EMD Oil Shale Committee

EMD Oil Shale Committee Semi-Annual Report - 2011

Jeremy Boak, Chair

November 10, 2011

Vice-Chairs:

Dr. Lauren Birgenheier (Vice-Chair – University) University of Utah

Dr. Ronald C. Johnson (Vice-Chair – Government) U. S. Geological Survey

Committee Activities

In the 2010-2011 business year, the Oil Shale Committee appointed two Vice-Chairs, (1) Dr. Ronald C. Johnson (Ron Johnson), Oil Shale Task Leader for the U. S. Geological Survey as Government Vice-Chair, and (2) Lauren Birgenheier, PhD (LBirgenheier@egi.utah.edu), of the Energy & Geoscience Institute at the University of Utah as the University Vice-Chair. The Industry Vice Chair will be appointed later this year.

The Oil Shale Committee has continued to engage in the international discussion about technical terminology regarding *oil shale* and *shale oil*.

Oil shale related presentations and posters at various AAPG meetings include:

AAPG International Conference and Exhibition, Milan, Italy, 23-26 October 2011

Mineralogy and Geochemistry of the Parachute Creek Member of the Green River Formation, Piceance Basin, Colorado, U.S.A, Malicse, Ariel [1]; Inan-Villegas, Esra [2] (1) Shell Exploration & Production Co., Houston, TX. (2) Shell Exploration & Production, Houston, TX. AAPG Search and Discovery Article #90135

Development Value of Oil Shales in Middle Jurassic Seven-Segment Yuka Area Qaidam Basin, China, Chenxu, Pu; Research Institute of Petroleum Exploration & Development Northwest, Lanzhou, China, AAPG Search and Discovery Article #90135

Characterisation of Potential Lacustrine Carbonate Reservoirs: The Microbial/Algal Buildups and Associated Carbonate Deposits from the Eocene Green River Formation, Seard, Claire [1]; Camoin, Gilbert [1]; Rouchy, Jean-Marie [2]; Virgone, Aurélien [3]; Pabian-Goyheneche, Cecile [3]; Poli, Emmanuelle [3] (1)Geosciences, CEREGE-CNRS, Aix en Provence, France. (2) Muséum National d'Histoire Naturelle, CNRS, Paris, France. (3) GSR/TG/ISS/CARB, TOTAL, Pau, France, AAPG Search and Discovery Article #90135

AAPG Eastern Section Meeting, Washington, DC, USA, 25-27 September 2011

USGS Assessment of In-Place, Oil Shale Resources of the Upper Devonian Antrim Shale in the Michigan Basin, Eastern United States, Alex W. Karlsen[1], Tracey J. Mercier[2], Frank T. Dulong[1], Sandra G. Neuzil[1], Ronald C. Johnson[2]**;** [1] U.S. Geological Survey, National Center M.S. 956, 12201 Sunrise Valley Dr., Reston, VA 20192, akarlsen@usgs.gov [2]U.S. Geological Survey, Box 25046, Denver Federal Center M.S. 939, Denver, CO 80225**,** AAPG Search and Discovery Article #90131

Revising the 2006 USGS Assessment of In-Place Oil Shale Resources of Devonian- Mississippian Black Shales in the Eastern United States, Sandra G. Neuzil[1], Frank T. Dulong[1], Joseph A. East[1], Alexander W. Karlsen[1], Michael H. Trippi[1], Tracey J. Mercier[2], and Ronald C. Johnson[2]**;** [1] U.S. Geological Survey, National Center M.S. 956, 12201 Sunrise Valley Dr., Reston, VA 20192, sneuzil@usgs.gov [2] U.S. Geological Survey, Box 25046, Denver Federal Center M.S. 939, Denver, CO 80225**,** AAPG Search and Discovery Article #90131

AAPG Rocky Mountain Section, Cheyenne, Wyoming, 25-29 June 2011

Stratigraphic Characterization of the Birds Nest Aquifer in the Uinta Basin, Utah: Updated Research Regarding the Aquifer's Potential as a Significant Saline Water Disposal Zone, Vanden Berg, Michael *; Carney, Stephanie; Morgan, Craig D.; Lehle, Danielle; Utah Geological Survey, Salt Lake City, UT.**,** AAPG Search and Discovery #90126

AAPG Pacific Section Meeting, Anchorage, Alaska, 8-11 May 2011

Stratigraphic Characterization of the Birds Nest Aquifer in the Uinta Basin, Utah: Updated Research Regarding the Aquifer's Potential as a Significant Saline Water Disposal Zone, Vanden Berg, Michael *; Carney, Stephanie ; Morgan, Craig D.; Lehle, Danielle; Utah Geological Survey, Salt Lake City, UT.**,** AAPG Search and Discovery Article #90125

AAPG International Conference and Exhibition, Calgary, Alberta, Canada, September 12-15, 2010

*Estimates of In-Place Oil Shale of Various Grades on Federal Lands, Piceance Basin, Colorado** Tracey J. Mercier, Ronald C. Johnson, and Michael E. Brownfield, Central Energy Resources Science Center, United States Geological Survey, Lakewood, CO, Search and Discovery Article #10305 (2011), Posted March 7, 2011

AAPG Hedberg Conference, December 5-10, 2010, Austin, Texas

Gas Shale, Oil Shale, and Oil-Bearing Shale: Similarities and Differences, Pierre Allix[1], Alan Burnham[2], Michael Herron[3], and Robert Kleinberg[3]**:** *[1]TOTAL Exploration & Production, Pau, France [2]American Shale Oil Co., Rifle, Colorado [3]Schlumberger-Doll Research, Cambridge, Massachusetts***,** AAPG Search and Discovery Article #90122

The premier international meeting on oil shale is the Oil Shale Symposium hosted by the Colorado School of Mines in October. The 31st Oil Shale Symposium occurred October 17-21, 2011, which also included an optional field trip to western Colorado and Eastern Utah. In addition, the Symposium included a workshop on Principles of Resource Assessment for Oil Shale. The 32nd Oil Shale Symposium will occur October 16-20, 2012 in Golden, with a field trip probably to both Colorado and Utah. All presentation materials from the 26th through 30th Oil Shale Symposia are posted at http://www.costar-mines.org/.

Planning is under way for an Oil Shale Symposium at the Dead Sea in Jordan in May 2012.

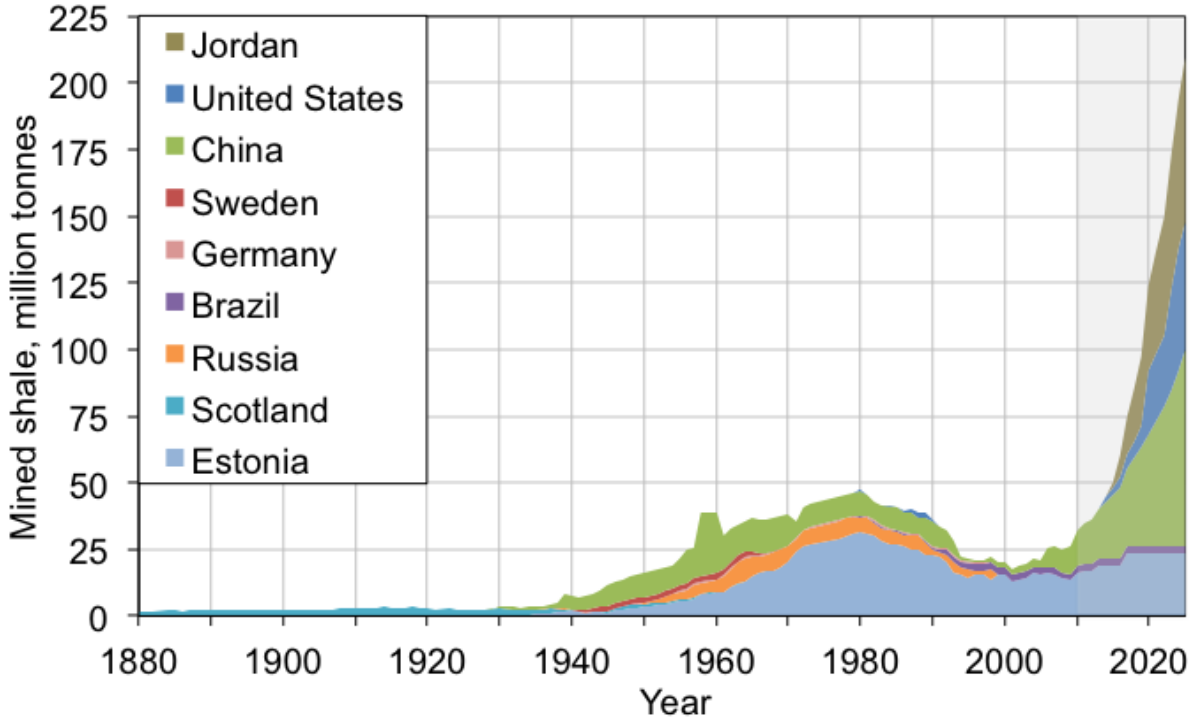
Oil Shale Commodity Report

World Oil Shale Production

Total global production of shale oil is currently about 25,000 barrels per day (BOPD). All of this production comes from mining and retorting operations in Brazil, China, and Estonia. Indications are that Chinese production, which was just over 10,000 BOPD in 2010, will increase to approximately 13,000 BOPD in 2011. Current projections show that oil shale will not be a significant part of global production (>500,000 BOPD) for another decade. However, projects are in line over the next four to five years that could increase production significantly.

The chart below shows an update to the plot by Dyni (2006) of mined oil shale in million tons. Data gathered by Alan Burnham and Pierre Allix of AMSO/Total update the chart to 2010. Addition of the production planned by Enefit in Estonia, Enefit and JEML in Jordan, and Enefit and Red Lead Resources in Utah out to 2025 are combined with a conservative projection of future Chinese production based upon the last fifteen years of production. No projections are made of any projects using in situ technology, although current RD&D leases will have to transition to production leases by that time.

This extrapolation is highly uncertain at this point, but the indication is that if current plans stay on track, mining production can be expected to increase by as much as eight-fold from today, and more than four fold over the peak in 1980. At present, the data are not detailed enough to provide a breakout of how much oil shale will be used for power generation vs. oil production.



Highlights

The last six months have seen a number of developments in oil shale both in the United States and globally, including:

- Conduct of scoping meetings on the revised Programmatic Environmental Impact Statement (PEIS) for oil shale and tar sands by the U. S. Bureau of Land Management (BLM) in Colorado, Utah, and Wyoming. The BLM received more than 28,000 comments, more than 27,000 from campaign forms. The revised draft PEIS is scheduled for release in December 2011. BLM expects to publish a notice of proposed rulemaking to address the royalty rate and environmental protection requirements applicable to oil shale leasing, no later than 11/18/12.
- Completion of the purchase of Oil Shale Exploration Company by Estonian energy company Enefit. Enefit intends to develop a mining and retorting operation that will contribute 50,000 barrels per day of production by 2023.
- Advancement of oil shale development in Jordan with concession agreements in place with Eesti Energia (Estonia) and with Jordan Energy Minerals Limited (JEML) Enefit plans to

produce 19,000 BOPD from its first plant in 2017, and 38,000 BOPD by 2022, as well as producing 600-900 MW of power. JEML expects startup in 2014 at 15,000 BOPD, estimated breakeven price of $38/barrel). The plan is to reach 60,000 barrels per day by 2024.

- Commencement of testing of oil shale production technology in the Tarfaya oil shale deposit in Morocco by San Leon Energy.

Research Funding Sources

Funding for oil shale research in the United States comes primarily from corporations actively pursuing oil shale development. These include Federal RD&D leaseholders (Chevron, Shell, American Oil Shale/Total) and others holding land underlain by the Green River Formation (ExxonMobil, Chevron). U.S. Federal sources include the U.S. Department of Energy through its National Energy Technology Laboratory, as part of the Fossil Fuel program. However, such funding has been essentially zero this year. Other companies may have provided smaller grants that are not widely publicized. Other private funding appears to support development at least of the Red Leaf Resources program. International funding comes from diverse sources, not all of them publicly acknowledged. It is clear that governments in Jordan and Morocco are actively supporting granting of concessions and dissemination of available data. Companies in Estonia (Eesti Energia, Viru Keemia Grupp), Brazil (Petrobras), and China (CNPC, Fushun Mining Company and others) are supporting internal development and, in some cases, external development efforts.

Current Research

Current research on oil shale is best identified through presentation at the Oil Shale Symposium held each October in Golden, CO at the Colorado School of Mines. All proceedings abstracts, presentations, and papers for the 26th through 30th Oil Shale Symposia are available at: http://www.costar-mines.org/oil_shale_symposia.html. Proceedings of the 31st Oil Shale Symposium should be available for sale by the end of the AAPG Annual Convention and Exhibition in Long Beach.

In addition, international research in oil shale processes and impacts is published in the journal Oil Shale, published in Estonia. The journal can be accessed at: http://www.kirj.ee/oilshale .

Current industry research focuses on development and testing of a variety of techniques for extracting oil from oil shale and on minimizing the environmental impacts of these techniques. These fall into three main categories: 1) mining and retorting, 2) in situ heating and extraction, and 3) in-capsule extraction.

The first is the traditional method of oil shale extraction, which has been pursued with some intermittency for more than one hundred years. Developments in this area generally relate to increasing the efficiency and decreasing the impact of retort operation. The development of advanced fluidized bed reactors is a current area of research and development. In addition, research continues on the impacts of past mining and retorting, and on utilization of spent oil shale and oil shale ash from burning of oil shale in power plants. The most obvious applications involve use of spent shale and ash in cement and brick manufacture, but more advanced techniques involving extraction of various constituents from the material have been investigated. The Fushun Mining Company in China has set as an objective no net waste products from oil shale production.

The second method, in situ heating and extraction, is the focus of intensive research to develop a method to heat and pyrolyze kerogen-rich rocks underground and efficiently extract the resulting oil and gas from the formation. Shell has been a leader in this area, but ExxonMobil, Total/AMSO, Chevron, and others are investigating different processes. In situ heating takes much longer (on the scale of years), but as a consequence pyrolysis occurs at lower temperatures, and additional reaction at depth leads to a lighter oil with a larger gas fraction. The amount of secondary

processing to meet refinery requirements is generally considered to be less than for retort products. Research on in situ processes and on processing the resulting material is ongoing at companies developing these methods, but results are generally proprietary. Symposium presentations have described general results in containment, heating, extraction, refining, and reclamation.

The third method, in-capsule extraction is the method being pursued by Red Leaf Resources of Cottonwood Heights UT. It involves mining of oil shale, encapsulation in a surface cell akin to a landfill, heating and extraction of the products, and final sealing of the exhausted retort. A recent trial has been completed and the results are favorable. The process is described in more detail at Red Leaf's website: http://www.redleafinc.com/. Currently, Red Leaf is not directly involved in supporting research on its method. However, results reported at the 30th Oil Shale Symposium indicate that the company anticipates moving forward with production of 9,500 BOPD within 24 months, and plans to expand that to a 30,000 BOPD facility that will start construction in 2013. This would be a globally significant development for oil shale. Red leaf currently estimates an energy return on investment of 11.5 to 1.

The U. S. Geological Survey (USGS) continues to conduct research evaluating the nature and extent of oil shale resources in the United States. A reevaluation is under way of the Eastern U. S. oil shale resources in Michigan, Indiana, Ohio, Kentucky, Tennessee, and Alabama. In addition, research continues at the USGS on the process of generation of oil from organic rich sedimentary rocks, both naturally and under simulated conditions of in situ production. General research on the geology, stratigraphy, geochemistry and rock physics of oil shale are under way at a number of institutions, including the Colorado School of Mines, University of Utah, University of New Brunswick and other North American and international universities.

List of Specialists in the United States

The list may not yet be complete.

Colorado School of Mines:

- Mike Batzle, Center for Rock Abuse, physical properties of oil shale
- Jeremy Boak, Center for Oil Shale Technology and Research (COSTAR), assessment of CO_2 emissions and water consumption by oil shale production; geologic characterization of oil shale.
- John Berger, COSTAR, modeling of fracturing in oil shale
- Mark Kuchta, underground methods for in situ production of oil shale
- J. Frederick Sarg, stratigraphy and sedimentology of Green River Formation, Colorado
- Kati Tanavsuu-Milkeviciene, stratigraphy and sedimentology of Green River Formation, Colorado
- Wei (Wendy) Zhou, Geographic Information Systems for oil shale water resource evaulation

Idaho National Laboratory

- Hai Huang, geomechanical behavior of oil shale
- Earl Mattson, Idaho National Laboratory, Idaho Falls, ID, hydrology of oil shale deposits and water consumption patterns for oil shale production
- Carl Palmer, mineralogic and chemical effects of pyrolysis on oil shale

Los Alamos National Laboratory

- Daniel Levitt, hydrology of oil shale deposits
- Jonathan Mace, explosives application to fracturing of oil shale
- Donatella Pasqualini, energy systems analysis for Western Energy Corridor

Schlumberger Doll Research Center

- Neil Bostrom, pyrolysis of oil shale, kinetics, and characterization
- Michael Herron, mineralogic and chemical characterization of oil shale
- Malka Machlus, stratigraphy of Green River Formation oil shale

ExxonMobil Upstream Research Company

- William Symington, Thermal behavior of Green River Formation oil shale and technology for application of heat in situ
- Jessie Yeakel, geology of Green River Formation oil shale

Shell Exploration and Production Company

- Wolfgang Deeg, freeze wall development and testing
- John Hardaway, environmental restoration for in situ production

U. S. Geological Survey

- Justin Birdwell, U. S. Geological Survey, Lakewood CO, organic geochemistry of oil shale and other source rocks
- Michael Brownfield, U. S. Geological Survey, Lakewood CO, geology, stratigraphy, sedimentology and resource evaluation of Green River Formation oil shale
- John Dyni, U. S. Geological Survey (ret.), Lakewood CO, geology and resource evaluation of oil shale
- Ronald Johnson, U. S. Geological Survey, Lakewood CO, geology, stratigraphy sedimentology and resource evaluation of Green River Formation oil shale
- Michael Lewan, U. S. Geological Survey, Lakewood CO, organic geochemistry of oil shale and other source rocks
- ***University of Utah***
- Lauren Birgenheier, Energy Geosciences Institute, University of Utah, Salt Lake City UT, stratigraphy of oil shale
- Milind Deo, Institute for Clean and Secure Energy, University of Utah, Salt Lake City, UT, chemistry and simulation of oil shale retorting processes
- Ronald Pugmire, University of Utah, Salt Lake City, UT, chemistry and kinetics of oil shale pyrolysis
- Philip Smith, Institute for Clean and Secure Energy, University of Utah, Salt Lake City, UT, chemistry and simulation of oil shale retorting processes

Others

- Gary Aho, Enefit American Oil, Rifle CO, oil shale production technology
- Adam Brandt, Stanford University, Stanford CA, assessment of CO_2 emissions from oil shale production
- James W. Bunger, Bunger and Associates, Salt Lake City, UT; production planning and impact assessment for U.S. oil shale
- Alan Burnham, AMSO LLC, Livermore, CA, properties of oil shale, in situ retorting of oil shale
- Alan Carroll, COSTAR, University of Wisconsin, Madison, WI, stratigraphy, sedimentology and geochronology of Green River Formation, Wyoming; lacustrine stratigraphy and sedimentology
- Gerald Daub, Daub and Associates, Grand Junction CO, geology of Green River Formation
- Benjamin Harding, AMEC Environmental, Boulder CO, water use for oil shale production

- Timothy Lowenstein, COSTAR, Binghamton University, Binghamton NY, chemistry and formation of evaporite minerals and spring deposits of the Green River Formation, Colorado and Wyoming
- Glenn Mason, Indiana University Southeast, New Albany, IN, geology of Green River Formation oil shale
- Judith Thomas, U. S. Geological Survey, Colorado Water Science Center, Grand Junction, CO, hydrology of Piceance Creek Basin
- Michael Vanden Berg, Utah Geological Survey, Salt Lake City, UT, geology and stratigraphy of oil shale, Utah

List of International Specialists

The current list is preliminary and incomplete.

- Omar Al-Ayed, Al-Balqa Applied University, Faculty of Engineering, Amman Jordan, properties of Jordanian oil shale and shale oil
- Yuval Bartov, Israel Energy Initiatives, Ltd., Jerusalem, Israel, lacustrine stratigraphy, Green River Formation and Israel
- Mohammed Bencherifa, Organization National des Hydrocarbures et des Mines (ONHYM), Rabat, Morocco, engineering and geology of Moroccan oil shale
- Alan Goelzer, Jacobs Consultancy, Durham, New Hampshire, modeling of retorting and hydrogenation processes
- Jaan Habicht, Tartu University, Tartu, Estonia, Environmental effects of oil shale ash and spent shale
- Uuve Kirso, Tallinn Technical University, Tallinn, Estonia, Environmental effects of spent shale and oil shale ash
- Shuyuan Li, China University of Petroleum, Beijing, China, Properties of oil shale in China
- Zhaojun Liu, Jilin University, Changchun, China, Geology, stratigraphy, and resource evaluation of Chinese oil shale
- Tsevi Minster, Geological Survey of Israel, Jerusalem, Israel, Resource characterization for Israeli oil shale
- Vaino Puura, Tallinn Technical University, Resource assessment of oil shale
- Jialin Qian, China University of Petroleum, Beijing, China, Properties of oil shale in China
- Aya Schneider-Mor, Ben-Gurion University of the Negev, Beer Sheva, Israel, Geology and stratigraphy of Israeli oil shale
- Jyri Soone, Tallinn Technical University, Tallinn, Estonia, Environmental effects of oil shale ash and spent shale
- Mahmoud Zizi, ZIZ Geoconsulting, Rabat Morocco, Geology and engineering for Moroccan oil shale

Leading Companies in Development of Oil Shale

Efforts by major international oil companies in the United States are generally led out of Houston, but Shell, ExxonMobil, Chevron and AMSO also have regional offices in western Colorado. International oil companies with activities in oil shale include:

- Chevron
- ExxonMobil
- Petrobras (Brazil)/ Oil Shale Exploration Company (OSEC)

- Shell
- Total/American Shale Oil (AMSO)

In addition, two other large oil companies have significant land holdings underlain by oil shale, and one major oilfield service company has acquired technology for oil shale production:

- Anadarko Petroleum Corporation
- ConocoPhillips
- Schlumberger

Smaller U. S. companies pursuing development, mostly in the United States include:

- Combustion Resources, Inc.
- EnShale Inc.
- General Synfuels International
- Independent Energy Partners
- Mountain West Energy
- Natural Soda, Inc.
- Red Leaf Resources
- Shale Tech International
- AuraSource Inc.

International leadership is held mainly by companies producing oil shale at the present time (listed first), but other companies are also currently pursuing development of oil shale (second group):

- Eesti Energia/Enefit (Estonia)/Outotec (Finland)
- Fushun Mining Company (China)
- Viru Keemia Grupp (Estonia)

- Altius Resources (Canada)
- Queensland Energy Resources (Australia)
- San Leon Energy (Ireland) [concession in Morocco]
- Jordan Energy Minerals Limited (England) [Agreement in Jordan]
- Israel Energy Initiatives Limited (Israel)
- International Corporation for Oil Shale Investment (Incosin) [MOA in Jordan]
- Aqaba Petroleum for Oil Shale (Jordan)

National agencies/oil companies involved in developing oil shale include:

- China National Petroleum Corporation (China)
- National Resource Administration (Jordan)
- Organization National des Hydrocarbures et des Mines (ONHYM), Morocco

Focus of Recent Activity

Recent oil shale activity in the United States has centered on the development and testing of oil shale technology. The U. S. Bureau of Land Management (BLM) continues to process three applications for a second round of Research Development and Demonstration (RD&D) leases. The technical review was completed in the Spring of 2010, and in September, the BLM announced that it would advance all three leases to the next stage of environmental analysis. This step is expected to take four to eighteen months to complete. The leases offer the same 160 acre RD&D area as the previous round. However, the lease preference area, which becomes available at fair market price

after a company has shown commercial feasibility for its technology, has been reduced to 480 acres, for a total of 640 acres.

BLM Conducted scoping meetings on the revised Programmatic Environmental Impact Statement (PEIS) for oil shale and tar sands in Colorado, Utah, and Wyoming. Revision of the PEIS represents BLM's approach to complying with settlement agreements for several lawsuits that challenged the process of the previous PEIS and subsequent revisions to Resource Management Plans. The BLM received more than 28,000 comments, more than 27,000 from campaign forms. The revised draft PEIS is scheduled for release in December 2011. BLM expects to publish a notice of proposed rulemaking to address the royalty rate and environmental protection requirements applicable to oil shale leasing, no later than 11/18/12.

Shell applied for a permit to begin testing on one of its RD&D leases in western Colorado. Shell continues to experiment with its In situ Conversion Process (ICP), which involves electric heating of a block of rock contained by a freeze wall to protect ground water and minimize heat loss to flowing water. Shell has demonstrated all of the elements of this system on a small scale, and has completed a test freeze wall on a larger scale on private land in Colorado. They have also reported on experiments that complete the process by circulating water through the block to remove hydrocarbons not extracted through the production wells. Shell is also moving forward on a multi-mineral test in the saline zone of the Green River Formation.

ExxonMobil continues work at its Colony site to investigate its ElectroFrac™ technology, which also involves electric heating, but through large plate electrodes created by hydraulic fracturing from horizontal wells and injecting an electrically conductive proppant to create what ExxonMobil itself characterizes as a "Giant Toaster". They have now demonstrated that the process can create an effective connected heating element. ExxonMobil has created a plan for a test of the ElectroFrac™ technology at the least it has applied for on BLM land.

American Shale Oil (AMSO) is conducting a pilot test of their in situ process (Conduction, Convection & Reflux – CCR™). They have drilled twelve wells in the area. The test is being conducted in the illitic oil shale of the Garden Gulch Member of the Green River Formation. Modeling of microseismic and other methods will be used to image the growth of the retort zone. Experimental results suggest the process yields a 35-40 API gravity oil with lower nitrogen than typical, metal contents below detection levels, and a net energy return of ~4:1.

Chevron has completed geologic and hydrologic characterization (and monitoring) wells at its RD&D lease in Colorado. Chevron presented plans for testing an explosive rubblization approach for creating permeability for injection of extraction gases at the 31st Oil Shale Symposium. They envision on-site testing in 2013. Initial testing is likely to occur at Chevron's Red Point Mine near DeBeque CO.

Red Leaf Resources Ecoshale Division has tested their in-capsule technology (described in a previous section of this discussion). They anticipate startup of a 9,500 barrel per day operation in 2013 or early 2014.

A number of companies, many located in Utah, are moving ahead with plans to build surface retorting systems. A substantial amount of work by these companies has centered on efforts to reduce the carbon and water footprints of the systems while still maintaining a positive energy balance.

Internationally, Estonia is in the process of significantly expanding its capability to produce oil from shale, while de-emphasizing the use of oil shale for combustion in power plants. Enefit, the international arm of Eesti Energia, the national energy company of Estonia, has begun aggressive development overseas, with projects in the U. S. and Jordan.

Jordan is actively pursuing partnerships to develop its significant resources of oil shale, partnering with Petrobras, Shell, Eesti Energia, Jordan Energy Minerals, Limited, and others to define a path toward energy independence.

Petrobras and Total have been working with Morocco to develop well-characterized oil shale deposits near Timadhit. San Leon Energy of Dublin Ireland has begun testing of its in situ technology in 2011. Eesti Energia has recently signed an agreement with Morocco to evaluate a group of other oil shale deposits around the country.

China appears to be rapidly increasing its capacity to produce shale oil through surface retorting. Currently, it appears there are over 500 retorts of various sizes (mostly 100 metric ton/day shale, Fushun-type retorts) installed with more than 200 under construction. Although total production was only about 13,000 barrels per day, the numbers do not make clear whether the current limitation is the capacity or the efficiency of the retorts. A significant number of the retorts are new in the last year, and may not yet be on line.

Professor Jialin Qian of China University of Petroleum, a leading investigator of oil shale in China for many decades, has authored a book entitled **Oil Shale – Petroleum Alternative**, and prepared an English translation. Copies are available through the Colorado School of Mines (contact Jeremy Boak at jboak@mines.edu). The book can also be ordered by contacting the publisher at ytt@sinopec.com.

Estimated U.S. and International Resources/Reserves and Strategic Impact

World resources of oil shale were previously estimated to be >3.0 trillion barrels, of which about two trillion barrels were located in the U.S.A. (Dyni, 2006). The largest oil shale deposit in the world is the Green River Formation of Colorado, Utah and Wyoming. The U. S. Geological Survey has completed its reevaluation of oil shale resources of the Green River Formation in Colorado, Utah, and Wyoming. The Colorado assessment was released last October, and increased the amount from the 1.0 trillion barrel previous estimate to 1.5 trillion barrels. A new assessment of Utah resources indicates 1.32 trillion barrels of oil in place. A Wyoming assessment is now complete, with total resources of 1.44 trillion barrels, although the cutoff value was lower for the Wyoming resource. The total resource is estimated at 4.28 trillion barrels.

Additional updates to the projected resources of oil shale come from Israel and Jordan. Each now estimates the potential for more than 100 billion barrels of oil (BBO) in place. Yuval Bartov of Israel Energy Initiatives Limited suggested resources as high as 250 BBO, and JEML reports an estimated resource of 102 BBO for Jordan. However, these estimates have not been evaluated in a consistent manner, a critical need as the industry matures. On the other hand, resource estimates have generally been increasing, and one estimate of the Jordanian resource raises the possibility of more than one trillion BBO.

Measurements of oil shale yield by Fischer Assay, a method designed to approximate the recovery of surface retorting methods, Provide the basis for most of these estimates. Most estimates of resource size tied to modern retort methods, whether retorting is done at the surface or in situ, are tied to this surrogate measurement. Some processes that focus on hydrogenation of the kerogen can recover amounts greater than the Fischer Assay. In addition, because the Fischer Assay calculates the gas fraction by difference, this measure does not adequately account for non-condensable hydrocarbon gases potentially present in the mass fraction lost during assay. In situ processes tend to have a higher gas/liquids ratio. Thus, it is difficult to provide consistent estimates of the potential resource of oil shale available at this time.

The U. S. is the only place where extensive analysis and evaluation has been published for a large oil shale resource. However, the estimates of Dyni are considered conservative estimates of the

resource potential. Estimates of the recovery potential for U. S. oil shale are generally near 50%, but vary widely. The current Chinese estimate postdates Dyni's estimate, and significantly increases the world estimate. However, China's assessment indicates that they expect only about 25% recovery of the available resource. Some resource evaluations are very old, and may be highly uncertain. An up-to-date method for assessment of oil shale resources, and modern resource estimates would provide a better picture of the significance of this resource. The producing countries have provided reasonably reliable estimates of the resource in place, although these can be challenging to track down.

The strategic significance of oil shale resources varies from country to country. In the U. S., much has been made of the size of the resource. However, its availability remains uncertain. Technology to produce the vast quantities of oil potentially recoverable is currently being tested, but no developer has projected significant production in less than a decade. The projection shown in Figure 1 indicates that oil shale may take longer still to become a significant player in the global petroleum supply. In the figure, the growth in oil shale production is compared to the growth rates for historic U. S. oil production and for Canadian oil sand production (Boak 2009). The growth rate required to reach one million barrels per year by the 2030s is >14% compared to ~9 and ~10% for historic U. S. oil and Canadian oil sand. These results are achievable, but will require considerable focus and investment.

However, especially for smaller countries with lower energy demands and no other hydrocarbon resources (Estonia, Jordan and Morocco for example) development of this resource can be very important strategically.

Critical Technology Needs

Critical technology needs mainly concern the development of more energy efficient and

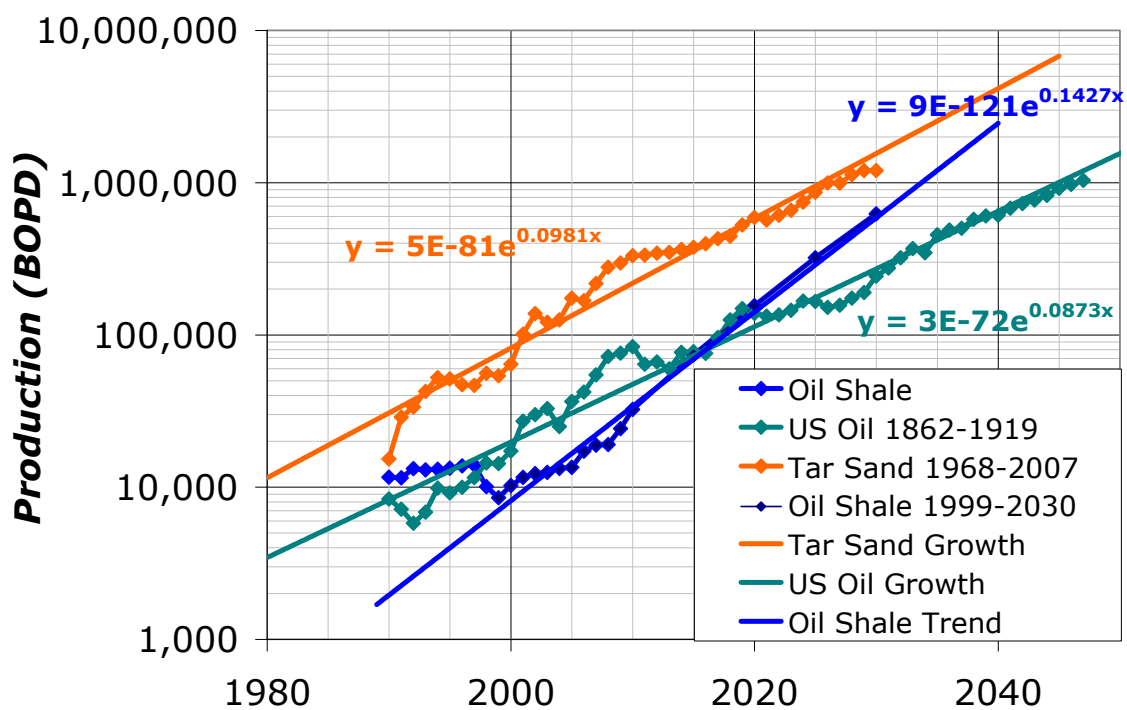


Figure 1: Projected oil shale production and historic production of U. S. crude oil and Canadian oil sands. The exponential curve fits to data indicate extended periods with growth rates of ~9% and ~10% for the U. S. and Canadian examples, and project >14% for oil shale even to reach one million barrels per day by

environmentally friendly methods of extraction, production and upgrading of oil shale. Especially in the U. S., issues have been raised about the greenhouse gas emissions and water consumption of an oil shale industry. The primary source of emissions for in situ production is power plant emissions of CO_2, and power plant water consumption is the second largest use for a Shell-type in situ operation (Boak 2008, 2010). So minimizing energy use for these processes is essential. ExxonMobil has suggested air-cooled power plants to reduce water use, but these may increase CO_2 emissions (Thomas, 2010). AMSO has emphasized the potential for sequestration of CO_2 in exhausted in situ retorts (Burnham and Collins, 2009). A presentation by Enefit at the 31st Oil Shale Symposium indicated that production from their retort system would result in a net carbon intensity of ~130 gCO^2/MJ of energy output (including burning of the fuel). This is ~30% higher than traditional crude oil. However, given a carbon offset for generating power in the Enefit unit rather than using a power plant, and for use of cement clinker substitute could reduce this to approximately that of crude oil. However, the offsets are not yet clearly accepted.

In the United States, understanding and mitigating the environmental affects of oil shale production across entire productive regions is clearly not the responsibility of individual leaseholders, but rather of the majority steward of the land, the Federal government. In the past, the U. S. Department of Energy managed an Oil Shale Task Force charged with defining and integrating baseline characterization and monitoring needs for environmental impacts within the basins of the Green River Formation. The Task Force included representatives of government and industry, including the environmental firms retained by major potential producers. Congress does not recognize this as a critical need, and therefore the need is not being addressed systematically. Similar issues may arise in other countries where multiple oil shale deposits are being developed, such as Jordan. Funding for the national effort to manage the environmental baseline and integrated database could be a significant issue.

Internationally, there is a lack of consistently structured resource assessments. As the energy security of the world stands to benefit from enabling otherwise resource poor developing countries to develop indigenous energy sources, it may be beneficial to support the development of resource assessment tools for countries that do not have the large database of Fischer Assay and other measurements available in the U. S. Developing criteria and methods for such assessments would be a contribution to the global development of this resource, and would potentially create good will between the U. S., the European Union, and the developing countries with oil shale resources. Critical to such assessments will be careful estimation of the uncertainty regarding resource estimates where data are sparse.

Critical Environmental or Geohazard Issues and Mitigation Strategies

The critical environmental issues are how to extract, produce and upgrade shale oil in an environmentally friendly and economically sound way such that:

1) The use of energy to pyrolyze the kerogen is minimized
2) The greenhouse gas emissions are reduced or compensated for by carbon trading or CO_2 sequestration
3) The water used in construction, operation, power generation, and reclamation is minimized and does not deplete the water resources of arid regions
4) The extraction, production and upgrading of the shale oil does not unduly affect the quality of the air, the native biological communities, or surface and ground water of the region.

Socioeconomic impacts are also issues of concern. The recent offering of Research, Development, and Demonstration leases required that each of these concerns be addressed explicitly in the lease application. In addition, Shell has determined that developers must interact with 47 separate regulatory bodies before production can begin. These interactions include at least two separate

environmental impact assessment stages likely to focus on the same impacts. It remains unclear whether this structure, with potential for heavy and potentially duplicative burdens of documentation will have a net protective effect on the environment.

References Cited

Boak, J., 2008, Estimate of Carbon Dioxide Production for In-Situ Production of Shale Oil from the Green River Formation in Western Colorado, Proceedings of the 27th Oil Shale Symposium, Colorado Energy Research Institute Document 2008-1, Colorado School of Mines, Golden CO USA (CD-ROM)

Boak, J., 2009, One Million Barrels of Shale Oil per Day: How and How Soon?; Oil Shale Symposium, Tallinn, Estonia, June 2009

Boak, J. and E. Mattson, 2010, Water use for in situ production of oil from oil shale Proceedings of the 29th Oil Shale Symposium, Colorado School of Mines, Golden CO USA (CD-ROM)

Burnham, A., and S. Collins, 2009, CO_2 Sequestration in Spent Oil Shale Retorts, Proceedings of the 28th Oil Shale Symposium, Colorado Energy Research Institute Document 2009-2, Colorado School of Mines, Golden CO USA (CD-ROM)

Dyni, J. R., 2006, Geology and Resources of Some World Oil-Shale Deposits, U. S. G. S. Scientific Investigation Report. 2005-5294, U. S. Geological Survey, Reston VA USA

Thomas, M., 2010, Responsible development of oil shale, Proceedings of the 29th Oil Shale Symposium, Colorado School of Mines, Golden CO USA (CD-ROM)