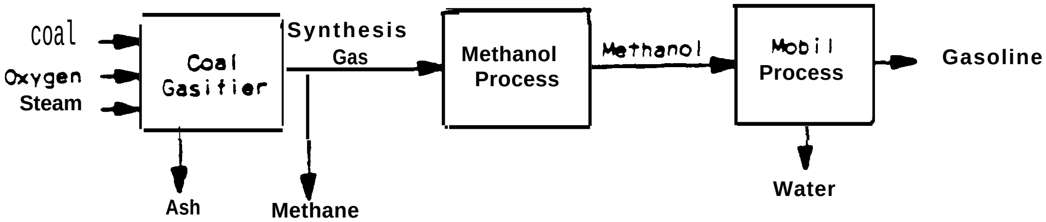
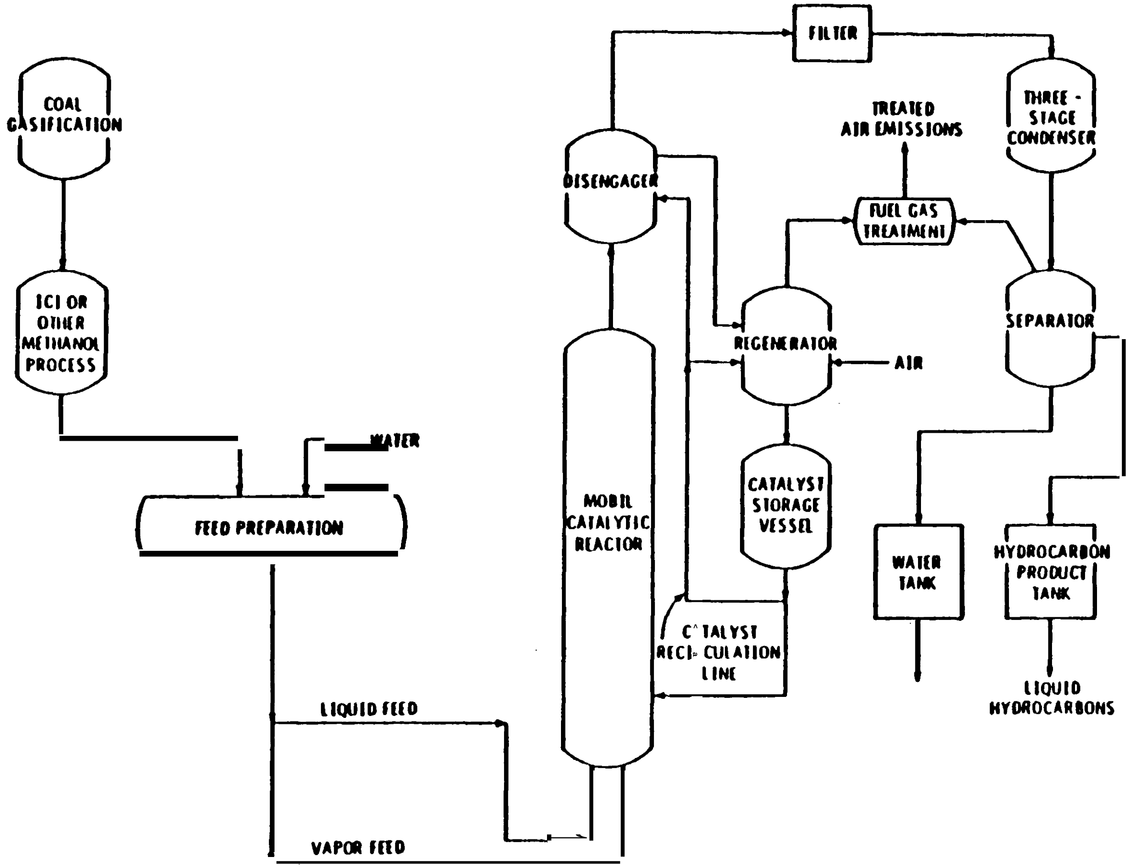


SOURCE: Reference 3S

Figure 3.8

Synthesized Gasoline From Coal



SOURCE: Reference 35

F gure 3.9

Mobl Ca·alyt c P o ess

e j b &a

Table 3.8

Thermal Efficiencies

	Methanol-to-Gasoline[7]		Fischer-Tropsch[7]	
	Btu/hour (10^6 Btu)	Percent of Input	Btu/hour (106 Btu)	Percent of Input
Input				
coal	19,383		19,708	
Coal Fines (excess)	(872)		—	
Methanol	.		3	
Total Input	18,511		19,711	
output				
SNG	6,067	32.8	7,243	36.8
C3 LPG	247	1.3	176	0.9
C_4LPG	385	2.1	26	0.1
10 RVP Gasoline	4,689	25.3	2,842	14.4
Diesel Fuel			514	2.6
Heavy Fuel Oil			147	0.7
subtotal	11,388	61.5	10,948	55.5
Alcohols			290	1.5
sulfur	19	0.1	19	0.1
Ammonia	83	0.5	83	0.4
Power	18	0.1	11	0.1
Total Output	11,508	62.2	11,351	57.6

6 Thermal efficiencies are highly dependent on product mix.

7 The indirect liquefaction processes shown here may be Considered as gasification processes for SNG, with the major coproduct being galosine, e.g. , for the "Fischer-Tropsch process" shown, the yield of SNG is 1.45 BOE/ton of coal, with a gasoline yield of 0.58 BOE/ton of coal. It is thus not representative of the SASOL-II process which emphasizes the production of liquid fuels.

8 Direct thermal equivalent value (thermal efficiencies are highly dependent on product mix (see Section 7. 5) .

SOURCE : Reference 35

TABLE 3.9

METHANOL-TO-GASOLINE BALANCES

	Methanol →	Hydrocarbons +	Water
Material Balance	100 tons	44 tons	45 tons
Energy Balance:	100 Btu	95 Btu	O Btu

YIELDS FROM METHANOL

Average Bed Temperature, °F	775°F
Pressure, psig	25
Space Velocity (WHSV)	1.0
Yields, wt % of charge	
Methanol + Ether	0.2
Hydrocarbons	43.5
Water	56.0
co, CO_2	0.1
Coke, Other	0.2
	100.0
Hydrocarbon products, wt %	
Light gas	5.6
Propane	5.9
Propylene	5.0
i-Butane	14.5
n-Butane	1.7
Butenes	7.3
C_5 + Gasoline	60.0
	100.0
Gasoline (including alkylates), wt, % (96 RON, 9 RVP)	88.0
LP Gas, wt %	6.4
Fuel Gas, wt %	5.6
	100.0

SOURCE: Reference 25

3.4 Oil Shale Retorting

3.4.1. General

Oil shale resources vary widely in their oil yields. High grade shale is normally defined as a deposit that averages 30 or more gallons of oil per ton of shale. Low grade shale averages 10 to 30 gallons per ton[9] (Reference No. 7) . Several factors determine whether or not an oil shale deposit is recoverable. These include oil yield (usually equal or above 20 gallons per ton) , zone thickness, overburden thickness, the presence of other materials in the shale, availability of needed resources such as water and services, and location relative to markets.

There are two major routes for converting oil shale to liquid or gaseous fuels. They are:

1. Conventional mining followed by surface retorting (heating) , and

2. In situ (in place) retorting

In addition, there is modified in situ. In this process, the permeability (i.e., void volume) of oil shale deposits is increased in order to enhance the in situ retorting by removing some of the shale. The methods of rein@ or increasing the permeability of the oil shale deposits are explained in reference 8.

3.4.2. Surface Retorting

In surface retorting of oil shale, the heating takes place above ground. The shale is crushed to the right size, and fed into a retorting vessel. Heating the shale to between 800°F and 1000°'F removes abut 75 percent of the kerogen from the shale (Reference No. 8) . Different retorting precesses apply heat to the shale in different ways. Gas or non combustible solids such as sand or ceramic balls can be used as heat carriers. The vapor produced during the heat@ is condensed to form crude shale oil. It can be further upgraded and refined to produce more marketable products.

As a generic surface retorting process, TOSCO II is described. Its schematic diagram is given in Figure 3.10 (Reference No. 8).

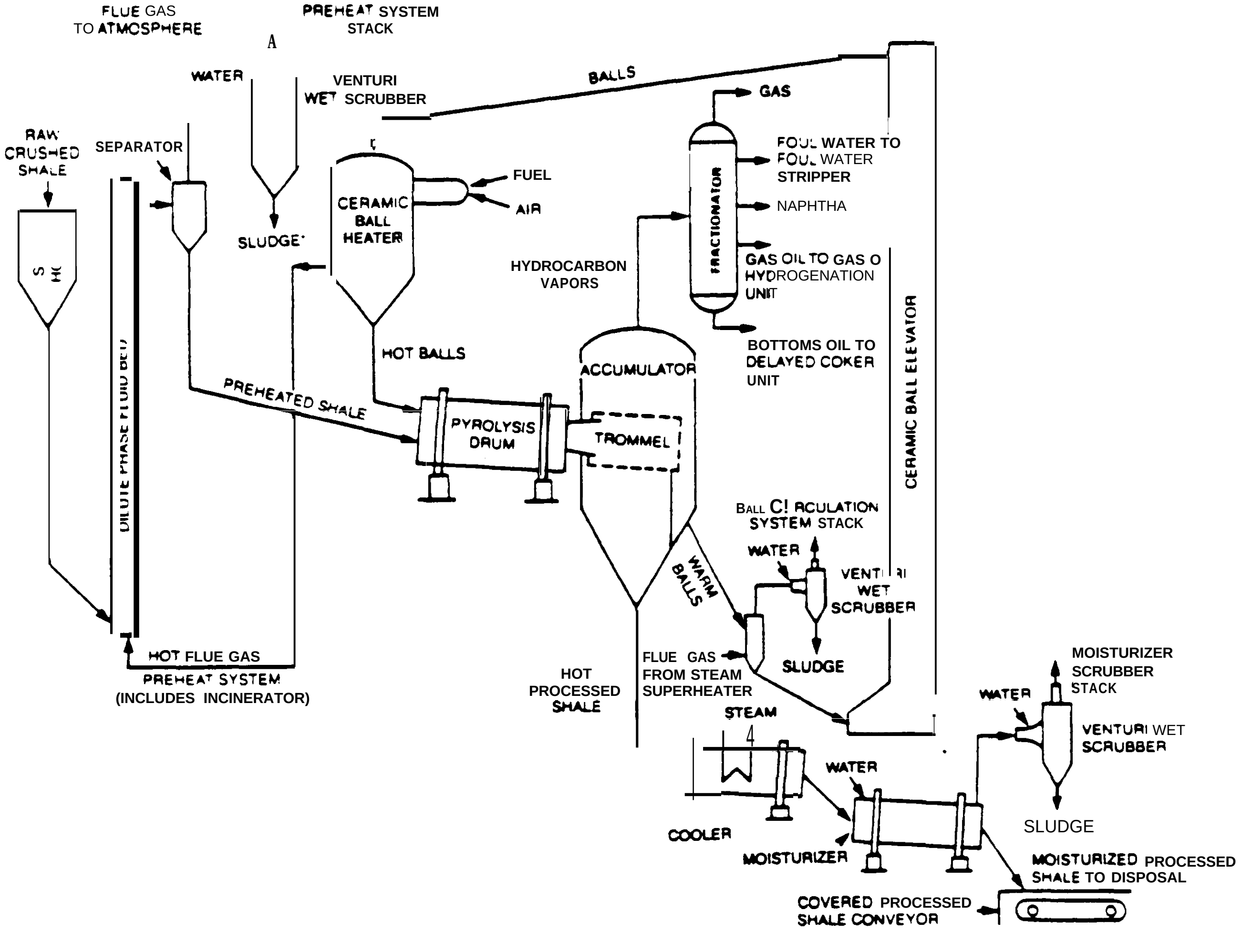
---

[9] Shale deposits yielding less than 10 gallons of oil per ton are normally omitted from USGS resource estimates.

Raw oil shale is crushed to 1/2 inch and preheated to 500° F. It is mixed with hot ceramic balls 3/4 inch in diameter and at 1200°F in a retorting Pyrolysis drum (Reference No. 25) . About two tons of balls mix with every ton of shale. The oil shale is heated to 900°F, releasing hydrocarbon vapors from the kerogen. The spent shale and the balls pass to the sealed accumulator vessel, in which the balls are separated from the shale by a heavy duty rotating cylinder with numerous holes. The balls are lifted by a bucket elevator to the gas fired ball heater, which heats the balls to 1270°F by direct contact heat exchanger. The spent shale goes through

FIGURE 3.10

The TOSCO II Oil Shale Retorting System



SOURCE *Oil Shale Retorting Technology* prepared for OTA by Cameron Engineers, Inc. 1978 a special heat exchanger which cools the shale for disposal and produces steam for plant use. Then the spent shale is quenched with water and moisturized to 14 percent, a level proper for disposal.

Hot flue gas from the ball heater is used to lift raw shale to a point at which it can subsequently flow by gravity into the pyrolysis drum. The flue gas also heats the raw shale to approximately 500°F.

Table 3.10 (Reference No. 25) summarizes the basic material balance for a TOSCO II retort module.

TABLE 3.10

BASIC MATERIAL BALANCE FOR
A TOSCO II RETORT MODULE

Oil Shale	
Feed rate, TPSD	10,700
Fischer Assay, GPT	20
Pipelineable Shale Oil Product	
production rate, BPSD	4,500
Properties	
Gravity, *API	28.6
Viscosity (SSU @ 30°F)	800
Pour Point, ‘F	30

Table 3.11 (Reference No. 35) summarizes the energy balance for a plant producing 47,000 barrels per day. Table 3.12 (Reference No. 17) summarizes the components, resource requirements and potential impacts of surface oil shale retorting.

Tab l e 3.11

Estimated Energy Balance For a TOSCO II Plant producing 47,000 BPSD* Upgraded Shale Oil From 35 Gallons Per Ton Oil Shale

	Btu/hour (lo Btu's)	Percent of Total Energy Input
Product Output		
Product oil	10.30	58.00
LPG	0.70	3.94
Diesel fuel	0.11	0.62
System Losses		
Spent shale and moisture	1.78	10.02
Residual carbon (coke)	0.93	5.24
Ammonia	0.11	0.62
Sulfur	0.06	0.34
Cooling water	1.07	6.02
Water evaporat on on shale	0.25	1.41
Losses (includ ing flue gas heat)	2.45	13.79
Energy Input	17.76	100.0
Raw shale	17.00	95.72
Steam	0.53	2.98
Electrical energy	0.23	1.30

* BPSD = barrels per stream day

SOURCE: Reference 35

TABLE 3.12 TOSCO II Oil Shale Retorting

ENERGY SYSTEM:

SIZE
- 50,000 bbls/day of crude shale oil
- 16.43 x 10^6 barrels of oil/year
- .29 x 10^{12} Btu/day
- 5.6 x 10^6 Btu/barrel
- operates 328.5 days/year
- total annual output 95.27 x 10^{12} Btu
- plant life 30 years
- plant efficiency (thermal) 6 %

DESCRIPTION
- Heated ceramic balls are fed into a horizontal rotating cylindrical retort and mixed with crushed shale (1/2 inch diameter). Pyrolysis occurs at 900°F. Shale oil steam and gases are emitted from one end of the retort and are collected and fed into a fractionator for product recovery. The ceramic balls are recycled to a vertical ball heater where reheating for further use occurs.

COMPONENTS
- horizontal cylindrical retort
- fractionator and coker
- naphtha hydrofiner
- gas oil hydrofiner
- hydrogen plant
- by-product recovery

ENVIRONMENTAL CONCERNS
- air quality deterioration
- health effects due to hydrocarbons
- modifications to biological environment
- deterioration of water quality due to leachates and runoff
- solid waste disposal
- socio-economic problems due to high influx of personnel in previously sparsely populated areas

RESOURCES USED:
(Per 10^{12} Btu Produced)

FUEL[b]	
raw shale	230,000 tons
oil content	35 gallons/tons

COMPOSITION[c]	(by weight)
oil	11.8
water	1.4
spent shale	84.9
gas	2.0

LAND[1]	Acres
retorting, upgrading and offsite facilities	3.36
expansion, water containment and greenbelt	3.42

WATER[b]	Acre-Feet
cooling towers	15.8
waste heat boilers	14.5
water treatment plant	0.4
processed shale	21.3
dust control on shale ash	3.9
moisture evaporator	7.9
dust scrubbers	10.4
revegetation	1.1
fire and drinking	2.4
total	77.7

COSTS[2]	Dollars (1978)
construction	
manpower	1,640,000
materials	671,000
equipment	1,655,000
other cost	337,000
total	4,303,000
operation & maintenance	NA

PERSONNEL	Workers
construction	2.1
operation & maintenance	11.5

RESIDUALS AND PRODUCTS:
(Per 10^{12} Produced)

AIR POLLUTANTS[b]	Tons
particulates	19.6
SO_2	11.4
NO	63.3
hydrocarbons	11.2
CO	2.3

WATER POLLUTANTS
assume zero direct discharge to any water-course

SOLID WASTE[b]	Tons
spent shale	190,000

ENERGY PRODUCT[b]	Barrels
refined shale oil	172,400 barrels
heat content	5.6 x 10^6 Btu/barrel

(1) Land use value represents land committed to use for the facility, divided by annual production, measured in trillion Btu.
(2) Costs are total costs for plant construction, divided by annual output, measured in trillion Btu.

SOURCES:
(a) Environmental Protection Agency, Monitoring Environmental Impacts of the Coal and Oil Shale Industries, 600/7-77-015, February 1977.
(b) University of Denver, Denver Research Institute. An Engineering Analysis Report on the TOSCO II Shale Process, March 1977.
(c) University of Oklahoma, Energy Alternatives: A Comparative Analysis, 1975.
(d) Bechtel Corporation, Energy Supply Planning Model, 1978.
(e) Cameron Engineers Incorporated, Synthetic Fuels Handbook, 1975.

SOURCE: Reference 17

ejb &a

3.4.3 Modified In Situ Retorting

Occidental modified in situ oil shale retorting process is selected as representative. It involves the mining out of about 10 to 25 percent of the shale deposit. This mined portion would presumably be retorted by one of the surface retorting processes, or if its oil content is too low, will be treated as waste (Reference No. 37).

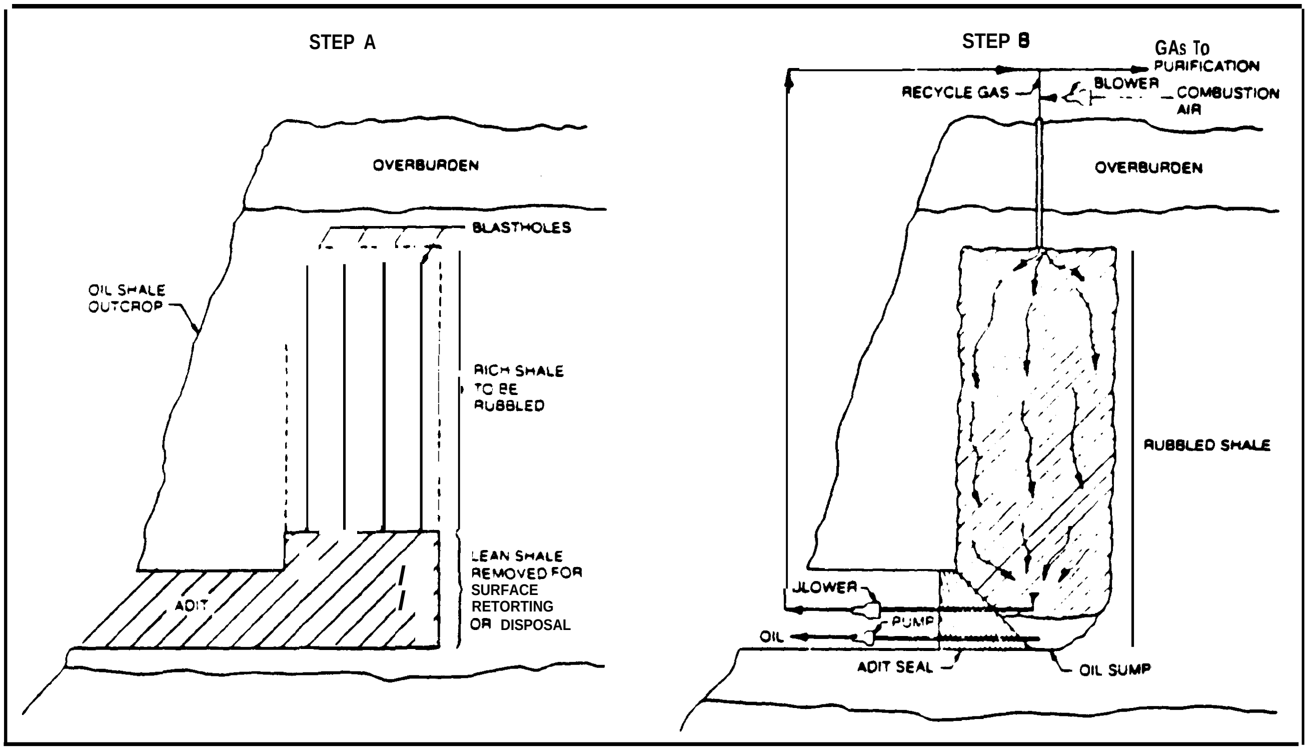
Figure 3.11 (Reference No. 8) represents in schematic form a generic modified in situ oil shale retorting process. ‘Figure 3.12 (Reference No. 37) is a more detailed description of the Occidental modified in situ retorting process. As observed in Figure 3.12 , in steps A or the pre-detonation phase, drifts (chambers) are excavated at the top and bottom of the shale deposit, which is about 300 feet-thick. An interconnecting shaft is dug to connect the drifts. Rooms with a volume of about 15 to 20 percent of the eventual volume of the planned chamber are then mined. Shot holes are drilled to allow blasting of the shale oil to produce the desired fragmentation.

In the burn phase, the explosives in the shot holes are detonated. A rubble-filled chamber is created which can function as a batch retort. The percentage of void space and the particle size distribution of the rubble are a function of the explosive loading. Connections are made to air/gas recycle and air supply compressors. An outside heat source (e.g., off gas or oil from other retorts) is used for heating the rubble at the top of the retort. Oil shale and hydrocarbon gases are produced which move downward. Residual carbon is left on the spent shale.

The retorting reaction is terminated after a predetermined amount of the rubble has been retorted by halting the external heating supply. The residual carbon is utilized to continue the combustion process, which now does not need external heating. The flame front moves downwards, preceded by the liquid and gaseous products retorted from the shale by the hot, oxygen-deficient combustion gases. The liquid hydrocarbons collect in a sump, from which they are pumped to the surface. The gaseous by-products are used partially, with steam, as a recycle stream to control the oxygen content of the inlet gas. The four distinct zones that develop during the retorting are shown in Figure 3.11 .

Table 3.13 (Reference No. 17) summarizes the components, resource requirements, and potential impacts of modified in situ retorting.

Figure 3.11: **Modified in Situ Retorting**



SOURCE: T. A. Sladek, "Recent Trends in Oil Shale—Part 2: Mining and Shale Oil Extraction Processes," *Mineral Industries Bulletin*, vol. 18, No. 1, January 1975, p. 18

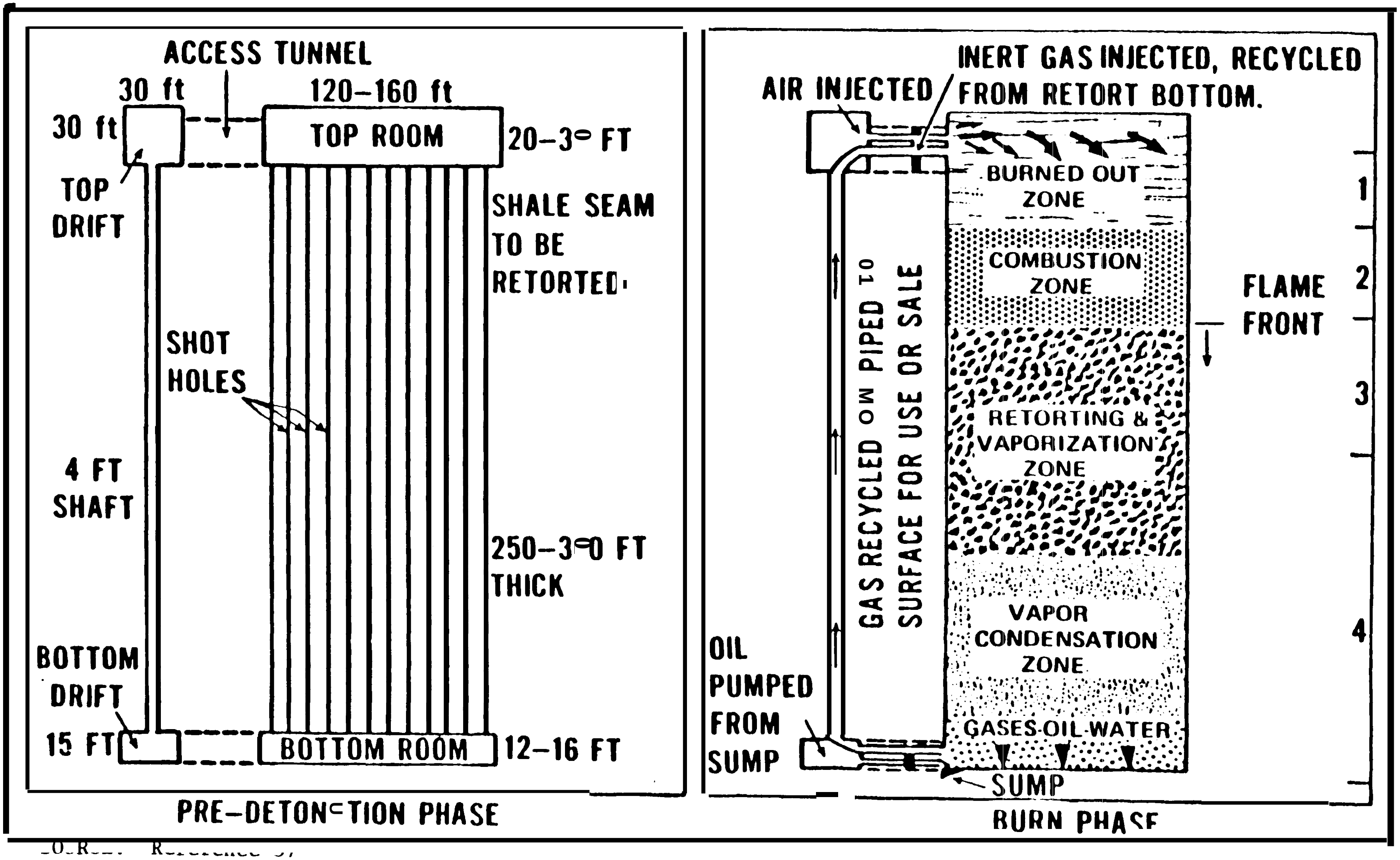


Figure 3.12: Occidental Modified In Situ Retorting

TABLE 3.13 — Modified In-Situ Shale Retorting (Occidental)

ENERGY SYSTEM:

SIZE
- 34,200 tons of raw shale mined/day[d]
- 102,600 tons of raw shale retorted in-situ/day[c]
- shale oil content 25 gallons/ton[d]
- 50,000 bbl/day
- .29 x 10^{12} Btu/day
- 95.3 x 10^{12} Btu/year
- operates 328.5 days/year
- plant life 30 years
- thermal efficiency 61% overall[d]

DESCRIPTION
- In modified in-situ approximately 15-20% of the deposit is mined using conventional mining techniques in the ground and fractured using either chemical, hydraulic, or electric means. Prior to fracturing of the deposit, parallel wells (productions and injection) are drilled on two opposing sides of the deposit. A retorting fluid (hot steam or gas) is injected within the formation. After ignition, retorting takes place and the oil mist, gas and steam produced are forced to the surface through the production wells. Liquid gathered at the base of the combustion zone is later pumped out. The products are refined using techniques similar to surface refining.

COMPONENTS
- underground retort created from blasting procedure
- fractionator and coker
- naphtha hydrofiner
- gas oil hydrofiner
- hydrogen plant
- by-product

ENVIRONMENTAL CONCERNS
- air quality deterioration
- health effects due to hydrocarbons
- modifications to biological environment
- deterioration of water quality due to leachates and runoff
- solid waste disposal
- socio-economic problems due to high influx of personnel in previously sparsely populated areas

RESOURCES USED:
(Per 10^{12} Btu Produced)

FUEL[c,d]	
mined shale	117,900 tons
unmined shale	351,800 tons
oil content	25 gallons/ton

COMPOSITION[a]	(by weight)
organic material	NA
water	NA
inorganic material	NA
spent shale	NA

LAND[c]	Acres
permanent disposal	207-310/Year
surface facilities	345
active well area	862/Year

WATER[c]	Acre-Ft.
retorting and upgrading	(22.2)*
power generation	24.6
revegetation	0.9
steam injection	20.9
miscellaneous	4.4
total	36.4

COSTS[b]	Dollars (1978)
construction	13,400,000
operation & maintenance	NA

PERSONNEL[b]	Workers
construction	30.6
operation & maintenance	NA

RESIDUALS AND PRODUCTS:
(Per 10^{12} Btu Produced)

AIR POLLUTANTS[d,e]	Tons
particulates	39.6
SO_2	6.21
NO_2	33.7
hydrocarbons	0.51
CO	10.0

WATER POLLUTANTS
There is assumed a zero direct discharge of effluent into any water course.

SOLID WASTE[d]	Tons
spent shale	99,000

ENERGY PRODUCT	Barrels
refined shale oil	172,400

*Approximately one barrel of water/barrel of oil is produced during retorting by the release of interstitial water and the combustion of hydrocarbons.

SOURCES:
(a) Cameron Engineers, Incorporated, Synthetic Fuels Handbook, 1975.
(b) HESS Data Group, Environmental Characterizations for Energy Technologies and End Uses, Revision b, 1978.
(c) Department of Energy, Draft Environmental Impact Statement for the (updated) Prototype Oil Shale Leasing Program, 1979.
(d) Environmental Protection Agency, A Preliminary Assessment of the Environmental Impacts from Oil Shale Development, 600/7-77-060, July 1977.
(e) Ashland Oil, Inc., Lessee & Occidental Oil Shale, Inc., Modifications to Detailed Developmental Plan, Oil Shale Tract C-b, February, 1977.

SOURCE: Reference 17

3.5 comparison of the Various Synfuel Systems With Respect to Resource Requirements[10]

In order to estimate the resource requirements of the coal and oil shale fuel cycles we need first to assess their energy utilization efficiencies. These are summarized in Table 3.14.

The resource requirements of coal and oil shale energy systems per 10^6 Btu of product delivered to end user are given in Tables 3.15 and 3.16. Tables 3.17 and 3.18 convert these requirements to energy systems producing 50,000 barrels of oil equivalent per day.

Manpower requirements for operating and maintenance labor of coal conversion plants are given in Reference 29.

They are:

Plant operators	
Operating supervisors	
Maintenance labor	
Maintenance labor supervisors	30
Administration	30
Total	355

These manpower requirements are for a basic (ESCOE) coal conversion plant that consumes 25,000 tons of coal per day with 22.4 million Btu/ton and produces 50,000 bbl/day liquids output.

Very considerable variations exist in the literature in respect to manpower requirements for the other phases of the fuel cycle. They depend on such variables as methods of mining, location of mine, kind of transportation system and extent of beneficiation. A table indicating the ranges of variables is given in the footnote in respect to the conversion plants.

---

10 Limitations of Data Sources: Evaluations carried out in this report are often sub ject to great uncertai" nties because:

(1) The information available is only of preliminary nature. There are no full scale operating synfuel plants in the U.S. (subject to U.S. siting considerations) , so that data needs to be extrapolated from pilot plants with many uncertainties of scale and dissimilarities associated with the extrapolation, as well as specific siting and f eedstock characteristics discussed below.

10 (cent'd)

(2) There are variations among sources which are often due to different assumptions or local influences. Changes in design account for some differences as the technology changes and the environmental regulations change. Many of the assumptions are not stated - or even referenced. Budget and time limitations, however, nessitate the need to use exist& data bases, rather than the development of new data.

Even estimating the range of uncertainties is often a value judgement process, unless more extensive on-site interviewing with site and process specific sources of information are developed.

Table 3. 4 Resource Utilization Efficiencies of Generic Synthetic Fuel Energy Systems

(In Percent)

	1	2	3	4	5	6
	Coal Gasification		Coal Liquefaction		Oil Shale Retorting	
	Medium-Btu	High-Btu	Direct	Indirect	Surface	Modified in Situ
Beneficiation[a]	96.4-97.3	96.4-97.3	96.4-97.3	96.4-97.3	96.4-97.3	100
Transportation to Conversion Plant[b]	98.5	98.5	98.5	98.5	99.5	100
Conversion to Fuel[c]	83	59	64-70	48-57	67	61
Upgrading and Refining[d]	N.A.[e]	N.A.[e]	75-95[f]	95-100[f]	77[g]	77[g]
Distribution to End User	96.9[h]	97.1[i]	98.8[j]	98.8[j]	98.8[j]	98.8[j]
Overall Energy Efficiencies	76.4-79.2	54.4-54.9	45.0-63.0	42.8-54.0	48.9-49.3	46.4

SOURCE: E. J. Bentz & Associates

Notes for Table 3.14

a. Estimates of losses of coal and oil shale from beneficiation (in terms of Btu's) vary broadly among authors, depending on the assumed degree of upgrading and the kind of coal or oil shale used. Estimates vary from 0% (Reference 37a) ; 2.7-3.6% (Reference 7) ; and 12.5% for intensive beneficiation (Reference No. 17) .

b. Average value of losses are 1.5% (time from Reference No. 7) . In the case of oil shale, where distances are shorter, 0 .5% is assumed.

c. The @et efficiencies (rather than the process efficiencies) were used. The efficiencies for coal conversion processes are derived from Roger and Hill. (Reference 29) . In the case of H-Coal, the syncrude efficiency was used. In the case of oil shale retorting processes, the efficiencyes are derived from DOE (Reference No. 17) .

d. Data on efficiencies of upgrading and refining syncrudes is very limited and unreliable (see Section 1.7) .

e. N.A. means not applicable.

f. Overall yields for SRC II of finished fuels range between 83 and 98 liquid volume percent of SRC II syncrude, depending on the product slate and how refinery fuel and hydrogen plant feed are supplied. An average of the net product yields ranging between 88 and 91 was assumed (Reference No. 22) . However, these values apparently do not include coal use for the production of hydrogen needs for the upgrading process. If coal-derived hydrogen is to be used (as against hydrogen from nuclear fission or from biosynthesis) , then the upgrading and refining efficiencies for coal conversion products become 75 percent. However, in some cases it may be expected that all of the hydrogen and energy required for the Upgrading/refining process would be obtained from residuals, higher boiler fractions, and methane produced in the process or plant refinery(which may include the use of Petroleum derived vacuum . In the case of indirect liquefaction Processes, all the needed hydrogen is accounted for in the gasifier, and higher upgrading efficiencies can be achieved, depending on product slate .

g. Derived from Reference 26a. However, MIS oil is easier to upgrade, so that higher efficiency may be in order.

h. Derived from Reference 17.

i. Derived from Reference 7.

j. Derived from Reference 7 and 10.

Table 3.15 Fossil Carbon Consumption of Generic Synthetic Fuel Energy Systems (In 10^{-3} ton of fossil carbon/10^{6} Btu fuel delivered to end user)

	1 Coal Gasification	2	3 Coal Liquefaction	4	5 Oil Shale Retorting	6
	Medium-Btu	High-Btu	Direct	Indirect	Surface	Modified in Situ
Beneficiation	1.2-1.6	1.7-2.2	2.0-2.7	2.1-2.8	0.9-1.2	⊝
Transportation to Conversion Plant	0.7	0.9	1.1	1.2	0.2	⊝
Conversion to Fuel	0.7	25.1	22.2-26.7	33.5-40.5	11.4	18.7
Upgrading and Refining	-	-	3.7-18.5	0-3.9	7.9	11.0
Distribution to End User	1.4	1.8	0.9	0.9	0.4	0.6
Overall Consumption	9.1-10.3	27.6-27.9	27.4-40.7	35.8-44.5	17.5-17.6	25.7

SOURCE: E. J. Bentz & Associates

Notes to Table 3.15

a This table summnarizes the consumption of fossil carbon contained in the feedstocks or products during the various phases of the various synfuel cycles.

b The numbers in the table are based on the following assumptions:

(i) The resource utilization efficiencies are those developed in Table 3.14.

(ii) The carbon content of bitumimous coal averages 87.8%, lignites - 72. 5% and sub-bituminous~ reals - 73. 5%. The carbon content of the kerogen (i. e., crude shale oil) averages 80. 5%. (Ref. 26b) . For convenience, an average figure of 80% for the carbon content of coals and kerogen is used.

(iii) The loss in fossil carbon is directly proportional to the loss in coal or kerogen.

(iv) The Btu content of a ton of coal is $24x10^6$ Btu and of ton crude shale oil is $36x10^6$ Btu.

c A sample calculation for medium Btu coal gasification is as follows:

A ton of feedstock bituminous coal has $24x.10^6$ Btu, of which 18. $34x10^6$ to 19. $Olx10^6$ Btu is delivered to the end users (74.4 to 79. 2% overall energy efficiency - see Table 3.14) . Since a ton of feedstock coal. has 80% fossil carbon content, and 20.8% to 23.6% of it is consumed during the medium Btu coal gasification fuel cycle, (see Table 3.14) , the total fossil carbon consumption o the cycle is between 0.1664-0.1888 tons per 18.34x10 to 19. $Olx10^7$ Btu delivered to end users. This translated to 0.009 to 0.010 tons of fossil carbon per 10^6 Btu.

Table 3.16 Water Consumption of Synthetic Fuel Energy Systems (Generic (In gallons per 10^6 Btu product delivered to end user)

	Coal Gasification		Coal Liquefaction		Oil Shale Retorting	
	1	2	3	4	5	6
	Medium-Btu	High-Btu	Direct	Indirect	Surface	Modified in Situ
Mining[a,b]	0.6-0.9	0.6-0.9	0.6-0.9	0.6-0.9	0.7-1.1	0.7-1.1
Beneficiation[c]	1.2	1.2	1.2	1.2	0	0
Transportation to Conversion Plant	0	0	0	0	0	0
Conversion 9 Fuel[d]	13-24	13-24	7-26	13-26	9-32	9-13
Upgrading and Refining[e]	0	0	–	–	24	24
Distribution to End User	0	0	0	0	0	0

SOURCE: E. J. Bentz & Associates

Notes to Table 3.16

a The water required for mining and preparation of the coal or shale and for the disposal of ash or spent shale is a function of location, mainly through the amount of material that must be mined or disposed; and the degree of attested surface reclamation. Assuminq 2/3 of coal is surface-mined and 1/3 is undergroundd mined, water consumption for surface mining ranges between 0.55 and 0.98 gallons per 10^6 Btu of product, and for underground mining - 0.75 gallons per 10^6 Btu of Product (Reference No. 17) .

b Assume 2/3 of oil shale is surface mined and 1/3 is underqround mined. Water consumption or both kinds of operations range between 0.7 and 1.1 gallons per 10^6 Btu of product (Reference No. 17).

c Consumption of 1.2 gallons of water 10^6 Btu Of product is assuned for beneficiation of coal (Reference No. 17) and none for shale oil.

d Consumption of water for the conversion of feedstock to fuels depends principally on the overall plant conversion efficiency, degree of water recycling, and the water content of the coal or shale. Consumption figures range from 13-24 gallons per 106 Btu of product for coal gasification; 7-26 for direct coal liquefaction; 13-26 for indirect coal liquefaction; 9-32 for surface shale retorting; and 9-13 for modified in situ shale retorting (Derived from References 17, 37b,c) .

e Water consumption for upgrading and refining is not available in the literature. The estimates presented for shale oil upgrading are based on private conversation with Mr. Bobby Hall and Ray Young of the American Petroleum Institute 3/81. For shale oil - 100 gallons per barrel are needed to make the raw shale oil suitable for pumping, and 40 more gallons per barrel to convert it to transportation fuels. Polling of a large number of oil companies and API experts did not result in water consumption estimates for upgrading of coal liquids (name1y: Robert Howell, Bonner and Moore, Fred Wilson Texaco, Patton, Nanny, Hall and Young of API - 3/81) .

Table 3.17* Annual Feedstock Requirements for Generic Synthetic Fuel Energy Systems Producing 50,000 bbl Oil Equivalent per Day to End User (In millions of tons or barrels of oil)

	Coal Gasification		Coal Liquefaction		Oil Shale Retorting	
	Medium-Btu	High-Btu	Direct	Indirect	Surface	Modified in Situ
Mining[5]	5.6-5.8	8.0-8.1	7.[illegible]-9.8	8.2-10.3	62.2-62.7	N.A.[7]
Beneficiation[5]	5.4-5.6	7.8	6.8-9.4	7.9-9.9	60.5-60.6	N.A.[7]
Transportation to Conversion Plant[5]	5.3-5.5	7.7	6.7-9.3	7.8-9.8	60.2-60.3	N.A.[7]
Conversion to Fuel[6]	18.9	18.8	19.4-24.6	18.5-19.4	24.0	24.0
Upgrading and Refining[6]	18.8	18.8	1[illegible]5	18.[illegible]	18.5	18.5
Distribution to End User[6]	18.3	18.3	18.3	18.3	18.3	18.3

* These are the quantities of coal, shale or equivalent oil leaving the indicated phase of the fuel cycle.

SOURCE: E. J. Bentz & Associates

Notes to Table 3.17

1. Same assumptions and references as those in Table 3.14.
2. Oil has energy content of 5.8 x 10^6 Btu/barrel.
3. Coal has energy content of 24 x 10^6 Btu/ton.
4. Oil shale has energy content of 3.45 x 10^6 Btu/ton (based on 25 gallons of oil per ton) .
5. Tons of coal or shale.
6. Barrels of oil equivalent.
7. N.A. is not applicable.

Table 3.18* Annual Water Consumption of Generic Synthetic Fuel Energy Systems Producing 50,000 bbl Oil Equivalent per Day to End User (In million gallons per year)

	Coal Gasification		Coal Liquefaction		Oil Shale Retorting	
	Medium-Btu	High-Btu	Direct	Indirect	Surface	Modified in Situ
Mining	64-95	64-95	64-95	64-95	74-120	74-120
Beneficiation	130	130	130	130	0	0
Transportation to Conversion Plant	0	0	0	0	0	0
Conversion to Fuel	1400-2500	1400-2500	740-2800	1400-2800	950-3400	950-1400
Upgrading and refining	0	0			2500	2500
Distribution to End User	0	0	0	0	0	0

* Sam assumptions and references as in Table 3.16.

SOURCE: E. J. Bentz & Associates

Table 1 Footnote to Chapter 3: Manpower Requirements of Generic Synfuel Plants Producing 50,000 Barrels of Oil Equivalent per Day

	1 Coal Gasification	2 Coal Liquefaction	3 Oil Shale Retorting	4
	Medium-Btu-High-Btu	Direct & Indirect	Surface	Modified in Situ
Peak Construction (men)	1,500-4,800[a]	2,200-8,000[b]	330[d]	4,900[d]
Construction (man-years)	3,400 - 10,800[a]	7,500-25,000[b]	1100[d]	16,000[d]
Operation and Maintenance (men)	320-500[a]	355-3800[c]	1200[d]	-

[a] DOE, 1980, Comparative Assessment of Health and Safety Impacts of Coal Use. DOE/EV 0069.

[b] The lower value is derived from DOE/EV 0069; the upper value - from Reference 34.

[c] The lower value is derived from Reference 29 ; the upper value - from Reference 34.

[d] Derived from Reference 17 and assuming 5 year construction of plant peaking at 30% of 9 3 1 man-years labor requirements (Reference 34).

SOURCE: E. J. Bentz & Associates