archive

A FINANCIAL ANALYSIS OF SELECTED SYNTHETIC FUEL TECHNOLOGIES*

by

SAMAN MAJD

January 1979

MIT-EL 79-004WP

* This work was supported by the Center for Energy Policy Research of the M.I.T. Energy Laboratory, and that support is gratefully acknowledged. I am particularly indebted to Professors Robert Pindyck and Paul Joskow for their help and guidance throughout my research. I would also like to thank Professors Morris Adelman, Carliss Baldwin, Henry Jacoby, Stewart Myers, and Martin Zimmerman for their helpful advice and comments, and Sid Huff and Chat-Yu Lam for their invaluable programming assistance.

A. CONTENTS

B. SUMMARY

This report aims to:

1. present some existing investment and operating cost estimates;
2. obtain quantitative measures of the profitability and riskiness of the projects.

The following technologies were chosen for analysis:

1. SRC II (coal liquefaction)
2. Synthoil (")
3. H-Coal (")
4. EDS (")
5. Modified in-situ shale oil.

Our method of analysis can be summarized as follows:

1. We chose five oil price scenarios to represent a range of reasonable future prices.
2. For each technology, under each scenario for the price of oil, we calculated the after-tax annual cashflows to the project.
3. The net present value (NPV) of each cashflow stream was calculated using a number of discount rates between 0 and 20 percent.
4. The above step was repeated for 20 percent and 40 percent cost overruns.
5. To obtain a measure of the variability of the NPV, we first assigned probability distributions to the investment and operating costs. Values for these parameters were generated from their distributions, and each time the NPV of the project was calculated. This procedure was repeated a large number of times, thus generating an approximate, discrete, probability distribution for the NPV. The standard deviation of this distribution is used as a measure of the variability or riskiness of the project.

In Section II we present the investment and operating cost estimates, and describe, in Section III, our financial analysis and present the results. In light of our results, we conclude, in Section IV, with a discussion of issues related to the government's involvement in the commercialization of synthetic fuels.

Appendix A contains a brief overview of the technologies analyzed in this report, and a breakdown of the cost estimates will be found in Appendix

B. Detailed results of the financial analysis are presented in Appendix C, and in Appendix D we summarize the major environmental issues involved.

Our analysis shows that the five technologies studied in this report (and any others in the same range of costs) are not economically viable unless world oil prices rise dramatically in the next five or six years, and then only if the domestic price of oil is deregulated. The simulations, although based on a very simplified model, indicate that there is a great deal of variability associated with the NPV of these projects.

I. INTRODUCTION

Ever since the 1974 energy crisis, when world oil prices increased dramatically, awareness of the United State's dependence on imported liquid fuels has greatly increased: this dependence is viewed as an economic, and hence a national security, threat. Consequently, independence from foreign supplies of oil, or more precisely, protection from the threat of another oil embargo, has become a primary goal of U.S. national energy policy, and policies aimed at increasing domestic supplies of oil and natural gas are being pursued by the Department of Energy.

The DOE is currently showing great interest in technologies for the production of synthetic oil and gas, particularly oil shale and coal liquefaction and gasification. The primary reason for this interest is the enormous quantity of synthetic fuel potentially recoverable from coal and shales. One source* estimates the U.S. share of the world's recoverable coal resources (approximately 800 billion barrels oil equivalent) to be 30.8%, and of the world's recoverable coal resources (approximately 1,100 billion bbl oil equivalent) to be 72.7%. The same source estimates the total world recoverable crude oil reserves to be 716 million barrels, and the U.S.'s share to be only 35 billion barrels (although these latter figures seem rather low).

The basic technology for producing oil and gas from coal and oil shales has been known for many years. During World War II, Germany built twelve coal liquefaction plants that accounted for a large proportion of her consumption of liquid fuels, and South Africa is at present using the German technology (the "Fischer-Tropsch" method) to produce both

* See Reference (1).

natural gas and liquids from coal.* Other technologies have been under research and development for many years: some are only just emerging from bench-scale experimentation, others are at the demonstration plant stage.**

Given the existence of such vast reserves, and the relative level of development of certain of these technologies, why has private industry not exploited these technologies to develop the coal and shale resources of the United States?

The oil companies involved in the research and development of synthetic fuels claim the need for government support at the commercialization stage, often quoting high costs and a high degree of risk and uncertainty. The major areas of risk and uncertainty associated with such projects can be identified as follows:

1. With any new and untried technology, there are technological problems encountered in scaling up the process to a commercial scale. These are "risks" in two ways: first, any unforeseen and lengthy delays in construction and operation of the plant caused by technological problems can greatly increase the cost of the plant; second, any design changes or refinements that must be made can increase both the construction and the operating costs.

---

* See Reference (1).

** Although there are no clear boundaries between the different stages from bench-scale experimentation to full commercialization, the demonstration stage falls roughly between development and commercialization. Demonstration essentially involves scaling-up the basic research and linking together the various components of the process, although not necessarily at full-scale. An important part of demonstration is the measurement of various technical parameters and obtaining cost estimates for the process. Commercialization is necessarily at full-scale, and involves pinning down the costs. It may also be interpreted as including the diffusion of the process into the market place.

2. There are uncertainties over the exact environmental impacts of full-scale operation of such plants, and over the future environmental regulations that will apply. If it transpires that the commercial-size plants do not satisfy the Federal or state environmental requirements, the pollution control equipment required to comply with the regulations will increase the costs. Even if the plant meets current requirements, pressure from environmental protection groups may cause future regulations to become more stringent. Finally, a very large number of permits must be obtained before construction of the plant can be completed, and inordinate delays in the time required to obtain them can delay construction and increase costs.

3. There is great uncertainty over the future world price of oil, and over government controls of the domestic price. Producers may not be allowed to sell their products at the world price, and if they are allowed to do so the path of world oil prices becomes critical in determining the profitability of the plant. On top of this there is the possibility that the government may tax away "excess profits" from such plants, leaving the company a distribution of returns that may be truncated at the upper tail.

Although it is relatively easy to identify the major areas of risk and uncertainty, it is not easy to quantify them. At this point, without going into issues of whether or not the government should be involved in risky projects in the private sector, it is clear that the economics of synthetic fuels production must be better understood before policy can be formulated. More specifically, we need a quantitative measure of the profitability and riskiness of such projects, and this is the principal aim of this report.

In the next section we present investment and operating cost estimates for some favored synthetic fuel technologies, and describe, in Section III, our financial analysis and present the results. In light of our results, we conclude, in Section IV, with a discussion of issues related to government involvement in the commercialization of synthetic fuels.

Appendix A contains a brief overview of the technologies analyzed in the report. A brief discussion of our sources of cost data and a detailed breakdown of the cost estimates will be found in Appendix B. Detailed results of the financial analysis are presented in Appendix C, and in Appendix D we present an overview of the major environmental issues involved.

II. INVESTMENT AND OPERATING COSTS FOR SELECTED TECHNOLOGIES

As stated in the Introduction, our principal aim in this study is to gain a better understanding of the economics of synthetic fuels production, so that we may have a sounder basis for discussing the role of the government in developing these technologies.

As a first step, we must obtain estimates of the construction and operating costs for a commercial-size plant for the technologies under consideration. Unfortunately, this is, for various reasons, the most difficult part of the study. First, there are the endogenous uncertainties regarding the technologies themselves. As no full-sized plants have yet been built in the U.S., all the hard engineering data is from small-scale testing, or at most, pilot plants. Furthermore, different components of the entire production process are at different stages of development, some more technologically uncertain than others. Hence, technical problems can be expected when scaling-up the process to full size, and this can cause cost overruns for two reasons: (1) inordinate delays during construction are costly, no matter what their origin; and, (2) any changes or refinements that may become necessary will also increase costs.

The other reasons for uncertainty in present cost estimates are essentially exogenous, and can cause cost overruns for the same reasons as above; that is, they can cause delays in construction or necessitate expensive alterations in design. One such reason is the concern over the environmental impact of synfuels production. The possibility of lengthy delays in obtaining the necessary permits or due to action by environmental protection groups has added to the perceived risks and costs of these projects.

In addition to the above problems, the researcher in search of cost estimates faces several others. First, the sources generally do not give adequate information about the assumptions or parameters used in arriving at their figures; second, the most recent and complete cost estimates are proprietary property of the companies involved, and hence unavailable.

The technological uncertainties do, in principle, lend themselves to quantitative treatment. The effect of cost overruns on profitability and the variance of the profitability can be calculated, and this is the subject of Section III. The other, exogenous, problems are relatively more difficult to quantify, and we have not attempted to do so in this report. The main environmental issues, however, are summarized and discussed qualitatively in Appendix D.

In this report we examine four coal liquefaction technologies (SRC, Synthoil, H-Coal, and EDS) and a modified in-situ oil shale technology. The four coal liquefaction technologies were chosen for two reasons: (1) they are at or near the pilot plant stage, and have received attention at the Department of Energy; and, (2) reasonably complete cost data was available, and the costs appear to be in the same range as those of other liquefaction and gasification technologies. A modified in-situ technology was chosen for oil shale as it is the variation considered most likely to be commercialized in the near future. A brief background to these technologies is given in Appendix A, and our sources of cost data are briefly discussed in Appendix B.

The investment and annual operating costs for the technologies are summarized in Table 1 (a more detailed breakdown is given in Appendix B). The assumptions and parameters used in arriving at these figures are summarized as follows:

1. 1976 dollars are used throughout.
2. The plants yield 50,000 bbl/steam day (60,000 bbl/sd for EDS), and operate 330 days/year.
3. Because the processes yield different products of differing value, the operating costs have been adjusted to reflect this fact, and to put them on a comparable basis. The calculations for this are described in Appendix B.
4. The operating costs do not provide for the replacement of worn-out equipment, and a provision for this is included in the cash-flow analysis in Section III.
5. As a contingency for difficulties with the process in the first year, the output in that year is taken as only 50% of normal, as is the consumption of coal (or shale) and utilities.
6. Wyodak coal will be at $7.50/ton and Illinois and Western Kentucky coal will be at $20/ton* throughout the life of the plant.
7. In Table 1, the figures refer to startup of operations in 1987, whereas the figures in Appendix B refer to startup in 1976. The costs have been escalated (in real terms) to account for increases in labor and materials costs in the interim.

From the figures in Table 1 we can see that EDS has the highest investment and operating costs of the coal liquefaction technologies, and that modified in-situ oil shale appears less expensive than the coal liquefaction technologies. Because we have adjusted the operating costs to account for the differing grades of liquid products from the technologies, H-Coal appears to have the lowest operating costs. This is due to the fact that the H-Coal process examined here includes some refining of the products to produce more expensive fuels. This is also reflected in the high investment costs of H-Coal as compared to SRC and Synthoil.

Our cost estimates are not as recent or reliable as we would have wished, and are subject to considerable uncertainty. What is important is that they are representative of the order of magnitude of the costs, and therefore will provide us with a range of values to work with in our financial analysis.

---

* From private communication with Professor Martin Zimmerman at the Sloan School of Management, M.I.T.

TABLE 1: Cost summary for selected technologies ($000)*

	First year operating costs	Annual operating costs	Subtotal for depreciation	Total investment
SRC	138,617	203,706	791,102	854,390
SYNTHOIL	189,725	245,004	647,051	711,756
H-COAL	127,350	143,500	1,171,796	1,265,539
EDS	246,747	374,760	1,648,843	1,741,687
IN-SITU SHALE	135,792	192,163	674,560	748,760

* For assumptions involved in arriving at these figures, see text. A breakdown of these figures is presented in Appendix B. Note, however, that these costs have been escalated at 2% per year to a 1987 startup (but in 1976 $), whereas the figures in the Appendix are for a 1976 startup.

III. FINANCIAL ANALYSIS

Having presented estimates of the investment and operating costs for our selected technologies, we now describe how these estimates are used to arrive at measures of profitability and risk.

As a first step, we calculate the after-tax annual cashflows to the plant, and use their net present value (NPV) as our measure of profitability. Our basic equation for calculating the cashflows is:

after-tax annual cashflow =
[(annual quantity of oil produced x world price per barrel) - annual operating costs] x (1 - tax rate) + (annual depreciation x tax rate).

The cashflow for each year is calculated using the appropriate values for the parameters and in accordance with the assumptions of the model (described below).

We have already mentioned the uncertainty over the future world price of oil. In order to illustrate the impact of the future prices on profitability, or more specifically, the future <u>path</u> of oil prices, we have chosen five scenarios for the world price of oil, all starting at $14/bbl in 1977. These scenarios range from highly optimistic to pessimistic price projections (from the point of view of the oil companies), and are illustrated in Figure 1. It must be emphasized that we are not attempting to forecast future oil prices, but have chosen the scenarios to illustrate a range of reasonable prices.

In addition to those listed in Section II, the assumptions and parameters on which our model is based are summarized as follows:

1. The plant has an operating life of 20 years. The initial investment in plant and equipment is made in one lump sum at the beginning of year one, and the cashflows are received at the end of each year.

2. The products can be sold at the prevailing world price of oil. (Adjustments have been made to allow for the different grades of fuel from the different processes, and the calculations are described in Appendix B.)
3. Total taxes amount to 50% of taxable income.
4. An annual deferred investment of $9.9 MM (except in the last two years) is added to the operating costs for replacement of worn-out equipment.
5. The initial investment is depreciated over thirteen years by the sum-of-years digits method (100% capitalization assumed).
6. The entire project is 100% equity funded.
7. The operating costs escalate at a real rate of 2% per year.

Having generated the stream of cashflows to the projects (one stream for each technology under each scenario), we calculate the NPV of each stream at discount rates between 0% and 20% in increments of 2%.* In order to determine the sensitivity of profitability to cost overruns, we repeat the calculations for 20% and 40% cost overruns.

The results of these calculations are presented in Tables C.1, C.2, and C.3 of Appendix C. For the case of no cost overrun (Table C.1), we see that none of the technologies are profitable (i.e. have positive NPV) under scenarios 4 and 5. Excluding EDS, they are profitable for discount rates less than 8-10% under scenario 2, and less than 16% under scenarios 1 and 3. EDS, the most expensive of the five technologies and the one

* Although net present value is fairly well accepted as a measure of profitability, there is some controversy over the discount rate that should be used in the calculation. Generally speaking, the discount rate should reflect the riskiness of the project: the more risky the project, the higher the discount rate that should be used. Alternatively, it may be argued that the discount rate should be the firm's weighted cost of capital. Rather than discuss these issues here, we have used the range of discount rates mentioned to illustrate the effect on NPV, and refer the reader to Reference (12) for discussion of alternative measures of profitability and the choice of discount rates.

Figure I. Scenarios for the world price of oil

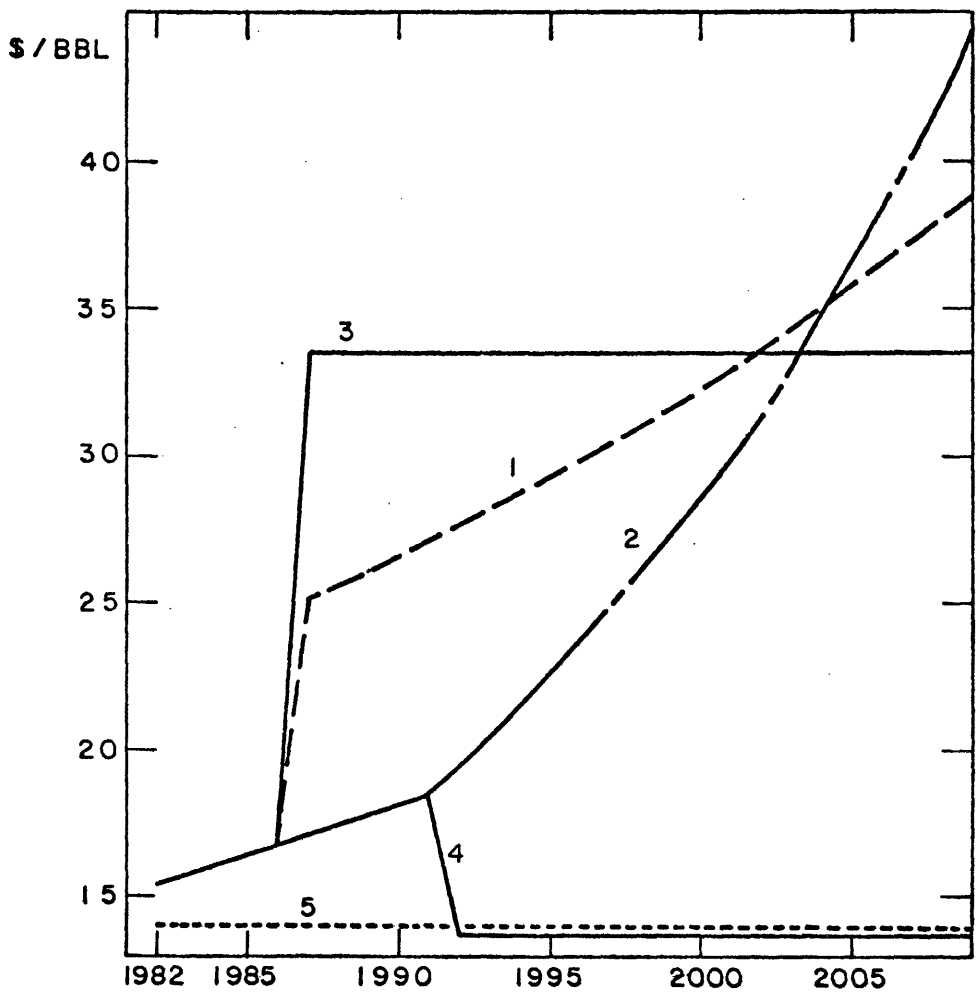


FIGURE 1: Scenarios for the world price of oil

Scenario 1: 2%/year rise from 1977 to 1986
50% jump in 1986
2%/year rise subsequently

Scenario 2: 2%/year rise from 1977 to 1991
3%/year rise subsequently

Scenario 3: 2%/year rise from 1977 to 1986
100% jump in 1986
constant subsequently

Scenario 4: 2%/year rise from 1977 to 1991
25% drop in 1991
constant subsequently

Scenario 5: constant at $14/bbl

for which our cost estimates are more realistic (see Appendix B) is only profitable under scenarios 1 and 3, and then only for discount rates less than 4 - 6%. The cost overruns (Tables C.2 and C.3) naturally have the effect of reducing profitability: in the case of a 40% cost overrun (which is not unheard of in large construction projects involving untried technology), none of the technologies have positive NPV for discount rates above 10%, even under extremely high oil price scenarios (for example, scenario 3). To sum up, then, the technologies examined in this report (and therefore other technologies in the same cost range) will only be profitable if the price of oil rises very rapidly in the next five or six years and remains high over the life of the plant.

Thus far in our financial analysis, we have used only expected values for the cost estimates, and our sensitivity analysis has been simply to examine the effects of 20% and 40% cost overruns on profitability. We would like, however, to obtain a measure of the variability of the net present value of the cashflow streams. More specifically, we would like to investigate a continuum of cost overruns, each weighted by the profitability of its occurrence. In general, this type of analysis is performed by first assigning appropriate probability distributions to the input parameters of the model (appropriate in the sense that the distribution captures as nearly as possible the probabilities of occurrence of the possible values of that parameter). Then, using a computer to generate values from the probability distribution for each parameter, the NPV is calculated using those values. This procedure is repeated a large number of times, each time drawing values from the same distributions, thus generating an approximate, discrete, probability distribution for the NPV. The standard deviation and mean of this distribution will approximate those of the "true" distribution of the net present value.*

In order to perform such simulations, we need to represent the probability distributions of the basic input parameters to our cashflow model, the investment and operating costs of each technology. To do this it is necessary to make several simplifying assumptions, which we summarize as follows:

1. The investment and operating costs are assumed to be normally distributed.
2. Experience shows that cost estimates given before the construction of the first commercial plant are nearly always too low, and that "cost underruns" are rarely heard of. Therefore it is not reasonable to use the cost estimates in Table 1 as the means of our distributions, as that would generate values both above and below the estimates. Rather, it would appear more reasonable to view the figures in Table 1 as lower bounds, and to arrange our distributions so that the bulk of the values generated lie above these estimates. This is achieved by choosing a suitable cost overrun as the mean of the distribution, and by taking the difference between this figure and the corresponding value in Table 1 as being equal to two standard deviations.**
3. In the case of EDS, Exxon Research and Engineering Company has estimated and employed a 40% overall contingency on costs based on their "process development allowance."† Since we did not include this in our EDS figures in Table 1, we use a 40% cost overrun as the mean of the EDS investment and operating cost distributions.
4. Because of the relatively greater uncertainty in our cost data (and not necessarily fundamental to the technology), we take 50% cost overruns for the SRC, Synthoil and H-Coal cost distributions, and a 60% cost overrun for the shale oil cost distributions.

---

* For a discussion of risk analysis in capital investment decisions, see References (13), (14), and (15).

** 95% of the area under a normal distribution lies within two standard deviations on either side of the mean.

† See Reference (5).

5. We assume that the investment and operating costs are perfectly correlated, as situations involving large investment but low operating costs (or vice-versa) are very unlikely to occur. For the purposes of the simulations, the subtotal for depreciation is taken as 93% of the total investment, and the first-year costs are held in the same ratio to the annual operating costs as found in Table 1.
6. As our main purpose in performing the simulations is to obtain order-of-magnitude estimates of the means and standard deviations of the NPV distributions, and to be able to compare across technologies, we have not used the range of discount rates employed above, and instead use the risk-free discount rate of 3% (use of a risk-adjusted rate would involve double-counting*).

The results of our simulations are summarized in Table 2, and are illustrated graphically in Figures C.1 - C.5 in Appendix C.**

As explained in points 2,3, and 4 above, we have taken the means of the distributions of investment and operating costs as being greater than the estimates in Table 1 (this was to avoid the large number of "cost underruns" which would have occurred if we had taken the estimates in Table 1 as the means). Hence it is not surprising that the mean net present values in Table 2 are much lower than those calculated previously. In particular, we see that only under the high oil price scenarios (scenarios 1 and 3) are the net present values positive, and then only for SRC, H-Coal and in-situ shale. Synthoil has positive NPV only under scenario 3, and EDS has negative NPV under all five scenarios.

The standard deviations of the net present value of each technology are fairly consistent from scenario to scenario (at least within the bounds of accuracy of our method). Across technologies, we find that EDS has the greatest absolute standard deviation, in-situ shale the

---

* See Reference (15).

** The means and standard deviations were calculated by assuming that all the points within each NPV range are located at the center of the range.

TABLE 2: Summary of the simulation results*

TECHNOLOGY	SCENARIO	DISTRIBUTION OF NPV: MEAN ($MM)	STANDARD DEVIATION ($MM)
SRC	1	40	627
	2	-659	591
	3	426	632
	4	-1806	541
	5	-1880	560
SYNTHOIL	1	-302	583
	2	-1062	694
	3	20	696
	4	-2215	648
	5	-2358	596
H-COAL	1	464	551
	2	-184	488
	3	945	496
	4	-1279	481
	5	-1482	517
EDS	1	-1671	966
	2	-2760	709
	3	-1224	861
	4	-3804	920
	5	-4654	1091
IN-SITU SHALE	1	56	710
	2	-772	755
	3	394	628
	4	-1820	656
	5	-1912	665

* The distributions are illustrated in Figures C.1 - C.5 in Appendix C.

next largest, followed by Synthoil, SRC, and H-Coal. They all have large standard deviations, ranging from approximately \$540 MM to \$1100 MM, and in the few instances where the mean NPV is positive, the standard deviation is significantly larger than the mean.

Although our simplified model and methodology makes it unreasonable for us to present these numbers without accompanying error bounds, we emphasize that our aim here was to obtain order-of-magnitude estimates. The results clearly depend on the distributions chosen for the input parameters and, as we have seen, these are subject to great uncertainty. In particular, our simple model has not captured the other uncertainties involved, both exogenous (e.g. due to environmental problems) or endogenous (e.g. uncertainty over the project life, etc.). We have assumed that all the uncertainty is resolved at the beginning of the plant life (i.e. when the investment and operating costs are drawn from their distributions), and have ignored both the pattern in which uncertainties are resolved over time and the interdependencies of cashflows and parameters from year to year.* We have assumed symmetrical distributions for the costs, and because we lacked better information on which to base our estimates of the standard deviations for these distributions, we did so in the approximate form of a percentage of the original estimates in Table 1. All the above are important factors and should be included in any thorough examination of the problem: unfortunately, this is beyond the scope of this report.

* See Reference (14).

IV. CONCLUSIONS

As we stated at the outset of the report, it is necessary to obtain some quantitative measure of the economic viability of synthetic fuels technologies before government policy regarding their commercialization can be formulated. It does not matter so much that our cost estimates for the technologies are subject to uncertainty, nor that we have had to make many simplifying assumptions in order to arrive at the measures of profitability. What is important is to realize where the uncertainties lie, and to appreciate that the order-of-magnitude of the results alone can help us understand the economics of the technologies.

We saw, in Section II, that the annual operating costs for our five technologies were in the range \$140 MM (1976 \$) to \$375 MM, and the total investment costs were in the range \$700 MM to \$1,750 MM (Table 1). In Section III, we calculated the net present value of the stream of cashflows to each project at a number of discount rates in the range 0 - 20%, and found that the NPV was positive only under very high oil price scenarios (assuming domestic oil price deregulation). The simulations in Section III yielded estimates of the standard deviations of the NPV distributions in the range \$540 MM to \$1,100 MM (Table 2).

In Section I, we outlined some of the major areas of risk and uncertainty facing synthetic fuels producers, and stated that these were often quoted as reasons why the government should support private industry in the commercialization of synthetic fuels. There are, however, several reasons why the government should not do so.

First, in perfect capital markets, the private sector will commercialize new technologies if and when they are economically viable (i.e. when the net present value of the cashflows from the project, discounted at a rate appropriate to the riskiness of the cashflows, is positive). If the government steps in and commercializes these technologies before they are viable, it is creating a social cost, which is ultimately borne by the taxpayers.

Second, heavy government funding of specific synthetic fuels technologies may take funds away from other technologies that may eventually prove more economical than those pursued by the government. Again, in efficient markets, the private sector will be able to evaluate the relevant information and choose the correct technologies when they make economic sense.

Finally, the technological problems and risks associated with synfuels production seem typical of those encountered in the development of any new and complex technology. Markets for such risks have functioned adequately in the past, and in the absence of any special reasons for market failure, should continue to do so in the future. One reason why markets may have failed, of course, is that existing government policy in certain areas, and lack of clear policy in others has created risks that are beyond the normal risks mentioned above. Financial markets may not be able to internalize these uncertainties regarding government policy, and therefore the government must either issue clear directives regarding its intended policy, or stimulate investment in synthetic fuels by some other means.

Another possible justification for government support may be summarized as follows: given that a primary goal of U.S. national energy policy is to reduce dependence on imported oil (and assuming for the moment that this is a worthwhile policy in its own right), the return to society from investment in domestic sources of liquid fuels may be greater than that perceived by private investors. Hence, it may be argued, society (i.e. the government) should bear the costs of development and commercialization of these new sources. It is not clear, however, that forcing the early commercialization of synthetic fuels is the least expensive or most efficient policy for reducing imports.

Our analysis shows that the five technologies studied in this report (and any others in the same range of costs) are not economically viable unless world oil prices rise dramatically in the next five or six years, and then only if the domestic price of oil is deregulated. We would recommend, therefore, that rather than provide direct support for commercialization through price supports, loan guarantees, or tax credits, the government should work to remove some of the disincentives to investments in synthetic fuels that it has created, particularly regarding domestic oil price regulation and the relevant environmental restrictions.

V. APPENDIX

A. The technologies analyzed in this report.

B. Our sources of cost data and a breakdown of the cost estimates.

C. The results of our financial analysis.

D. Overview of the major environmental issues.

APPENDIX A: The Technologies analyzed in this report.

Although our discussion and method of analysis in this report is applicable to any of the synthetic fuels technologies, we have chosen specific technologies on which to perform our analysis. These include four coal liquefaction technologies and a modified in-situ oil shale technology.

The four coal technologies were chosen for two reasons: (1) they are at or near the pilot plant stage, and have received much attention at the Department of Energy; and, (2) reasonably complete cost data was available, and the costs appear to be in the same range as those of other coal liquefaction and gasification technologies. Hence the financial analysis will give results that may be considered representative of the other technologies.

H-COAL *

An ebullated bed catalytic reactor containing a fixed, solid, catalyst is used, and a mixture of finely ground coal in oil and hydrogen is passed through it. Pressure and temperature parameters can be controlled to produce either syncrude (equivalent to a no. 2 fuel oil) with low quality naphtha or fuel oil with low quality naphtha. The H-coal process requires dried coal, but can accept all common types of coal, with minor impacts on product quality and output rate. The variation of the process examined in this report uses Wyodak coal. Because this process yields high nitrogen fuels, further refining is both difficult and expensive. The process studied in this report includes the refining stage, and we have adjusted the operating costs for the different grades of products from the technologies.

* See Reference (4).

(see Appendix B). The reactor system is the only part of the different technologies that is unique, and because of its sophisticated design, H-coal's reactor system involves the greatest technical uncertainty. A 200-600 ton/day pilot plant is under construction at Cattlesburg, Kentucky.*

EXXON DONOR SOLVENT (EDS) **

A special coal-oil base solvent dissolves the coal and increases the hydrogen-carbon ratio: the recycled solvent is then re-hydrogenated continuously during the process. In this way, direct contact of the coal with a solid catalyst is avoided. A "flexicoker" stage is included in the Exxon proprietary process and converts the heavy residual products to higher grades. The EDS process can accept all the usual types of coal, again with differences in the quality of the products recoverable and the output rate. The process studied in this report uses Illinois coal. The fuel oil derived from this process is high in nitrogen, has a low gravity, and is not compatible with petroleum-derived fuel oil. The operating costs have been adjusted for the quality of the product (see Appendix B). Like H-coal, the process has not been demonstrated at full scale, but the sub-units involved are fully developed (technical problems still exist, however). Construction will soon begin on a 250 ton/day pilot plant in Baytown, Texas.†

* See Reference (10).

** See Reference (4).

† See Reference (10).

SOLVENT REFINED COAL (SRC) *

Apart from the solvent used, the process is similar to the EDS process. SRC has two modes of operation: solid (SRCI) or liquid (SRCII) product. In this report we study only the latter, referring to it simply as SRC. Again, it can accept all common types of coal. The process covered in this report, however, uses Wyodak coal. The main product of the SRC process is industrial boiler fuel, and can satisfy current air pollution requirements. However, if the sulfur removal requirements are made more stringent, the SRC process may have problems. A 50 ton/day pilot plant has successfully been operated, and plans are underway to construct a 6000 ton/day commercial-size module. **

SYNTHOIL†

The process uses dried, finely ground, coal which is mixed with recycled heavy oil. The mixture is then catalytically hydrogenated in the presence of hydrogen in the char and coal gasification unit. The process studied in this report uses Western Kentucky coal with a high sulfur content. The main product is a heavy fuel oil, low in sulfur, suitable primarily for use as a boiler fuel. The U.S. Bureau of Mines has developed a 10 ton/day pilot plant. ††

Oil from shale rock does not, in principle, require sophisticated technology: the rock must be crushed and then heated to very high temperatures ("retorting") before it gives up its crude oil. Most problems,

---

* See Reference (4)

** See Reference (10)

† See Reference (7)

†† See Reference (3)

however, are associated with the very large scale of mining activities involved in the process. There are basically two kinds of oil shale technology: (1) the rock is mined and retorted at the surface; and, (2) modified in-situ retorting, where only a portion of the overburden is mined. The rest is blasted to form an underground cavern of crushed rock which is then retorted and the resulting oil is brought to the surface. The in-situ process offers potential economic and environmental advantages over above-ground retorting, and is considered the one most likely to be commercialized in the near future. Different variations of the in-situ technology are required for different deposits of shale rock, and no single technology can process all types. Unfortunately, we were unable to obtain reasonable cost data for any particular form of the technology (the data is still proprietary),and were forced to rely on data from a "conceptual process model" of the modified in-situ technology. Apart from the cost data itself, which we discuss in the next section, the general process studied in this report will serve as a representative of the various modified in-situ oil shale technologies.

APPENDIX B: Our sources of cost data and a breakdown of the cost estimates.

As we have already discussed in Section II of the report, there are many sources of uncertainty in the cost estimates for synthetic fuel technologies. Most of these uncertainties are difficult, if not impossible, to quantify, and are often taken into account by adding on an overall contingency for delays and other problems during construction and operation. For most of the technologies, large-scale plants have not been built, and for the most developed, only small-scale pilot plants have been operated. Hence all cost estimates are necessarily projections from engineering data, and their accuracy depends a great deal on the depth of engineering detail used in preparing the estimates.

Although we have tried to put the costs on a comparable basis, the sources of our figures are not all the same. The figures for SRC, Synthoil, and H-coal are from engineering studies by the U.S. Bureau of Mines.[*] The estimates are "assumed to be at a point on the learning curve where there are relatively few areas of uncertainty. Therefore spaces have been provided for only the very corrosive or other severe conditions; also no alternate processing equipment has been provided".[**] It would appear, then, that the Bureau of Mines estimates are optimistic and should be taken as a minimum almost certain to be exceeded in practice.

The figures for EDS are taken from a report by the Exxon Research and Engineering Company,[†] representing the commercial study phase of the EDS process development. Again, the estimates are based on engineering data, but this time the work was carried out at a later stage of development,

* See References (6), (7), (8).

** See References (6), (7), (8).

† See Reference (5).

using more up-to-date data and a great deal of engineering detail. The figures for EDS, therefore, can be considered to be the more realistic of the coal liquefaction data, and in order of magnitude are probably representative of other liquefaction and gasification technologies.

We had great difficulty in obtaining cost data for modified in-situ oil shale processing, the version considered most likely to be commercialized in the near future. Occidental Petroleum, one of the leaders in this technology, has kept its data proprietary. The only data in an appropriate form was that presented by the Synfuels Interagency Taskforce in 1975.* Their report included cost estimates for modified in-situ oil shale processing based on a conceptual process model. These figures are not as recent as those for the other technologies in this report, nor are they based on the same degree of process development or engineering detail. They are therefore considered the most uncertain of our cost estimates, and experience shows that they are likely to be on the low side.

Tables B.2 through B.11 present the investment and operating cost estimates for the five technologies studied in this report (these costs are summarized in Table 1 in the text). Table B.1 shows how we have calculated the adjustment to the operating costs to correct for the different values of the products of these technologies. The adjustment is made so as to put the costs on a comparable basis for our financial analysis. The assumptions in Section II of the report should be read in conjunction with this section of the appendix. In particular, note that the figures in the tables that follow are in 1976 $, and that these have been escalated at a real rate of 2% per year to bring them to their values for a 1987 start-up.** This is to account for increases in construction, materials, and labor costs.

---

* See Reference (2).

** These escalated values are in Table 1 in the text.

TABLE B.1: Adjustment for the differing grades of products from the processes.

From Platt's Oil Price Handbook and Oilmanack,* we find that in 1976 the average price of:

gasoline	was	$137.13/metric ton	=	$16.89/bbl
boiler fuel	"	66.46 " "	=	9.80 "
naphtha	"	130.69 " "	=	17.87 "

The average price of Middle Eastern crude oil in 1976 was $12.24/bbl. Assuming that the price differential between these products and crude oil remains approximately constant over time, we adjust the operating costs of the processes by:

$4.65/bbl of gasoline produced
-$2.44/bbl " boiler fuel "
$5.63/bbl " naphtha "

The processes produced the following quantities of:

	SRC	Synthoil	H-Coal	EDS	In-situ shale
gasoline	0	0	32,500	0	0
boiler fuel	45,978	50,000	0	60,000	50,000
naphtha	4,022	0	17,500	0	0
(bbl/stream day)	50,000	50,000	50,000	60,000	50,000

Therefore, we must add to the operating costs:

SRC	(45,978x330x2.44) + (4,022x330x-5.63)	= 29,549
Synthoil	(50,000x330x2.44)	= 40,260
H-Coal	(17,500x330x-5.63)+ (32,500x330x-4.65)	=-82,385
EDS	(60,000x330x2.44)	= 48,312
In-situ shale	(50,000x330x2.44)	= 40,260

Note that this adjustment is made only so that we may compare the technologies at the world price of oil.

* See Reference (9).

TABLE B.2: SRC Wyodak Coal.

Total Capital Requirements (1976 $)

	$000
Coal preparation	29,284
Coal slurrying and pumping	2,055
Coal liquefaction and filtration	169,345
Dissolver acid gas removal	59,738
Coal liquefaction and product distillation	8,793
Fuel oil hydrogenation	65,658
Naphtha hydrogenation	5,763
Fuel gas sulfur removal	4,804
Gasification	20,791
Acid gas removal	22,592
Shift conversion	17,917
CO_2 removal	12,042
Methanation	824
Sulfur recovery	2,172
Oxygen plant	28,236
Product storage and slag removal	17,371
Steam and power plant	53,810
Process waste water treatment	3,815
Plant facilities	39,376
Plant utilities	56,438
Total construction	620,826
Initial catalyst requirements	2,239
Total plant cost (insurance and tax bases)	623,065
Interest during construction	93,460
Subtotal for depreciation	716,525
Working capital	57,322
TOTAL INVESTMENT	773,847

(Source: Reference (6)).

TABLE B.3: SRC - Wyodak Coal: Annual Operating Costs (1976 $)

Direct cost:	$000	
Raw materials & utilities:		
Coal ($7.50/ton x 33,904 tpd x 330 sd/yr)	$3,912	
Raw water (15 Mgpm x $0.15/Mgal x 1440 min/day x 330 sd/yr)	1,069	
Catalyst and chemicals	4,989	
		89,970
Direct labor:		
864 manhour/day ($6/manhour x 365 day/yr)	1,892	
Supervision (15% of labor)	284	
		2,176
Plant maintenance:		
708 men ($15,000/yr)	10,620	
Supervision (20% of maintenance labor)	2,124	
Materials	15,930	
		28,674
Payroll overhead (30% of payroll)		4,476
Operating supplies (20% of plant maintenance)		5,735
Total direct cost		131,031
Indirect cost (administration & general overhead) (40% of labor, maintenance & supplies)		14,634
Fixed cost		
Taxes & insurance (2% of plant cost)		11,475
Total operating costs, before credits		157,140
Credits: Sulfur (222 tpd x $25/ton x 330 day/yr)		1,832
Power (11,680 Kwhr/hr x $0.01/Kwhr x 24 hr/day x 330 day/yr)		925
Total operating costs, after credits		154,383
Adjustment to operating costs (see Table B.1)		29,549
TOTAL		183,932

(Source: Reference (6)).

TABLE B.4: Synthoil - Western Kentucky Coal

Total Capital Investment (1976 $)

	$000
Coal preparation	20,692
Paste preparation	18,070
Coal hydrogenation	140,857
Coal hydrogenation - heat exchange	66,225
Char de-oiling	20,136
H_2S removal	9,483
H_2S and NH_3 recovery	15,300
Hydrogen production*	108,744
Steam & power plant	29,174
Plant facilities	32,151
Plant utilities	46,083
Total construction	506,912
Initial catalyst requirements	2,700
Total plant cost (insurance & tax bases)	509,612
Interest during construction	76,442
Subtotal for depreciation	586,054
Working capital	58,605
TOTAL INVESTMENT	644,659

* Includes gasification, dust removal, shift conversion, oxygen plant, sulfur recovery.

(Source: Reference (7)).

TABLE B.5: Synthoil: Annual Operating Costs (1976 $)

	$000	
Direct cost:		
Raw materials & utilities:		
Coal (825.8 tph x 7,920 hr/yr x $20/ton)	130,807	
Raw water (792 Mgph x 7920 hr/yr x $0.15/Mgal)	941	
Catalyst and chemicals	3,511	
Methane (40.4 Mscfh x 7920 hr/yr x $0.75/Mscf)	240	
		135,499
Direct labor:		
1584 manhour/day ($6/manhour x 365 day/yr)	3,469	
Supervision (15% of labor)	520	
		3,989
Plant maintenance:		
629 men ($15,000/yr)	9,435	
Supervision (20% of maintenance labor)	1,887	
Material & contracts	14,152	
		25,475
Payroll overhead (30% of payroll)		4,593
Operating supplies (20% of maintenance)		5,095
Total direct cost		174,651
Indirect cost (administration and general overhead) (40% of labor, maintenance & supplies)		13,824
Fixed cost		
Taxes & insurance (2% of plant cost)		10,192
Total operating cost, before credits		198,667
Credits: $(NH_4)_2SO_4$ (21.4 tph x 7920 hr/yr x $45/ton)		7,627
H_2SO_4 (15.86 tph x 7920 hr/yr x $20/ton)		2,512
Sulfur (564.6 tpd x 330 sd/yr x $25/ton)		4,658
Fuel gas (850 Mscfh x 7920 hr/yr x $0.33/Mscf)		2,222
Total operating cost, after credits		181,648
Adjustment to operating costs (see Table B.1)		40,260
TOTAL		221,908

(Source: Reference (7)).

TABLE B.6: H-Coal - Wyodak coal

Total Capital Investment (1976 $)

	$000
Coal preparation	47,964
Hydrogenation	372,672
Refinery gas cleanup	24,604
Oxygen plant	62,977
Hydrogen production	100,998
Hydrogen compression	44,531
Ammonia and H_2S removal	2,180
Sulfur recovery	5,087
Oil refining	40,092
Hydrogen plant	14,424
Steam and power plant	58,443
Plant facilities	58,048
Plant utilities	83,202
Total construction	915,223
Initial catalyst requirements	7,674
Total plant cost (insurance & tax bases)	922,897
Interest during construction	138,435
Subtotal for depreciation	1,061,332
Working capital	84,907
TOTAL INVESTMENT	1,146,238

(Source: Reference (8)).

TABLE B.7: H-Coal: Annual Operating Costs (1976 $)

	$000	
Direct cost:		
Raw materials & utilities:		
Coal (1,625.19 tph x 7920 hr/yr x $7.50/ton)	96,536	
Water (1056 Mgph x 7920 hr/yr x $0.15/Mgal)	1,255	
Catalyst & chemicals	17,369	
		115,160
Direct labor:		
1560 manhour/day ($6/manhour x 365 day/yr)	3,416	
Supervision (15% of labor)	513	
		3,929
Plant maintenance:		
1049 men ($15,000/yr)	15,735	
Supervision (20% of maintenance labor)	3,147	
Materials & contracts	23,603	
		42,485
Payroll overhead (30% of payroll)		6,843
Operating supplies (20% plant maintenance)		8,497
Total direct cost		176,914
Indirect cost (administration & general overhead) (40% of labor, maintenance & supplies)		21,964
Fixed cost		
Taxes and insurance (2% of plant cost)		16,996
Total operating cost, before credits		215,874
Credits: Ammonia (78.48 tpd x 330 day/yr x $60/ton)		1,554
Sulfur (206.40 tpd x 330 day/yr x $25/ton)		1,703
Coke (78.06 tpd x 330 day/yr x $10/ton)		258
Total operating costs, after credits		212,359
Adjustment to operating costs (see Table B.1)		-82,385
TOTAL		129,974

(Source: Reference (8)).

TABLE B.8: EDS - Illinois coal

Plant Investment

		($MM)
On sites:	liquefaction	246.3
	solvent hydrogenation	83.5
	flexicoker	163.8
	hydrogen recovery & generation	246.3
	gas & water treatment	49.7
	product recovery	8.5
	Total on sites	798.0
Off sites:	coal receipt storage & crushing	27.5
	ash handling	13.7
	building, mobile equipment	23.3
	utilities	26.4
	waste water treatment	67.6
	electric power distribution	34.9
	tankage/product loading	26.4
	Total off sites	253.7
	Total erected cost (TEC)	1051.7
	Startup costs (6% TEC)	63.1
	Total plant cost (insurance & tax bases)	1114.8
	Interest during construction (@9%)	378.6
	Subtotal for depreciation	1493.4
	Working capital (8% TEC)	84.1
	TOTAL INVESTMENT	1577.5

(Source: Reference (5)).

TABLE B.9: EDS - Illinois coal

Annual Operating Costs

	($MM)
coal (24 kT/sd x $20/ton x 330 days/yr)	158.40
power	39.12
water	0.45
catalyst & chemicals	7.82
manpower	42.39
repair materials & other	65.14
LESS: byproduct credit (sulfur & ammonia)	(22.20)
Annual operating costs	291.12
Adjustment to operating costs (see Table B.1)	48.31
TOTAL	339.43

(Source: Reference (5)).

TABLE B.10: Modified in-situ shale oil

Plant Investment

	($000)
plant facilities	20,769
plant utilities	58,031
equipment capital	258,249
Total construction	337,049
Initial catalyst & startup expense	26,772
Total plant cost (tax & insurance bases)	363,821
Interest during construction	56,030
Subtotal for depreciation	419,851
Working capital	67,208
Total investment	487,059
Cost of shale land*	287,100
TOTAL	774,159

* In a lecture at Boston University, Dr. R.E. Lumpkin of Occidental Research Corporation quoted the cost of one of Occidental's shale leases to have been $211 mm (1972 $), which we have included here in 1976 $.

(Source: Reference (2)).

TABLE B.11: Modified in-situ shale oil

Annual Operating Costs

	($000)	
Direct costs:		
raw materials & utilities	17,514	
direct labor	30,814	
payroll overhead	12,087	
maintenance	9,055	
operating supplies	44,337	
Subtotal		113,808
Indirect costs:		3,143
Fixed costs:		
taxes & insurance	14,381	
royalty	2,456	
Subtotal		16,837
Total operating costs		133,788
Adjustment to operating costs (see Table B.1)		40,260
TOTAL		174,048

(Source: Reference (2)).

APPENDIX C: The results of our financial analysis.

In this section of the appendix we present the results of our financial analysis. Tables C.1, C.2, and C.3 show the net present values of the technologies under each of the oil price scenarios for no cost overrun, 20% cost overrun, and 40% cost overrun, respectively. Figures C.1 - C.5 present the results of the simulations for each of the five technologies. For a discussion of the tables and figures, refer to Section III of the text.

TABLE C.1: No cost overrun

TECHNOLOGY	DIS-COUNT RATE (%)	NET PRESENT VALUE ($MM) UNDER SCENARIO: 1	2	3	4	5
SRC	0	2016	1172	2491	-636	-765
	2	1485	751	1923	-602	-726
	4	1084	441	1486	-584	-702
	6	776	208	1146	-577	-690
	8	536	32	878	-577	-684
	10	347	-105	662	-581	-683
	12	196	-211	487	-588	-685
	14	74	-295	344	-597	-689
	16	-27	-363	224	-606	-694
	18	-110	-418	124	-616	-699
	20	-180	-463	38	-625	-705
SYNTHOIL	0	1563	719	2038	-1090	-1218
	2	1140	405	1577	-948	-1072
	4	819	176	1221	-849	-968
	6	573	5	944	-780	-893
	8	382	-123	723	-731	-839
	10	231	-221	546	-697	-799
	12	111	-296	402	-673	-771
	14	13	-356	283	-657	-749
	16	-67	-403	184	-646	-734
	18	-133	-441	101	-638	-722
	20	-188	-471	30	-634	-714

(Continued on next page.)

TABLE C.1: No cost overrun (continued from previous page)

TECHNOLOGY	DISCOUNT RATE (%)	NET PRESENT VALUE ($MM) UNDER SCENARIO: 1	2	3	4	5
H-COAL	0	2523	1679	2998	-129	-258
	2	1829	1095	2266	-258	-382
	4	1303	660	1706	-365	-483
	6	900	332	1270	-454	-566
	8	585	80	926	-529	-636
	10	336	-116	651	-592	-694
	12	137	-270	428	-647	-744
	14	-24	-393	245	-695	-787
	16	-157	-493	94	-736	-824
	18	-268	-575	-34	-773	-857
	20	-360	-643	-142	-805	-885
EDS	0	437	-576	1006	-2746	-2901
	2	83	-798	608	-2422	-2570
	4	-190	-962	293	-2192	-2334
	6	-404	-1085	41	-2028	-2163
	8	-573	-1179	-164	-1910	-2038
	10	-710	-1252	-332	-1824	-1942
	12	-821	-1310	-472	-1763	-1879
	14	-914	-1356	-590	-1718	-1829
	16	-991	-1394	-690	-1686	-1791
	18	-1056	-1425	-775	-1662	-1763
	20	-1112	-1451	-849	-1646	-1742
SHALE	0	2131	1287	2606	-521	-650
	2	1577	843	2015	-510	-633
	4	1159	516	1562	-509	-627
	6	839	272	1210	-514	-627
	8	591	86	932	-523	-630
	10	395	-57	710	-534	-636
	12	239	-168	530	-547	-643
	14	113	-256	382	-558	-650
	16	9	-327	260	-570	-658
	18	-76	-384	157	-582	-666
	20	-148	-431	70	-593	-673

TABLE C.2: 20% cost overrun

TECHNOLOGY	DISCOUNT RATE (%)	NET PRESENT VALUE ($MM) UNDER SCENARIO: 1	2	3	4	5
SRC	0	1413	569	1888	-1239	-1368
	2	974	241	1412	-1113	-1236
	4	641	-2	1044	-1027	-1145
	6	385	-183	755	-968	-1081
	8	185	-320	526	-929	-1036
	10	26	-426	340	-903	-1005
	12	-102	-509	189	-887	-984
	14	-206	-575	64	-876	-969
	16	-292	-628	-41	-871	-959
	18	-363	-671	-129	-868	-952
	20	-423	-706	-205	-868	-948
SYNTHOIL	0	869	25	1344	-1783	-1912
	2	559	-175	997	-1528	-1652
	4	323	-320	726	-1345	-1463
	6	142	-426	512	-1212	-1324
	8	-1	-506	341	-1114	-1222
	10	-114	-566	201	-1042	-1144
	12	-204	-612	87	-989	-1086
	14	-278	-647	-9	-949	-1086
	16	-339	-675	-89	-919	-1007
	18	-390	-698	-157	-896	-980
	20	-433	-716	-215	-878	-958

(Continued on next page.)

TABLE C.2: 20% cost overrun (continued from previous page)

TECHNOLOGY	DIS-COUNT RATE (%)	NET PRESENT VALUE ($MM) UNDER SCENARIO:				
		1	2	3	4	5
H-COAL	0	2021	1177	2496	-631	-760
	2	1387	653	1824	-700	-824
	4	905	262	1307	-763	-881
	6	533	-34	904	-820	-733
	8	243	-262	584	-871	-978
	10	12	-440	327	-916	-1018
	12	-173	-580	118	-957	-1054
	14	-324	-693	-54	-994	-1087
	16	-448	-784	-197	-1027	-1115
	18	-552	-860	-318	-1057	-1141
	20	-639	-922	-421	-1085	-1164
EDS	0	-687	-1700	-117	-3870	-4024
	2	-873	-1754	-348	-3378	-3526
	4	-1022	-1794	-539	-3024	-3165
	6	-1142	-1824	-698	-2766	-2901
	8	-1241	-1847	-832	-2577	-2706
	10	-1323	-1866	-945	-2438	-2560
	12	-1392	-1881	-1043	-2334	-2450
	14	-1451	-1894	-1127	-2255	-2366
	16	-1501	-1905	-1200	-2197	-2307
	18	-1545	-1914	-1265	-2152	-2252
	20	-1583	-1923	-1321	-2118	-2213
SHALE	0	1567	722	2041	-1085	-1215
	2	1100	366	1538	-987	-1111
	4	747	104	1150	-921	-1039
	6	476	-92	847	-877	-990
	8	265	-240	606	-849	-956
	10	98	-354	413	-831	-933
	12	-36	-443	255	-820	-917
	14	-144	-513	126	-815	-907
	16	-233	-569	17	-813	-901
	18	-307	-615	-74	-813	-897
	20	-370	-653	-151	-815	-895

TABLE C.3: 40% cost overrun

TECHNOLOGY	DIS-COUNT RATE (%)	NET PRESENT VALUE ($MM) UNDER SCENARIO: 1	2	3	4	5
SRC	0	810	-34	1285	-1842	-1971
	2	464	-270	901	-1623	-1747
	4	199	-444	602	-1469	-1587
	6	-6	-574	364	-1359	-1472
	8	-167	-672	174	-1281	-1388
	10	-296	-748	19	-1225	-1327
	12	-400	-808	-109	-1185	-1282
	14	-486	-855	-216	-1156	-1249
	16	-556	-893	-306	-1136	-1224
	18	-616	-923	-382	-1121	-1205
	20	-666	-949	-448	-1111	-1191
SYNTHOIL	0	176	-669	650	-2477	-2606
	2	-21	-755	417	-2108	-2232
	4	-172	-815	231	-1840	-1958
	6	-290	-858	80	-1643	-1756
	8	-383	-888	-42	-1497	-1604
	10	-459	-911	-144	-1387	-1489
	12	-520	-927	-229	-1304	-1401
	14	-570	-939	-300	-1241	-1333
	16	-612	-948	-361	-1191	-1279
	18	-648	-955	-414	-1153	-1237
	20	-678	-961	-460	-1123	-1203

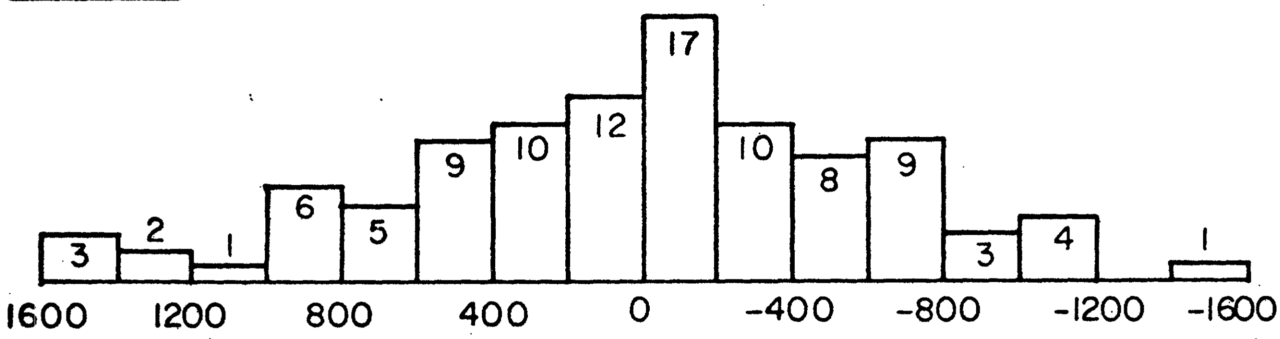
(Continued on next page.)

TABLE C.3: 40% cost overrun (continued from previous page)

TECHNOLOGY	DISCOUNT RATE (%)	NET PRESENT VALUE ($MM) UNDER SCENARIO: 1	2	3	4	5
H-COAL	0	1520	676	1995	-1133	-1261
	2	945	211	1382	-1142	-1266
	4	506	-137	909	-1162	-1280
	6	167	-401	537	-1186	-1299
	8	-99	-604	242	-1213	-1320
	10	-312	-764	3	-1240	-1342
	12	-483	-890	-192	-1267	-1365
	14	-623	-992	-353	-1294	-1386
	16	-739	-1075	-488	-1318	-1406
	18	-836	-1144	-602	-1342	-1425
	20	-918	-1201	-700	-1364	-1443
EDS	0	-1811	-2824	-1241	-4994	-5148
	2	-1829	-2710	-1304	-4334	-4482
	4	-1854	-2625	-1370	-3855	-3997
	6	-1881	-2562	-1436	-3505	-3640
	8	-1909	-2515	-1499	-3245	-3374
	10	-1936	-2479	-1559	-3051	-3173
	12	-1963	-2452	-1614	-2904	-3021
	14	-1988	-2431	-1665	-2793	-2904
	16	-2012	-2415	-1711	-2707	-2813
	18	-2034	-2404	-1754	-2641	-2741
	20	-2055	-2395	-1793	-2589	-2685
SHALE	0	1002	157	1476	-1651	-1779
	2	623	-111	1061	-1464	-1588
	4	335	-308	738	-1333	-1451
	6	113	-455	483	-1240	-1353
	8	-61	-566	280	-1175	-1282
	10	-199	-651	116	-1128	-1230
	12	-310	-718	-19	-1095	-1192
	14	-401	-770	-131	-1071	-1164
	16	-476	-812	-225	-1055	-1143
	18	-538	-846	-305	-1044	-1128
	20	-591	-874	-373	-1036	-1116

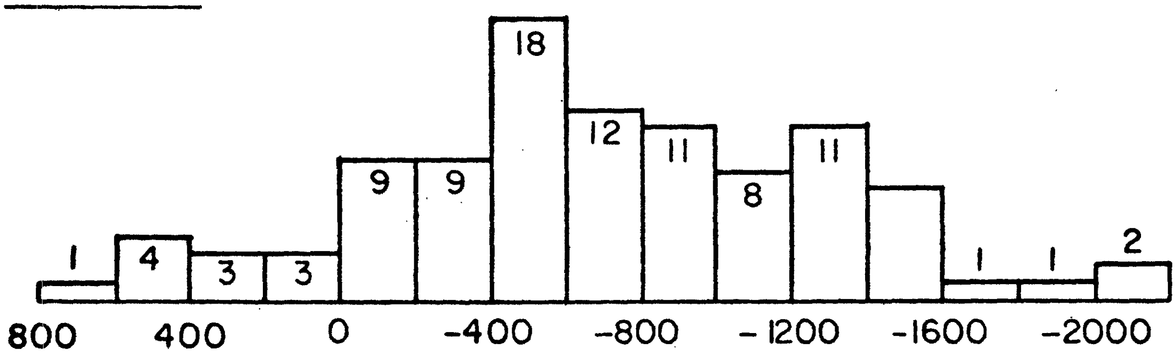
Figure C.1 – SRC

Scenario 1



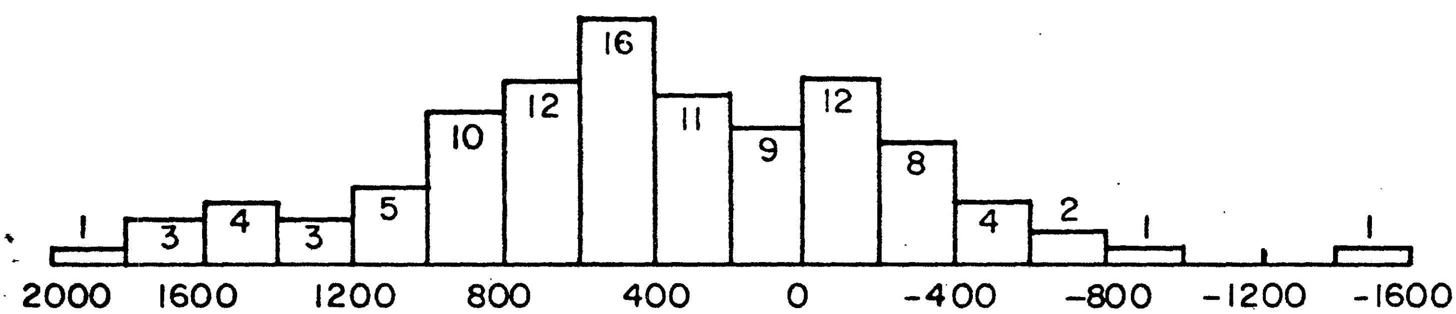
NPV ($MM)

Scenario 2



NPV ($MM)

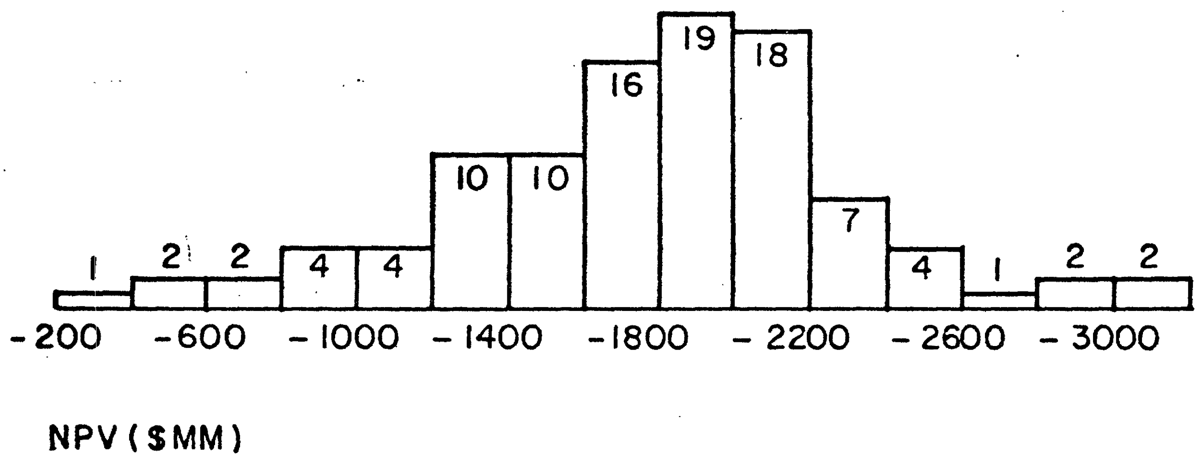
Scenario 3



NPV ($MM)

Figure C.1 – SRC (cont.)

Scenario 4



Scenario 5

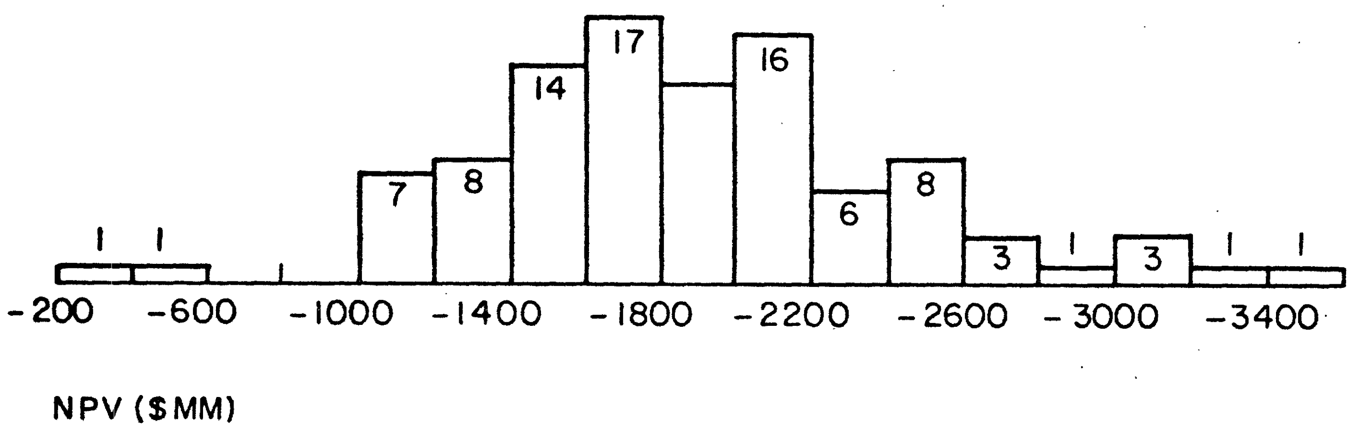
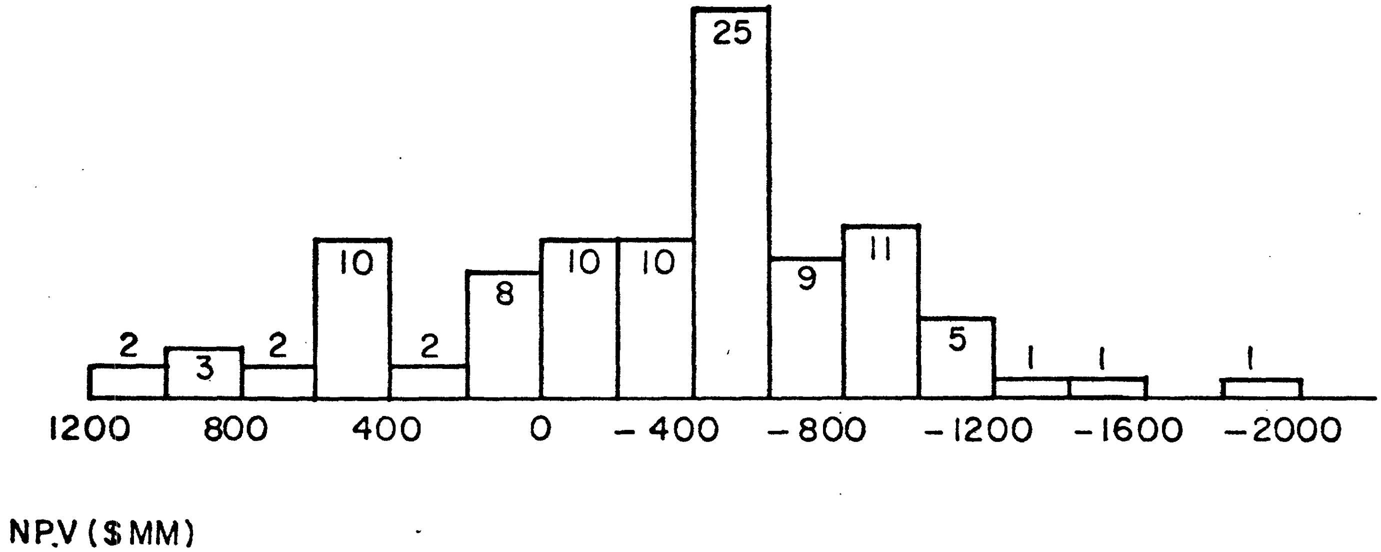
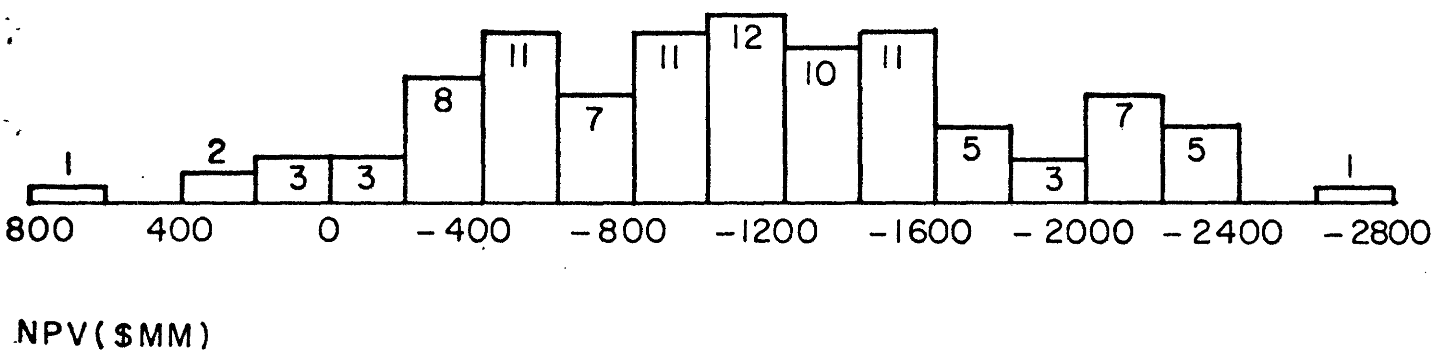


Figure C.2 - Synthoil

Scenario 1



Scenario 2



Scenario 3

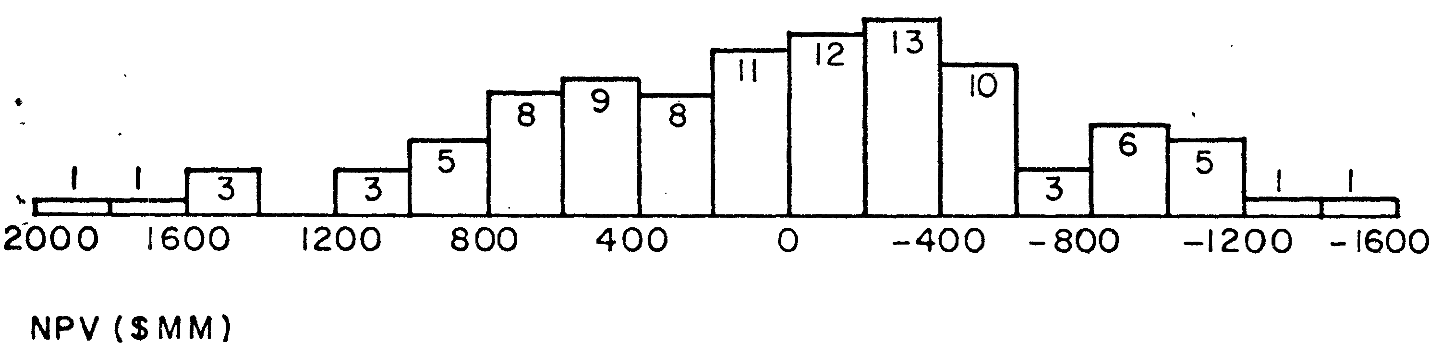
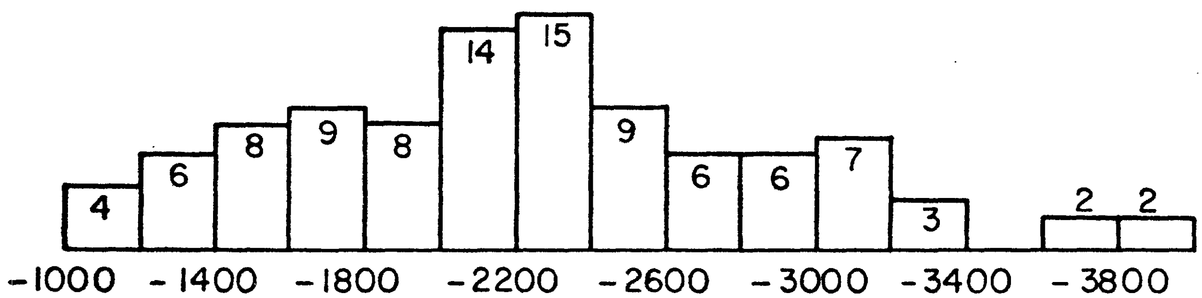


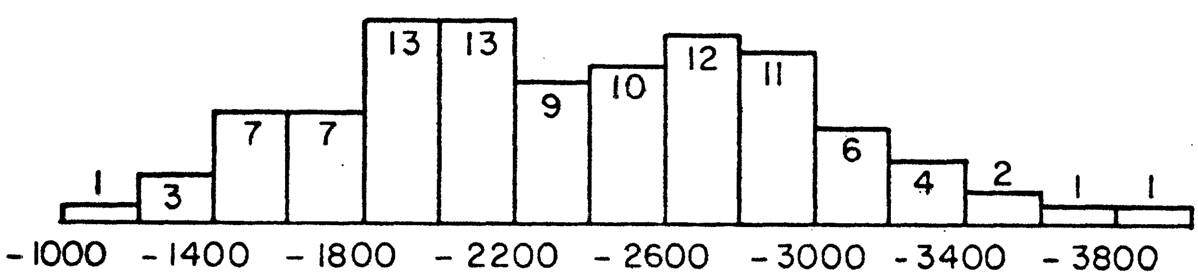
Figure C.2 - Synthoil (cont.)

Scenario 4



NPV ($MM)

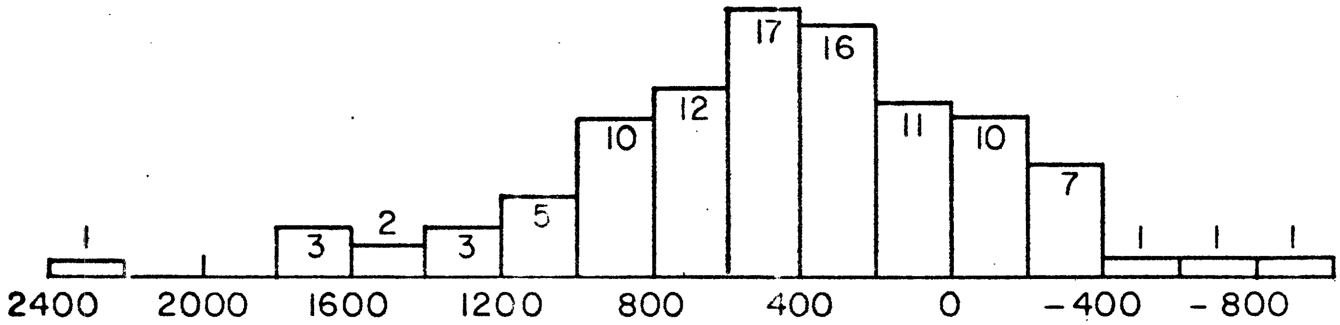
Scenario 5



NPV ($MM)

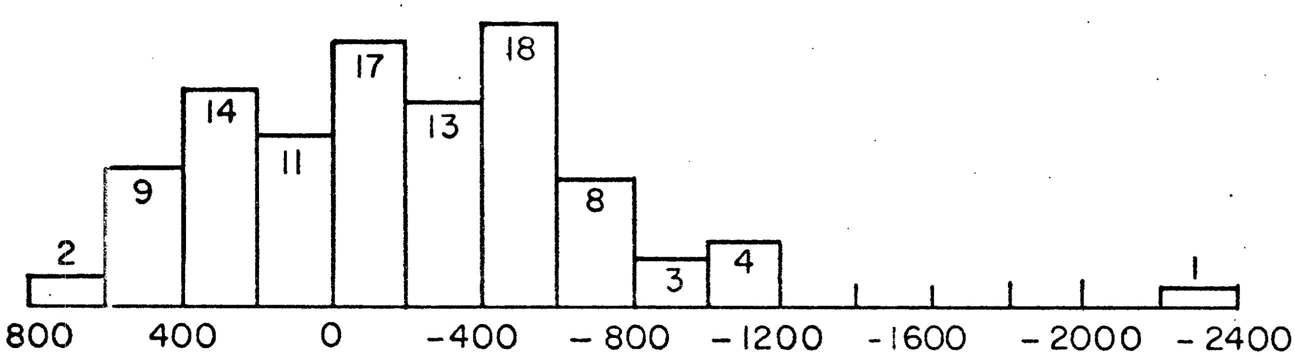
Figure C.3 – H – Coal

Scenario 1



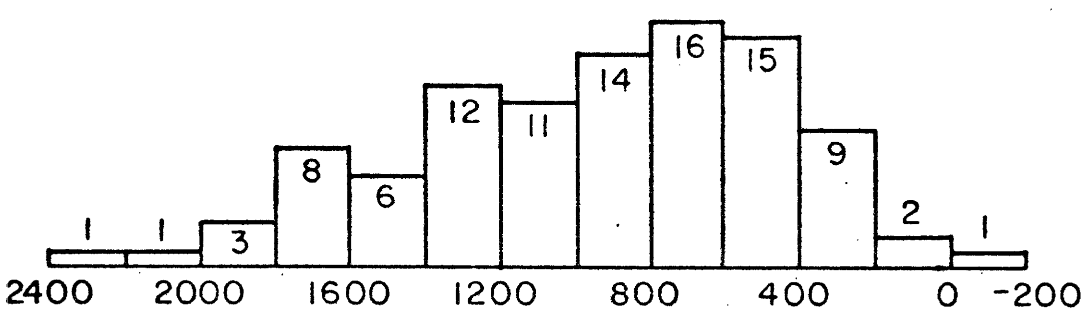
NPV ($ MM)

Scenario 2



NPV ($MM)

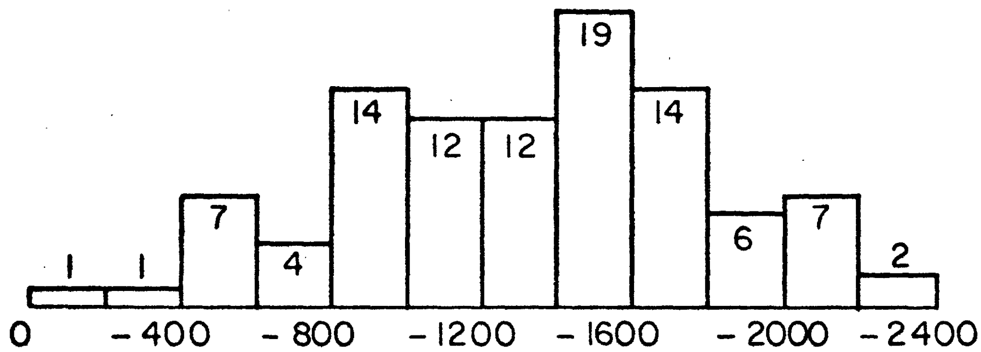
Scenario 3



NPV ($MM)

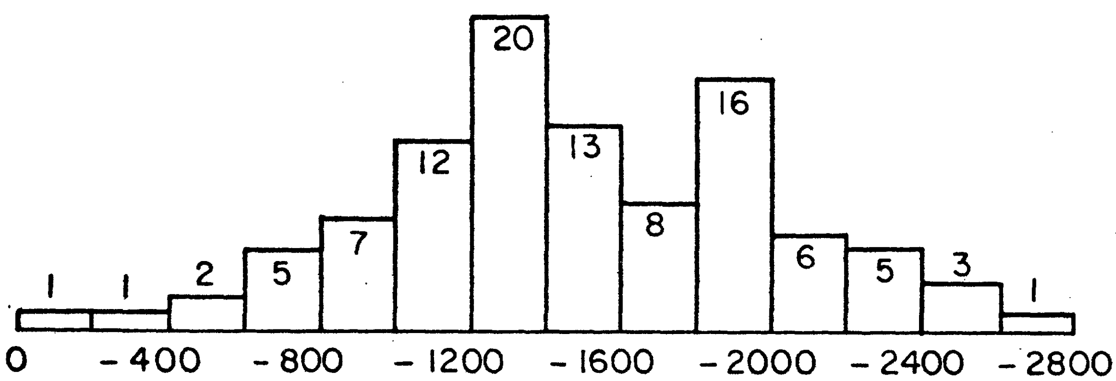
Figure C.3 - H - Coal (cont.)

Scenario 4



NPV (\$MM)

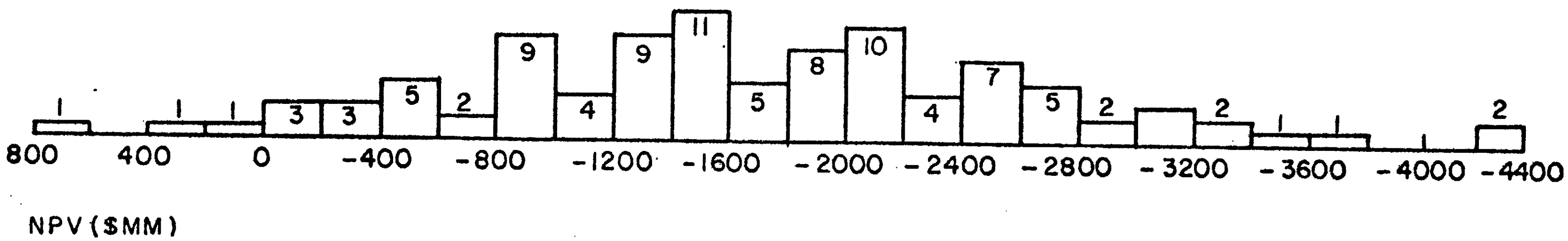
Scenario 5



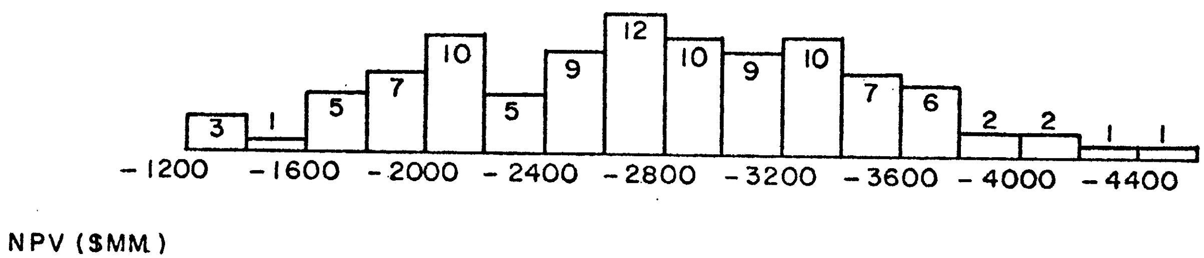
NPV (\$MM)

Figure C.4 – EDS

Scenario 1



Scenario 2



Scenario 3

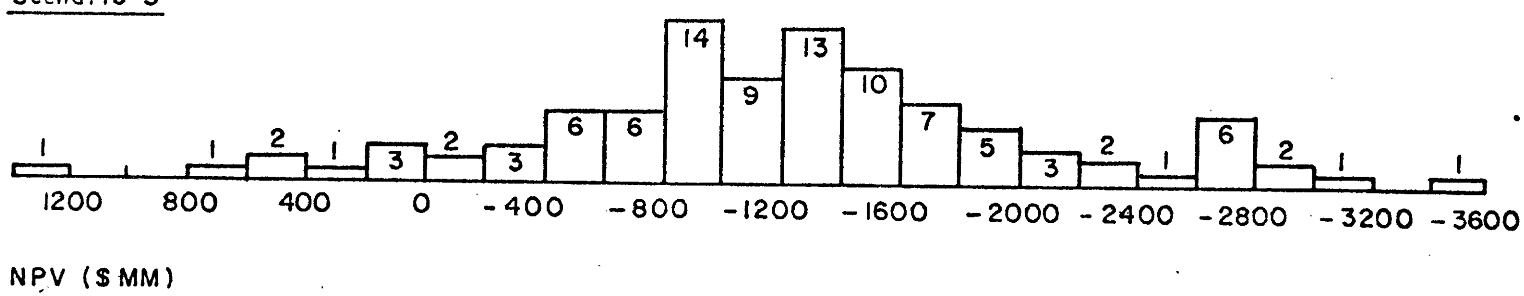
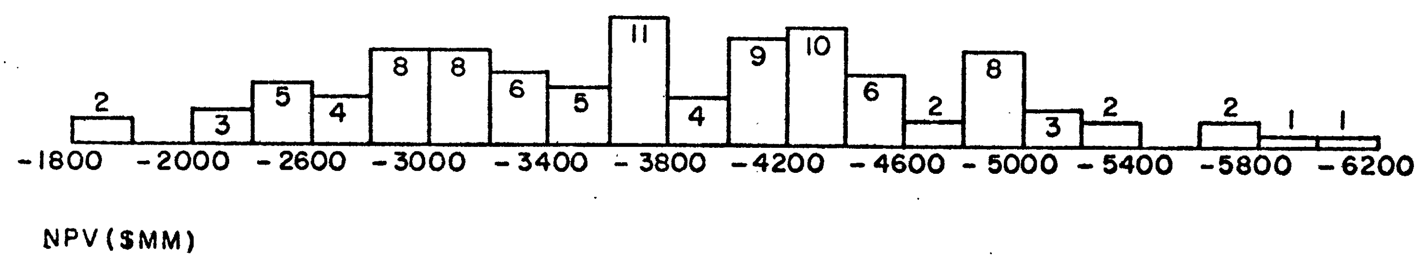


Figure C.4 – EDS (cont.)

Scenario 4



Scenario 5

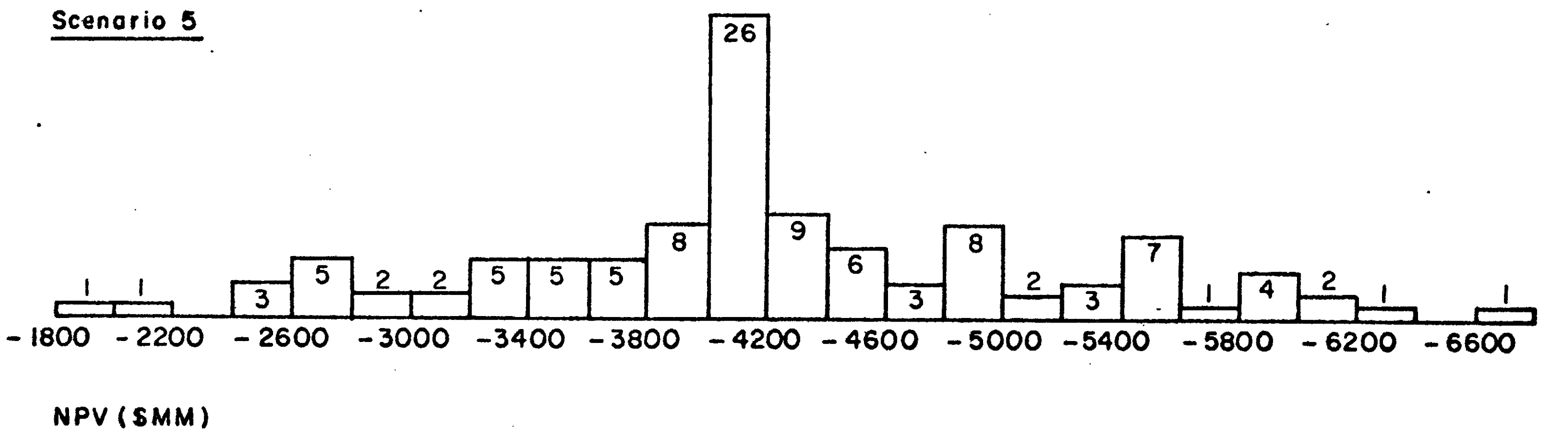
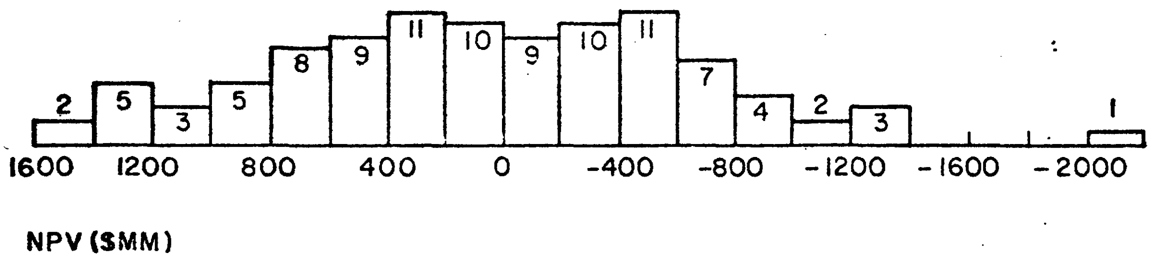
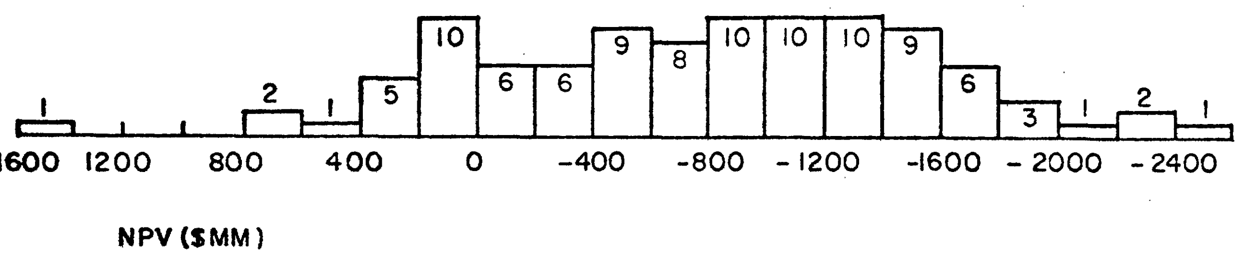


Figure C.5 – INSITU SHALE

Scenario 1



Scenario 2



Scenario 3

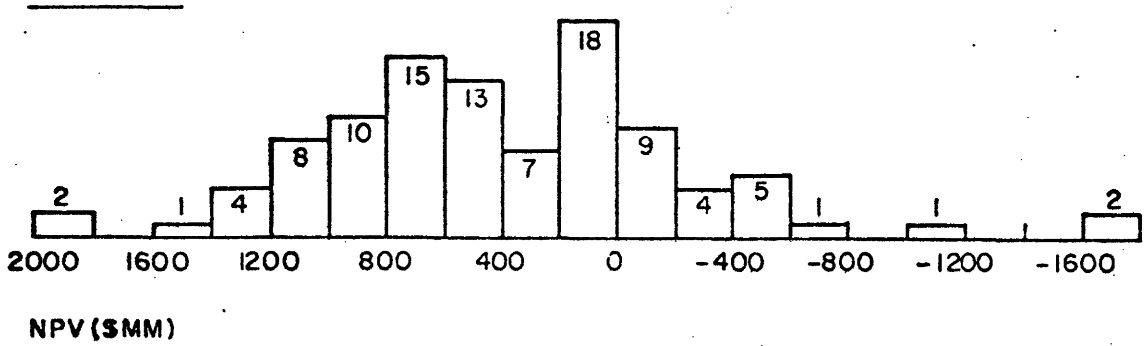
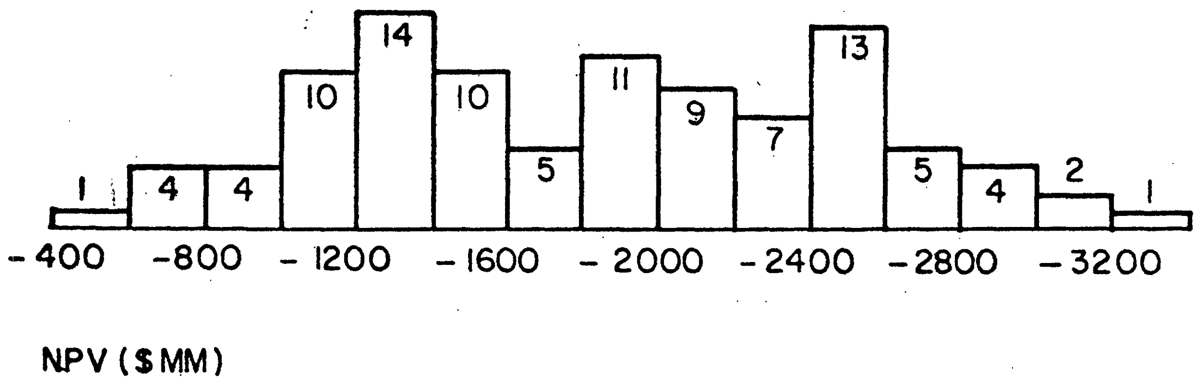
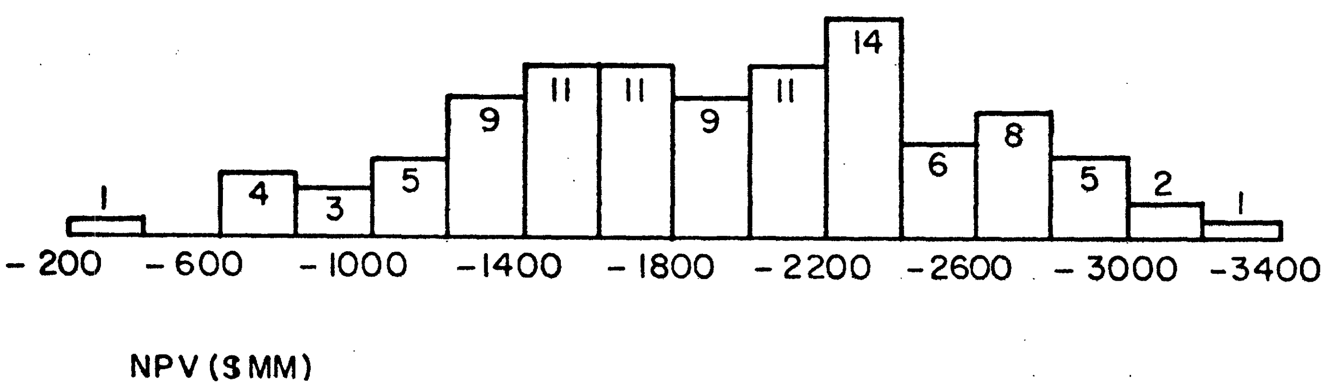


Figure C.5 - INSITU SHALE (cont.)

Scenario 4



Scenario 5



APPENDIX D: Overview of the major environmental issues. *

Each of the technologies within the areas of oil shale processing, coal liquefaction, and coal gasification, differs in the exact form and level of its environmental impact. In general, however, the environmental impacts of concern occur in three distinct forms: (1) the release of pollutants into the atmosphere and water sources; (2) disturbance of the physical environment; and, (3) the allocation and commitment of valuable resources that are non-renewable. The effects of these impacts are manifest in the ecology, in occupational health and safety, and in public health (or community exposure). Furthermore, in rural, non-industrialized, low-population areas, the socioeconomic effects of the development of such industries will not be negligible and can have a number of adverse effects. The major areas of impact may be summarized as follows:

1. air quality: Both Federal and state air quality standards exist, and the more stringent of the two is applicable. The concern is mainly over plant emissions during processing and fugitive dust during mining and transportation. In addition, there is concern over the impact on air quality of the eventual use of the synthetic fuels (e.g. impacts of synthetic boiler fuels when used by industry). One of the risks faced by a synthetic fuels project is that, for many pollutants, the permissible increases in pollutant levels are low relative to the background levels. This, coupled with the naturally occurring wide variation in the background levels makes the determination of the impact of the plant subject to great uncertainty.**

---

* Although there are numerous sources that deal with the environmental issues connected with synthetic fuels development, the most complete is Reference (3).

** See Reference (11).

Hence, even if the plant is operating within the restrictions imposed, there is a risk that it will be held responsible for the increases in the ambient levels of those pollutants. Furthermore, even in the absence of a synthetic fuels plant, the existing air quality standards present problems: the ambient standards on some of the shale tracts are being violated by naturally occurring hydrocarbons.* This would clearly make the monitoring and control of the emissions from an oil shale plant on that tract subject to further uncertainty.

2. land: A major concern here is the scarring of the landscape due to the plants, mines, and other peripherals, and the disposal of spent shale in the case of oil shale. Equally important is the fact that the use of the land for these plants can permanently alter land use in that neighborhood, destroying vegetation and driving out or destroying wildlife. For example, in the case of coal liquefaction or gasification facilities in the Appalachian regions, agricultural and forest lands would not be available for other uses, and reclamation would not totally restore them to their original state. Reclamation and revegetation would be particularly difficult in areas of low precipitation.

3. water: Concern here is both over the availability of adequate supplies and the pollution of existing sources. Synthetic fuels production requires large quantities of water at the sites, and in some regions this would mean a shortage of water for other uses (e.g. for agriculture). The discharge of pollutants into surface streams and leaching into underground sources can be dealt with at the planning

* See Reference (11).

stage by designing the plants for "zero discharge," where the spent water is recycled for use at the plant site. Whether or not the discharge is quite "zero" during full-scale operation is not, however, known.

4. occupational health and safety: Although there are dangers present for the operators of the plants, this should not be an insurmountable problem, and has been dealt with in other areas (for example, oil refining).

5. socioeconomic: The socioeconomic impacts are those that can arise from a sudden influx of population into sparsely inhabited, non-industrialized areas lacking the infrastructure necessary to support them (the Appalachian and Eastern Interior regions, though, would not be as seriously affected because of the existing labor pools). With careful planning, however, the population influx and the attendant problems can be adequately handled.

Many of the above problems have been encountered, and satisfactorily dealt with, by other industries (coal mining and oil refining, for example) and can therefore be solved in principle. What is often presented as unique to synthetic fuels is the uncertainty over future air and water quality standards. This is in addition to the uncertainty regarding the exact level of the impacts of full-scale production and, consequently, some companies have indicated that they are unwilling to proceed until the environmental requirements are fully clarified. It is essential, therefore, that the government issue clear directives in this, and related, areas, thereby removing some of the uncertainties it has helped to create.

VI. REFERENCES

1. Brown, W.M. and H. Kahn, Suggestions for a Phase-II National Energy Policy, Hudson Institute, Inc. September 1977.

2. Recommendations for a Synthetic Fuels Commercialization Program, Volume 3, Synfuels Interagency Task Force. November 1975.

3. Draft Environmental Impact Statement, Volume 4, Synfuels Interagency Task Force. December 1975.

4. Rogers, K.A., A.S. Wilk, B.C. McBeath and R.F. Hill, "Comparison of Coal Liquefaction Processes," The Engineering Societies Commission on Energy, Inc. Final Report on Task 006. April 1978.

5. "Exxon Donor Solvent Coal Liquefaction Commercial Plant Study Design," Interim Report (FE-2353-13), Exxon Research and Engineering Company.

6. "50,000 BBL/DAY Liquid Fuels Plant, SRC Process - Wyodak Coal, An Economic Analysis," Report No. 76-26, Process Evaluation Group, U.S. Department of Interior, Bureau of Mines. May 1976.

7. "50,000 BBL/DAY Liquid Fuels Plant, Synthoil - Western Kentucky Coal, An Economic Analysis, Report No. 76-33, Process Evaluation Group, U.S. Department of Interior, Bureau of Mines. June 1976.

8. "50,000 BBL/DAY Liquid Fuels Plant, H-Coal Process and Oil Refining - Wyodak Coal, An Economic Analysis, Report No. 76-19, Process Evaluation Group, U.S. Department of Interior, Bureau of Mines. May 1976.

9. Platt's Oil Price Handbook and Oilmanack. 53rd Edition, 1976 prices.

10. "Washington Report: Coal Liquefaction in the Limelight at DOE," EPRI Journal. May 1978.

11. "Oil Shale Technologies," Hearings before the Subcommittee on Energy Research and Development, 95th Congress, 1st session on S.419, March-April 1977, Statement by Charles H. Brown, TOSCO Corp., p. 152.

12. Baldwin, C.Y., "Managing the Capital Investment Process," unpublished manuscript, Harvard University. 1977.

13. Hertz, D.B., "Risk Analysis in Capital Investment," Harvard Business Review, 24. January-February 1964.

14. Lewellen, W.G. and M.S. Long, "Simulation versus Single-Value Estimation in Capital Expenditure Analysis," Decision Sciences, 3. 1972.

15. "Postscript: Using Simulation for Risk Analysis," in Modern Developments in Financial Management, edited by S. Myers. Dryden Press: 1976.