SHALE OIL: POTENTIAL ECONOMIES OF LARGE-SCALE PRODUCTION, WORKSHOP PHASE

by

Malcolm A. Weiss
Ben C. Ball, Jr.
Robert J. Barbera

Energy Laboratory Working Paper No. MIT-EL 79-031WP
July 1979

SHALE OIL: POTENTIAL ECONOMIES OF LARGE-SCALE PRODUCTION, WORKSHOP PHASE

by

Malcolm A. Weiss[1]
Ben C. Ball, Jr.[2]
Robert J. Barbera[3]

M.I.T. Energy Laboratory Working Paper No. MIT-EL 79-031WP
July 1979

1. Deputy Director
M.I.T. Energy Laboratory

2. Adjunct Professor of Management and Engineering
M.I.T. Energy Laboratory

3. Research Engineer/Lecturer
M.I.T. Department of Civil Engineering

CONTENTS

ABSTRACT

A workshop on shale oil, sponsored by M.I.T., was held on June 4-5, 1979. The purpose of the workshop was to identify technological opportunities for significant reduction in the cost of producing shale oil on a large scale (at least 2 million barrels per day). Large-scale production of shale oil is of current interest as one of the alternatives for reducing imports of petroleum. The workshop participants included 11 industry and 9 M.I.T. people expert in technologies or approaches potentially applicable to shale oil.

The participants reached general consensus on three major conclusions:

- Large-scale production of shale oil would make possible a reduction of cost through new technological applications and innovations. There are opportunities for new technology in individual mining, retorting, and upgrading steps. Perhaps more important, there are also opportunities for combinations of technology which would make best use of various processing methods, the natural resources in place, economies of scale, the mix of products, etc.
- A shale oil industry must exist and must be producing shale oil on a meaningful scale in order to develop these improved technologies most effectively. This is particularly true for those technologies whose impact is on the whole system (such as combinations of technology) rather than on individual process steps. If industry growth is not accelerated, it will be a long time before shale oil can contribute significantly to easing U.S. energy problems, and current technical, economic, and environmental uncertainties will remain uncertainties.

- Creating a large-scale shale oil industry soon would require capital, human skills, and materials well beyond the capacity of one company or a small group of companies. Those needs, plus some unique characteristics of the shale land (its federal ownership, and its concentration with consequent potential for heavy local impact on population and envrionment), suggest the desirability of a new structure to manage U.S. shale resources in the common interest. That structure would include some type of joint participation by the private sector, the public, and government (federal, state, and local) to ensure getting contributions and cooperation of all affected groups, and to best meet all their needs.

1. INTRODUCTION

The main purpose of M.I.T.'s current interest in shale oil has been to consider whether production of shale oil on a large scale could present opportunities for significant cost reduction through improved technology. Large-scale production of shale oil is one possible means for reducing the need to import petroleum. Our definition of "large-scale" is 10-25% of current consumption of liquid fuels in the U.S., or about 2 to 5 million barrels per day.

While this introduction is written (July 1979), newspaper headlines again feature the sharply rising prices and uncertain supplies of imported petroleum. If there is any aspect of energy upon which most informed people agree, it is that our heavy, and prospectively heavier, reliance on foreign petroleum is not good for the United States. The unfavorable nature of that dependence may be seen as arising from national security or foreign policy considerations or as stemming from strictly economic effects; in any case the overall conclusion is the same, and the headlines seem to confirm that conclusion.

There is much less agreement about which particular alternatives are less objectionable for the United States than importing so much oil. One broad alternative is to consume less liquid fuel through conservation or through substitution of non-liquid forms of domestic energy like coal, gas, and renewable sources. The other broad alternative is to increase supplies of domestic substitute liquids like coal liquids, frontier oil, tertiary oil, and shale oil.

The debate over the alternatives--the specific ones even more than the broad ones--has been exhaustive and public. It is not our purpose to review the advantages and disadvantages of each or to choose among them.

Unhappily, all the alternatives seem to have significant economic penalties or significant environmental penalties or both associated with them. In fact, government policy is likely to employ all the alternatives simultaneously to various degrees. We are considering some of the possibilities for shale oil in order to determine whether shale oil could become a more desirable alternative than it now seems to be. Our concentration on shale oil implies no overall judgment about the desirability of shale oil compared to other alternatives.

Interest in shale oil is motivated largely by the enormous size of oil shale deposits in the United States. Known rich and accessible resources contain about 600 billion barrels; a recovery of about one-third of that resource would equal almost one hundred years of imports of petroleum at the current rate.

A further reason for interest is that processes for the production of liquid fuels from oil shale appear cheaper than those that start from coal. This is primarily because oil shale contains a much higher ratio of hydrogen to carbon (H/C), and process costs tend to correlate directly with the increase in the net H/C ratio needed. This advantage is somewhat offset by the cost of increased solids handling and disposal required by shale.

Industry is being clear, as demonstrated by both its behavior and its public statements, that it does not regard shale oil ventures as very attractive now. Industry dissatisfaction is most frequently expressed about the "non-economic" barriers--innumerable permits, changing environmental regulations, tax and pricing uncertainties, lease limitations, water rights conflicts, legal challenges, and so on--but the crucial barrier is the fact that the cost of shale oil is greater than the price of imported oil now. If shale oil cost less, we would probably see more determined and more successful efforts by both industry and government to surmount the non-economic barriers. ("Non-economic" is shorthand, of course; there are costs, often large ones, resulting from those barriers.)

Industry's continued interest in shale oil, despite its current unattractiveness, is sustained primarily by the belief that the price of imported oil will continue to rise, ultimately catching up to and then surpassing the cost of shale oil at some unpredictable future date. Government assistance is sought by industry before that date on the grounds that a) there is a public value, which cannot be directly captured by a company undertaking a shale oil venture now, in reducing imported oil--for reasons discussed at the start of this introduction, and b) we need to start now if we want to have significant shale oil production in place when the cost/price curves do intersect.

A second reason for industry's continued interest is the belief that the real cost of producing shale oil may be reduced through technological improvement. Current R&D activities in the "pre-industry" era will lead to improvement. But other types of technological improvement might result if the industry was thought about in a different way.

Encouraging that new thinking was the objective of a workshop sponsored by M.I.T. held on June 4-5, 1979 in Lexington, Massachusetts. The specific purpose of the workshop, as described in the invitation letter to participants, was ". . . to identify technological opportunities to reduce substantially the costs of producing shale oil on a large scale, say 2-5 million barrels/day -- opportunities which would ordinarily not be applicable to an individual shale oil project of, say, 50-100,000 B/D. The opportunities might consist of applying existing technology which has not been seriously considered on a small scale, or of developing new technology which looks reasonably susceptible to successful development and which would have important impact on a large scale."

A total of 20 invitees participated in the workshop including 11 from industry and 9 from various M.I.T. departments. All are listed in the Appendix. The invitees were chosen to play one or more of three roles: a) provide expertise about shale oil technology and economics, b) provide expertise from related technical fields that might be applicable to shale oil production, and c) examine overall systems of shale oil production. Each participant was sent in advance an early version of an M.I.T. report summarizing the first phase of this research project.[1] The participants took no exception to the general conclusions of that report. Funding for the work resulting in that report and for the shale oil workshop was supplied by grants from the Edna McConnell Clark, Ford, and Alfred P. Sloan Foundations, and we are grateful to them.

All invitees were encouraged to express their personal views candidly and were assured that no report of the workshop would attribute any view to any individual. No proprietary information was solicited or discussed. Although the workshop was intended to be confined to technological opportunities, the participants' enthusiasm for encouraging

---

[1]Weiss, M.A., Ball, B.C. Jr., and Barbera, R.J., "Shale Oil: Potential Economies of Large-Scale Production, Preliminary Phase", M.I.T. Energy Laboratory Working Paper No. MIT-EL 79-012WP; Revised June 1979. Part of this introduction is reproduced from that report.

action on shale oil development carried the group into discussions of other issues. This report accordingly covers some of those issues too.[1]

[1]For convenience and completeness, this report also includes some technological opportunities previously identified by the authors whether or not they were discussed at the workshop.

2. MINING: OPPORTUNITIES FOR TECHNOLOGY

The group's consensus was that significant cost savings should be achievable in the mining operations necessary for producing shale oil on the scale considered in this workshop. However, the enormity of a mining operation moving 3 to 8 million tons per day of rock calls for innovative materials handling approaches by either identifying old technologies applicable to this new situation or developing new technologies for it. As an example, if labor productivity were not increased over the maximum current level of about 150 tons/man shift in other underground mines, the industry would need 20,000 to 50,000 underground miners -- and supplying just that part of the total labor force would be an enormous problem.

Technical Proposals and Needs

The most obvious way to increase mining productivity is to mine on the surface rather than underground. Therefore, proposals to surface mine all or major portions of the Piceance Creek Basin should be reevaluated since that may be the most practical way to produce enough oil, especially considering the difficulty of attracting mining labor to the region.

A related proposal would examine the possibility of developing "surface" mines underground, i.e. large underground mines with perhaps 100-foot ceilings excavated as though they were on the surface.

There appear to be no technological barriers to the development or use or both of mining equipment on a much larger scale than now planned. Very large equipment -- conspicuously, large-scale excavators and high-speed conveyors -- has been built and operated economically, for example in surface lignite mining in Germany. Surface mining there involves stripping 900 feet (soon to be 1600 feet) of overburden; that compares with a maximum Piceance Creek Basin overburden of about 1800 feet overlying a maximum shale strata thickness of about 1300 feet. Although there are no obvious technical limitations on increasing the size of mining equipment, two caveats are: 1) Size increases have to be coordinated among all elements of the mining system; and 2) Continued increases in size do not invariably result in decreases in cost, i.e. some mining systems have shown that total costs (including maintenance, service factor, etc.) may be a minimum at some size less than the largest sizes tested.

Retorting in-situ is, in principle, the oil recovery strategy with potential for reducing the environmental problems and solids-handling costs of surface retorting. The key to in-situ retorting is "mining"in the sense of making the rock in place permeable so that heat can be introduced (or created) pervasively and oil (and gas) withdrawn efficiently. In practice, of the various in-situ methods hypothesized or tested, only modified in-situ (in which some rock is removed to provide void volume so that the remaining rock can be fragmented and made permeable) has commercial promise on a wide scale.

Continuous processes for in situ or conventional mining to replace cyclic drilling/blasting/mucking would improve labor productivity and safety. Tunneling or honeycombing machines capable of handling the hard (relative to coal) shale rock are needed. Improved mining and controlled rubbling both depend on a better understanding of rock mechanics including the special case of rubbling to a controlled void in a confined volume.

A combination of in-situ and surface retorting may make best use of the shale resource in place. One can think of surface retorting the mined-out rock from a primary in-situ operation, or of in-situ retorting the rock left behind after underground mining for a primary surface operation.

Difficult environmental problems are associated with large-scale mining operations and will require solution. Coping with large aquifers above, between, and below shale strata is a major problem which may be easier to cope with on an industry scale (e.g. by grouting) than on a project-by-project basis. Fugitive dust is another problem, especially with surface mines. The crucial problem of spent shale disposal may be eased by high-temperature retorting which seems to reduce both the volume of and the soluble alkalis in the spent shale.

Several more speculative suggestions were made for technologies capable of reducing mining cost significantly. A whole new in-situ system was proposed (see Section 5). Rubbling by new methods -- hydraulic cone fracture, chemical or nuclear techniques, mechanical leverage -- was hypothesized. Underwater mining could be a way of coping with major aquifer problems.

3. RETORTING: OPPORTUNITIES FOR TECHNOLOGY

Discussions about improvements in retorting technology emphasized surface retorts. In-situ retorting was regarded as primarily a mining problem (see previous section) rather than a retorting problem in the usual sense. That is, most -- although not all -- improvements in in-situ retorting are expected from improved methods of preparing the retorts (tunneling, rubbling, etc.) rather than from improved methods of operating those retorts.

Only heating has so far been demonstrated to have potential for recovering oil from shale on a commercial scale. Exploratory R&D on other recovery techniques such as action of microorganisms, solvent extraction, and RF heating was not regarded as promising. Beneficiation or enrichment of retort feed by some mechanical or other means may be worth investigating.

Opportunities for improved technology in heated retorts, both specific suggestions and identified needs, can be classified in the four groups shown below:

Increased Throughput Per Train

Economies of scale in retorting seem most likely if a major increase in production can be obtained in each retort train (or module) rather than by replication of small modules. The retort technology that appears capable of very large single-train throughputs (based on demonstrated solids-handling capacity in refining processes) is fluidized bed technology. Fluidized bed technology for shale retorting was investigated briefly and then abandoned many years ago and we are not aware of any current major projects. Nevertheless, advances in that technology, especially for operations with higher gas velocities and larger particles, justify another evaluation.

Operating under pressure is another general technique for increasing throughput in both conventional and fluidized bed retorts; it deserves evaluation.

Flexibility in Feed Handling Ability

Good utilization of resources in place means that retorting processes should be able to handle shales of different richnesses, crushed to different sizes, and located at different places and depths. Retorting of local coal along with shale rock may be advantageous in special circumstances. Thinking about retorting in this broader context means that different types of both surface and in-situ retorts will be employed in an optimum large industry and that there is value in developing retorting systems which have inherent feed flexibility. No specific suggestions were made about how that flexibility could best be achieved (although fluidized bed systems have more inherent flexibility than most systems).

Optimization of Product Slate

In addition to having flexibility to accommodate different feeds, a retorting system could profitably have flexibility to make different mixes of products including oil, gas, and steam (or electric power). The optimum product mix would differ for different technologies, locations, and degrees of integration into the surrounding industry. Different retorting atmosphere gases (H_2, O_2/steam, etc.) offer one means by which product slate can be varied. Accessory equipment like fluid bed combustors may make it possible to economically and acceptable (environmentally) convert energy from one form to another more useful one, say coal or lean shale or low-Btu gas or carbon on spent shale to steam or electric power.

Improved Environmental Control

Costs for controlling or disposing of waste streams in an environmentally acceptable way are significant in shale oil production. Improved retorting technologies can help reduce those costs. Retorting at higher temperatures reduces soluble alkali in spent shale and thus reduces long-term leaching problems after spent shale disposal; investigation of this effect in surface retorting should be undertaken. Cheaper treatment of contaminated water streams, from mining or retorting, and with the objective of reuse or discharge, should be possible.

High-temperature retorting can also reduce the volume of spent shale to about (or perhaps even less than) the volume of the original rock, thus making it easier to dispose of all the spent shale by returning it to the mine; however, high-temperature retorting does incur costs because of losses in thermal efficiency and increased gaseous emissions.

The alkalinity of the spent shale suggests possible use in gas scrubbers to remove acidic sulfur compounds.

Cleaning up and using low-Btu gas from in-situ retorting is a particularly expensive operation and cheaper "one-step" technologies are needed; improved technology of this type would have a large impact.

In addition to the specific suggestions and needs identified above, there are obvious opportunities for cost saving during equipment manufacturing by a) mass production methods for replicated pieces of equipment, and b) shop fabrication replacing field fabrication wherever practical.

4. UPGRADING: OPPORTUNITIES FOR TECHNOLOGY

The workshop participants reached a quick and early consensus that they preferred not to spend much time discussing the technology of upgrading raw retort shale oil to refinery feedstock. That consensus seemed to be based on several assumptions including:

- The end products of shale oil will be similar to the current end products of petroleum in quality characteristics, even if not necessarily in volume distribution.
- The conversion of raw shale oil to end products will occur at existing petroleum refinery sites, or at new refineries generally similar (in technology) to existing ones but tailored to shale oil feed.
- That conversion will be carried out primarily by existing petroleum refining companies or combinations of existing companies who already have expertise.
- Large-scale production of shale oil involves very long lead times and therefore refiners will have ample notice of the need to design for large amounts of raw shale oil.
- Petroleum refining technology has shown its ability in the past to cope rapidly and efficiently with new feedstocks and changing product slates and qualities.

As a result of these assumptions, the workshop participants concluded that upgrading technology would occur naturally and effectively in the petroleum refining industry when it became evident that large volumes of shale oil would be produced and would have to be refined.

During their studies on shale oil preceding the workshop, the authors identified some of the technology that would probably be developed or used for refining large volumes of shale oil. The most important economices of application in a large-scale industry could result from:

- Pipeline transportation of raw shale oil to existing refining centers. Movement of raw shale oil (in heated pipelines or with additives or other pretreatment) to existing centers would a) make use of existing refining capacity presumably idled by reduced supplies of imported petroleum, and b) shift some demand for human, mechanical, and natural resources to locations better able to supply them than Colorado/Utah/Wyoming which have some infrastructure limitations.
- Development or modification of refining catalysts and processes to make them less sensitive to contamination by the nitrogen present in raw shale oil.
- Rebalancing of new and existing refinery process capacity to regard shale oil as a primary feed rather than a contaminant -- analogous to shifting from a sweet crude refinery to a sour crude refinery -- with a corresponding shift of product slate (consistent with overall market demand) to best exploit the different optimum product mixes from shale oil and petroleum.

5. THE "SYSTEMS" APPROACH

It would be unwise to consider cost reductions by looking only at the individual functional steps by which oil has traditionally been recovered from shale. The result could be sub-optimization and the possibility of a whole new approach or system might be completely missed. Therefore, the workshop considered the systems approach, and from two aspects. The first concerned technology including combinations of some individual functions. The second concerned implementation of industry development in such a way as to encourage systemic technological cost reductions.

Technology

Obvious examples of "systems" thinking about technology are referred to in the preceding sections as combinations of various approaches. Combinations of both in-situ and surface retorts should be able to best exploit the resource in place in some locations; the shale mined for modified in-situ, which creates the void needed for rubbling, would be charged to surface retorts and the exact balance between modified in-situ and surface retorting could be optimized depending on shale quality and depth, etc. Combinations of different types of retorts should make best use of mined shale and should make a product mix of maximum value. Integration of shale oil refining into the total refinery process should reduce refining costs. Other examples of combinations or serving multiple purposes were also cited.

A more basic approach might be the following:

Imagine an extraction device which travels through the shale, breaking rock, heating the rubble, separating the oil and gas, cooling the solid residue and replacing the rock in the mined out volume. The products would be shipped to the surface through pipes which follow the extractor. Air or other gases and/or liquids are fed to the device through pipes. Possibly, the extractor could be operated by remote control so that men would not be required underground as a routine matter. A key issue in such a concept is the ability of the process to reduce the volume of the waste rock to the original volume. It appears that this may be achievable by high processing temperatures and compaction.

In order to reduce unit costs through mass production, perhaps 1000 units should be manufactured. In order to produce 5 million barrels per day, each unit might have a frontal area of about 10 square meters and would advance about 60 centimeters per minute.

The design of such a device would clearly call for a major technical effort. A number of important mining, mechanical, electrical, and chemical engineering problems must be faced. The entire unit would likely be more than 30 meters in length, weight 500 to 1000 metric tons and cost in production perhaps $30 million each. On the other hand, the revenue from such a unit even at 50% utilization could amount to $30 million per year if the oil were sold at $15 per barrel.

No such device is under development, or has even been thought about seriously to our knowledge. And, of course, there may be little probability that such a system can be developed at acceptable cost, if at all. But the example illustrates that there are other ways of thinking about shale oil recovery that should be studied, at least.

Implementation

History suggests that the sheer existence of a significant industry is what provides the environment necessary for the kinds of systemic technological innovations that produce significant cost reductions. Therefore, the workshop developed an example of a form which might make such a significant industry possible. Such a form would also serve to:

- Stimulate inputs and contributions (of technology, skill, experience, perspective, and funds) from all relevant industries.
- Provide for Federal support at start-up without Federal control or a continuing Federal role.
- Provide for authentic participation at state, local, and public levels.
- Provide a mechanism appropriate to the enormous size of the task.

The example developed to permit these advantages would be creation of a publicly held firm along the lines of COMSAT. Its purpose would be to produce shale oil and its by-products. The process firms presently active in the development of shale oil would be invited to provide process expertise and lease holdings. Mining companies, equipment manufacturers, engineers, and construction firms would be invited to provide expertise, accepting as payment a limited early profit plus an equity position. The Federal government would provide leases (land) and research funds which would be repaid out of earnings. State governments would provide assistance in meeting the social and economic impacts of construction and operation. Shale oil would compete in the marketplace, without price control, with a negotiated royalty to the Federal government. Principal funding would be through sale of equity to the public, with debt financing as appropriate. The creation of a strategic planning function capable of managing the effect of changing technology would be important.

Through such a vehicle, the rudiments of an "industry in place" would be created, so that new systemic ideas and concepts can emerge and so that economies of scale can be identified. R&D would be centralized at least in part, with the attendant increase in efficiency and synergy (as well as some accompanying loss of diversity). The focus would be on optimum exploitation of the shale oil resource from the total perspective.

6. CONCLUSIONS AND SUGGESTIONS FOR FURTHER WORK

There was a clear consensus among participants in the workshop that:

- Production of shale oil on a large scale could provide opportunities for significant technological economies not otherwise realizable.
- Prompt accelerated development of shale oil production should be encouraged in the national interest; production will facilitate, and may be essential, to the technology development that should occur to reduce current uncertainties and to make informed decisions about any future large-scale industry.
- Further work is justified on more detailed evaluation of the technological opportunities, of their potential economic consequences, and of various structural options that would encourage accelerated development.

In general, institutional and other "non-economic" problems were not discussed in detail. The participants recognized the critical nature of such problems, for example the potential production constraints due to water availability or air degradation. But this workshop was intended to be confined to new technology which could have important impact on a large scale and it was assumed that other constraints, like environmental regulations, would not be limiting.

Technological Opportunities

Suggestions about mining were numerous. The single theme with the greatest potential for saving during mining for surface retorts was treatment of part or all of the Piceance Creek Basin as a single surface mine -- even though major aquifer disturbances and other environmental problems would be encountered and would have to be solved. Opportunities in mining for in-situ retorting were less well defined but they seemed to focus on continuous tunneling and controlled fragmentation replacing cyclic methods of drilling/blasting/mucking.

The largest potential for surface retorting appears to lie in large fluidized bed retorts. Operations under pressure, or with retorting atmospheres other than air, look interesting for both fluid and non-fluid retorts.

There was little discussion of upgrading. Workshop participants took it for granted that refiners faced by large quantities of raw shale oil feed would (in their traditional ways) develop new refining technologies to handle that feed at significantly lower cost than now foreseen for brute force hydrogenation followed by conventional petroleum refining.

The primary contributions from "systems" technology emphasized the advantages in large-scale production of combinations of technology to exploit all resources most effectively, e.g. combinations of in-situ and surface retorting to make best total use of the shale resource in place, combined shale and coal retorting, and multi-product (oil, gas, electric power) retorts.

Accelerated Development

Diverse new technology that best meets the overall needs of an industry is proposed, developed, demonstrated, and exploited most effectively in an industry in being. The workshop participants agreed that it was urgent to accelerate the rate of development of the shale oil industry in order to accelerate the rate of development of its technology. That would lead to a reduction of technical, economic, and environmental uncertainties and would put the nation in position to exploit oil shale on a large scale rapidly if it became necessary or desirable to do so. New large-scale structures involving both the private and public sectors would help and may be essential to accelerate development and to produce shale oil on the huge scale potentially desired. A possible model for consideration is COMSAT. An R&D operation could be linked to such an organization through a wide range of funding, programming, and administrative devices.

Further Work

The workshop participants encouraged M.I.T. to take a leadership role in shale oil activities by undertaking its own projects or through participation in joint projects with other groups. Three types of activities would be useful in new shale oil projects:

- Some possible technological alternatives for a large-scale industry should be hypothesized and the economics for those alternatives should be estimated. Studies of that type would yield costs of debatable absolute accuracy, but the relative costs could help identify the most promising technologies for further R&D and the potential gain relative to current technology. Although M.I.T., like most universities, is not ideally suited for process engineering/cost estimating studies, it can usefully work with other groups having such skills.
- Specific promising technical R&D projects have been identified, and further projects will probably be identified through subsequent economic studies. M.I.T.'s laboratories have the

resources and experience to specify, propose, and execute many of those projects successfully.

- Various structural options for a shale oil industry can be examined. The options should be described in detail with the advantages and disadvantages of each option evaluated as objectively as possible. In that way, we can catalyze the debate about selecting an implementation mechanism that best fits the policy constraints. M.I.T's policy and management groups have the skills and experience to undertake studies of this type.

Appendix: M.I.T. SHALE OIL WORKSHOP

June 4-5, 1979
Sheraton-Lexington Motor Inn
Lexington, Massachusetts

Participants

Mr. John Arnold
Vice President, Engineering
Peabody Coal Company
301 N. Memorial Drive
St. Louis, Missouri 63102
(314) 342-3583

Mr. Ben C. Ball, Jr.
Adjunct Professor of Management
and Engineering
Room E38-510
M.I.T.
Cambridge, Massachusetts 02139
(617) 253-6611

Dr. Robert J. Barbera
Research Engineer/Lecturer
Department of Civil Engineering
Room 48-317
M.I.T.
Cambridge, Massachusetts 02139
(617) 253-1636

Mr. R.J. Fernandes
President
Occidental Oil Shale, Inc.
5000 Stockdale Highway
Bakersfield, California 93309
(805) 395-8567

Professor Albert G. Hill
Consultant to the President and Chancellor
Room 4-232
M.I.T.
Cambridge, Massachusetts 02139
(617) 253-1645

Dr. Christopher T. Hill
Senior Research Associate
Center for Policy Alternatives
Room E40-206
M.I.T.
Cambridge, Massachusetts 02139
(617) 253-6460

Mr. John S. Hutchins, P.E.
President
Energy Development Consultants, Inc.
2221 East Street
Golden, Colorado 80401
(303) 278-1055

Dr. Charles Kojabashian
President
Foster Miller Associates
135 Second Avenue
Waltham, Massachusetts 02154
(617) 890-3200

Prof. John P. Longwell
Department of Chemical Engineering
Room 66-554
M.I.T.
Cambridge, Massachusetts 02139
(617) 253-4534

Dr. Robert G. Lundquist
Mining Research Consultant
35 Mohegan Road
Acton, Massachusetts 01720
(617) 263-1059

Mr. Carl L. Maurer
Vice President
H.B. Zachry Company
P.O. Box 21130
San Antonio, Texas 78285
(512) 922-1213

Mr. Walter E. Morrow
Director
Lincoln Laboratory, M.I.T.
LIN-A-183
Lexington, Massachusetts 02173
(617) 862-5500 Ex. 361

Dr. Dale Nesbitt
Decision Focus Inc.
1801 Page Mill Road
Palo Alto, California 94304
(415) 494-7721

Dr. Louis L. Petrovic
President
Resource Engineering, Inc.
109 Massachusetts Avenue
Lexington, Massachusetts 02173
(617) 862-5150

Dr. Bernard L. Schulman
Director of Research
Tosco Corporation
18200 W. Highway 72
Golden, Colorado 80401
(303) 425-6021

Mr. Stanford O. Tostengard
Consultant
5006 Lymbar
Houston, Texas 77096
(713) 723-1984

Dr. James M. Utterback
Research Associate
Center for Policy Alternatives
Room E40-202
M.I.T.
Cambridge, Massachusetts 02139
(617) 253-1657

Mr. Hans Weise
North American Mining Consultants
P.O. Box 5406
Denver, Colorado 80217
(303) 770-7740

Dr. Malcolm A. Weiss
Deputy Director, Energy Laboratory
Room E40-143, M.I.T.
Cambridge, Massachusetts 02139
(617) 253-3441

Professor David C. White
Director, Energy Laboratory
Room E40-131
M.I.T.
Cambridge, Massachusetts 02139
(617) 253-3401