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 isaunit 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.
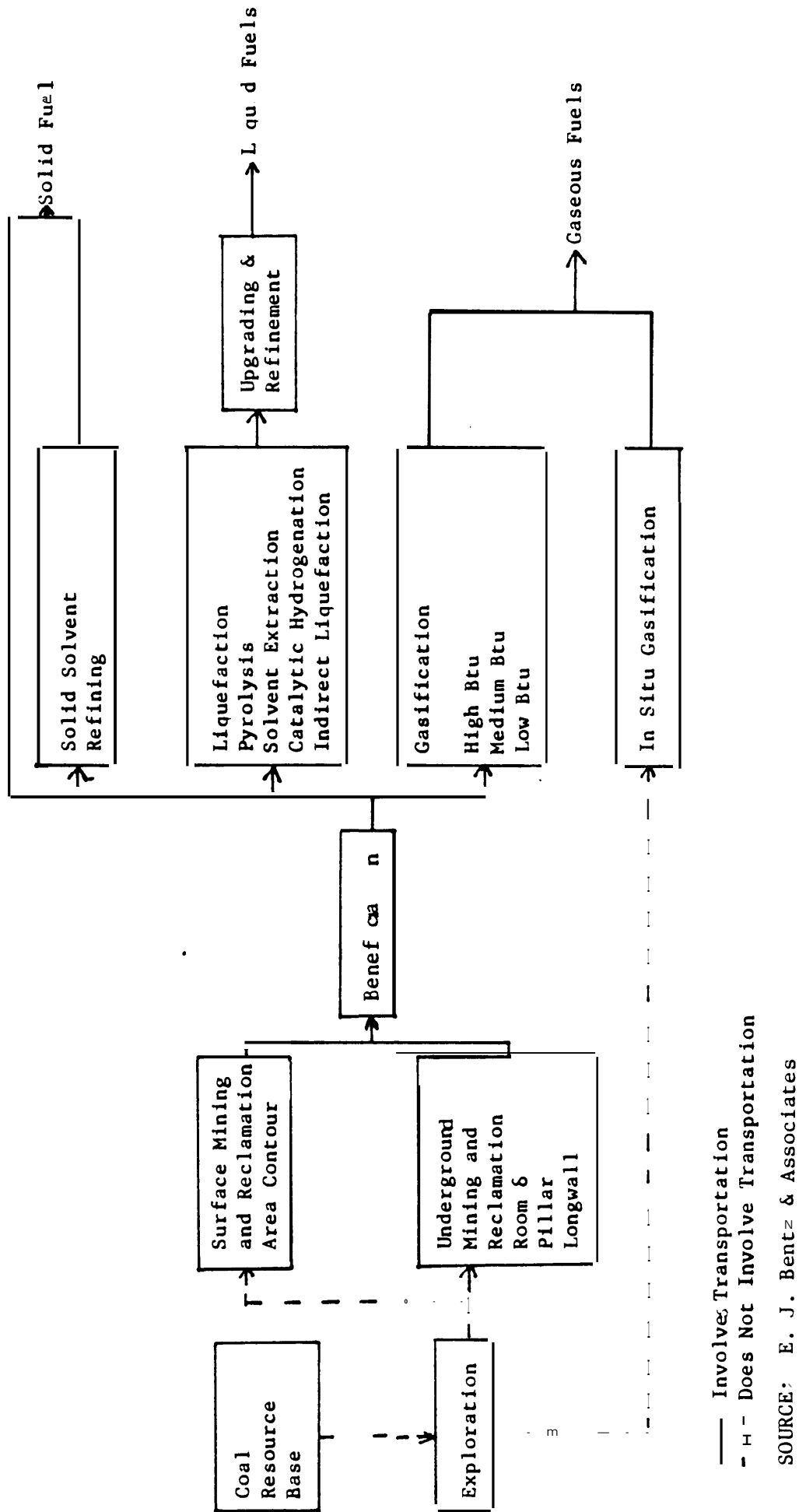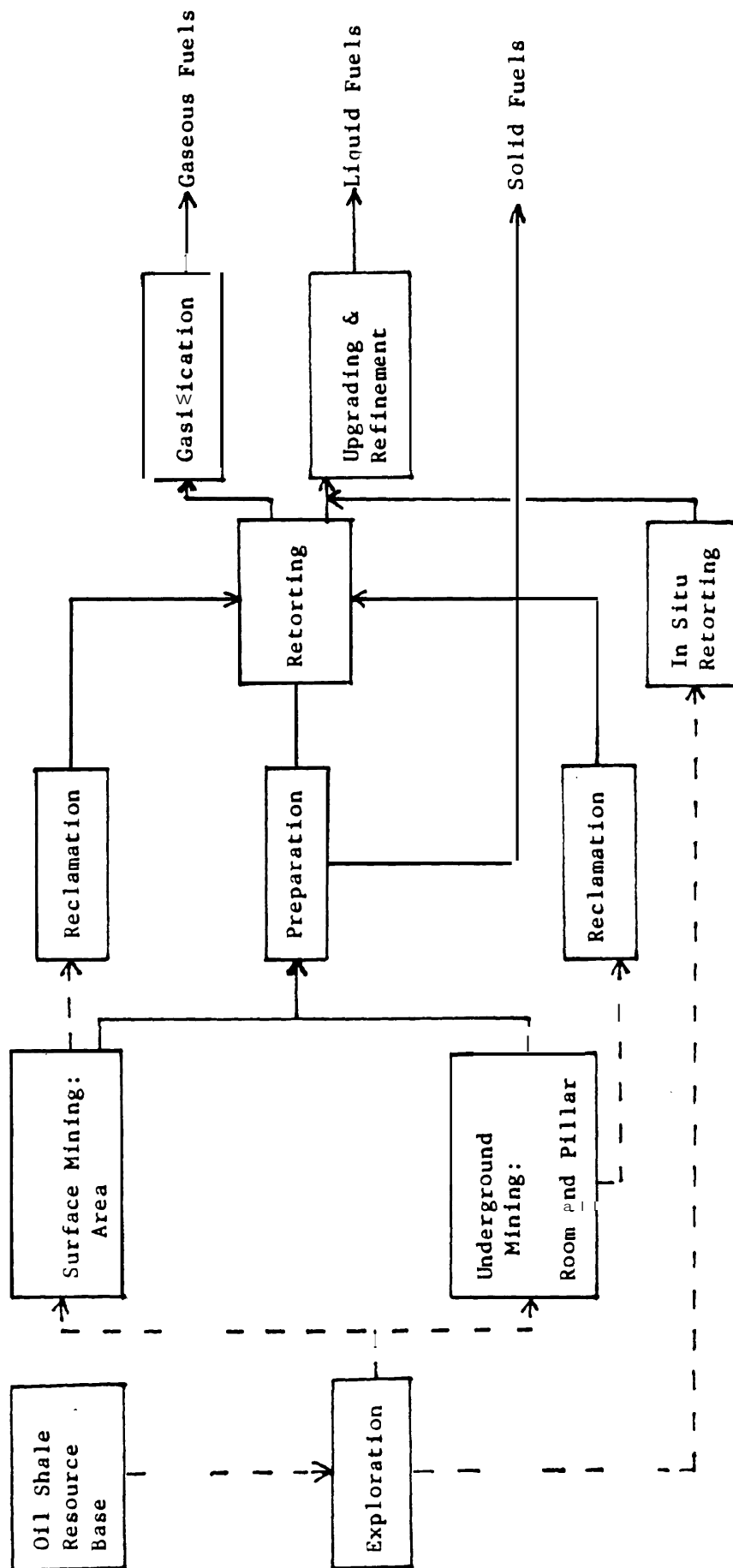
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Solid Fuel

Liquid Fuels

Gaseous Fuels

Upgrading & Refinement

Solid Solvent Refining

Liquefaction
Pyrolysis
Solvent Extraction
Catalytic Hydrogenation
Indirect Liquefaction

Gasification
High Btu
Medium Btu
Low Btu

In Situ Gasification

Benef c a   n

Surface Mining and Reclamation
Area Contour

Underground Mining and Reclamation
Room &
Pillar
Longwall

Coal Resource Base

Exploration

——— Involve Transportation

— ⊢ — Does Not Involve Transportation

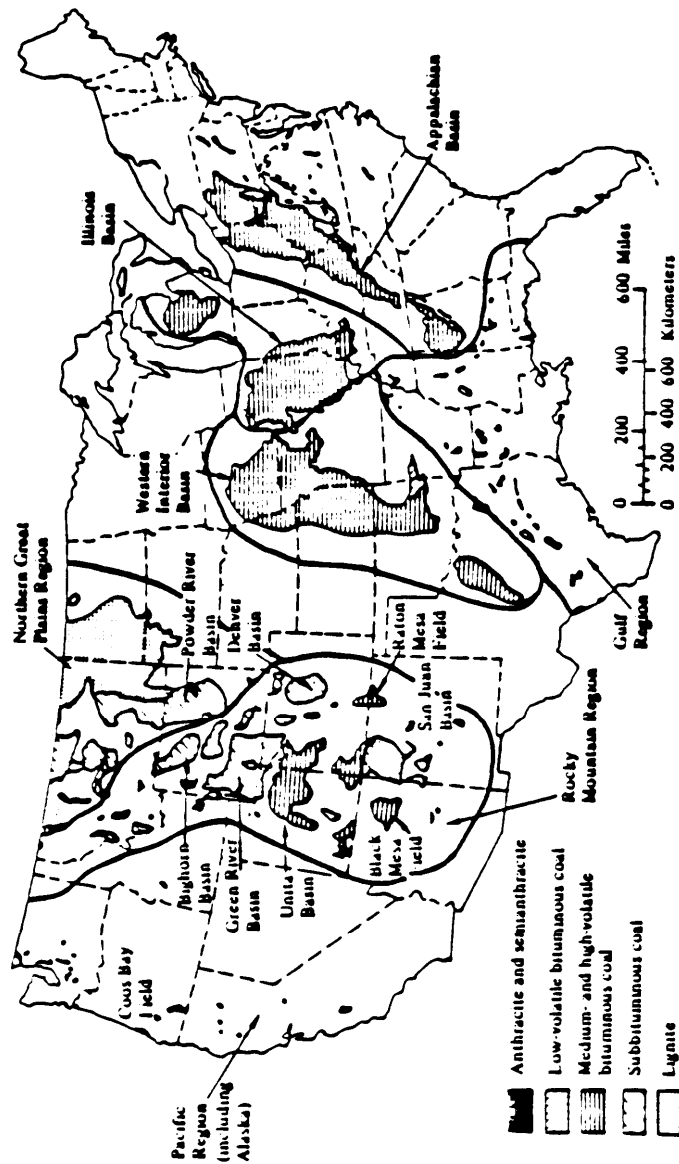SOURCE: E. J. Bentz & Associates

FIGURE 2.1 Coal Conversion System

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FIGURE 2.2: Oil Shale Retorting System

——— Involves Transportation
— — Does Not Involve Transportation

SOURCE: E. J. Bentz & Associaes

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Pacific
Region
(including
Alaska)

Coos Bay
field

Bighorn
Basin

Green River
Basin

Uinta
Basin

Black
Mesa
field

Northern Great
Plains Region

Powder River
Basin

Denver
Basin

Raton
Mesa
Field

San Juan
Basin

Rocky
Mountain Region

Western
Interior
Basin

Illinois
Basin

Appalachian
Basin

Gulf
Region

0   200   400   600   Kilometers

0   200   400   600 Miles

▮ Anthracite and semianthracite

☐ Low-volatile bituminous coal

▦ Medium- and high-volatile
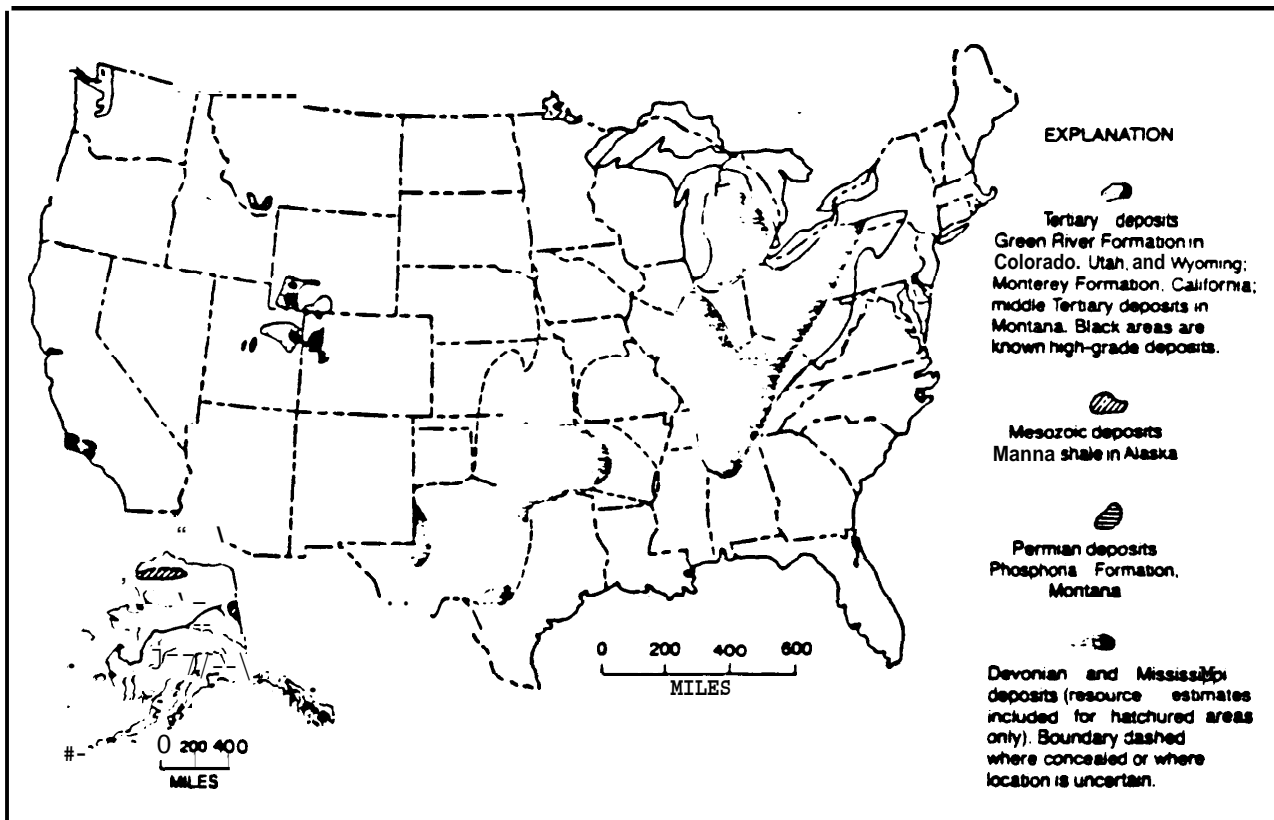   bituminous coal

☐ Subbituminous coal

☐ Lignite

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.

Figuro24: Oil Shale Deposits of the United States

EXPLANATION

Tertiary deposits
Green River Formation in
Colorado. Utah, and Wyoming;
Monterey Formation, California;
middle Tertiary deposits in
Montana. Black areas are
known high-grade deposits.

Mesozoic deposits
Manna shale in Alaska

Permian deposits
Phosphoria Formation,
Montana

Devonian and Mississippi
deposits (resource estimates
included for hatchured areas
only). Boundary dashed
where concealed or where
location is uncertain.

0   200   400   600
MILES

0 200 400
MILES

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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

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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	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.*.*.*** .******** .*******9	134,000	22,500	(?)
Total.*e*9.. .***O**** .******** .**9***	140,000+	26,000	2,000(?)

[a] Order of magnitude estimate includes known deposits, extrapolation and inter-
polation 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.

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associated with <u>generic</u> 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 1<u>4a)</u> .

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. 1&** and 14c) , and on the abundant quantities of coal that can be mined by existing surface mining techno-**logies** (References **7** and 14<u>a)</u> .

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 14<u>a)</u> .

5. Water resources can become a constraint on coal development in the Rocky Mountain and Northern Great Plains Provinces (References No. 7, 9, and 1<u>4d)</u> .

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 <u>Beneficiation</u>

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

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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 **pro-**cedures 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 *al so 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 Conver~sion

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 **some** 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 particu-
larly 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 <u>selective</u> 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 <u>least cost</u>. 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 **conven-
tional** petroleum (Reference No. 19) .

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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 effi- ciencies 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.

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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 petroleun. 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) .

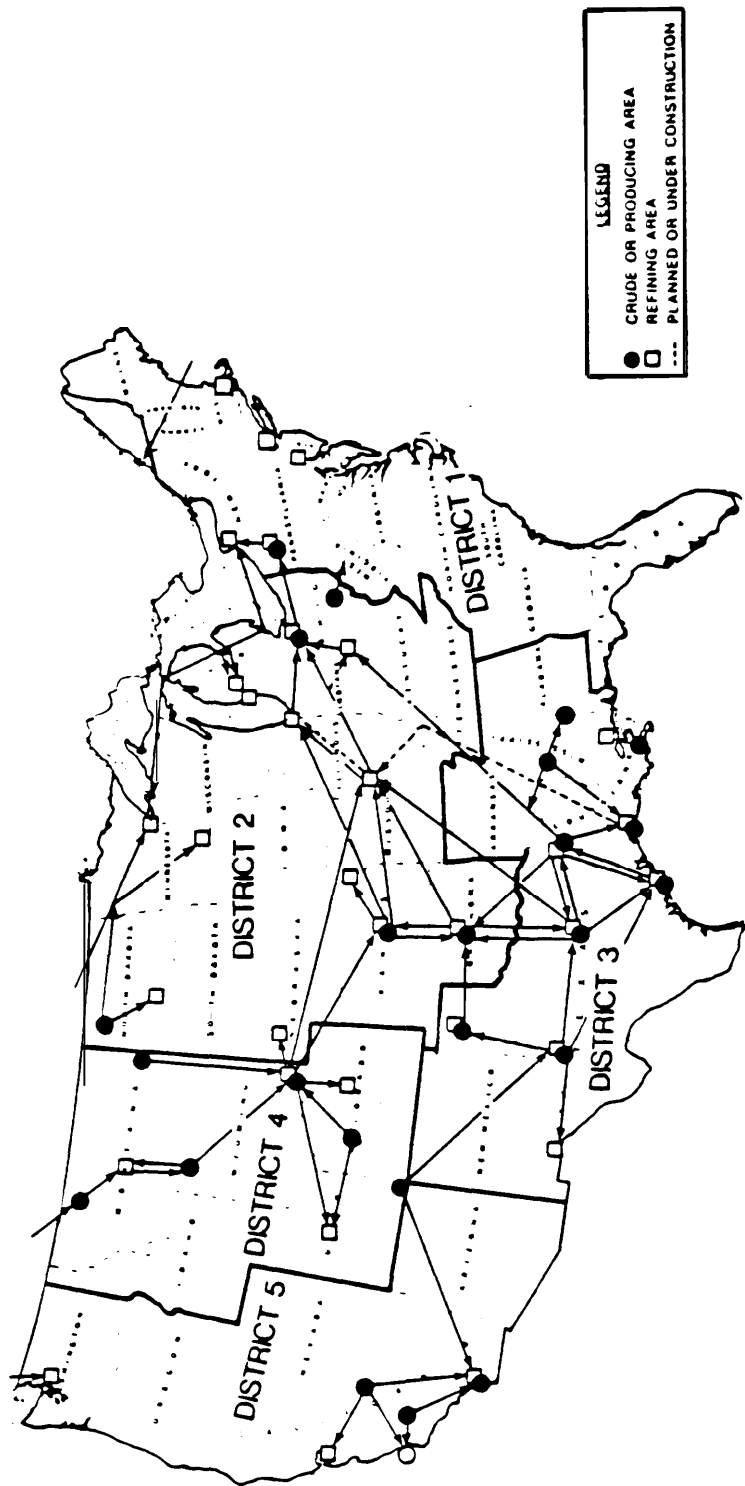## (I I)   Synfuel Technologies Parameters

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 producti"on. 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 constucti"on 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) .

FIGURE 2.5: CRUDE OIL PIPELINE NETWORK

LEGEND
● CRUDE OR PRODUCING AREA
□ REFINING AREA
‥‥ PLANNED OR UNDER CONSTRUCTION

DISTRICT 1
DISTRICT 2
DISTRICT 3
DISTRICT 4
DISTRICT 5

SOURCE: IONAL PETROLEUM COUNCIL

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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 brings 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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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.

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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:

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

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 producti"on. 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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    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 Require ments. 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 Requir ements. 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 Requi"rements. 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-Tropech	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	/40	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 Medium Btu Gas	None None	All	1972	C-4 C-4	/38.4 /83	Efficiency shown with induction
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 NAG-analyzed by Stearns-Roger

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mainly used for hydrogen production, coding, waste dis-
posal, 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, revege-
tation, and spent shale disposal (Reference Nos 8, 31, 33) .

o 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.