ECONOMICS, BARRIERS, AND RISKS OF OIL SHALE DEVELOPMENT IN THE UNITED STATES

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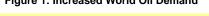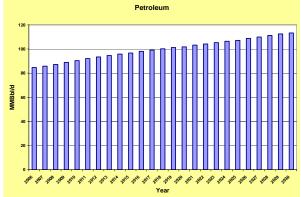Hitesh Mohan, Vice President, INTEK Incorporated

Abstract

World oil prices have nearly doubled in 2008, and have risen by 400% since 2004. Crude oil prices reached more than $145 per barrel before pulling back significantly. High oil prices, and the national security issues associated with the United States' reliance on unstable foreign sources of crude oil, have reignited interest in America's enormous domestic oil shale resources.

Oil shale is one of the world's largest known fossil fuel resources. Global resources well exceed 10 trillion barrels. More than 1.8 trillion barrels of oil are trapped in shale in Federal lands in the western United States in the states of Colorado, Utah and Wyoming, of which 800 billion is considered recoverable. This amounts to three times the proven reserves of Saudi Arabia.

During the past decade, much attention has been given to advancing various extraction technologies to make oil shale economically feasible. This paper describes many of these technologies and recent and ongoing advances. The objective of this paper is to quantify the costs and benefits of oil shale industry development and consider the hurdles to such development.

Detailed economic analysis has been conducted on the potential development of oil shale. This paper will describe the four representative production technologies being considered by companies for oil shale development. The paper will provide details of various components of capital and operating costs for each of these technologies and the price at which each of these technologies will be economic. In addition to presenting an evaluation of the economic viability of an oil shale industry, this paper also describes the costs and benefits of such an industry to local, state, and Federal governments. Measures such as jobs created contribution to Gross Domestic Product, and imports avoided will be described.

Figure 1: Increased World Oil Demand[1]

Introduction

The United States, along with the rest of the world, faces significant challenges to meet future demand for liquid fuels. These challenges are caused by rising demand for oil and other petroleum products. The world demand for petroleum is expected to continue to increase over the next twenty five years, from approximately 85 million barrels to nearly 115 million barrels per day (MMBbl/d) by 2025 (Fig. 1).

The question is where the increased supply will come from to meet the additional demand? In the past, the Organization of Petroleum Exporting Countries (OPEC) served as the world's swing oil producer. However, over the past decade, OPEC's excess production capacity has not kept pace with actual production (Fig. 2). By 2005, OPEC excess productive capacity fell to approximately one MMBbl/d. The growth in demand and the tightness of the supply has contributed to increasingly high and volatile world oil prices.

If left unaddressed, these increasing prices and tightness of supply will significantly impact the United States. The U.S. economy is highly dependent on petroleum consumption. In 2007, petroleum accounted for 39% of the Nation's energy demand[2],
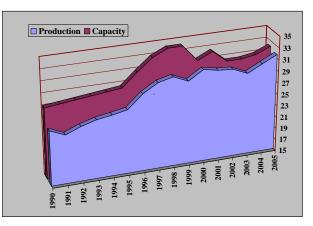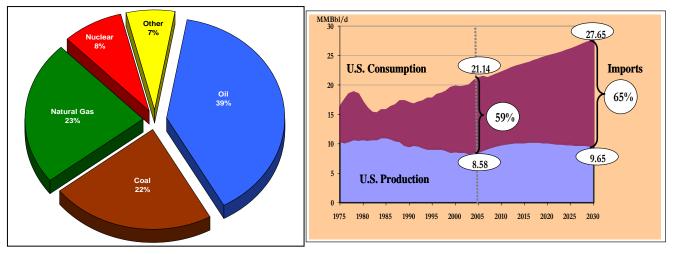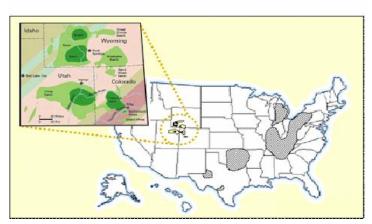

Figure 2: OPEC Excess Capacity[14]

largely to support the transportation sector (Fig. 3). The United States now faces increasing competition for world oil supplies from rapidly growing economies. This increased competition raises concern over the future reliability of liquid fuels for both military and civilian uses. In 2007, the United States consumed 21.14 MMBbl/d of petroleum and petroleum products, 12.5 MMBbl/d of which was imported. By 2030, U.S. oil consumption is forecast to grow to 27.65 MMBbl/d, of which 18 MMBbl/d will be imported (Fig. 4).

The percentage of U.S. consumption met by imports will increase from 59% to 65% by 2030. The challenge facing the United States is to locate and develop domestic sources of liquid fuels that will meet demand increases and offset the growth in imports.
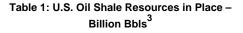
Rising world oil prices, combined with the increased need for secure alternative liquid fuel sources have spurred considerable interest in alternative fuels resources, including renewables, alternatives, and unconventional fossil fuels (including: oil shale, tar sands, coal–to–liquids, and heavy oil), as well as enhanced oil recovery. While all of these resources can contribute to U.S. liquid fuel supply, the focus of this paper is on the massive resources and significant potential of the U.S. oil shale deposits, particularly in the Western states.

Oil Shale Resources

U.S. oil shale is carbonate rock, generally marlstone that is very rich in organic sedimentary material called "kerogen." Oil shales are "younger" in geologic age than crude oil-bearing formations; natural forces of pressure and temperature have not yet converted the sediments to crude oil. Kerogen can be used to create superior quality jet fuel, #2 diesel, naphtha, and other high value by-products. The amount of kerogen in "oil shale" ore can range from 10 to 60 or more gallons per ton[3] of shale. The most concentrated hydrocarbon deposits on earth are found in America's western oil shale resources. It is estimated that the total amount of oil shale resource in the United States is over 6 trillion barrels of oil equivalent[3]. This resource has already been identified and extensively characterized. Table 1 displays the richness of the various oil shale deposits in the United States. Yields greater than 25 gallons per ton (gal/ton) are generally viewed as the most economically attractive, and hence,

Figure 5: Principal Oil Shale Deposits in the Western United States[4]

Table 1: U.S. Oil Shale Resources in Place – Billion Bbls[3]

Deposits	Richness (Gallons/ton)		
Location	5 - 10	10 - 25	25 - 100
Colorado, Wyoming & Utah (Green River)	4,000	2,800	1,200
Central & Eastern States	2,000	1,000	NA
Alaska	Large	200	250
Total	6,000+	4,000	2,000+

the most favorable for initial development. Of the 6 trillion barrels of resource in place, over 2.0 trillion barrels have yields greater than 25 gal/ton[3]. The majority of this high-quality resource, 1.2 trillion barrels, is located in the Green River Formation. This region underlies 17,000 square miles or 11 million acres in the Piceance (CO), Uinta (UT), Green River, Washakie (WY), and Sand Wash (CO) Basins (Fig. 5).

About 73 percent of the lands that contain significant oil shale deposits in the west are owned and managed by the U.S. Government. These lands contain about 80 percent of the known recoverable resource in Colorado, Utah, and Wyoming. Private company ownership of oil shale lands totaled about 21% of the Piceance Basin (Colorado), 9% of the Uinta Basin (Utah), 24% of the Green River Basin (Wyoming), and 10% of the Washakie Basin (Wyoming)[3] as of 1978.
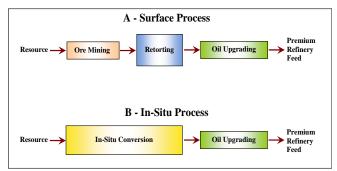
Oil Shale Technology

Oil shale rock must be heated to temperatures between 400 and 500 degrees centigrade (650-750 degrees fahrenheit). This heating process is necessary to convert the embedded sediments to kerogen oil and combustible gases. Over the past 60 years, energy companies and petroleum researchers have developed, tested, enhanced, and in many cases, demonstrated a variety of technologies for recovering shale oil from oil shale and processing it to produce fuels and byproducts. Both surface processing and in-situ technologies have been examined. Generally, surface processing consists of three major steps: (1) oil shale mining and ore preparation, (2) pyrolysis of oil shale to produce kerogen oil, and (3) processing kerogen oil to produce refinery feedstock and high-value chemicals. This sequence is illustrated in Figure 6-A. For deeper, thicker deposits, not as amenable to surface or deep-mining methods, the kerogen oil can be produced by in-situ technology. In-situ processes minimize, or in the case of true in-situ, eliminate the need for mining and surface pyrolysis, by heating the resource in its natural depositional setting. This sequence is illustrated in Figure 6-B[4].

The U.S. Department of Energy, Office of Naval Petroleum and Oil Shale Reserves (NPOSR), has recently published a comprehensive report detailing oil shale conversion technologies[5]. This report describes the technologies being pursued by 27 different companies in the United States. Figure 7 provides a listing of the companies currently pursuing oil shale technology in the design phase, laboratory, or pilot testing.
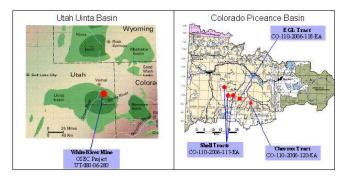
Figure 6: Oil Shale Recovery Processes[5]

Figure 7: Companies with Oil Shale Technologies[5]

RD&D Leasing Program

In response to the President's National Energy Policy in 2003, the Department of the Interior's Bureau of Land Management (BLM) prepared a report[6] and a plan to address access to unconventional resources (such as oil shale) on public lands. The report also included a plan for addressing impediments to oil shale development on public lands, industry interest in research and development and commercial development opportunities on public lands, and, options to capitalize on those opportunities.

On November 22, 2004, the BLM published a proposed oil shale lease form and request for information in the *Federal Register*[7] to solicit comments about the design of an oil shale program. Based on its findings and responses to the Federal

Register notice**,** the BLM determined that offering Research, Development, and Demonstration (RD&D) leases prior to issuing commercial leases would facilitate economic and technology demonstration, provide an opportunity to better understand the environmental impacts, and then gauge the 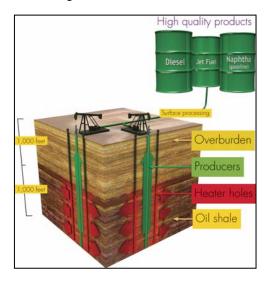effectiveness of mitigation measures. The BLM RD&D lease program allows tracts of up to 160 acres to be used to test or demonstrate the economic feasibility of technologies over a lease term of 10 years, with an option for up to a 5-year extension. The payment of royalties is waived during the RD&D lease and the rental fee is waived for the first 5 years. Lessees that demonstrate successful technology may reserve an additional contiguous 4,960 acres for a preference right commercial lease.

Figure 8: Location of Oil Shale RD&D Leases[15]

The BLM received 19 nominations in response to its June, 2005 oil shale RD&D lease announcement. On December 15, 2006, Chevron Shale Oil Company, EGL Resources, Inc., and Shell Frontier Oil & Gas were awarded leases (three to Shell). A sixth lease was later granted to Oil Shale Exploration, LLC (OSEC). The Chevron, EGL, and Shell leases are located on BLM lands in Colorado, while the OSEC lease involves parcels in Utah. Five of the projects selected involve in-situ retorting (Fig. 8). A brief description of these technologies is provided below[8].

- **Chevron Oil Shale Company, USA.** Chevron's technology for the recovery and upgrading of oil from shale (CRUSH) process is an in-situ conversion process. This process involves the application of a series of fracturing technologies which rubblize the formation, thereby increasing the surface area of the exposed kerogen (Fig. 9). This exposed kerogen in the fractured formation is then converted through a chemical process resulting in the kerogen changing from a solid material to a liquid and gas. The hydrocarbon fluids are then recovered and improved to refinery feedstock specs[5].

- **American Shale Oil, LLC (AMSO).** AMSO has developed a new process for in-situ retorting of Green River oil shale. The AMSO Oil Shale Process (patent applied for) involves the use of proven oil field drilling and completion practices coupled with AMSO's unique heating and recovery technology (Fig. 10). The AMSO approach is a closed loop in-situ retorting process with advantages of energy efficiency and manageable environmental impacts. The oil shale is heated with superheated steam or other heat transfer medium through a series of pipes placed below the oil shale bed to be retorted. Shale oil and gas are produced through wells drilled vertically from the surface and "spidered" to provide a connection between the heating wells and production system. Convection and refluxing are mechanisms that improve heat trans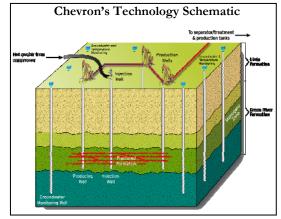fer to retort the oil shale. After initial start-up, the process uses the gas produced from retorting to supply all the heat required to extract the shale oil and gas from the deposit. Surface disturbance is minimized with this process by heating through lateral piping. Energy efficiency is optimized by recovery of heat from the shale rock after retorting is completed[5].

Figure 9: Chevron's CRUSH Technology[5]

Figure 10: AMSO Resources Process[5]

Figure 11: Shell's ICP Process[5]

- **Shell Frontier Oil & Gas Inc.** Shell's innovative In-situ Conversion Process generates more oil and gas from a smaller surface pad area than previous oil shale processes (Fig. 11). Shell's Conversion Process does not involve surface mining. Rather, heaters are inserted underground to convert kerogen in oil shale into high quality transportation fuels. In the Shell ICP process: 5: Electric heaters gradually heat shale beneath the surface at target depths typically from 1,000 to 2,000 feet; the rock formation is heated slowly over time to 650 to 750° F, changing the kerogen in oil shale into oil and gas; products are pumped to the surface using traditional methods. The process produces approximately one third gas and two thirds light oil. Fewer processing steps are required than in surface processes to produce high quality fuels.

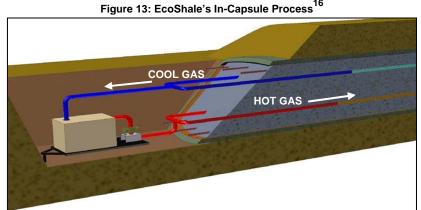- **Oil Shale Exploration Company, LLC.** OSEC has tested the Alberta Taciuk Process (ATP), a horizontal rotating kiln process, for development of Utah oil shale. OSEC has arranged for an exclusive right from AECOM, a worldwide engineering firm, to license the ATP Process for purposes of research, development and demonstration on the BLM lease at the White River Mine south of Vernal, Utah. The ATP Process is a unique thermal processing technology, applicable to numerous industrial uses, for vaporizing and recovering organic constituents

Figure 12: Oil Shale Exploration's Alberta Taciuk Process (ATP) Retort[5]

that exist in a large range of feedstock materials (Fig. 12). Developed in 1976, the ATP Process was originally designed for treating Alberta oil sands and was later refined for use in oil shale and contaminated waste treatment options. According to OSEC, the ATP Process has been successfully used in a project in Stuart, Australia which produced more than 1.5 million barrels of shale oil. OSEC believes that the ATP Process is a proven, environmentally-sound, economic and efficient process for extracting oil from oil shale and oil sands[5]. OSEC has also recently entered into agreements to test Petrobras's PetroSix vertical Gas Combustion Retort technology.

In addition to the technologies being tested as part of the RD&D program, an additional technology is currently being field tested. **The EcoShale In-Capsule Process** is an innovative new approach to oil shale processing that is being developed and tested by Red Leaf Resources, Inc. in the State of Utah. Red Leaf's Eco-Shale is a hybrid approach that integrates surface mining with a lower-temperature, "roasting" method that occurs in an impoundment that is constructed in the void space created by the shale mining excavation (Fig. 13). When filled with shale, the capsule is heated using pipes circulating hot gases derived from burning natural gas or

Figure 13: EcoShale's In-Capsule Process[16]

its own produced gases. By using an impoundment engineered with an impermeable barrier, RedLeaf expects tailings to be sequestered and ground water to be protected. To maximize energy efficiency, the process heat used in one capsule can be recovered by circulating lower temperature gases which transfer remaining heat into adjacent capsules. External energy inputs are limited to process initiation, thereafter produced gases supply most of the energy for shale heating. The EcoShale In-Capsule process's lower-temperature, slower "roasting" approach also minimizes CO_2 emissions and is amenable to carbon capture and sequestration. The unique impoundment approach allows for rapid reclamation and approximate restoration of the topography.
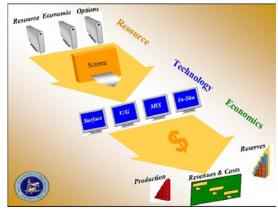
Oil Shale Development Economics

The potential for oil shale production and the resulting benefits to the national economy are discussed in the section. The results presented are not intended to be a forecast of what will occur. Rather, they represent estimates of potential under certain economic, technological, and market assumptions and constraints.

Analytical Approach

The U.S. Department of Energy (DOE) has developed a new National Oil Shale Model[9]. This analytical system was developed to evaluate potential U.S. oil shale development under different economic and public policy regimes. This model has the capability to perform sensitivity analyses relative to price, tax, royalty and incentives, perform cash flow analyses under alternative leasing options and evaluate costs and benefits of various public policy options to stimulate oil shale project investment. (Figure 14). The model consists of three parts: a detailed resource module, technology screening module, and a detailed economic module.

Figure 14: DOE's National Oil Shale Model[9,10]

- **The Resource Module** contains detailed petrophysical and geological characterestics for 25 development tracts in the states of Colorado, Utah, and Wyoming. Seventy billion barrels of resource in place are collectively found in these tracts. Characteristics of these 25 tracts were studied in detail as part of the 1973 Department of Interior Prototype Oil Shale Leasing Program. Because of prior industry nomination, it is assumed that these tracts represent locations of commercial interests. These nominated tracts therefore provide a solid technical basis for the present analysis.

- **Screening Module:** Screening criteria for various technologies were developed based on the geological characteristics such as depth, dip angle, yield and thickness of the resource. The technologies considered are: 1) Surface mining with surface retorting, 2) Underground mining and surface retorting, 3) Modified In-Situ (MIS), and 4) True In-Situ (TIS) similar to Shell's ICP process. Each of these 25 tracts was screened for each of the above technology options. Each tract was then assigned the most appropriate technology and evaluated under the specific process. Each tract was also assigned a specific development schedule based on the type of technology applied.

- **Economic Module:** The production forecasts, predicted for each tract (based on its development schedule), are used in the economic model for cash flow analysis. The economic model estimates annual and cumulative cash flow before and after taxes, capital costs, operating cost, transfer payments (royalties), revenues, and profits. The tracts that meet the economic hurdles are then carried forward and results are aggregated to national total. The economic model has average capital and operating costs based on technology and development schedule over the life of the project. The different technologies used for mining, retorting, and upgrading were considered in the components of the costs.

In addition to estimating benefits at the national level, the model also estimates a number of economic benefits at state levels. The benefits to local, state, and Federal treasuries are attributed to the implementation of economically feasible projects over the next 25 years. These benefits include: 1) Direct Federal Revenues; defined as the sum of business taxes as well as one-half of royalty payments on oil shale production from Federal lands, 2) Direct State Revenues; defined as the sum of business taxes, production taxes, as well as one-half of royalty payments on oil shale production from Federal lands, and 3) Direct Public Sector Revenues; defined as the sum of the Direct Federal and Direct State Revenues.

Oil shale production can benefit the nation as a whole on many levels. For example, each additional barrel of domestic production can replace a barrel of oil imports. and reduce the trade deficit by the cost of that barrel. To estimate the direct effects on the GDP (excluding the multiplier effect and potential negative impacts on other domestic export industries), the model uses the gross revenue from the potential oil shale production, inclusive of oil, natural gas, and ammonia. Similarly, the value of potential production is used to measure the impact on the trade deficit. The model also estimates potential employment associated with the oil shale projects. Labor costs (wages and fringe benefits) are calculated by isolating the labor component of all major cost elements. Labor costs are then converted into estimated annual employment using average wages (including benefits) for comparable industries as reported by the U.S. Department of Labor.

Project Costs

Oil shale projects, on a commercial scale, could range in size from 10,000 to 100,000 barrels per day (Bbl/d) for a surface retort to as much as 300,000 Bbl/d for full-scale in-situ projects. The capital and operating costs will vary depending on the process technology and the quality of the resource. The model estimates the operating costs to be in the range of $12 to $20 per barrel ($/Bbl) of shale oil produced. The capital costs are estimated to range from $40,000 to $55,000 per stream day barrel of daily capacity[10]. Mining (or drilling), retorting, and upgrading are also included in these costs. It is important to note that these costs pertain to fully operational first generation projects; They will change with time as technologies matures.

Minimum Economic Price

The minimum economic price is defined as the world crude oil price needed to yield a 15% rate of return (ROR) on the

project. The 15% ROR is to cover the cost of capital and the technical and financial risk on the project. Depending on the technology used, and the quality of the resource, the minimum economic price for oil shale projects is variable. Under the assumptions utilized in this analysis, the model estimates that for a mature 100,000 Bbl/d capacity plant, the average minimum economic prices are $38/Bbl for True In-Situ, $47/Bbl for Surface Mining, $57/Bbl for Underground Mining, and $62/Bbl for Modified In-situ. While these estimates are highly sensitive to both technological and economic assumptions, discussions with industry have proven these estimates reasonable. A rationale for these estimates is provided in Reference 10.
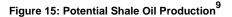
Potential Shale Oil Production

The production potential of the 25 tracts (70 billion barrels of resource in place) was measured in three development scenarios. These scenarios are: 1) Business as usual scenario (BAU) -- assumes no changes to current law and that future oil prices remain in the range of high $40s to $60/Bbl as predicted by the Energy Information Administration (EIA) in its 2006 Annual Energy Outlook (Reference Price Track)[1], 2) The Tax incentive scenario, assumes targeted tax incentives are available until project payback to encourage investments. Examples are price guarantees and production tax credit, and 3) The RD&D scenario assumes limited public support for R&D and field demonstration projects at commercially viable scale to reduce project risk. *These scenarios were selected for sensitivity analysis purposes, and are not intended to be policy recommendations.*

Under the BAU scenario, shale oil production could reach 500,000 Bbl/d by 2020 and would remain steady through 2035 (Fig. 15). With targeted tax incentives, shale oil production could reach 1.5 MMBbl/d by 2035 as shown in Fig. 15. Risk reduction through RD&D could have a significant positive impact on future shale oil development in the United States. RD&D projects would work to accelerate the rate of oil shale development. With successful RD&D, it is estimated that the oil shale production could reach 2.4 MMBbl/d by 2025. It is important to note that because oil shale project development requires long lead times, no significant production is expected until 2015 under any of the three analyzed scenarios.

In addition to shale oil, a significant quantity of hydrocarbon gas could also be produced. Gas production varies as a percentage of total production depending on the surface retorting or in-situ technology; however, gas production could reach as much as 3.2 billion cubic feet per day (BCF/d). Although a significant quantity of produced gas could be consumed within oil shale facilities for process heat, power generation, or other process requirements. Alternatively, much of this gas could be upgraded to pipeline quality and contribute to meeting regional and national natural gas demands (Fig. 16).

Economic Benefits

The potential economic benefits associated with the oil shale development activities for the three analyzed scenarios are summarized in Table 2. These estimates reflect the benefits cumulated over the next 30 years. Cumulative shale oil production could reach 12.8 billion barrels. This level of
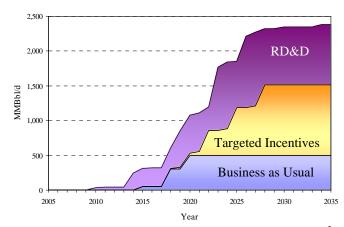

Figure 15: Potential Shale Oil Production[9]

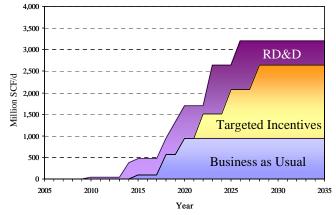Figure 16: Associated Natural Gas with Shale Oil Production[9]

Table 2: Example Benefits of Oil Shale Development
(Cumulative Over 30 Years)[9]

Item	Unit	Business as Usual	With Targeted Tax Incentive	With RD&D
Production	Billion Bbls	3.2	7.4	12.8
Direct Federal Revenues	Billion $	15	27	48
Direct Local/State Revenues	Billion $	10	21	37
Direct Public Sector Revenues	Billion $	25	48	85
Contribution to GDP	Billion $	310	770	1300
Value of Imports Avoided	Billion $	70	170	325
New Jobs	FTE (Thousand)	60	190	300

production could generate an additional $15 billion to $48 billion of Direct Revenues to the Federal treasury. Direct State Revenues could increase by as much as $37 billion across the analyzed scenarios. The contribution to GDP is estimated to be between $310 billion and $1.3 trillion. The value of imports avoided due to domestic production could reach $325 billion over the next 30 years. The impact on employment is also significant. It is estimated that up to 300,000 new high paying jobs could be generated in support of oil shale development.

Oil Shale and the Environment

Land Use and Surface Impacts
The technology that will be used to mine and produce oil shale is dependent on depth, thickness, richness, and accessibility of the deposit. Deeper and thicker beds will likely be produced in-situ. A combination of approaches will likely be used in the western U.S. basins. Various land impacts are associated with each type of oil shale processing. Open-Pit (surface) mining involves significant surface disturbance and can impact surface-water runoff patterns and subsurface water quality. Experience in coal mining and other mining industries has demonstrated that impacted lands can be very effectively reclaimed with minimal long-term effect.

In 1972, the Department of the Interior estimated the cumulative surface area impacted by a domestic oil shale industry, over a 40 year period, would be approximately 31 square miles per million barrels of daily shale oil production capacity. The Department of Interior has also estimated that the cumulative surface area impacted by a domestic oil shale industry, over the same 40 year period, would be approximately 21 square miles per 1.5 MMBbl/d capacity for an In-situ processes. In total, a 2.5 MMBbl/d industry would impact approximately 0.5% of the surface area overlaying the Green River Formation[12].

Air Quality Impact
Oil shale is a carbonate rock that, when heated to 450 to 500 degrees centigrade, creates kerogen oil and hydrocarbon gases along with a slate of other gases, that may include: (1) oxides of sulfur and nitrogen, (2) carbon dioxide, (3) particulate matter, and (4) water vapor. Commercially available stack gas clean-up technologies that are currently in use in electric power generation and petroleum refining facilities have improved over the years and should be effective in controlling oxides and particulates emissions from oil shale projects. Carbon dioxide (CO_2) will also be produced in large quantities and may need to be captured for use in other commercial applications (such as enhanced oil recovery or coalbed methane operations), or otherwise sequestered. Depleted oil and gas reservoirs in the region provide potentially effective sequestration targets[12].

Water Requirements
The water required for oil shale retorting is estimated at one to three barrels of water per barrel of shale oil. Still, some processes may be net producers of water. For an oil shale industry producing 2.5 MMBbl/d, this equates to between 105 and 315 million gallons of water per day (MGD). A 2.5 MMBbl/d oil shale industry would require 0.18 million to 0.42 million acre feet of water per year, depending on location and processes used.

In the West, water will be drawn from local and regional sources. The major water source is the Colorado River Basin, including the Colorado, Green, and White Rivers. The Colorado River flows between 10 and 22 million acre feet per year. Water may also be purchased from other existing reservoirs. In addition, transfers may be possible from other water basins, including the Upper Missouri. Another water source will come from western oil shale itself, which has high water content. Oil shale typically holds 2-5 gallons of water per ton, though some oil shale can contain as much as 30-40 gallons of water per ton. Much of this connate water can be recovered during processing and used to support mining, disposal, or reclamation operations. Though this produced water will contain organic and inorganic substances, the impurities can be removed with conventional water treatment technologies. Recycling and re-use of process water will help to reduce water requirements[13]. Produced water from other conventional and unconventional oil and gas operations may also provide a water source.

Limitation of the Economic Analysis

The economic analysis presented in this paper has important limitations that should be considered before using its results. These limitations include:

- The results pertain only to the 25 Federal tracts analyzed. These tracts collectively account for about 70 billion barrels of oil shale resource in the states of Colorado, Utah, and Wyoming. No extrapolation was attempted to include the balance of the resource in these three states. The analysis makes the assumption that these tracts are accessible for development.
- The analysis assumes that current technologies are successfully demonstrated to be viable at commercial scale over the next five to ten years. To the extent that this is not achieved, the development of the resource will be impeded.
- The analysis assumes that the environmental permitting process for the oil shale projects could be completed within three to five years. To the extent that the permitting process is not streamlined, and additional time is required, the timing of the oil shale production will be impacted.

- The analysis is based on the AEO 2006 oil price projection (Reference Price Track) over the next 25 years. To the extent that the prevailing oil prices over this period are different from the AEO projections, the estimated benefits will be different from the level shown in this paper. Moreover, the BAU case analysis assumes an average minimum rate of return of 15 percent by operators. To the extent that different operators may require differing return on their investments, the potential benefits in this analysis may be overestimated or understated.
- The economics are based on the use of average costing algorithms. Although developed from the best available data and explicitly adjusted for variations in energy costs, they do not reflect site-specific cost variations applicable to specific operators. To the extent that the average costs (used) understate or overstate the true project costs, the actual results will be impacted accordingly.
- The estimates of potential contribution to GDP, values of imports avoided, and employment do not take into account potential impacts to other sectors of the U.S. economy from altering trade patterns. It is possible that reduction in petroleum imports, depending on where the petroleum was coming from, could reduce the quantity being exported of some other good. It is likely, however, that such effects would be small.
- The analysis assumes that operators have access to capital to start and sustain the oil shale projects. The oil shale projects are typically characterized as "capital intensive" and have longer payback period relative to oil and gas development projects. To the extent that capital is constrained, then the potential benefit estimated in this report is overestimated.

None of the above limitations, however, invalidate the results in this analysis if they are viewed for what they are intended for, which is an estimate of *upside potential*. Given the uncertainty of the size and combinations of the optimistic and pessimistic biases introduced by these limitations, it is assumed that the approach is valid, and the estimates are reasonable, again for what they are intended.

Conclusions

The U.S. oil shale resources are the most concentrated hydrocarbon deposits on earth, with over two trillion barrels of high quality resource in place. Rapidly advancing conversion technologies, high oil prices, rising world demand for liquid hydrocarbons, and the continued decline of U.S. conventional oil production, have all recently attracted significant attention to the development of the oil shale resource. Currently, twenty seven companies are actively pursuing the development of oil shale conversion technologies with significant progress. The development of this resource could have a significant positive impact on the local, state, and national economy by means of revenues, royalties, contributions to GDP, the value of avoided oil imports, and a possible production rate of about 2.4 MMBbl/d. Collaborative efforts are needed among local, state, and Federal Governments, along with the private sector to encourage the development of this very important strategic resource.

Acknowledgements

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