TOPIC PAPER #27

OIL SHALES

On July 18, 2007, The National Petroleum Council (NPC) in approving its report, *Facing the Hard Truths about Energy,* also approved the making available of certain materials used in the study process, including detailed, specific subject matter papers prepared or used by the Task Groups and their Subgroups. These Topic Papers were working documents that were part of the analyses that led to development of the summary results presented in the report's Executive Summary and Chapters.

These Topic Papers represent the views and conclusions of the authors. The National Petroleum Council has not endorsed or approved the statements and conclusions contained in these documents but approved the publication of these materials as part of the study process.

The NPC believes that these papers will be of interest to the readers of the report and will help them better understand the results. These materials are being made available in the interest of transparency.

The attached Topic Paper is one of 38 such working document used in the study analyses. Also included is a roster of the Subgroup that developed or submitted this paper. Appendix E of the final NPC report provides a complete list of the 38 Topic Papers and an abstract for each. The printed final report volume contains a CD that includes pdf files of all papers. These papers also can be viewed and downloaded from the report section of the NPC website (www.npc.org).

NATIONAL PETROLEUM COUNCIL

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OF THE
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Oil Shale

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I. Executive Summary

Oil shale comprises a host rock and kerogen. Kerogen is organic matter that has not gone through the "oil window" of elevated temperature and pressure necessary to generate conventional light oil. Kerogen has a high hydrogen-to-carbon ratio, giving it the potential to be superior to heavy oil or coal as a source of liquid fuel. Globally, it is estimated that there are roughly 3 trillion barrels of shale oil in place, which is comparable to the original world endowment of conventional oil. About half of this immense total is to be found near the common borders of Wyoming, Utah, and Colorado, where much of the resource occurs at a saturation of more than 25 gallons of product per ton of ore (about 10% by weight) in beds that are 30 m to 300 m thick. Like heavy oil reservoirs, oil shales are found near the surface, ranging from outcrops down to about 1,000 m.

In the past, the most common production technology has been surface mining, followed by processing in above-ground retorts. Process temperatures are about 500°C, which converts kerogen to oil in about an hour. This approach has the virtue of simplicity, but requires expensive surface facilities, and the disposal of vast quantities of spent rock. Both have significant economic and environmental problems. Moreover, raw product quality is poor compared to conventional crude oil; however upgrading using conventional hydroprocessing techniques yields high-quality finished products.

The mining + retort method is an old approach that could benefit from new technology. Improved methods for spent shale remediation would clearly make this approach more acceptable. Improved retorting methods are also a priority.

Innovations that allowed oil shale to be processed at lower temperature without an increase in reaction time would result in improved economics and improved product quality.

An alternative process still in development, in situ conversion, has captured the industry's attention. Wells are drilled, and the oil shale reservoir is slowly heated to about 350°C, at which point kerogen is converted to oil and gas on a time scale of months. Using an in situ conversion process at pilot scale, Shell has extracted a good quality, middle-distillate refinery feedstock, requiring no further upgrading. In order to contain nascent fluids, and to prevent ingress of ground water into the reaction zone, Shell generates a freeze wall around the production area. Chevron has proposed a simpler technique that takes advantage of the low hydraulic permeability of oil shale formations to isolate heated process volumes from surrounding aquifers.

Since in situ conversion technology is just emerging, it is not yet clear which specific technologies can advance the state of the art over the coming decades. However, the efficient use of heat is almost certain to be an important issue. The ability to map the temperature and the saturation of generated oil and gas throughout the reservoir would enable advanced control strategies. It will also be useful to monitor the freeze wall or low permeability barrier, to ensure that there is no fluid mixing between the reaction zone and surrounding formations.

As a domestic source of transportation fuel, oil shale could compete with heavy oil and coal-derived liquids. Oil shale, heavy oil, and coal are all abundant in North America. Canadian tar sand production is already commercial. Coal can be treated with coal-derived solvents and gaseous hydrogen at high temperature to produce high grade synthetic crude. An advantage of oil shale is that it has the potential to produce a superior liquid-fuel product. However, the direct and indirect costs of fuel production from oil shale have not yet been fully evaluated.

II. Overview of Methodology

Recent reports on oil shale research and development
"Survey of Energy Resources: Oil Shale," World Energy Council (2001).
"Strategic Significance of America's Oil Shale Resource," Department of Energy (March 2004).
"America's Oil Shale: A Roadmap for Federal Decision Making," Department of Energy (December 2004).
"Resources to Reserves: Oil & Gas Technologies for the Energy Markets of the Future," International Energy Agency (2005).
"Oil Shale Development in the United States," RAND Corporation (2005).
"Oil Shale: History, Incentives, and Policy," Congressional Research Service (April 2006).
"Geology and Resources of Some World Oil Shale Deposits," Scientific Investigations Report 2005-5294, U.S. Geological Survey (June 2006).

Shell test project reports
Submissions to Bureau of Land Management, reports available at http://www.co.blm.gov/wrra/WRFO_Oil_shale.htm:
- "Plan of Operations: Oil Shale Test Project," Shell Frontier Oil and Gas Inc. (15 February 2006).
- "Environmental Assessment: Shell Oil Shale Research, Development & Demonstration Projects, Rio Blanco County, Colorado, August 2006."

Chevron test project reports
Submissions to Bureau of Land Management, reports available at http://www.co.blm.gov/wrra/WRFO_Oil_shale.htm:
- "Plan of Operations: Oil Shale Research, Development & Demonstration Project," Chevron USA (15 February 2006). Available at http://www.co.blm.gov/wrra/documents/OILSHALEPLANOFOPERATIONS.pdf.
- "Environmental Assessment: Chevron Oil Shale Research, Development & Demonstration," CO-110-2006-120-EA (August 2006).

III. Background

A. Geology and History

The term "oil shale" is a misnomer on two counts. Firstly, the mineralogy of these deposits is not always clay- or shale-rich. Some of the most important deposits in the western United States are carbonate-dominated. Secondly, the organic phase is not oil, but kerogen that has never been exposed to the temperatures and pressures required to convert organic matter into oil. Heavy oils, by contrast, are true oils produced at high temperature, and later degraded by microbial and chemical activity at lower temperature. Heavy oil tends to be deficient in hydrogen, a problem not shared by oil shale.

Oil shale is abundant in many parts of the world; Table IIIA.1 is a list of nations with the largest resources. The use of oil shale as a source of mineral oil dates back to the sixteenth century; a brief history is available online.[1] A number of small oil shale retorting plants were built in the nineteenth and twentieth centuries, a few for commercial production, but the majority for test and development purposes. The DOE has published an international survey of availability.[2]

Country	Recoverable Resources (billion bbls)
United States	626
Brazil	300
Russia	41
Zaire	38
Australia	17
Canada	16
Italy	13

[1] "Oil Shale", *Encyclopedia Britannica Online* (2006). Available at www.britannica.com.
[2] "Strategic Significance of America's Oil Shale Resource," Department of Energy (March 2004), Volume II, Section 2.1.

China	10
Total world	**1,067**

Table IIIA.1. Recoverable shale oil resources of the world (37.5 percent of estimated in-place resource).[3]

In view of the immense potential of the resource in Colorado, Utah, and Wyoming (Figure IIIA.1), oil shale has been subject of Congressional interest. It was identified as a U.S. naval petroleum reserve in 1910, and was incorporated into national energy planning during World War II and the Korean War, and during the oil price shocks of the 1970s. A comprehensive legislative history is available from the Congressional Research Service.[4] Responding to price signals and government incentives, private enterprise initiated several large pilot projects in the 1970s and 1980s. However, these efforts were terminated as a result of falling conventional oil prices, the realization that retorting methods were expensive and produced low quality feedstock requiring further upgrading, and the termination of development incentives.

[3] *Encyclopedia Brittanica*, reference 1, which includes data from *Oil & Gas Journal*, USGS, AAPG.
[4] "Oil Shale: History, Incentives, and Policy," Appendix, Congressional Research Service (April 2006).

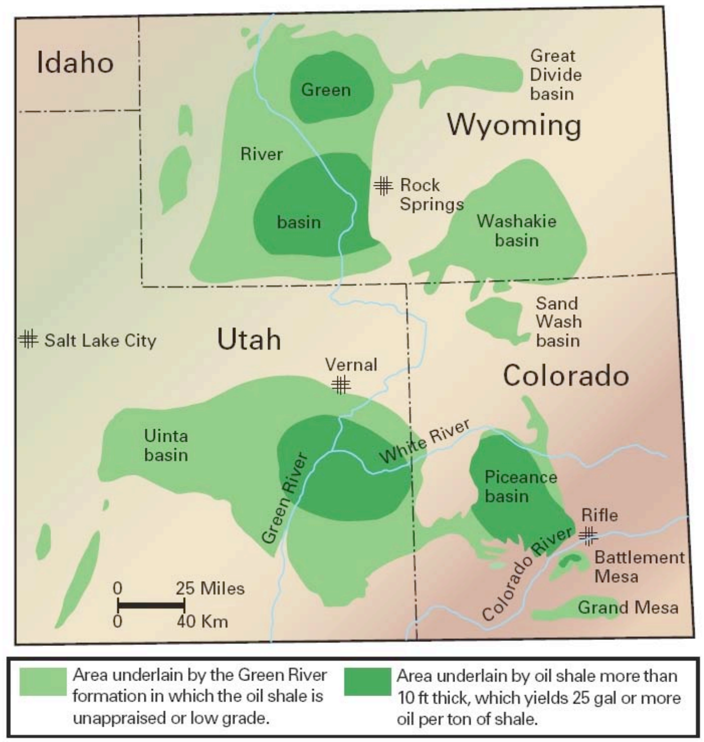

Figure IIIA.1. Oil shale resources of Wyoming, Utah and Colorado .[5]

B. Mine and Retort Approach

Until and through the 1980s, the preferred method for exploiting oil shale was to mine it, either from the surface, or via the room-and-pillar method. The ore was then sent to retorts that used high temperatures to extract product at an economically viable rate. A careful review of this approach is provided elsewhere.[6]

The economics of surface mining depends on depth of the deposit below the surface, the thickness of the deposit, and the presence of ground water. As with other such resources, there is an economy of scale and, if implemented in the United States, oil shale mines are projected to be among the largest of any type in the world. The development of such mines would have to clear significant regulatory hurdles. Room-and-pillar mines have less surface impact, but are inefficient in the thickest oil shale

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[5] Bunger JW, Crawford PM, and Johnson HR: "Is oil shale America's answer to peak-oil challenge?" *Oil & Gas Journal* (9 August 2004).
[6] "Oil Shale Development in the United States," RAND Corporation (2005).

seams. In both cases, spent oil shale is inconveniently left on the surface at the end of the process.

Oil shale kerogen is the source of the conventional crude oils that have been produced over millions of years of slow and relatively gentle heating in the "oil window" below 200°C. As of the early 1980s, the state of the art was to accelerate the conversion of kerogen to oil in surface reactors. Economic viability dictates that this process take no more than about an hour, requiring a process temperature of around 500°C. This retort process leads to significant hydrocarbon degradation, and the product must be further upgraded before it is an acceptable refinery feedstock or finished commodity.

There is broad recognition that the retort methods used in the 1970s and 1980s will not enable oil shales to compete with other fossil fuel resources in the future. New approaches are needed, and in recent years two have been introduced.

The Alberta Taciuk Process was developed in Canada for extracting bitumen from oil sands. This method was adapted for use with Australian oil shale in the 1990s. It appears to be more suitable for sandy Queensland oil shales than for western U.S. shales. The Stuart Oil Shale Project, which produced 4,500 bbl/d in a pilot plant using this process, was judged a technical success, but was suspended in 2004.[7]

Oil Tech Inc. has announced a second approach involving innovations in retort architecture that they claim improve the product quality and economics of the retort method. Details are available at the company's web site.[8]

C. *In Situ Conversion Process*

The in situ conversion process uses the oil shale reservoir itself as a giant retort. Conversion from kerogen to oil takes places over months, allowing the use of relatively low temperatures. Shell uses temperatures around 350°C, which is above the oil window maximum of 200°C, but still low enough to avoid significant product degradation.

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[7] Department of Energy, Volume II [reference 2].
[8] Available at www.oiltech.com.

The in situ process produces a superior hydrocarbon mix, consisting of one-third propane and butane, with the balance a moderately low-sulfur 34°API mix of 10% naphtha, 40% kerosene, 40% diesel, and 10% heavy residual oil. By contrast, the conventional surface retort product is 20°API or below.[9]

The economics of the in situ process depends on the efficiency with which the kerogen can be heated to reaction temperature. In the Piceance Basin, Shell uses electric heaters in boreholes. This allows good measurement and control of heat distribution for experimental purposes, but is probably not the most efficient method for raising the temperature of the reservoir.[10]

Chevron has also proposed an in situ conversion process for use in the Piceance Basin.[11] Wells are drilled into the oil shale formation, which is then heavily fractured by gas injection. Hot gas, preferably carbon dioxide, is circulated through the rubblized zone to effect the in situ conversion. Conditions are presumably similar to those of the Shell in situ conversion process. After the desirable hydrocarbon components are produced with the CO_2 stream, in situ combustion of the residual hydrocarbon is initiated. This process further elevates the temperature of the formation, so that it can effectively heat circulating carbon dioxide for use in an adjacent rock volume.

The primary environmental problems of the in situ techniques are the ingress of water into the heated zone, and the escape of hydrocarbons and heavy metals into surrounding aquifers. Shell creates a freeze wall around the heated volume to prevent exchange of fluids between the reaction zone and external aquifers. The post-production phase consists of repeatedly flushing the reaction zone with recirculated and reclaimed ground water. Shell estimates that 20 pore volumes of water must be

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[9] Department of Energy, Volume II, Table 2 [reference 2].
[10] "Plan of Operations: Oil Shale Test Project," Shell Frontier Oil and Gas Inc. (15 February 2006).
"Environmental Assessment: Shell Oil Shale Research, Development & Demonstration Projects, Rio Blanco County, Colorado, August 2006."
Both reports available at http://www.co.blm.gov/wrra/WRFO_Oil_shale.htm.
[11] "Plan of Operations: Oil Shale Research, Development & Demonstration Project," Chevron USA (15 February 2006). Available at
http://www.co.blm.gov/wrra/documents/OILSHALEPLANOFOPERATIONS.pdf.
"Environmental Assessment: Chevron Oil Shale Research, Development & Demonstration," CO-110-2006-120-EA (August 2006). Available at http://www.co.blm.gov/wrra/WRFO_Oil_shale.htm.

circulated through each producing formation before the groundwater quality meets acceptable standards. For the Shell Oil Shale Test project, this process is anticipated to take five years following the completion of oil shale production. The freeze wall must remain intact during this period.[12]

Chevron has proposed a different approach to ground water protection, in which conversion takes place within an artificially fractured volume, which is separated from nearby aquifers by unfractured and impermeable oil shale.[13]

Little detailed economic information about the in situ conversion processes have been published, so it is difficult to estimate the cost of oil produced in this manner. Shell has estimated that its method is competitive with conventional crude oil selling at about $25 per barrel.[14] Shell has recently announced that it will decide whether to proceed with oil shale production in Colorado by 2010, with first production expected by the middle of that decade.[15]

IV. Table of advances

A. Advances that might be in commercial use by 2010

- None.

B. Advances that might be in commercial use by 2020

- Improved methods of shale remediation.
- Innovative surface retort architecture and chemistry.
- Pilot scale in situ conversion methods.

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[12] Shell reports, reference 10.
[13] Chevron reports, reference 11.
[14] RAND Corporation, reference 6.
[15] "Shell to decide Colorado project by 2010," *Denver Post* (23 October 2006).

C. Advances that might be in commercial use by 2030

- Large scale oil shale production.

V. Discussion

There is little or no discussion of innovative mining techniques in the contemporary literature. Oil shale mines are likely to be very similar to the oil sand mines of Alberta, for which equipment and techniques are well developed. However, improved remediation of spent shale is a worthwhile technical objective, and is probably necessary to make the mining + retort method environmentally acceptable.

The key to economic surface retorting is to design a rapid process that does not thermally degrade the hydrocarbon. This goal has been the object of considerable effort over many years. However, it remains possible that advances in reactor design (such as claimed by Oil Tech) or in catalysis could change the economic prospects of this technology.

Shell has been working on in situ kerogen conversion for at least twenty years, while keeping the technique largely secret until recently. Although (and partly because) its patent portfolio is voluminous, identifying technology gaps is difficult. Environmental issues are complex and probably still not well understood. Of particular significance is the protection of nearby aquifers over the entire lifecycle of oil shale extraction and site abandonment.

No matter what method is used, there are powerful economies of scale, which suggest very large, capital-intensive projects. As has been pointed out above, if western-U.S. oil shales are ever mined, those mines will be the largest of any type on earth. In the case of in situ conversion, the isolation of the reservoir from nearby aquifers becomes simpler and more economical as the area of the heated region grows, regardless of whether the Chevron or Shell method is used.

The future of oil shale production depends not only on projections of the price of conventional crude oil, but also on the prospects for heavy oil and coal to serve as sources of petroleum liquids. Heavy oil production is a reality today and is ramping up very quickly, with production prices below $15/bbl. Although not as far advanced, coal liquefaction is reasonably well understood, and recent estimates assert that coal liquids can be produced for about $45/bbl. In this competitive environment, oil shale technology is important because it has the potential to provide a superior liquid fuel product. However, technological, economic, and environmental issues remain to be fully assessed.