ECONOMIC EVALUATION OF COMBINED IN SITU AND SURFACE RETORTING OF OIL SHALE

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This study, completed in 1976, was made to provide Shell Oil Company's management with information that could affect their decision whether to continue the already substantial investment in the C-b project or not.

The successful bidders on federal lease Tract C-b in Colorado in 1974 were Tosco, Atlantic Richfield, Ashland and Shell. At the end of 1975, seeing that the project had no economic future and facing institutional obstacles, Tosco and Atlantic Richfield withdrew from this venture. At year's end, 1976, Shell also withdrew, citing many environmental and political obstacles, including the federal lease limitation of 5,000 acres per company (2,500 ha). These obstacles, in all, added non-technical risks the company felt were not commensurate with the potential return on a billion-dollar investment.

One of the reasons the project was not economically sound was its basic design. Mining was expected to take place in the Mahogany Zone, by room and pillar method, with surface retorting of the mined out shale. Due partly to lower quality rock strength, total resource recovery was lower than anticipated. Shell therefore made a study of alternate methods of developing Tract C-b. Aimed primarily at increasing recovery, one of the most interesting possibilities the study discovered was in situ retorting, using a process similar to that proposed by Occidental Petroleum Company.

Mining problems related to in situ retorting can be very complex. It is difficult to make a realistic evaluation of in situ retorting or the combination of in situ and surface retorting without a good, detailed mining study. Pressed for time, Shell arranged with the Bureau of Mines to use the Fenix & Scisson study data (before final publication) for a study of the mine design and associated costs as they might be related to the C-b tract.

The basic Fenix & Scisson design utilized for this evaluation was the room and pillar, vertical drill and blast method to create an upper level drill station and a lower level room that provides, in combination with the drill station, a void volume of 25 percent. Figure 1 shows a cross section of the retort used in this evaluation.

For Tract C-b, with an overburden of over 300 meters, the maximum retort height considered feasible in the Fenix & Scisson studies was about 70 meters (230 ft). Core data from Tract C-b indicate a maximum Mahogany Zone mining height of 24 meters. The preferred, richer mining section is 11 meters high with an average assay of about 42 gallons of oil a ton. In order to create the desired void volume for in situ retorting, it is preferable to mine out as much as possible from the rich Mahogany Zone for two reasons:

(1) For this study, we assumed that mined out shale would be retorted on

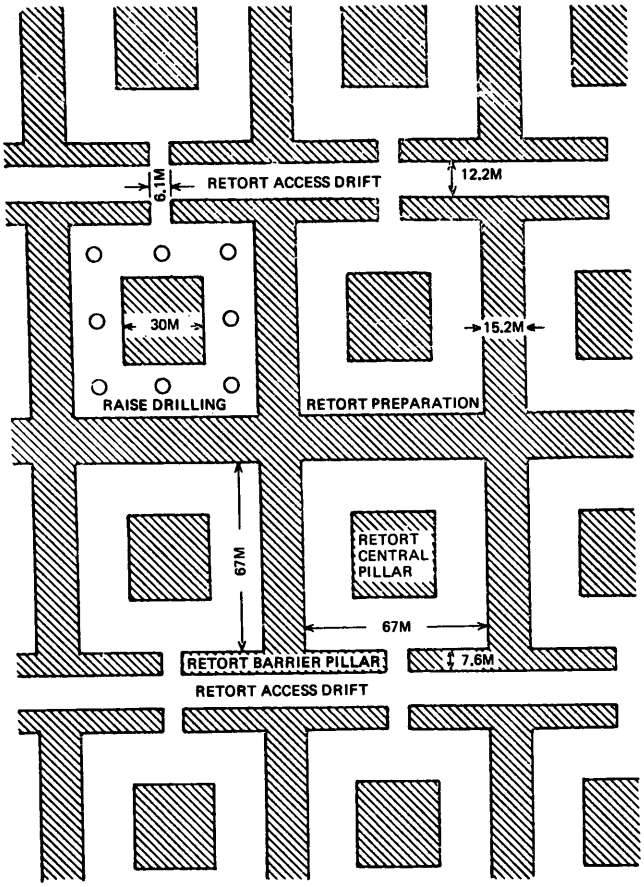

Figure 1. - In situ mine design, by Fenix and Scisson, Inc.

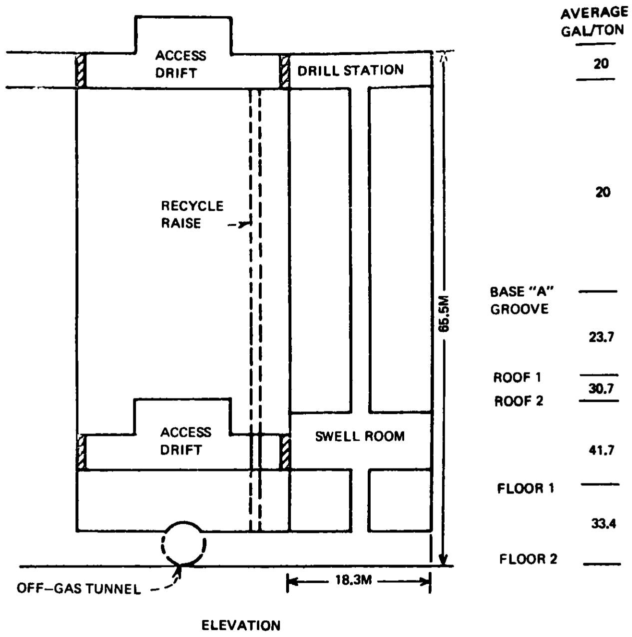

Figure 2. - Tract C-b in situ retort development.

the surface in Tosco-II type units whose liquid yield is over 95 percent of Fisher assay, compared to an estimated 60 percent yield by in situ retorting. Clearly, overall yield is improved by surface retorting of as much of the rich shale as possible.

(2) Richer shales are more susceptible to plastic deformation than lean shale. In situ retorting of these richer shales could cause non-uniform gas distribution and/or excessive pressure drop.

With these considerations in mind, the mining plan was modified for use on Tract C-b as shown in figure 2. Although it would be preferable to extend the retort downward from the identified mining zone to cover the desired depth, rock quality below the mining zone was poorer than that above it. This is not expected to be a limiting factor for in situ retorting. As a conservative approach for a screening evaluation, Shell's study assumed development only in the higher quality rock above the Mahogany Zone.

The overall processing concept for a combination of in situ and surface retorting is shown in figure 3. The liquid product from in situ retorting comes to the surface as an oil and water emulsion. It must be separated and the water treated for further plant use. This minimizes the requirement for external supplies of clean water. In the Fenix & Scisson study, the low Btu gas exiting from the in situ retorts was flared, probably not an acceptable disposition for both economic and environmental reasons. Although this gas has a low heating value, it represents about 25 percent additional liquid yield on an equivalent Btu basis. So it is necessary to use that heat value within the plant either for power generation or as fuel for the surface processing facilities.

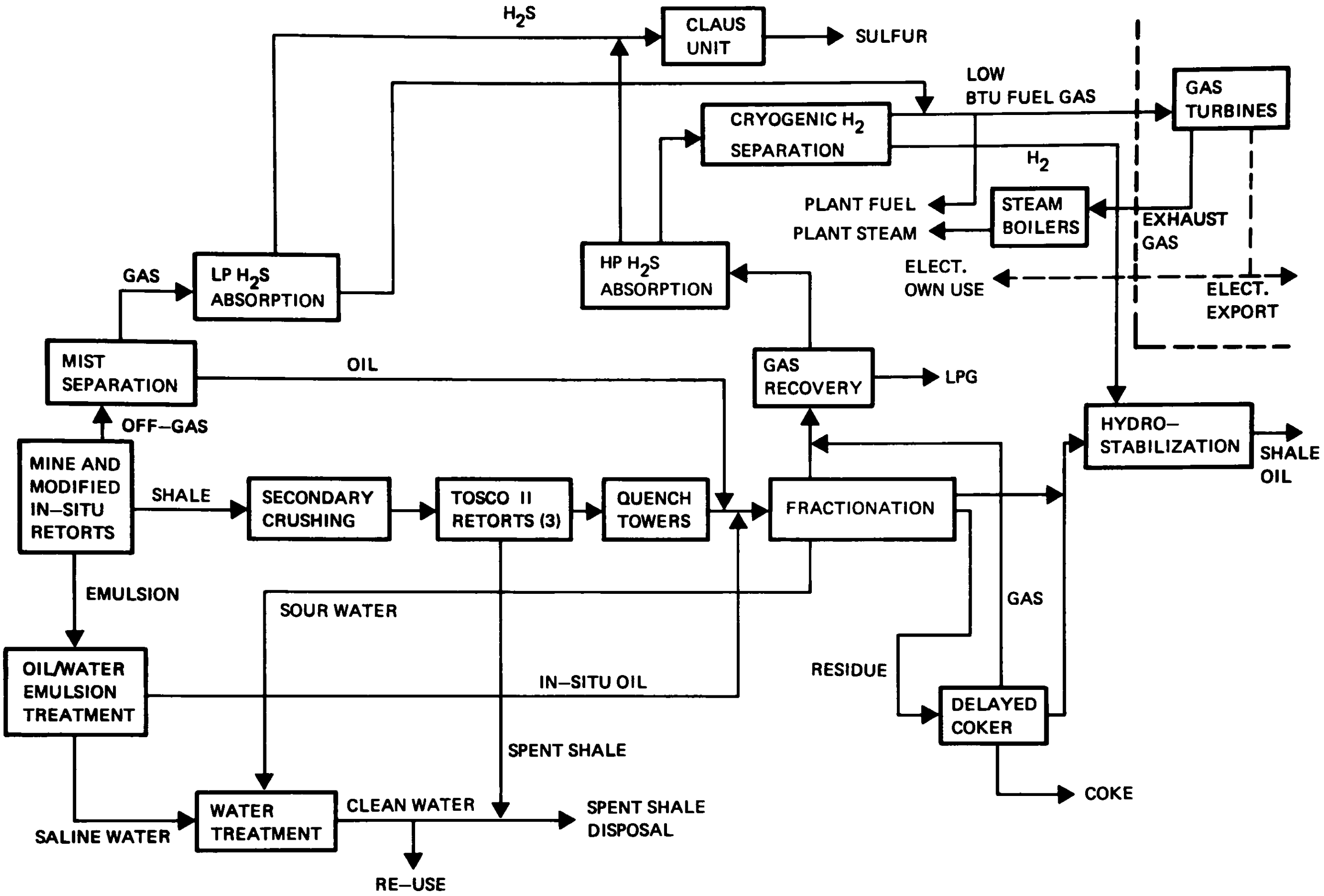

Figure 3. - Overall processing concept, combined in situ and surface retorting.

Design and cost estimates from the Colony Project were used for most of the surface retorting facilities. Oil product from both the in situ and surface retorts goes to a common fractionation system which strips out the gas components and separates the 480°C+ residual fraction. The latter is processed in delayed cokers so that the final oil product will have an end point of about 500°C. The viscosity and pour point of the residue-free shale oil are also reduced, thereby making a product that can be shipped to distant markets in conventional pipeline facilities. The residual material which is fed to the cokers contains appreciable mineral matter as very fine particles. This must be removed by high temperature centrifuges or other means before coking in order to produce a saleable coke product.

Earlier evaluations of the Colony and C-b Projects have shown that severe, high pressure hydrotreating of the shale oil to very low nitrogen levels increases product cost by $4-$5 a barrel. This adds a strong incentive to eliminate the additional capital and operating costs for this process, at least for the first prototype plants. Considering the high risks of such plants, using as yet commercially unproven technology, added on-site investment for denitrification unnecessarily compounds the risks involved. Prototype or modular demonstration plants should, therefore, be designed to produce no more than transportable and saleable synthetic fuel. Any additional processing should be done in existing refineries. In fact, some limited direct blending of high nitrogen shale oil fuel fractions with low nitrogen fuels may be feasible in certain applications.

Storage stability of raw shale oil can, however, be a problem. To correct this, we assume that the diolefins in the raw shale oil would be selectively saturated by hydrostabilization at low temperature over conventional hydrotreating catalysts. We estimate the hydrogen consumption for this to be about a hundred standard cubic feet per barrel of feed, compared to approximately 1,800 standard cubic feet per barrel for severe hydrodenitrification.

In this design, the high Btu product gas from the Tosco retorts would be treated with DEA to remove essentially all hydrogen sulfide and carbon dioxide. High purity hydrogen from the Tosco retorts can then be recovered by cryogenic separation technology. We also note that proprietary processes can be used in conjunction with hydrostabilization to remove arsenic from the shale oil.

Capital investment and operating costs for this combined in situ and surface retort system are shown in figure 4. The initial capital expenditure required to reach full production of 54,000 barrels per stream day, is over 600 million dollars. This does not include 71 million dollars in lease bonus payments for Tract C-b. It also does not include any sunk costs for environmental background monitoring, engineering studies and preparation of the detailed development plan.

Capital Investment ($MM,1976)	
In-situ Retorting:	
Surface plants	8.3
Shafts, tunnels, drifts	56.6
Retort development and operation	58.9
Crushing, ore handling, spent shale disposal	65.4
Surface pyrolysis	141.7
Process facilities	126.6
Utilities and general facilities	120.6
Predevelopment, community assistance and miscellaneous	38.4
	616.5
Deferred mining equipment ($7.7MM/year average)	223.3
	839.8
Operating costs ($MM,1976)	
Annual cost, at full capacity	69
Initial in-situ demonstration	70

Figure 4. - Capital investment and operating cost for combined in situ and surface retorting.

Low Btu gas exiting from in situ retorts is both a problem and an opportunity. It could be used to generate over 300 megawatts of power on either a combined cycle system or a conventional steam power plant. For purposes of this study, we assumed that retort gas had zero value but no capital or operating costs were included for gas compression, selective low pressure H_2S removal, or power generation from the gas. A later study of this portion of the system indicates that compression and treating costs would be less than $1.00 per million Btu, assuming compression only to a level sufficient to fire a conventional steam boiler.

This combination of in situ and surface retorting would yield 54,000 barrels a day of oil plus propane. Total oil production over a 30-year plant life would be on the order of 500 million barrels. This represents a 55 percent increase in resource recovery, as compared to the estimated 330 million barrels that could be produced solely by room and pillar mining in the Mahogany Zone with all surface retorting.

Discounted cash flow calculations were made at several oil price levels to obtain a curve depicting the annual rate of return as a function of the value of the shale oil product. All calculations are based on constant 1976 dollars. The oil price can, therefore, be related to the 1976 cost of imported oil and the controlled price of domestic oil. As a first approximation, the rate of return will be close to the true return on investment if product prices continue to rise at the same rate as the inflation of construction and operating costs. Of course, if we have an abnormal inflation in construction and operating costs and prices remain controlled by the government, then these return on investment figures would not apply, since they are based on constant dollars.

The results of this evaluation are shown in figure 5. We estimate the value of this low end point shale oil, not hydrotreated, at $12.50 per barrel at the plant site relative to 1976 prices. At this price, the annual rate of return is about 12 percent. By comparison, in situ retorting alone would yield less than 9 percent return on investment; surface retorting alone, only slightly better than 9 percent return. The combined operation offers economic advantages.

At this time, we should consider the differences between the modified in situ process as described in this study, and the process described by Occidental in the latest detailed development plan submitted by the new partners in the C-b project, Ashland and Occidental. One difference is that Occidental rubblizes the shale to a "bulked full" retort. They claim that the rubble provides sufficient support to the barrier pillars and roof to permit areal extraction efficiencies of 60-70 percent. This concept also permits retorting of shale to a greater depth without subsidence, and, consequently, greater use of the resource vertically. The second major difference is the use of super-heated steam as a diluent for combustion air rather than recycled gas from the retorts.

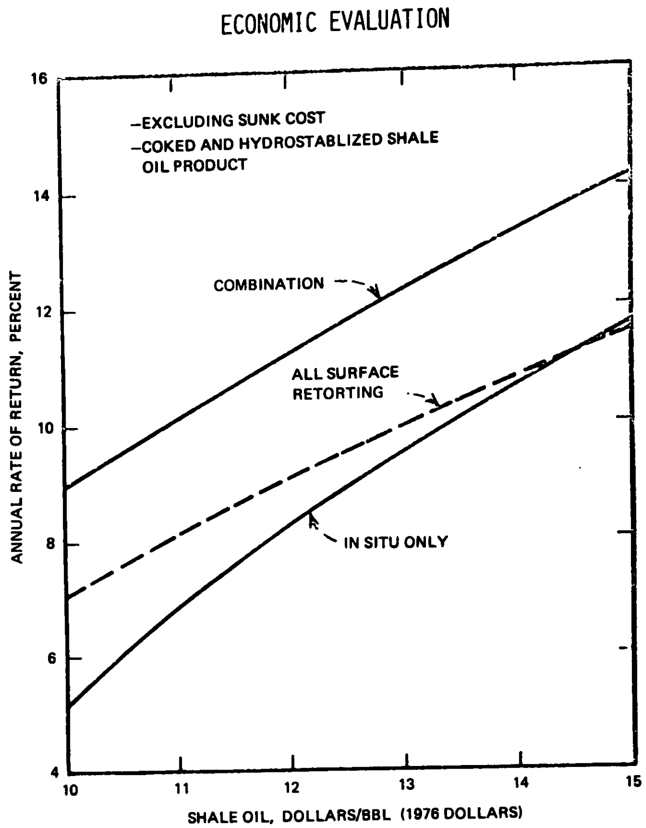

Figure 5. - Return on investment.

The Occidental design for use of their modified in situ process on the C-b tract is based upon a retorting interval of 95 meters, starting just below the top of the Mahogany Zone and ending just above the bottom of the R-6 Zone, as shown in figure 6. Individual retorts are 61 meters square but lack a central support pillar.

By operating "bulked full" and with steam diluent, Occidental anticipates a resource recovery from Tract C-b of 1.2 billion barrels by in situ alone or over 1.6 billion barrels with the combination of in situ and surface retorting. Compare this to only 330 million barrels by the original room and pillar mine design with surface retorting alone. Given that high a resource recovery, we estimate the return on investment for combined in situ and surface retorting at over 15 percent, basis 100 percent equity investment. Such a rate

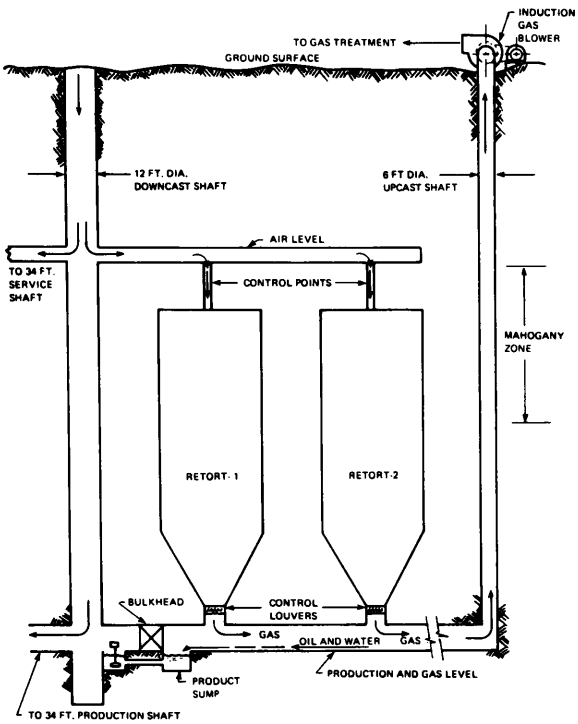

Figure 6. - DDP modification, C-b shale oil venture.

of return appears to justify proceeding with the development of Tract C-b, as Occidental and Ashland now seem prepared to do.

Although a 15 percent rate of return would appear to justify proceeding with even a high risk project such as the C-b shale venture, major political obstacles pose a significant threat to the success of the venture. For example, pending divestiture legislation against the major oil companies, adding severely restrictive, non-degradation amendments to the Clean Air Act, and continuation of crude oil price controls. If shale oil is produced in commercial quantities, will Congress then include it under controlled prices at a level that prohibits a return on investment commensurate with the risks involved? Will it prohibit the major oil companies from participating in shale oil projects under the misguided concept that oil companies are not competitive? Will Congress continue to limit the federal shale leases to 5,000 acres per company, thus preventing them from fully using the technology that they have developed at great risk and expense? Considerations such as these weighed very heavily in Shell's decision to abandon its interest in Tract C-b, rather than continue a high risk investment in the face of these potential federal restrictions.

In conclusion, we offer two suggestions to speed up development of oil shale as a supplemental source of liquid fuels: First - directed to ERDA, whose directors are seeking the most effective ways of spending their share of the tax pie - It appears that Occidental and Ashland are the only companies ready to proceed with a commercial shale oil venture at the present time. They will use Occidental's modified in situ process on Tract C-b, but the detailed development plan, submitted in March, indicates they have deferred any decision to use mined out shale in surface retorts. On the other hand, ERDA and Congressional committees have been considering proposals to finance full-scale surface retort modules. It appears logical to install one or two such demonstration modules on Tract C-b since no additional mining costs would be involved, utilities and roads will be available, and the product could be treated and shipped to markets at a nominal incremental cost. Occidental may not welcome such activities in the midst of their in situ development, but this would lead more rapidly to the combination retorting which this analysis indicates will increase resource recovery and reduce overall unit product costs.

Second - related to the non-technical, institutional and legal obstacles to both conservation and the commercialization of alternative energy sources such as shale oil and coal conversion to gaseous fuel - Technical solutions to these problems are being resolved by industry, but attempts to commercialize the new technologies are thwarted by institutional barriers. The net result is delay and added costs and hardships to the consumers. A report by the Office of

Technological Assessment over a year ago recommended that ERDA devote a substantial effort to resolving the non-technical barriers to development of alternate energy sources. Regardless of whether this or another agency takes on the job, it is clear that Congress must take the lead in reducing the obstacles that they themselves have imposed on energy development.