ECONOMIC EVALUATION OF OIL SHALE
AND TAR SANDS RESOURCES
LOCATED IN THE STATE OF UTAH

PHASE II: INTERIM REPORT
For the Period July 1, 1981, to June 30, 1982

PREPARED FOR:
DIVISION OF STATE LANDS
SALT LAKE CITY, UTAH

PREPARED BY:
STATE COLLEGE OF MINES AND MINERAL INDUSTRIES
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October, 1982
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APPENDIX
SECTION 1
Introduction

Technically accurate economic evaluation of Utah resources is essential to the future health of Utah's economy and for the sound management of Utah's lands and mineral/hydrocarbon resources. This report presents the results of the second year of research aimed at resources in the State of Utah. The system will allow the quantity, quality and economic worth of Utah's resources to be assessed. Phase I of this project was completed on June 30, 1980.* Its purpose was essentially to study and demonstrate proposed methodologies for information accessing, resource characterization, and economic evaluation. Following an interim assessment period, the Division of State Lands decided to proceed to Phase II which calls for the practical implementation of the methodologies proposed in Phase I. This program covers a two-year period. The first year was completed on June 30, 1982, and forms the substance of this interim report.

This interim report gives the status of (a) the acquisition of resource data and information, (b) the development of a data base and evaluation models, and (c) the application of these to State of Utah management issues. Application of the methodologies is expected to cut across a broad range of executive and legislative issues. A discussion of current and future work is also given. A comprehensive listing of data and programs being developed will be given in the final report of this project.

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SECTION 2
Data Acquisition

The most critical and valuable aspect of this project is the compilation of raw resource data upon which to base evaluations. The acquisition of this data has proven to be, as expected, a laborious task.

In the case of tar sands, there is no central location of data. There is no accepted method for assaying tar sands so the data that exist are often not comparable. As a result of these factors, coupled with the fact that the number of bore holes existing in tar sands deposits is quite limited, the information base is significantly inferior to the mathematical calculating capability of the evaluation models. A concerted effort is underway to bring the tar sand data base to its best possible condition in time for the completion of this project in June of 1982.

For oil shale, the acquisition of resource data has progressed more readily. Oil shale assay data have been consistently reported for about three decades in terms of the Fischer assay; thus, the data are internally consistent. Emerging technologies report process yields as related to Fischer assay. Finally, through the efforts of the U.S. Bureau of Mines at Laramie (now part of DOE), the U.S.G.S., and others, most data have been compiled in a single location. These data were accessed through a consulting sub-contract for about 140 cores and another 300 or more drill cuttings, drilled through oil shale in Utah. Considering that oil shale is much more uniform and predictable over a given aerial extent, the oil shale data are relatively more comprehensive than those for tar sands. Information from tens of thousands of Fischer assays is currently being entered into the data base and verified for accuracy of the transposition process.
SECTION 3

Development of Computer Data Base and Evaluation Model

The main thrust of research has centered around the development of a suite of computer programs designed to store and access critical information; to perform the necessary calculations for estimating the recoverable resource within specified land areas; and to evaluate this resource in terms of its economic significance as a commercial exploitation prospect. (See Figure 1.)

The complexities of this analytic sequence become apparent when one considers the wide range of possible variations in the physical and chemical character of the in-situ resources, the stratigraphical variations in the thickness of enriched zones and the depth of overburden cover, and the impacts of surface topography and infra-structure availability. It is clear that site specific evaluations cannot be accomplished purely by an automated computer process. Educated human judgmental input is required between all the interfacing components of the modular computer suite. Under these circumstances the computer can perform the tedious data storage and processing functions, thus allowing the human operator to compile meaningful results in a fraction of the time and with greater accuracy than would otherwise be possible.

The purpose of this report is to describe the progress achieved to date in the development of this integrated evaluation program, and to indicate the current thinking regarding the work proposed for the forthcoming year to bring this project to a satisfactory conclusion.

3.1 The Computer System

The computer functions are performed by a number of independent program modules connected through operator-controlled interfaces. Figure
Figure 1 shows the primary divisions within this system, where "H" represents Human input in the forms of judgement or selection of data to be passed forward to the succeeding module.

\[ \text{DATA BASE} \]

\[ H = \text{Human Input} \]

\[ \text{A RESERVES} \]

\[ \text{1. COSTING}\]

\[ \text{H EVALUATION}\]

\[ \text{LEASING & POLICY DECISIONS} \]

3.2 The Data Base Module

The foundation of the entire system is the data base module which performs the functions of storage and retrieval of information required for the resource evaluation. Provision was made in Phase I to store data with respect to land area identification (township and range) under the headings of land classification, land use, transportation, geology, oil shale and tar sand resource data, hydrology, and ecology.

Work on the data base structure and maintenance program during the period under review has been primarily directed toward improving its flexibility and simplifying the manipulation of data. A fourth data file has been added specifically for storing the voluminous bore hole and measured section sample records. The structure of the file allows
for efficient maintenance (add, delete and change functions) and facilities access by the subsidiary programs that draw upon this information.

Work is currently proceeding on reviewing other aspects of the program with a view to improving computing efficiency and operator convenience.

3.3 Reserves Module

This module deals with the calculation of the in-situ tonnage and grade of recoverable ore within any designated land area. The hydrocarbon concentration in the laminated oil shale beds is extremely variable in vertical sections, although the richest beds occur in the mahogany zone, which may extend from a few feet to 100 or more feet. It is clear that the selection of the economically optimum intercept for mining is of paramount importance. The mining width can be increased at the expense of grade, or conversely, the average grade over the intercept can be increased by reducing the mining width. The economics of oil shale exploitation depend to a large extend extent on the optimum selection of these two parameters. This can only be accomplished by repeated optimization evaluation exercises.

The reserve module is made up of five subsidiary programs which are outlined below:

3.3-a. Compositing Program: This program can work in two ways:

(1) to calculate the maximum average Fischer assay grade for a specified core intercept width, or (2) to calculate the maximum intercept width for a specified average grade.

3.3-b. Core Profile Pilot Program: This program plots the value profile in the form of a bar graph over the length of the sample core. The intercept selected by the
compositing program can be demarcated on this plot. Visual examination may show up undesirable low-grade inclusions which may indicate more suitable intercept selections. The amended intercept may then be referred back to the compositing program for re-assessment at the average value.

3-3'C. Core Location Plot Program: This program produces a geographic plot of all core holes in the general vicinity of a section of ground to be evaluated. It is helpful in selecting the source data to be used in the evaluation.

3-3-d. Variogram Program: This is a geostatistical program that determines the change in association of values (either intercept width or intercept grade) with respect to their distances apart. It is a primary tool in assessing correlations that determine the weightings to be applied to the source data used in the evaluation.

3-3-e. Kriging Program: This program calculates the average value (width or grade) for the area of ground under consideration. It should be noted that the application of point values to represent an area of ground will overestimate the average value of high-grade areas selected for mining. Kriging automatically corrects this bias. This program is still in the process of development.
SECTION 4
Cost Estimation Module

The estimation of capital and operating costs forms an important component in the evaluation process. Mining and surface treatment costs are discussed separately but they will be combined into one program for evaluation purposes.

4-1 Mining Costs

These costs include all expenditures connected with the breaking of the in-situ ore through loading and transportation up to discharge onto the primary surface stockpile. In some instances primary crushing may take place in the mine.

Mining methods may vary extensively according to the depositional characteristics of the resource. In view of the wide range of possibilities, it is clearly necessary to have a general costing system based on fundamental mining operations which can be combined to simulate different mining methods.

After careful review, it was decided to adapt the system followed by the U.S. Bureau of Mines and published in their costing handbook. A visit was paid to the Denver office of the M.A.S. Section of the U.S.B.M. in order to study their computerized application of this system. The computer methodology would be imminently suitable for our purposes. Unfortunately, the programming is hardware specific and not suitable for our installation.

A work program has now been commenced to adapt the U.S.B.M. system to the more general Fortran language and to integrate it into the computer suite being developed for the Division of State Lands. This calls for a separate data base to store basic costing information and for an inter-
active management program that will allow cost estimates to be made in a fraction of the time normally required.

4.2 Tar Sands Bitumen Recovery and Processing Costs

A determination of the cost of bitumen recovery and processing has, in the past, been difficult to ascertain due to lack of technical data. In recent years, primarily through the University of Utah tar sand research and development effort, sufficient material and energy balance data have been accumulated to afford a reasonable estimation of the economics of surface plant recovery and upgrading. It is our judgment that current in-situ recovery research is not sufficiently advanced to be considered in the economic evaluation models.

When considering the approach to recovery and upgrading, numerous options are available. For recovery of bitumen from mined ore, the following are the principal options:

- Hot water extraction
- Ambient temperature water flotation
- Thermal retorting (fluid bed, rotary kiln, etc.)
- Solvent extraction

It is not practical nor advisable for this project to build a cost evaluation model for each of these. Economic evaluation of these processes when applied to Athabasca, Canada, deposits have shown that water-based or thermal processes are economically similar while solvent-based processes are not economical in comparison.

For purposes of the state model, a water-based recovery system was chosen for the following reasons:

(a) Water-based recovery is commercially practiced in Canada and is the currently accepted method for bitumen recovery;

(b) Water-based recovery has been shown to be applicable to Utah tar sands at the pilot plant level by both GNC Energy and Enercor;
(c) There is good reason to believe that water-based technology will not require unacceptable quantities of water when compared to other technologies;

(d) Water-based recovery appears to be the most technically straight-forward providing the least technical (and therefore economic) risk of current, available options.

For bitumen primary upgrading there are also numerous options. These include:

coking
visbreaking
catalytic hydrocracking
catalytic cracking
hydropyrolysis

Of these options, the choice for the cost model was determined to be coking followed by hydrotreating of the coked product for production of sweet, synthetic crude oil. The pros and cons of this decision are as follows:

Coking - This is the accepted way of upgrading bitumen. It is the method practiced for Athabasca, Canada, bitumens. Numerous cokers are in operation in refineries for coking petroleum bottoms including the Chevron refinery in Salt Lake City. It is economical as a unit operation and no new technology needs to be developed. The process produces coke as a by-product which is generally of lower value than the syncrude product, thus, there is an economic penalty paid for coking when compared to hydrogenating processes. This factor allows room for improvement as better technology is developed and becomes more accepted.

Visbreaking - This is the least expensive option for on-site processing. However the product is not high quality and would require major retrofitting of an existing refinery.

Catalytic hydrocracking - This process is practiced commercially on a limited basis. It is a rather expensive process but the yield of syncrude is higher than in coking. Because economics for catalytic hydrocracking of tar sand bitumen are not known, the model could not use this option.

Catalytic cracking - Direct catalytic cracking of bitumen at the University of Utah has been proven to produce high quality products in greater yields than coking. However, direct catalytic cracking of bitumens is not commercially practiced and the economics are not known. Thus, this option could not be used.
Hydropyrolysis - This process is currently under development at the University of Utah and promises to provide maximum production of syncrude with little or no coke. This option holds promise for maximizing resource recovery and high utilization of the state's human and natural resources. Hydropyrolysis has not yet been proven at the pilot plant scale and economic costs have not been determined.

As a result of this considerations, a cost model was developed which included the following unit operations or cost modules:

- ore crushing
- ore conditioning
- bitumen flotation
- solvent treatment
- fines removal
- solvent recovery
- sand removal
- sand disposal
- coking
- hydrotreating
- steam reforming
- electric power generation
- electric lines
- product pipeline
- water pipeline
- roads
- storage tanks
- scrubbers
- utilities
- cooling towers
- buildings
- socio-economic costs
- working capital

A sample output of this cost model is given in the Appendix. The recovery and processing costs program can be linked to the mining model so that overall plant costs and profitability analyses can be done on a site specific basis. This is extremely important to the success of the program. The preliminary development of this integrated cost evaluation method is perhaps a key accomplishment for the current reporting period.

4.3 Oil Shale Recovery and Upgrading Costs

For oil shale recovery the number of general options is very narrow.
The most likely process sequence will be some retorting configuration followed either directly or secondarily by hydrogenative upgrading to syncrude. Within these limits, numerous technical approaches have been demonstrated at the pilot and semi-works level.

For purposes of developing an economic evaluation model with the broadest acceptance, it was decided not to consider variations of in-situ or modified in-situ recovery. These techniques have not been proven either technically or economically in sufficient detail to form the basis of an evaluation model. As a result, the model utilizes above-ground retorting and upgrading technology.

Of the various approaches to above-ground retorting technology, there is no single accepted method. A cost comparison of the various options would not be either feasible or meaningful. A search was made for relevant information. A particular study by Straam Engineers for the Bureau of Land Management provided very detailed cost data. Total costs, based on this study, however, appeared to be unrealistically low. Thus, the following strategy was devised.

From information held by Ford, Bacon and Davis, Utah, and other sources, a consensus was agreed on by project personnel which estimated the capital costs of an oil shale plant at $55,000/daily bbl capacity, in 1982 dollars. This capital cost was further broken down to 40% (or $22,000/daily bbl capacity) mine and 60% (or $33,000/daily bbl capacity) retorting, upgrading, and associated costs. The non-mine capital cost distribution based on the Straam study can be further broken down.
The cost evaluation model for oil shale retorting and processing is still under development but should be ready to tie into the mine cost model soon. The interactive nature of these modules will represent a unique, integrated approach to site specific cost evaluation. All of the assumptions made have been done on a technically and fiscally conservative basis and have been done to maximize the general acceptability of the assumptions by the industry and the state. The model makes every attempt not to underestimate the true cost of development of oil shale.

4.4 The Variable Module

The computer program used in Phase I has been considerably upgraded in effectiveness and sophistication. It now includes provision for probabilistic evaluation as well as the more conventional "best estimate" method.

A probabilistic evaluation declares the outcome in terms of a proba-
bility distribution. This enables one to specify the probability of a particular result occurring—for example, the probability that the project may be commercially acceptable. The quantification of risk in this manner adds a new dimension of knowledge which can be of considerable value in the formulation of state policy and decision making.

An example of decision making under uncertainty occurred during the past year. This involved a lease application for a tract of federal land which may possibly revert to Utah at some time in the future. It was argued that the decision depended on the probability that the land would revert to Utah and the probability that the resource on the land would support an economic operation. The latter probability was assessed by means of a statistic evaluation, while the former was assessed on political grounds. A simple bayesian type of analysis indicated a decision rationale based on the "best expectation."

Similarly, policy decisions involving leasing and taxation formulae may be compared on the basis of the "best expectation" to the State. This is computed by declaring the monies accruing to the state in the form of a probability distribution, based on the premise that the state would receive nothing for a commercially uneconomic proposition. The policy that produces the highest statistical expectation would clearly be preferable.

A work program is currently proceeding to develop this technique and to demonstrate its efficacy in relation to various hypothetical policy simulations.
SECTION 5
Application to State Issues

The primary function of the project is to provide an economic evaluation model which can be used to guide state resource management policies. The model will allow comparison of various tracts of land, their economic worth to the private sector, and, in general, allow the state to obtain an optimum return on its resource.

Because the model uses the original assay data for its primary input data there is potential for a considerably expanded output. Note that the model as it stands was built for use with the Division of State Lands and Forestry issues and in most cases additional work would be required to expand the output. Nevertheless, it is instructive to look at the breadth of issues which might make use of the model for their resolution.

5.1 Leasing Fees, Royalties and Bonuses

An assessment of what a prudent investor would be willing to pay in bonus money for a given tract of land is a direct output of the model. The impact of raising or lowering lease fees (flat fees) or royalties (production fees) on profitability can be directly and easily assessed.

5-2 Impact of Taxation or Regulation

The impact of change in tax legislation and cost of complying with regulatory requirements can be assessed through use of the model. Through imaginative thinking of the state's policy leaders, it may be possible to assist development in reducing certain front-end costs which would allow a higher rate of production revenues to the state. In such a scenario both the state and the producer benefit as a result of improved efficiency of the overall process.
5-3 **Delineation of Leasing Tracts**

The model is directly amenable to determining optimum mining and development units. Extended over all of the state's resources, the state can optimize its revenue by delineating tracts in a technically logical manner. Land ownership will constrain this optimization and the state can assess the value of sales, purchases, or exchanges on the basis of expected returns to the state. Delineation of tract boundaries often has a major impact on the value of the tract. This factor has not formally entered into most of the decisions which have resulted in the present land ownership pattern.

5-4 **Socio-economic Impact Assessment**

Of appreciable importance to the state's growth management is the socio-economic impact of development. The model has been designed to output the construction and operating work force requirements by trade. Also, the impact on project profitability for socio-economic impact mitigation costs can be assessed in a first order way. Identification of sites particularly sensitive to socio-economic impacts can also be determined to a first approximation.
SECTION 6

Conclusion

The objectives of this research program are being pursued in a diligent and constructive manner. It is anticipated that by the end of the second year of Phase II the various components will have been coalesced into a highly effective facility for evaluating the oil shale and tar sand resources in the State of Utah. There will always be scope for further development in terms of technique and application to the less prevalent situations. However, two areas of caution should be voiced at this time, namely:

no matter how sophisticated the evaluation system may be, it cannot replace the need for an adequate information base on which to operate. The evaluation of a section isolated from resource sample data will always be speculative at best. Similarly, cost data for unproved treatment technologies cannot be accepted at face value. The stochastic evaluation does have some capability to reflect these uncertainties in terms of a probability distribution.

the computer modules should be viewed as sophisticated calculators, capable of saving time and ensuring accuracy. Intelligent human input is required all along the way to provide discussion, experience and judgment. The quality of the service performed will depend largely upon the quality of this person, who should be competent in handling problems of mining engineering, process plant design, and computer application, fault finding, and maintenance.
SECTION 7

Acknowledgments

This opportunity is taken to acknowledge the assistance and friendly guidance provided by Mr. Donald G. Prince, Assistant Director of the Division of state Lands. The indispensable assistance of Mr. Howard Ritzma and the Utah Geological and Mineral Survey is also acknowledged.

It is a pleasure to acknowledge the unstinting assistance provided by the officials of the M.A.S. Section of the U.S. Bureau of Mines.

While the principal investigators have been responsible for directing the research program, the valuable contributions made by the following graduate students in the departments of Mining and Fuels Engineering should not be overlooked: John D. Gardner, Robert E. Cameron, Arnold C. Love, Ken Wong, Chris West, and J. David Dalton. A substantial in-kind contribution by the University of Utah to this project is recognized.

The use of university personnel and facilities is a most cost effective way of undertaking research of this nature. It would not be possible to achieve these objectives at similar cost in any other way.
APPENDIX A

EXAMPLE OF COST MODEL
APPENDIX A

EXAMPLE OF COST MODEL

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<td><strong>Total Capital Investment is:</strong></td>
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The 5 year depreciable portion of this capital is $1,222 million
The 15 year depreciable portion of this capital is $212 million
Annual Fixed Operating Costs Are $163 million

Sand Processing Costs ($/ton) 0.56
Bitumen Processing Costs ($/bbl) 2.04
Total Processing Costs ($/bbl) 8.50

Annual Oil Revenues $1,056 billion
Annual Electric Revenues 0.053 billion
Total Annual Revenues $1,109 billion

Revenue ($/bbl) is $33-6

CAPITAL FUNDS EXTENDED AT 1.5 YEARS ARE 196 MILLION
CAPITAL FUNDS EXTENDED AT 1.0 YEARS ARE 440 MILLION
CAPITAL FUNDS EXTENDED AT 0.5 YEARS ARE 603 MILLION
CAPITAL FUNDS EXTENDED AT 0 ARE 391 MILLION
TOTAL $1,630 MILLION