conversion plants. On the one hand, the immature and undemonstrated nature of many of the synfuel precesses suggests cost reductions when the industry will reach maturity. On the other hand, experience has shown that cost overruns in major projects utilizing uncertain technologies are frequent – and perhaps unavoidable occurrence. Exhibit 4-16 depicts cost growth in pioneer energy process plants.

2.13 Conversion Efficiency

High conversion efficieny is an important factor to be desired. It affects not only the product costs and the conservation of resources, but also reduces undesirable health, environmental and socio-economic impacts which are related to the quantities of needed feedstocks that need extraction, transportation, and processing and to the size of the plant . Efficiency is often defined as the ratio of the useful energy leaving the plant in the form of products and by-products to the energy in the input streams, including feedstocks and ancillary energy. In designing conversion plants, optimum efficiency is selected to give the least costly synfuel production. The calculations are relatively simple when applied to balancing of investments with consideration of savings expected on more efficient processes or equipment versus the costs of the investments. However, the calculations become very complicated when they take into account the energy balance of the plant and assume credits for the sensible heats contained in the feedstocks or the products. Since the price of coal, oil shale and many by-products is relatively low on the basis of energy content (relative

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[10] This exponential rule does not apply to multiple train systems.

to other economic factors) , there are economic constraints to increase absolute efficiency. Also in tires of crash programs, the pursuit of the most efficient design and equipment may need to be compromized to reduce delivery times of equipment and services.

Table 2.3 (Reference No. 29) , summarized process efficiencies for various coal conversion processes. They range between 65 and 70 percent for the coal gasification and direct coal liquefaction processes. They are estimated to be between about 50 to 60 percent for indirect coal liquefaction. When gasification and electric power production are combined, the efficiency drops to about 40 percent.

2.14 Other Requirements and Concerns

In addition to the above mentioned factors that characterize synfuel technologies (size, complexity, costs, conversion efficiencies. ..) , there are additional requirements and concerns that the development of a synthetic fuels industry have. Among them are:

. Labor Requirements. Large labor requirements, both during construction and for operation of the synfuel plants are typical. They are also closely associated with potential socio-economic impacts due to the relatively sudden increases in demand for services and resources* These impacts are mainly influenced by the size of the demand for labor relative to the size of the communities involved. For oil shale facility development in the West, these potential impacts can be large (Reference Nos. 31, 32 and 33) .

. Feedstock Requirements. As stated earlier, the amount of feedstocks that are required for a generic conversion plant producing 50,000 barrels of oil per day equivalent are very large. About 30,000 - 40,000 tons of coal per day are needed by a typical coal conversion plant and double that amount of shale by an oil shale retorting plant. The demand on coal feedstocks alone has been projected by the EPA (Reference Nos. 31, 32, 33) to increase from about .5% of projected U.S. coal output in 1985, to over 25% in 2000.

. Land Requirements. As discussed earlier and specifically in Reference No. 31. the land requirements for synthetic fuel development includes not only the on-site land requirements of the physical plant, but also the land associated with extraction (mining) and with disposal.

. Water Requipments. As discussed earlier, and specifically in Reference Nos. 31, 32 t synthetic fuel plants require significant quantities of water. In the coal conversion industry, water is

Table 2.3: PROCESS SUMMARY

Process	Developer	Primary Product	Secondary Product	Feed Coal Type/Size	Year Begun	Conf. Index	% Efficiency[11] Process/Product	Remarks
SRC - I[12]	Southern Co. Services + EPRI + DOE + Gulf	Solid Boiler Fuel	Naphtha	All types	1962	B-3	71/70	
SRC - II	Gulf + DOE	Liquid Boiler Fuel	Gas LPG Naphtha	All types with ash restrictions	1976	B-4	70/70	
EDS	Exxon	Liquid Boiler Fuel	LPG Naphtha Gas	All acceptabl	3966	C-3	66/64	
H-Coal Fuel Oil	HRI	Fuel Oil	Naphtha Gas			C-2	/74	
H-Coal Syncrude		Syncrude				C-2	/69	
Fischer-Tropsch	Standard Technology used M 50 years	Range of Hydrocarbons	LPG Alcohols NO. 2 Oil Fuel Oil Gas	All coal is gasified	Before 1930	A-2	/48	Depends on gasifier efficiency
M-Gasoline	Mobil for Methanol to Gasoline Conversion	Premium Gasoline	LPG	Any gasifier to methanol process may be used		C-3	/32	
Methanol		Methanol	—	Depends on gasifier		A-2	/57	

[11] Efficiencies are highly dependent on product mix.

[12] The SRC I process as presently designed for the SRC I precommercial demonstration plant would be a two-stage process which produces liquid fuels, as well as SRC solid. SRC II and EDS produce a distillate syncrude.

SOURCE: Reference 29

Table 2.3: PROCESS SUMMARY
(continued)

Process	Developer	Primary Product	Secondary Product	Feed Coal Type/Size	Year Begun	Conf. Index	% Efficiency Process/Product	Remarks
CO_2 Acceptor	Conoco Coal Development Co.	High Btu Gas Low Btu Gas	None	Lignite or Sub-Bituminous /8x100 mesh	1968	B-2	68/67	Claimed to be the only fluidized bed process that can handle lignites
Hygas	IGT	High Btu Gas	Naphtha	All with pretreat	1954	C-3	78/66	
Bigas	Bituminous Coal Research	High Btu Gas	None	All	1963	C-4	64/60	
Synthane	BuMines PERC Lummus	High Btu Gas	Char	All/20 to max 20%-200	1961	C-3	65/63	
CE	Combustion Engineering	Low Btu Gas Electric Power	None	All	1974	C-4	/40	
Westinghouse	Westinghouse	Electric Power	None	All	1972	C-4	/38.4	Efficiency shown with induction
		Medium Btu Gas	None			C-4	/83	
Lurgi	Lurgi	High Btu Gas	Tar, Oils Char Naphtha Coal Fines	Non-to low caking	Before 1930	A-2	72/59	Based on 1975 FPC application by ANG-analyzed by Stearns-Roger

mainly used for hydrogen production, coding, waste disposal, and revegetation (Reference Nos. 31, 32, 33). In the case of the oil shale retortirg industry,the main uses are for oil shale rein@, retorting, fuel upgrading, revegetation, and spent shale disposal (Reference Nos 8, 31, 33) .

, Equipment Requirements. There are many kinds of equipment that will be required by the synthetic fuel industry. Among these items are:

For coal conversion: fabricated vessels, heat exchangers, rotating machinery, materials handling equipment, packaged plants, turbine generator sets, pollution control devices, piping, valves, and instruments and controls. The largest items are fabricated vessels, instruments and controls. They alone have been considered (Reference No. 34) to amount for over 50% equipment needs.

For shale conversion: steel castings valves, air coolers, shell and tube exchanqers, fired heaters, and boilers, preps, compressors, and pressure vessels, and tanks.

In the following chapters, we will look at these factors in more detail. Chapter 3 will discuss the individual process technologies; chap* 4 will discuss the important assesment of costs; and Chapter 5 will discuss the projected deployment schedules of synfuel production.