SYNCRUDE FROM EASTERN OIL SHALE

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ABSTRACT

Recently, a detail study was made to make resource assessment, mining and process economic evaluations of oil shale in Lewis and Fleming Counties, Kentucky. Two surface retorting processes, Paraho and HYTORT, were selected and the process and economic analyses were made for a 30,000 tons/day oil shale retorting facility. This paper presents the results of this eastern oil shale feasibility study.[1]

INTRODUCTION

Oil shale exists in Western as well as Eastern states of the U.S. The shales in the West have higher oil yields per ton (20-30 gal/ton) than in the East (10-20 gal/ton). The organic carbon content of both the shales is similar, but the western shales contain more hydrogen. Because of the higher hydrogen content, on an average the western shales' Fischer Assay oil yields are higher than the eastern shales'. However, it is important to recognize that the overall energy content of both the shales is similar; but in the case of eastern shales, higher amounts of by-products such as gas, coke, and steam/electricity are produced compared with western shales.

The recent rapid OPEC oil price increases have raised the value of oil to a level where the production of shale oil from eastern shales is beginning to receive commercial attention. Comparatively, larger amounts of by-products produced while retorting eastern shales may not be a big disadvantage, as eastern oil shale deposits are much closer to markets than western oil shale deposits. Factors that have encouraged interest in eastern oil shale include the vastness of the resource, and its closeness to markets and supporting infrastructure. Also, the availability of mining, operating and construction labor, abundant water resources and the shales' location in an industrial area, add significantly to the commercial feasibility of developing this resource. In addition, the eastern shales that cropout in Kentucky, Ohio, and Tennessee are located on privately held land and can be mined and shipped economically. The socioeconomic impact of an oil shale project is far less on the Eastern United States than the Western United States.

RESOURCE ASSESSMENT

The U.S. Geological Survey has estimated the total "known resources" of Devonian eastern oil shale at 400 billion barrels, and the "probable extensions of known resources" at an additional 2600 billion barrels, including both deep and surface deposits. These estimates are based on Fischer Assay test results.

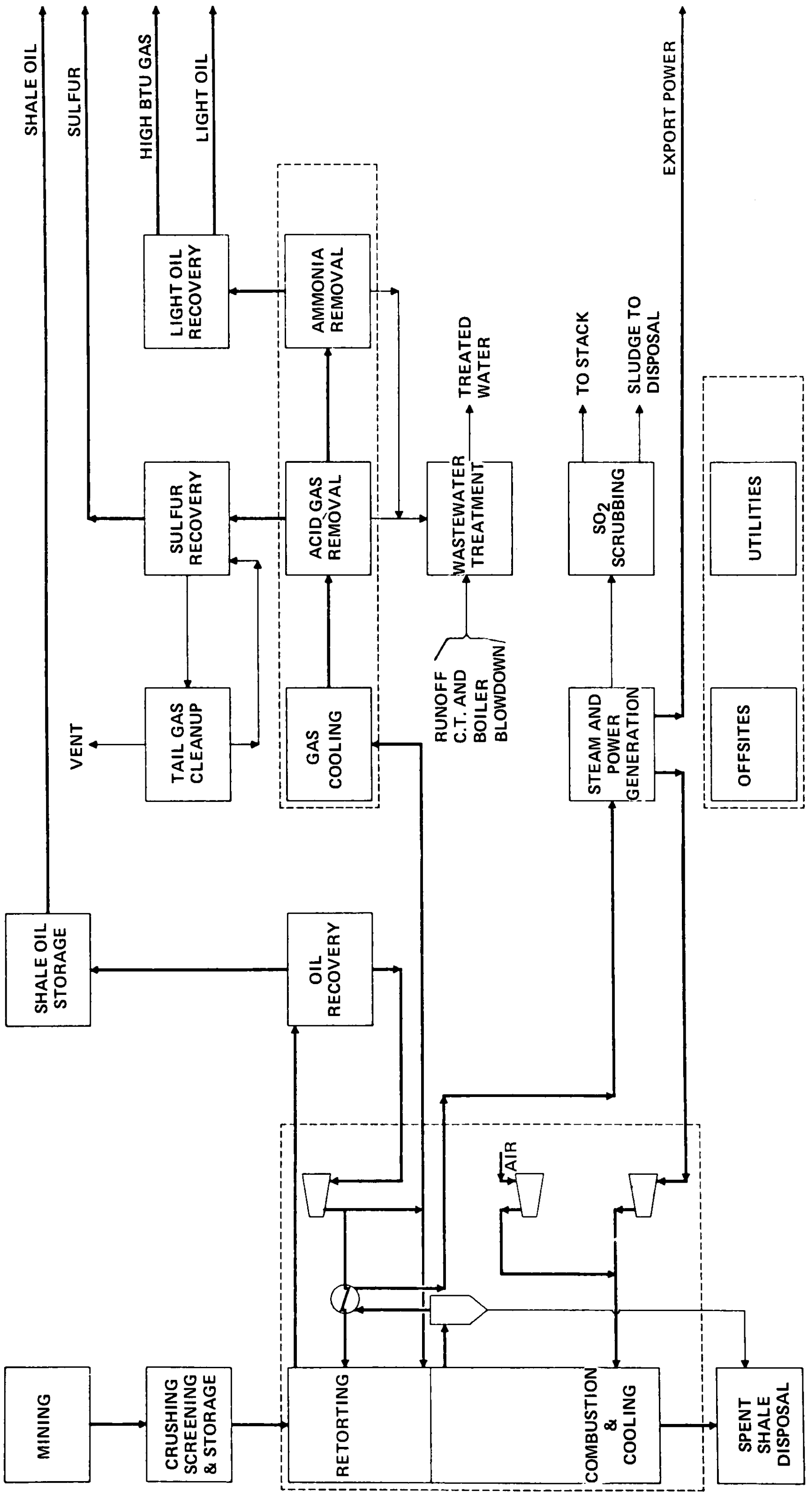
In this study, the resource assessment of oil bearing shales of Lewis and Fleming Counties, Kentucky was made. The pertinent geologic strata consist of (from top to bottom) the Borden Formation (series of siltstones and shales), the Sunbury Shale (oil-bearing black shale), the Berea Sandstone (shaly siltstone), the Bedford Shale (silty shale), the Ohio Shale (oil-bearing black shale), the Bisher Limestone (dolomite), and the Crab Orchard Shale. The Sunbury Shale ranges from 15 to 20 feet in thickness throughout most of the area. The Ohio Shale ranges from approximately 200 to 300 feet in thickness in the study area. These two oil shales are separated by the Berea Sandstone and Bedford Shale, which combined are approximately 100-120 feet thick in northern Lewis County, decreasing southward to 30-35 feet in Fleming County. The oil shale reserves in these two counties represent about 4.4 billion barrels of oil. Of this, 1.3 billion barrels of oil are formed in oil shale having an overall stripping ratio of 2.5:1.

For the selected plant site, the average carbon and hydrogen content of the shale is about 11.7 percent and 1.5 percent respectively. The Fischer Assay oil content of the shale is about 12.5 gal/ton.

PROCESS EVALUATION

Based on the resource analysis data, a detailed process analysis was made to develop $\pm$ 25 percent capital cost in this project. Based on the preliminary evaluation, Paraho and HYTORT processes were selected for detailed process and economic analysis. Paraho is low pressure process and produces shale oil about 90-95 percent of Fischer Assay yield. The HYTORT process oil shale is retorted at a high pressure in the presence of hydrogen and produces more shale oil than the Fischer Assay yield. In the retort, about 46 percent of the organic carbon in the Sunbury Shale is converted to shale oil and this oil yield comes out

FIGURE 1 PARAHO PROCESS FLOW DIAGRAM



to be about 116 percent of the Fischer Assay yield. Also, it is important to note that the oil yield in the HYTORT process is directly related with the organic carbon content of shale rather than the Fischer Assay yield. In comparison with the HYTORT process, Paraho has a simple process configuration.

Paraho

The Paraho retort was developed by Paraho Development Corporation by modifying vertical kiln technology. Paraho has developed direct-heated and indirect-heated mode retorts for western shale and the combination heated retort (CH retort) for eastern oil shale. The overall process block flow diagram is presented in Figure 1.

The Paraho retort is a refractory-lined, vertical kiln, in which a moving bed of crushed oil shale flowing downward through a kiln is contacted countercurrently with an upward flow of hot gases having an adequate heat content to heat the shale to about $1000^{0}F$ and to retort the organic constituents in the shale. Temperatures near the top of the retort are controlled so that the oil vapor is condensed in the gas stream as an entrained oil mist and oil is recovered in the oil recovery system. The retorted eastern oil shale, high in carbon content, is passed through a dynamic seal and goes to the combustor where the leftover carbon is burned. The shale is cooled and discharged by grate at the bottom of the retort. The hot flue gas generated in the combustor is used in heating the recycle gas for retorting and then it is passed through a boiler to generate a high pressure steam for in-plant use and power generation.

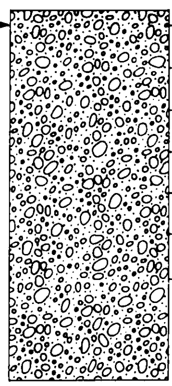
A portion of the oil mist free gas is recycled to the retort and the remaining portion is passed through gas cooling, acid gas removal and ammonia removal system. The sulfur free gas is then passed through the light oil recovery system, and a high Btu gas and light oil are recovered as by-products. As shown in Figure 1, this plant is also equipped with a sulfur recovery system, an SO_2 scrubbing system, a waste water treatment facility and all the necessary utilities and off-site facilities.

The process analysis is based on the results of the test performed by the Paraho Laboratory on the eastern oil shale samples. Two samples were sent to the Paraho Laboratory for chemical and physical testing. Both samples were treated in identical fashion to develop design data.

This grass roots plant is designed for a 30,000 tons/day retorting capacity. The overall material and energy balances are presented in Figure 2. In addition to raw shale, the plant requires about 2000 gpm of makeup water, 1066 tons/day of crushed limestone and 428,600 scfm of air. This plant produces about

FIGURE 2 OVERALL MATERIAL AND ENERGY BALANCES
PARAHO PROCESS
30,000 T/D EASTERN OIL SHALE PLANT

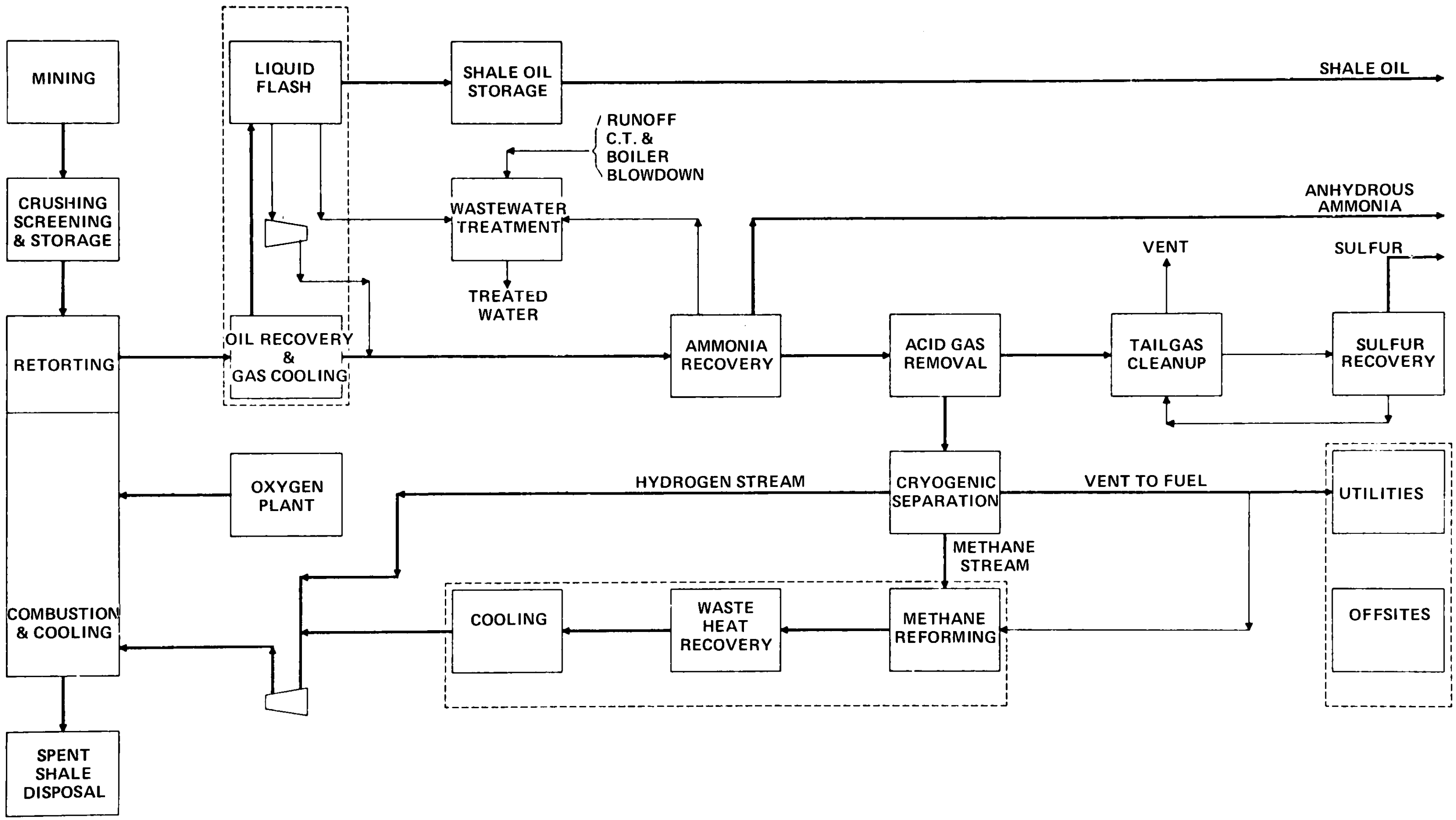
PLANT INPUT	T/D	MMBTU/DAY
RAW SHALE	30,000*	140,400
AIR @ 428,600 SCFM	23,514	
CRUSHED LIMESTONE	1,066	
WATER @ 2,034 GPM	12,221	
TOTAL	66,801	



PLANT OUTPUT	T/D	MMBTU/DAY	%
SHALE OIL @ 8,132 B/D	1,402	51,574	36.7
LIGHT OIL @ 2,282 B/D	252	10,536	7.5
HIGH BTU GAS @ 14,473 SCFM	499	20,725	14.8
EXPORT POWER @ 10,000 BTU/KWH	–	11,590	8.2
SULFUR	126	1,340	1.0
SPENT SHALE & SLUDGE	27,875	10,487	7.5
STACK AND VENT GASES, COOLING TOWER LOSSES,ETC.	36,647	34,148	24.3
TOTAL	66,801	140,400	100.0

* ACTUAL PLANT INPUT IS 33,600 T/D
3600 T/D SHALE FINES GENERATED DURING
CRUSHING & SCREENING

FIGURE 3 HYTORT PROCESS FLOW DIAGRAM



8132 bbl/day shale oil, 2282 bbl/day light oil 14,473 scfm of high Btu gas and about 48.3 Mw of excess power. About 44.2 percent of the input energy is recovered as liquid products, 14.8 percent as high Btu gas and 8 percent as excess power. This plant requires about 65 acres or 2300 feet by 1200 feet land area.

<u>HYTORT</u>

The HYTORT retort was developed by the Institute of Gas Technology (IGT). The HYTORT process concept is based on direct, noncatalytic hydrogenation of kerogen at high pressure and controlled heat-up rates. The overall process block flow diagram is presented in Figure 3.

The HYTORT retort is a refractory-lined, high pressure, vertical vessel in which a moving oil shale flowing downward through the retort is contacted countercurrently with an upward flow of hot gases. As this retort is operated at about 550 psia, high pressure raw shale feeding and spent shale removal systems are required. The shale is progressively heated to retorting temperatures of 1200^{o}F and the heat required for retorting is supplied by combusting part of the hydrogen stream with oxygen and raising its temperature to 1450^{o}F. The retorted shale is cooled using the hydrogen-rich stream in the bottom section of the retort. The cooled spent shale is removed from the retort through lock hoppers. The retort top gases containing oil mist and vapors are recovered in the oil recovery system.

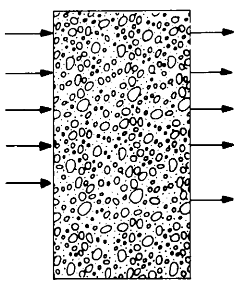
The gas from the oil recovery system is passed through the ammonia recovery and acid gas removal system. The clean gas is then passed through the cryogenic separation plant where methane-rich and hydrogen-rich gas streams are separated. The hydrogen-rich stream is recycled to the retort and the methane-rich stream is passed through a conventional steam reformer to produce more hydrogen to meet the retort need. As shown in Figure 3, this plant is also equipped with a sulfur recovery system, an oxygen plant, a waste water treatment facility and all the necessary utilities and off-site facilities.

The process analysis is based on the test results published by the Institute of Gas Technology (IGT) in various publications. An extensive survey of the Devonian shale resources[2] was made by IGT, involving 242 samples from 94 locations in Kentucky and has published HYTORT performance data for Sunbury Shale in various publications.[3] Therefore, there was no need for further test work for this project.

This grass roots plant is designed for a 30,000 tons/day retorting capacity. The overall material and energy balances are presented in Figure 4. In addition to raw shale, the plant requires about 4100 gpm of makeup water, 565 tons/day oxygen, 45.3 Mw electric power and 269,700 scfm of air. The plant produces about 10,217 bbl/day of shale oil, and 104 tons/day of anhydrous ammonia. About 44.9 percent of the input energy is recovered as liquid product. This plant requires about 65 acres of 2300 feet by 1200 feet land area.

FIGURE 4 OVERALL MATERIAL AND ENERGY BALANCE
HYTORT PROCESS
30,000 T/D EASTERN OIL SHALE

PLANT INPUT	T/D +	MMBTU/DAY	%
RAW SHALE	30,000	140,400	92.8
PURCHASED POWER @ 10,000 BTU/KWH		10,882 •	7.2
AIR @ 269,720 SCFM	14,797		
WATER @ 4079 GPM	24,508		
OXYGEN @ 9,280 SCFM	565		
TOTAL	69,870	151,282	100.0



PLANT OUTPUT	T/D	MMBTU/DAY	%
SHALE OIL @ 10,217 B/D	1,760	64,752	44.9
ANHYDROUS AMMONIA	104	2,155	1.5
SULFUR	430	4,552	3.2
STACK AND VENT GASES, COOLING TOWER LOSSES, ETC.	41,951	56,336	39.1
SPENT SHALE	25,625	16,319	11.3
TOTAL	69,870	144,114•	100.0

+ ACTUAL PLANT INPUT IS 37,500 T/D.
7500 T/D SHALE FINES GENERATED DURING CRUSHING AND SCREENING.

•PURCHASED POWER IS ACCOUNTED @ 10,000 BTU/KWH, HOWEVER,HEAT INPUT IS ONLY 3413 BTU/KWH

ECONOMIC ANALYSIS

Based on the detailed process analysis, $\pm$ 25 percent capital cost was developed for these projects. Table 1 presents the capital and operating costs for a 30,000 tons/day eastern oil shale plant.

The initial plant investment costs for the Paraho and HYTORT are $504 million and $695 million respectively. These costs are for the grass roots plant and include mining, material handling, retorting, oil recovery, facilities to meet environmental standards and all the necessary off-sites. The working capital includes 6 weeks payroll, 15 days oil storage at $40/bbl and accounts receivable and payable in 45 days. Total initial capital required for the Paraho and HYTORT projects is $647.2 million and $890.3 million respectively.

The gross annual operating costs for the Paraho and HYTORT processes are $63.1 million and $86.1 million respectively (Table 1). The consumable costs include the costs of catalyst for chemicals, water, electricity, and operating and maintenance supplies. The labor and overhead costs include the costs of operating and maintenance labor, payroll burden, general and administration. The annual by-product credits are $52.5 million for the Paraho plant versus $12 million for the HYTORT plant. The credits for the various by-products are taken as follows: High Btu gas at $3/MM Btu, light oil at $0.60/gal, electricity at $0.0275/kwh, sulfur at $60/ton and ammonia at $100/ton. After by-product credits, the net annual operating cost is about $10.6 million and $74.1 million for the Paraho and HYTORT processes respectively.

Several cash flow analyses were developed for each process, and some of the results are presented in Table 2. Two analysis methods were employed:

1. 100 percent equity to determine an Internal Rate of Return (IRR).
2. 75 percent/25 percent equity to determine a Return on Equity.

The following bases were used for the economic analysis:

- Project life - 20 year's plant operation
- Construction - 3 1/2 years
- U.S. Income Tax - 46 percent
- Kentucky Income Tax (as this is an energy project, assume 50 percent exemption) - 3 percent
- Investment tax credit
  Qualifying equipment - 20 percent
  Balance of plant (except pollution control) - 10 percent
- Depletion allowance - 15 percent of oil sales not to exceed 50 percent of taxable income
- Constant dollars - no escalation
- Mine development - expensed
- Depreciation - as applicable, accelerated depreciation based on Class Life Assets Depreciation Range (CLADRD) is used.

The important consideration in determining the IRR and ROE for the project is the ability to use the tax investment incentives at the time they are available rather than deferring or losing them.

To illustrate the magnitude of tax factors, the project is analyzed on a stand-alone and on a pass-through basis. The pass-through basis assumes the project venture is structured such that book losses from the project can be used to offset taxable income elsewhere at the same tax rate that the venture incurs. Thus, the venture in effect can experience a negative income tax. The stand-alone case assumes only income from the project is offset by the incentives. This may result in carry-forward treatment as allowed to prevent a negative income tax.

All of the analyses are done in constant 1980 dollars. The capital and operating costs are based on costs in effect as of the fourth quarter of 1980. No escalation of plant costs or inflationary effect have been included over the period 1981-2003.

Internal Rate of Return (IRR)

The IRR is that interest rate which, when applied to the future cash flows to discount them for their present (1980) value, make the cumulative discounted cash flow zero at the end of the study period (2003). At 100 percent equity, the Paraho project provides a return of about 12 percent at $40/bbl shale oil price and provides about 14 percent return at $50/bbl shale oil price. The HYTORT project, at 100 percent equity, provides about 12 percent return at $60/bbl shale oil price and provides about 14 percent return at $70/bbl shale oil price. The variation in selling price with IRR requirements is shown in Figure 5. The effect of the variation of the by-product credits on the selling price and IRR is given in Figure 6.

TABLE 1
CAPITAL AND OPERATING COSTS
30,000 TONS/DAY EASTERN OIL SHALE PLANT
(4TH QUARTER 1980 DOLLARS)

	Paraho		HYTORT	
	Initial	Deferred*	Initial	Deferred*
A. Capital Cost ($ MM)				
Total Direct Cost	382.5		539.7	
Professional Services, Field Indirects, Insurance, Etc.	122.0		155.3	
Plant Investment Cost	504.5		695.0	
Working Capital	17.4		21.8	
Interest During Construction	125.8+		173.5+	
Startup Cost	Expensed++		Expensed++	
Total Capital	647.7	126.1	890.3	140.8
B. Operating Cost ($1,000)				
Consumables	23,614		39,525	
Labor & Overhead	23,556		24,571	
Taxes & Insurance	15,908		21,955	
Total Gross Operating Cost	63,078		86,051	
By-Product Credit	(52,499)		(11,946)	
Net Operating Cost	10,579		74,105	

* Additional Investment from year 2 to 20.

\+ On the 75% of the initial plant investment @ 12% interest.

++Expensed at 50% of the first year's revenue

TABLE 2
ECONOMIC ANALYSIS
30,000 TONS/DAY EASTERN OIL SHALE PLANT

	Paraho		HYTORT	
	Stand-Alone Venture	Pass-Through Venture	Stand-Alone Venture	Pass-Through Venture
A. 100% Equity				
Selling Price - $/bbl	Internal Rate of Return %			
40	11.4	12.1	5.7	5.9
50	13.7	14.4	8.8	9.1
B. 75% Debt @ 12%/25% Equity				
Selling Price - $/bbl	Return on Equity			
40	10.4	24.1		
50	18.2	30.8		
C. 100% Equity				
Return on Equity %	Selling Price $/bbl			
12	42.50	39.70	61.90	58.00
14	51.80	48.20	72.00	68.40

FIGURE 5 ECONOMIC ANALYSIS
30,000 TONS/DAY EASTERN OIL SHALE PLANT

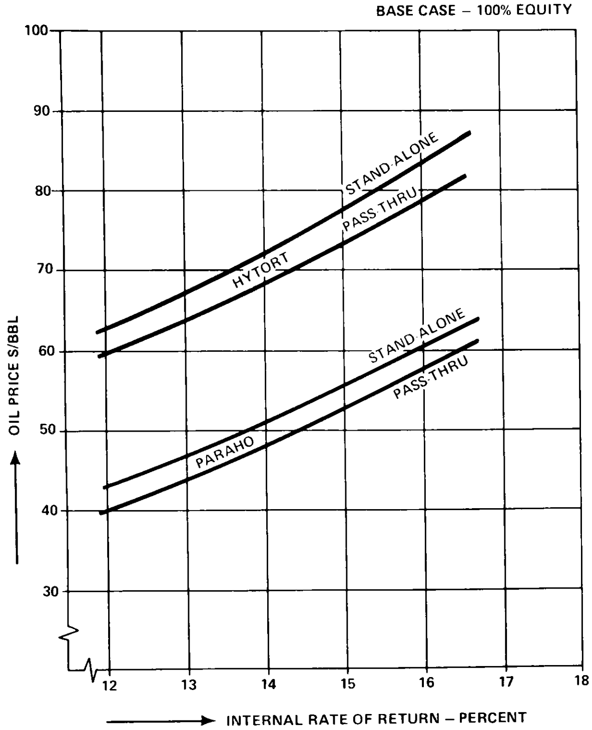
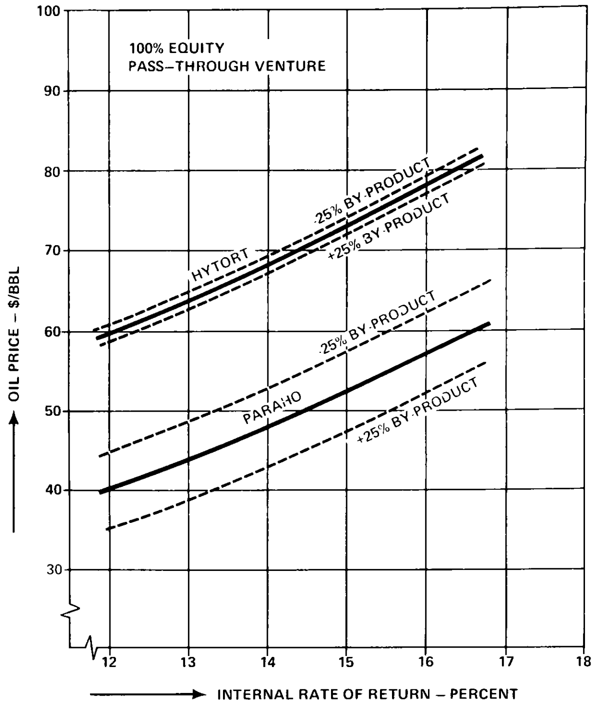


FIGURE 6 ECONOMIC ANALYSIS
30,000 TONS/DAY EASTERN OIL SHALE PLANT
EFFECT OF BY-PRODUCT CREDITS



Return on Equity (ROE)

The financial analysis is made to determine the return on equity (ROE) for a capitalization based on borrowed funds and equity. The debt is retired over a medium term (10 years) from the project cash flow. The ROE is that interest rate which made the cumulative discounted equity and retained earnings flow (after debt services) equal to zero over the study period (1980 through 2003).

The financial analysis assumes that equity and debt are used to finance the project prior to operation. Interest on debt during construction is capitalized and financed with the project in the ratio of 75 percent debt/25 percent equity. The interest on the loan is assumed at 12 percent on draw-down basis without any commitment fee. For the Paraho project, the return on equity at $40/bbl shale oil price is about 24 percent and at $50/bbl is about 30 percent on a pass-through basis.

CONCLUSIONS

The following conclusions can be drawn from this investigation:

- About 4.4 billion barrels of oil can be recovered from oil shale of Lewis and Fleming Counties, Kentucky. The shale reserves having an overall stripping ratio of less than 2.5:1, represent about 1.3 billion barrels of oil.
- A 30,000 tons per day retorting plant can produce about 10,000 bbl/day of shale oil.
- A total capital required for the grass roots Paraho plant facility, having a capacity to retort 30,000 tons per day of eastern oil shale, will be about $647 million and the HYTORT plant having the same capacity will require about $890 million. The initial plant investment costs for Paraho and HYTORT are $504 million and $695 million respectively.
- For the same return on equity, the Paraho process is cheaper than the HYTORT process by about $20/bbl.
- For the Paraho process, for a 75 percent debt (at 12 percent interest) and a 25 percent equity cash flow analysis, the return on equity at $40/bbl shale oil price is about 24 percent.
- Based on these results, it can be concluded that the production of shale oil from eastern oil shale is commercially feasible.

AKNOWLEDGEMENTS

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NOTES

[1]Kirit C. Vyas, Gary D. Aho and Thomas L. Robl, "Synthetic Fuels From Eastern Oil Shale--Volume I". Final report prepared for Buffalo Trace Area Development District, Maysville, Kentucky, by Davy McKee Corporation, Cleveland, Ohio, January 1981.

[2]S. A. Weil and et. al., "The IGT Hytort Process for Hydrogen Retorting of Devonian Oil Shales". Presented at the Chattanooga Shale Conference, Oak Ridge, Tennessee, November 14, 1978.

[3]S. A. Weil and et. al., "Synthetic Fuels From Eastern Devonian Oil Shale". Presented at the 7th Energy Technology Conference and Exposition, Washington, D.C., March 24-26, 1980.