Case I - Oil Shale Processing with Thermal Refining

The equivalent of 21-1/2 oil-shale mines of the type proposed by the Bureau of Mines (19,200 tons per calendar day) and discussed in the first part of this report can produce 411,000 tons per calendar day. When retorted by the gas-combustion process this amount of oil shale will yield 250,000 barrels of crude shale oil. For the present study, mines have been located in groups at five different sites along the Colorado River and its tributaries - Roan and Parachute Creeks - in the Grand Valley-DeBeque area of northwestern Colorado. The mines are similar in each case, developing the formation horizontally from an outcrop variously located 1,000 to 3,000 feet above the valley floor.

Gas-combustion-process retorting plants are situated below each mine on ridges abutting the outcrop. Crushing and screening plants, shale-storage bins, and retorts are placed to take advantage of the terrain.

The present conception of a commercial-scale gas-combustion retort is a battery of five rectangular cells operated as a group. Each cell is 19 by 38 feet in plan and processes about 2,000 tons of shale per day. Two such batteries constitute the retorting plant for one mine. The top of the retort structure is about 80 feet above grade and the entire five-cell battery is about 100 feet long. Separate rubber conveyor belts, running longitudinally over and under each battery, feed shale to the retorts and remove the ash or spent shale to adjacent canyons for disposal. Gas blowers and oil-recovery equipment are housed in a building paralleling each battery. The area requirement for a plant to consume the shale output of one mine is less than 2 acres.

Crude shale oil is prepared for pipeline transportation from Colorado to California by a light thermal treatment to reduce its viscosity and pour point. Five viscosity-reduction plants of 50,000 barrels-per-calendar-day capacity are located nearby in the valleys to serve each retort plant and mine group. The oil is gathered to a central point to be pumped through a 710-mile, 30-inch-diameter pipeline to Los Angeles for final refining.

Byproduct gas (80 B.t.u. per cubic foot) from retorting is used as fuel for viscosity reduction and to generate electric power. The energy from retort gas is sufficient to supply all power requirements for Colorado facilities, with a sizable excess for sale to the local public utility company for power generation.

In case I, the proposal for shale-oil refining is based on conventional processes that will produce good yields of liquid products with nominal investment. It is assumed that the shale-oil-refining units would be additions to existing petroleum refineries in the Los Angeles area, although, if the advent of shale oil were caused by petroleum shortages, much existing equipment could be utilized. To simplify the evaluation, specification products are made entirely from shale oil by the plan presented; however, numerous advantages would accrue from blending petroleum and shale-oil stocks. Without doubt, the latter procedure would be used by refineries adding shale oil as a source of crude.

At the Los Angeles refineries, the pipeline oil is charged to a typical recycle thermal cracking unit. The light naphtha from cracking is treated with sulfuric acid at reduced temperatures to remove objectionable impurities. Heavy naphtha is catalytically reformed under 400 p.s.i.g. hydrogen pressure (using cobalt molybdate catalyst), then acid-treated. Hydrogen is produced from refinery gases. Other refinery units include catalytic polymerization, sulfuric acid manufacture, and ammonia-recovery plants. Light and heavy naphthas, polymer gasoline, and butanes are blended and leaded to make a finished regular-grade gasoline.

Cracked residuum is utilized for refinery fuel and power generation. The balance of the residuum is blended with treating plant polymer to produce No. 6 fuel oil. Excess refinery gas is sold to outside consumers. Liquid ammonia, propane, butane, and 98-percent sulfuric acid also are marketed. Products from both Colorado and California operations are listed in table 20. Physical properties of the principal products are shown in table 20A. Figure 41 is a schematic flow diagram of the over-all process, showing the principal quantities of material.

TABLE 20. - Raw-material and product summary for 250,000-barrel-per-calendar-day operation; case I - oil-shale processing with thermal refining

Raw material - Green River oil shale:		
Fischer assay	gal. per ton	30
Oil shale mined	tons per calendar day	411,000
Retort feed	do.	390,000
3/16 inch fines and dust loss	do.	21,000
Crude-oil production	bbl. per calendar day	250,000
Final products:		
Colorado		
Fuel gas (1,060 B.t.u.)	M std. c.f. per calendar day	7,120
Fuel gas (80 B.t.u.)	do.	865,000
California[1/]		
Gasoline	bbl. per calendar day	103,680
No. 6 fuel oil	do.	73,790
Commercial propane	do.	13,820
Commercial butane	do.	2,160
Fuel gas (1,300 B.t.u.)	M std. c.f. per calendar day	62,750
Sulfuric acid (98 percent)	tons per calendar day	400
Anhydrous ammonia	do.	69

1/ Additional 45,400 bbl. per calendar day of cracked residuum consumed to satisfy plant energy requirements.

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TABLE 20A. - Properties of major products from 250,000-barrel-per-calendar-day operation; case I - oil-shale processing with thermal refining

	Shale oil	Pipeline oil	Gasoline	Fuel oil
Gravity ..... °A.P.I.	19.9	22.3	59.5	5.9
Reid vapor pressure			10.0	
Sulfur ..... wt. percent	0.85	0.66	0.1	0.6
Nitrogen ..... do.	2.12	2.08	Nil	3.0
Pour point ..... °F.	+90	+10		
Viscosity ..... S.U.S. at 130° F.	130	75		
Viscosity ..... S.F.S. at 130° F. (122°)			-	300
Flash ..... °F.			-	175
Tar acids ..... vol. percent			Nil	
Tar bases ..... do.			Nil	
Gum, A.S.T.M. ..... mg./100 ml.			4.5	
Doctor test			Sweet	
Induction period ..... minutes			350+	
Octane number F-1 ..... clear			72.5	
+3 cc. TEL			82.0	
Octane number F-2 ..... clear			78.5	
+3 cc. TEL			88.5	
A.S.T.M. distillation:				
I.B.P. ..... °F.	356	159	90	375
10 percent ..... do	523	426	135	500
50 percent ..... do.			250	
90 percent ..... do.			370	
E.P. ..... do.			400	
Recovery	30 percent at 680° F.	42 percent at 680° F.	96	25 percent at 680° F.

Case II - Oil-Shale Processing with Mild Hydrogenation

Crude shale oil would be produced as described under case I, using the Bureau's methods for mining, shale preparation, and gas-combustion retorting. Retort gas supplemented by a part of the coke produced in refining supplies all process fuel and electric power requirements for the Colorado facilities.

The proposal for case II envisages collection of the crude shale oil for refining at three locations in nearby valleys. The first refining step is coking to produce a light distillate for subsequent processing. The fraction of coker distillate boiling above 400° F. is hydrogenated at 1,000 pounds per square inch over cobalt molybdate catalyst to yield a sulfur- and nitrogen-free stock for catalytic cracking. The gasoline fraction from both the

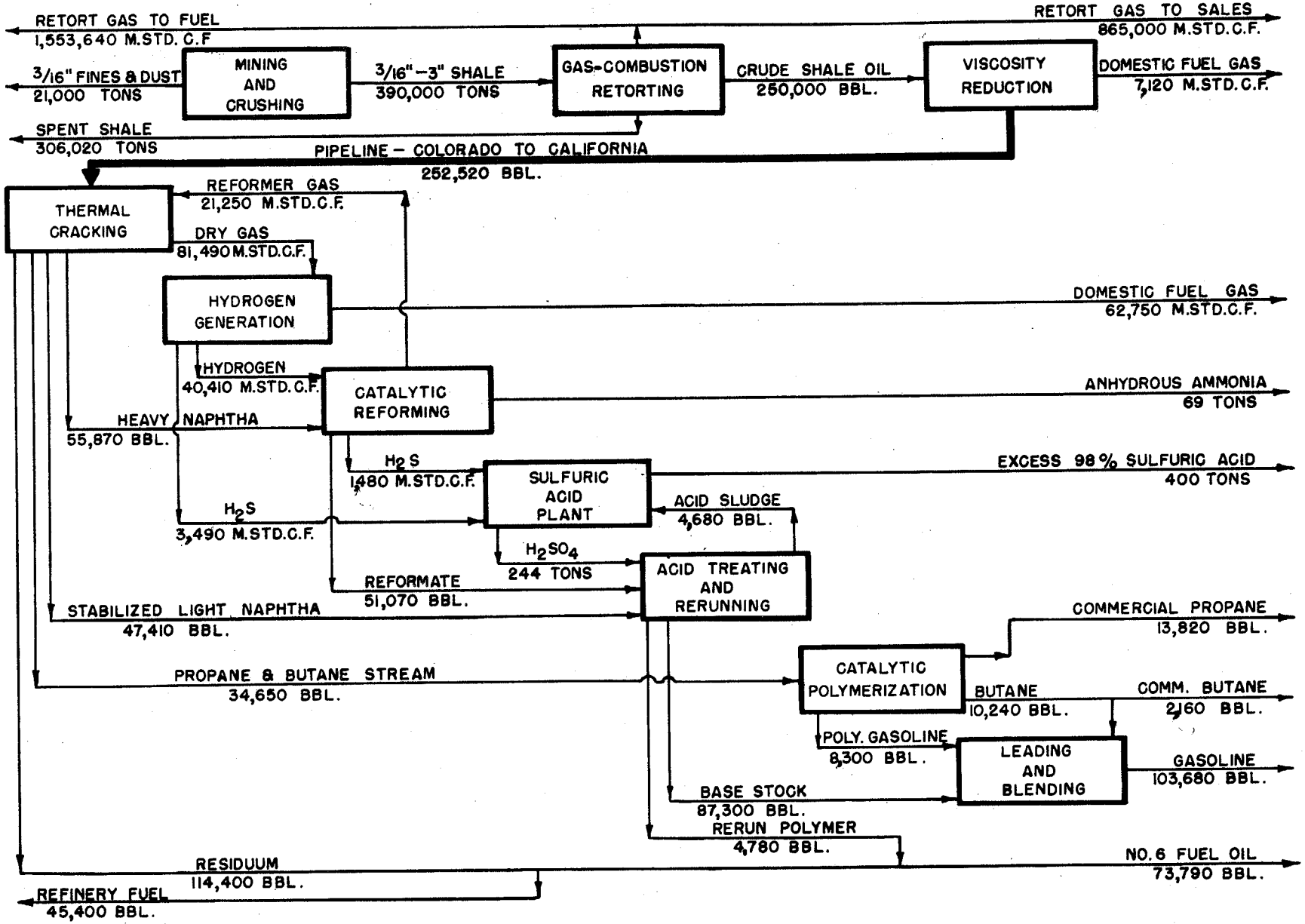

Figure 41. - Flow diagram of 250,000-barrel-per-calendar-day industry-scale operation with thermal refining.

hydrogenation and coking steps is reformed over cobalt molybdate catalyst at 400 pounds per square inch hydrogen pressure for sulfur and nitrogen reduction and octane improvement. Hydrogen is produced from the hydrocarbons in the coker and hydrogenation plant gases. Anhydrous ammonia and sulfur also are recovered from the refinery gases and hydrogenation-plant liquors.

The liquid-hydrocarbon products, gas oil and reformed gasoline, are gathered to a central point to be pumped through a 710-mile, 20- and 24-inch pipeline to southern California for further refining and product blending before being marketed. These partly refined oils are assumed to be distributed to three Los Angeles area refineries, where a portion of the gas oil is catalytically cracked to produce high-quality gasoline base stock. Regular- and premium-grade motor fuels and Diesel are the major products. Products from processing 250,000 barrels per calendar day of crude shale oil are listed in table 21, and their physical properties are shown in table 21A. Figure 41A is a block flow diagram of the over-all process, showing the principal quantities of material.

TABLE 21. - Raw-material and product summary for 250,000-barrel-per-calendar-day operation; case II - oil-shale processing with mild hydrogenation

Raw material - Green River oil shale:		
Fischer assay	gal. per ton	30
Oil shale mined	tons per calendar day	411,000
Retort feed	do.	390,000
3/16 inch fines loss	do.	21,000
Crude oil production	bbl. per calendar day	250,000
Final products:		
Colorado		
Coke	tons per calendar day	4,070
Ammonia	do.	460
Sulfur	do.	215
California		
Premium gasoline	bbl. per calendar day	63,450
Regular gasoline	do.	63,450
Diesel fuel	do.	62,360
Fuel oil	do.	3,050
Commercial propane	do.	2,140
Commercial butane	do.	6,780

TABLE 21A. - Properties of major products from 250,000-barrel-per-calendar-day operation; case II - oil-shale processing with mild hydrogenation

	Shale oil	Regular gasoline	Premium gasoline	Diesel fuel
Gravity ..... °A.P.I.	19.9	-	-	35
Reid vapor pressure	-	10	10	-
Sulfur ..... wt. percent	0.85	0.01	0.05	0.08
Nitrogen ..... do.	2.12	0.001	0.003	0.01
Pour point ..... °F.	+90	-	-	0
A.S.T.M., gum ..... mg per 100 ml.	-	1.0	1.0	-
Viscosity .....S.U.S. at 100° F.	-	-	-	37
S.U.S. at 130° F.	130	-	-	-
Carbon residue ..... 10 percent btm.	-	-	-	0.03
Flash point, PMCC ..... °F.	-	-	-	160
Induction period ..... minutes	-	500+	500+	-
Octane No. F-1 +3 cc. TEL	-	85	96	-
Octane No. F-2 +3 cc. TEL	-	80	85	-
Cetane No.	-	-	-	47
A.S.T.M. distillation:				
I.B.P. ..... °F.	356	95	95	-
10 percent ..... do.	523	135	130	460
50 percent ..... do.	-	240	230	540
90 percent ..... do.	-	350	340	610
E.P. ..... do.	-	400	400	640
Recovery	30 percent at 680° F.	-	-	-

Cost Estimates

The estimates of construction costs for the 250,000 B/CD project are shown in tables 22 and 22A. Power, water and sewage plants, access roads, shops, offices, warehouses, fire and protective systems, rolling stock, etc., as well as processing equipment, are included in the estimate for Colorado facilities. Employee housing and community facilities are not charged to the plant investment. However, in both cases $1,250,000 is provided to assist local planning groups in expanding existing communities and to protect the interests of the plant owners and of the employees. California refineries are assumed to be additions to each of three existing Los Angeles area refineries, and the estimated construction cost includes necessary expansion of plant utilities, laboratories, etc.

In estimating operating costs, items such as personnel, chemicals, catalysts, and utilities, quantities were determined by detailed analysis of requirements. Certain other costs were estimated as percentages of labor or capital investment based on experience with similar operations. Tables 23 and 23A, show operating costs for crude oil production, transportation and refining for cases I and II, respectively, and explain the basis for the individual charges.

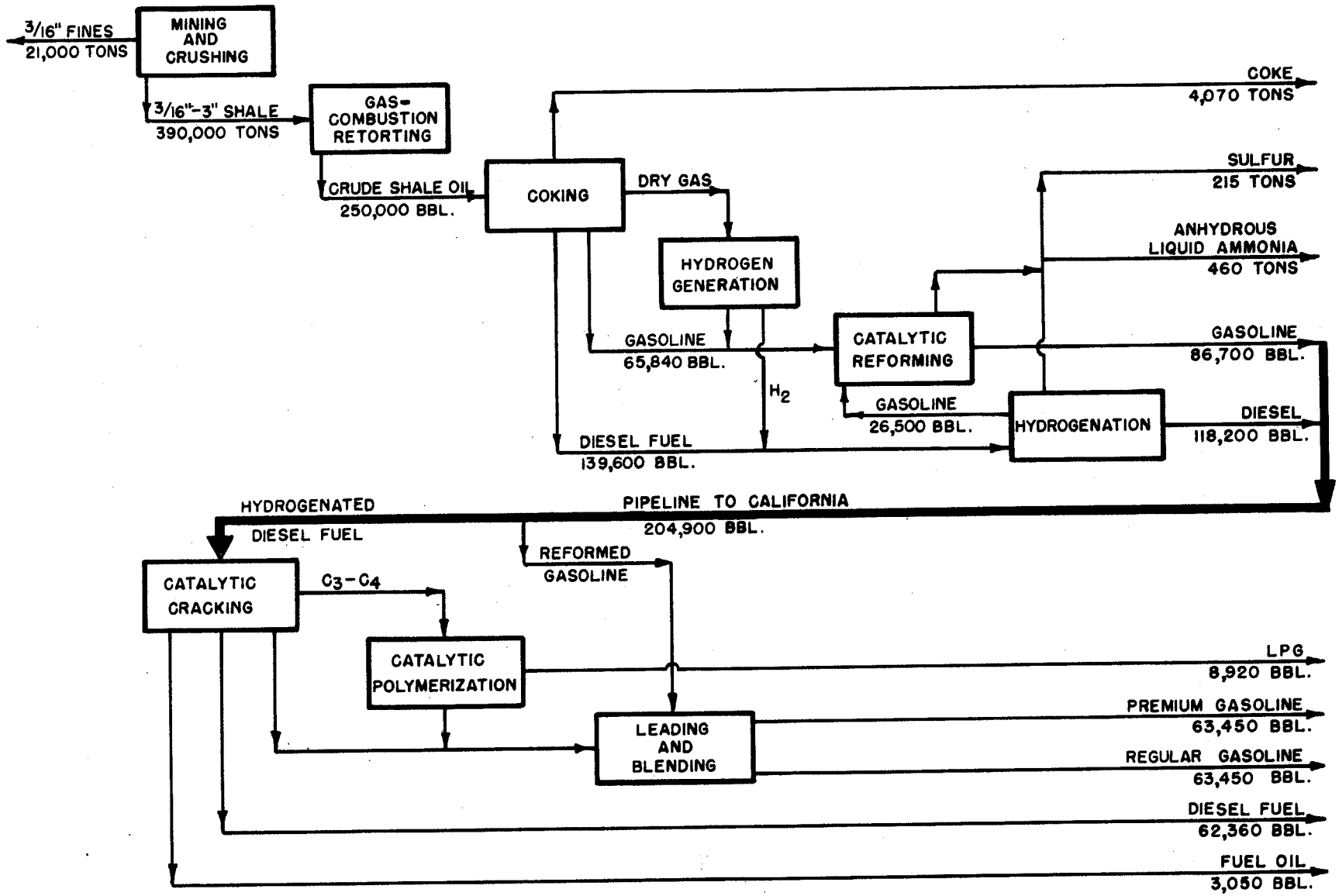

Figure 41A. - Flow diagram of 250,000-barrel-per-calendar-day industry-scale operation with mild hydrogenation.

TABLE 22. - Estimated capital requirement for 250,000-barrel-per-calendar-day operation; case I - oil-shale processing with thermal refining

Construction cost:	
Crude-oil production	
Mining and crushing	$128,900,000
Retorting	121,800,000
General facilities and utilities	99,400,000
Total for crude-oil production	$350,100,000
Crude-oil transportation	
Viscosity breaking	22,000,000
Pipelines	101,800,000
General facilities and utilities	11,000,000
Total for crude-oil transportation	$134,800,000
Refining	
Thermal cracking and gas processing	90,500,000
Catalytic reforming	43,300,000
Catalytic polymerization	17,200,000
Acid treating and redistillation	13,500,000
Hydrogen production	18,300,000
Ammonia recovery	1,300,000
Sulfuric acid manufacture	8,000,000
General facilities and utilities	68,100,000
Total for refining	$260,200,000
Total construction cost of process facilities[1/]	$745,100,000
Operating capital	97,100,000
Process royalties	10,700,000
Start-up expense	18,000,000
Total capital requirement for process	$870,900,000
Community facilities[2/]	1,250,000
Total capital requirement	$872,150,000

1/ Includes interest during construction, and extraordinary labor cost.
2/ Funds intended to assist local planning groups in expanding existing communities.

TABLE 22A. - Estimated capital requirement for 250,000-barrel-per-calendar-day operation; case II - oil-shale processing with mild hydrogenation

Construction cost:	
Crude-oil production	
Mining and crushing	$128,900,000
Retorting	121,800,000
General facilities and utilities	99,400,000
Total for crude-oil production	350,100,000
Colorado refining	
Coking	$107,500,000
Catalytic hydrogenation	72,500,000
Catalytic reforming	71,000,000
Hydrogen production	63,200,000
Ammonia recovery	3,900,000
Sulfur recovery	4,000,000
General facilities and utilities	178,200,000
Total for Colorado refining	$500,300,000
Transportation	
Pipelines	$ 70,400,000
General facilities and utilities	1,800,000
Total for transportation	$ 72,200,000
California refining	
Catalytic cracking	$ 41,000,000
Catalytic polymerization	11,600,000
Redistillation	12,700,000
Total for California refining	$ 65,300,000
Total for process facilities[1/]	$987,900,000
Operating capital	$128,700,000
Process royalties	44,800,000
Start-up expense	22,300,000
Total capital requirement for process	$1,183,700,000
Community facilities[2/]	1,250,000
Total capital requirement	$1,184,950,000

1/ Includes interest during construction, and extraordinary labor costs.
2/ Funds intended to assist local planning groups in expanding existing communities.

TABLE 23. - Estimated daily operating costs for 250,000-barrel-per-calendar-day operation; case I - oil-shale processing with thermal refining

Item	Basis for estimate	Crude-oil production	Crude-oil transportation 2/	Refining	Total
Operating costs - $ per day					
1. Operating labor	Calculated in detail	$ 8,930	$ 2,800	$14,535	$ 26,265
2. Maintenance labor	1.6 percent per year of invest.	7,400	5,905	11,405	24,710
3. Supervision and clerical	15 percent of items 1 and 2	2,450	1,305	3,890	7,645
4. Payroll overhead	20 percent of items 1, 2, and 3	3,755	2,005	5,965	11,725
5. Maintenance supplies	1-1/2 percent per year of plant investment	6,935	5,540	10,695	23,170
6. Operating supplies	8 percent of items 2 and 5	1,145	915	1,770	3,830
7. Utilities	Charge at out-of-pocket cost	--	6,240	960	7,200
8. Catalyst and chemicals	Calculated in detail	30	85	10,680	10,795
9. Tetraethyllead	Calculated in detail	--	-	7,235	7,235
Total direct expense		$ 30,645	$24,795	$67,135	$122,575
10. General plant overhead	40 percent of items 1, 2, 3, 5, and 6	10,745	6,585	16,920	34,250
11. Administrative overhead	10 percent of items 1, 2, 3, 5, and 6	2,685	1,650	4,230	8,565
12. Taxes and insurance	1 percent per year of plant investment	4,625	3,690	7,125	15,440
13. Contingency	5 percent of items 1 through 9	2,550	1,240	3,357	7,147
Subtotal for retorting		51,250	--	--	--
14. Mining and crushing		$165,565 1/	--	--	$165,565
Total operating expense, excluding depreciation 3/		$216,815	$37,960	$98,767	$353,542

1/ Adjusted from mining section estimate, pp. 11-13, to include proportionate share of general facilities and utilities.

2/ Includes viscosity reduction.

3/ Research and development costs are not included because it is felt that savings resulting from such activities would more than balance the expenditures.

TABLE 23A. - Estimated daily operating costs for 250,000-barrel-per-calendar-day operation; case II - oil-shale processing with mild hydrogenation

Item	Basis for estimate	Crude-oil production	Colorado refining	Transportation	California refining	Total
Operating costs - $ per day						
1. Operating labor	Calculated in detail	$ 8,930	$ 18,510	$ 1,135	$ 2,465	$ 31,040
2. Maintenance labor	1.6 percent per year of invest.	7,400	21,970	3,165	2,865	35,400
3. Supervision and clerical..	15 percent of items 1 and 2	2,450	6,075	645	800	9,970
4. Payroll overhead	20 percent of items 1, 2, and 3	3,755	9,310	985	1,225	15,275
5. Maintenance supplies	1-1/2 percent per year of plant investment	6,935	20,560	2,970	2,685	33,150
6. Operating supplies	8 percent of items 2 and 5	1,145	3,400	495	445	5,485
7. Utilities	Calculated in detail	-	-	900	1,670	2,570
8. Catalyst and chemicals ...	Calculated in detail	30	15,125	5	4,020	19,180
9. Tetraethyllead	Calculated in detail	-	-	-	17,910	17,910
Total direct expense ...		$ 30,645	$ 94,950	$10,300	$34,085	$169,980
10. General plant overhead ...	40 percent of items 1, 2, 3, 5 and 6	10,745	28,205	3,365	3,705	46,020
11. Administrative overhead...	10 percent of items 1, 2, 3, 5 and 6	2,685	7,050	840	925	11,500
12. Taxes and insurance	1 percent per year of plant investment	4,625	13,700	1,980	1,790	22,095
13. Contingency	5 percent of items 1 through 9	2,550	4,748	515	1,704	9,517
Subtotal for retorting		51,250	-	-	-	-
14. Mining and crushing		$165,565[1]				$165,565
Total operating expense, excluding depreciation[2]		$216,815	$148,653	$17,000	$42,209	$424,677

1/ Adjusted from mining section estimate, pp. 11-13, to include proportionate share of general facilities and utilities.

2/ Research and development costs are not included because it is felt that savings resulting from these activities would more than balance expenditures.

TABLE 24. - Estimated cost of gasoline from 250,000-barrel-per-calendar-day operation; case I - oil-shale processing with thermal refining

Items	Basis for estimate	$ per calendar day
Direct operating cost	See table 23	353,542
Oil-shale royalty	None estimated	-
Depreciation of mining facilities	Mining estimate, p. 13	35,675
Depreciation of process facilities	20 year	84,410
Amortization of process royalties, start-up expense, and community assistance	20 year	4,110
Subtotal		477,737
Product value:		
Gasoline (regular grade)	at $0.12 per gal.	522,547
No. 6 fuel oil	at 1.70 per bbl.	125,443
Byproducts:		
Fuel gas (1,060 B.t.u.)	at $0.148 per M std. c.f.	1,055
Fuel gas (80 B.t.u.)	at $0.0089 per M std. c.f.	7,700
Fuel gas (1,300 B.t.u.)	at $0.182 per M std. c.f.	11,420
Commercial propane	at $0.025 per gal.	14,510
Commercial butane	at $0.06 per gal.	5,445
Sulfuric acid	at $21.00 per ton	8,400
Ammonia	at $77.50 per ton	5,350
Total sales		701,870
Total operating cost		477,737
Gross profit on sales		224,043
Interest on debt	1/2 of investment at 4 percent (ave.)	23,900
Net income before income tax		200,143
Income tax	50 percent rate	100,072
Net income after income tax		100,071
Net income after taxes in percent of original equity investment		8.4 percent

TABLE 24A. - Estimated cost of gasoline from 250,000-barrel-per-calendar-day operation; case II - oil-shale processing with mild hydrogenation

Items	Basis for estimate	$ per calendar day
Direct operating cost	See table 23A	424,677
Oil-shale royalty	None estimated	-
Depreciation of mining facilities	Mining estimate, p. 13	35,675
Depreciation of process facilities	20 year	117,670
Amortization of process royalties, start-up expense, and community assistance	20 year	9,370
Subtotal		587,392
Product value:		
Premium gasoline	at $0.13 per gal.	346,437
Regular gasoline	at $0.12 per gal.	319,788
Diesel fuel	at $0.09 per gal.	235,720
Byproduct:		
Coke	at $4.00 per ton	16,280
Residual fuel oil	at $1.60 per bbl.	4,880
Commercial propane	at $0.025 per gal.	2,245
Commercial butane	at $0.06 per gal.	17,085
Sulfur	at $20.50 per ton	4,410
Ammonia	at $77.50 per ton	35,650
Total sales		982,495
Total operating cost		587,392
Gross profit on sales		395,103
Interest on debt	1/2 of investment at 4 percent (ave.).	32,450
Net income before income tax		362,653
Income tax	50 percent rate	181,326
Net income after income tax		181,327
Net income after taxes in percent of original equity capital		11.2 percent

The economics of shale fuels production is expressed in terms of the rate of return on the initial equity investment after income taxes, assuming a 50 - 50 split between equity and borrowed funds. All products are assigned current values. Tables 24 and 24A, summarize the economic calculations.

Tables 25 and 25A, show the requirements for steel, other metals, and manpower for construction and operation.

TABLE 25. - Estimated metals, manpower, and time requirements for 250,000-barrel-per-calendar-day operation; case I - oil-shale processing with thermal refining

Item	Mining, crushing and retorting	Visbreaking and pipeline transportation	Refining	Total
Construction metals				
Steel ..... tons	110,000	290,000	150,000	550,000
Alloy steel ..... do.	19,000	1,100	8,900	29,000
Nonferrous metals ..... do.	2,300	740	960	4,000
Construction period				
Months to 1/5 capacity	18	18		
Months to 1/3 capacity			24	
Months to 2/5 capacity	30	30		
Months to 3/5 capacity	42	42		
Months to 2/3 capacity			36	
Months to 4/5 capacity	54	54		
Months to full capacity	66	66	54	66
Construction manpower				
Man-shifts (total)	6,500,000	1,000,000	3,500,000	11,000,000
Operational manpower				
All employees	8,600	900	3,200	12,700