EMD Oil Shale Committee

**EMD Oil Shale Committee Annual Report - 2014**

**Alan Burnham, Chair**

**March 17, 2014**

**Vice-Chairs:**

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

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

**Dr. Harry Posey (Vice-Chair – Industry) Shell International Exploration and Production**

**Highlights** (Additional details in the Appendix)

Oil Shale Symposia were held in Estonia and Colorado in 2013, and two symposia will also be held in 2014: one in Jordan in April as well the annual symposium in Golden, Colorado, in October. Discussions are underway to better coordinate international oil shale meetings in the future.

For the U.S. BLM RD&D leases, Enefit USA and American Shale Oil LLC continued efforts to demonstrate their oil shale processes, with the goal of conversion to a commercial lease. Natural Soda and ExxonMobil received approval of their Plans of Development for the next RD&D Leases. Shell continued activities related to disposal of their Colorado oil shale assets, preferring to concentrate on Jordan.

On non-federal lands, the Utah Division of Water Quality issued a groundwater permit to Red Leaf Resources, which now has the go-ahead to establish a small-scale commercial production system based on the EcoShale process. A consortium of environmental groups immediately challenged the decision with a "request for agency action." TomCo also applied for permits to establish a commercial operation using the EcoShale process 15 miles from the Red Leaf operation.

The Saudi Arabian Corporation for Oil Shale announced that Jordan's Lower House had approved agreements signed by the Jordanian government for a project that will start producing shale oil in five years and build to 30,000 barrels per day by 2025. The venture will use the Russian UTT-3000 technology, a version of a hot-burned-shale process. Oil shale development activities also continue in Israel and Mongolia by Genie Energy using an in-situ process, in Morocco by San Leon Energy using the Enefit 280 process and TAQA using the EcoShale process.

Oil shale continues to be mined, retorted, and burned in power plants in Estonia and China. An ATP processing unit is almost completed in China, and production is expected to rise significantly in 2014 and beyond. In Estonia, Viru Keemia Grupp has a second Petroter plant in construction. Small-scale commercial production also continues in Brazil by Petrobras, and Irati Energy Limited is launching a feasibility study of its plan for an 8,000 barrel per day shale oil plant.

The National Oil Shale Association released a new report on water use associated with development of oil shale from the Green River Formation. The new study assumed a smaller industry of 500,000 bbls/day, with a mix of 40% ex-situ, 45% in-situ, and 15% modified-in-situ processes. Of course, this split is speculative. Ranges of water consumption, including upgrading, were developed for each type, with an overall average of 0.7 to 1.2 barrels of water per barrel of oil. This would amount

to less than 1% of the water entering Lake Powell from the Colorado basin and only 5% of the trans-basin transfer of water from western Colorado to the Front Range.

**Active Basins, Recent Focus, and Future Growth** (Additional details in the Appendix)

China produces shale oil from the Fushun, Huadian, Huangxian, Junggar, Maoming, and Luozigou Basins, and from the Dalianhu and Haishiwan areas. Operating oil shale retorting plants are located in Beipiao, Chaoyang, Dongning, Fushun, Huadian, Jimsar, Longkou, Luozigou, Wangqing and Yaojie. Evaluation is continuing in four other basins and a number of other areas. New retorts are being built rapidly in China.

In Estonia, Viru Keemia Grupp has a second Petroter plant in construction, and has just received permission to start a third retort. They have also decided to acquire a new turn-key boiler flue gas desulphurisation plant for the Northern power plant in Kohtla-Järve, Estonia. They had considered developing a refinery targeting diesel fuel production, but that has been shelved for the time being. Eesti Energia continues hot testing of its Enefit 280 retort. New technology has enabled Eesti Energia to increase electricity production by 30% over the last decade while decreasing sulfur emission by 66%.

In Brazil, Petrobras continues mining and retorting operation in the Irati oil shale. However, startup Irati Energy Limited will soon launch a feasibility study of its plan for an 8,000 barrel per day shale oil plant, and expand its South Block oil shale resource through drilling. Irati, based in Southern Brazil, controls >3,100 $km^2$, with over 2 billion barrels of potential oil shale resources.

In Australia, Queensland Energy Resources (QER) successfully completed the operation of its demonstration plant near Gladstone in November 2013, Now that the moratorium on oil shale development has been lifted, QER is moving ahead towards design and construction of a commercial plant (5,000 BOPD) and is seeking investors.

In the United States, Red Leaf Resources has obtained the necessary permits from the State of Utah and is proceeding with plans for a commercial-scale demonstration from its Ecoshale™ technology to begin heating in 2014. Shell has cancelled its multimineral test of sequential production of nahcolite and shale oil on one of its three Research, Development and Demonstration leases. Freeze Wall de-commissioning began in 2012 and is progressing. AMSO, a partnership of Total and Genie Energy, encountered problems with its downhole heater in 2013, and is systematically evaluating different electrical and hot gas heater concepts to complete its pilot, with a nominal start date in 2015. Enefit American Oil (EAO) continues to refine its process for Utah oil shale, including incorporation of a potential fix for a fines generation problem. The have also started their EIS with the BLM to bring utilities to their site. ExxonMobil and Natural Soda received approval from BLM of their Development Plans for in-situ projects on their 2nd round R.D&D leases awarded in 2012.

Jordan has signed agreements to explore oil shale development in 2009 (JOSCo[Shell] and Aqaba Petroleum for Oil Shale), in 2010 (Enefit Jordan/Eesti Energia), in 2011, (Karak International Oil); in 2012 (Global Oil Shale Holdings and Whitehorn Resources), and in 2013 ( Saudi Arabian Oil Co). Enefit Jordan has received approval from Jordan's Ministry of Environment to proceed with its oil shale fired power plant, following a review by a committee appointed by the ministry of an Environmental Impact Assessment (EIA). Enefit Jordan has selected Guangong Power International Corporation for the engineering, procurement and construction of the power plant and mandated Bank of China and Industrial Commerical Bank of China to arrange debt financing. Currently negotiations are ongoing on the Power Purchase Agreement with the Government of Jordan. Jordan is scheduled to sign a memorandum of understanding with a Chinese company for the exploration and utilization of oil shale as part of the country's efforts to increase dependence on local energy resources. The Natural Resources Authority (NRA) has received the Cabinet's approval to sign the

memo with China's Fushun Mining Group Co. Ltd. Under the memo, the Chinese firm will conduct geological and geophysical studies over an 87-square-kilometre area in Wadi Al Naadiyeh in the central region, Zyoud said.

In Morocco, San Leon Energy has begun investigations on a tract of land in the Timhadit area, working with Enefit Outotec Technology (EOT) to conduct an initial study of the oil shale, based on surface retorting utilizing the Enefit 280 process. TAQA from Abu Dhabi is currently working on the Timhadit area in order to evaluate a potential development using the EcoShale Technology.

Genie Oil Shale Mongolia, LLC, and the Petroleum Authority of Mongolia (PAM) have entered into an exclusive five year development agreement to explore and evaluate commercial potential of oil shale resources on 34,470 $km^2$ in Central Mongolia, the first such oil shale agreement in Mongolia.

**Current and Forecast Production**

Total global production of shale oil is currently about 30,000 barrels per day (BOPD). All of this production comes from mining and retorting operations in Australia, Brazil, China, and Estonia. Indications are that Chinese production, which was approximately 15,000 BOPD in 2013, will increase substantially in 2014. 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.

Figure 1, presented by Boak at the 33rd Oil Shale Symposium, shows past and projected shale oil production, based upon informal data from producers. Addition of production planned by VKG and Enefit in Estonia, Enefit and JEML in Jordan, Irati Energy Ltd. in Brazil, and Enefit and Red Leaf Resources in Utah out to 2025 are combined with a conservative projection of future Chinese production based upon the last fifteen years. No in situ production is shown, although current RD&D leases will have to transition to commercial leases by that time. If current plans stay on track (an uncertain assumption), production can be expected to reach more than 400,000 barrels of oil per day by 2030.

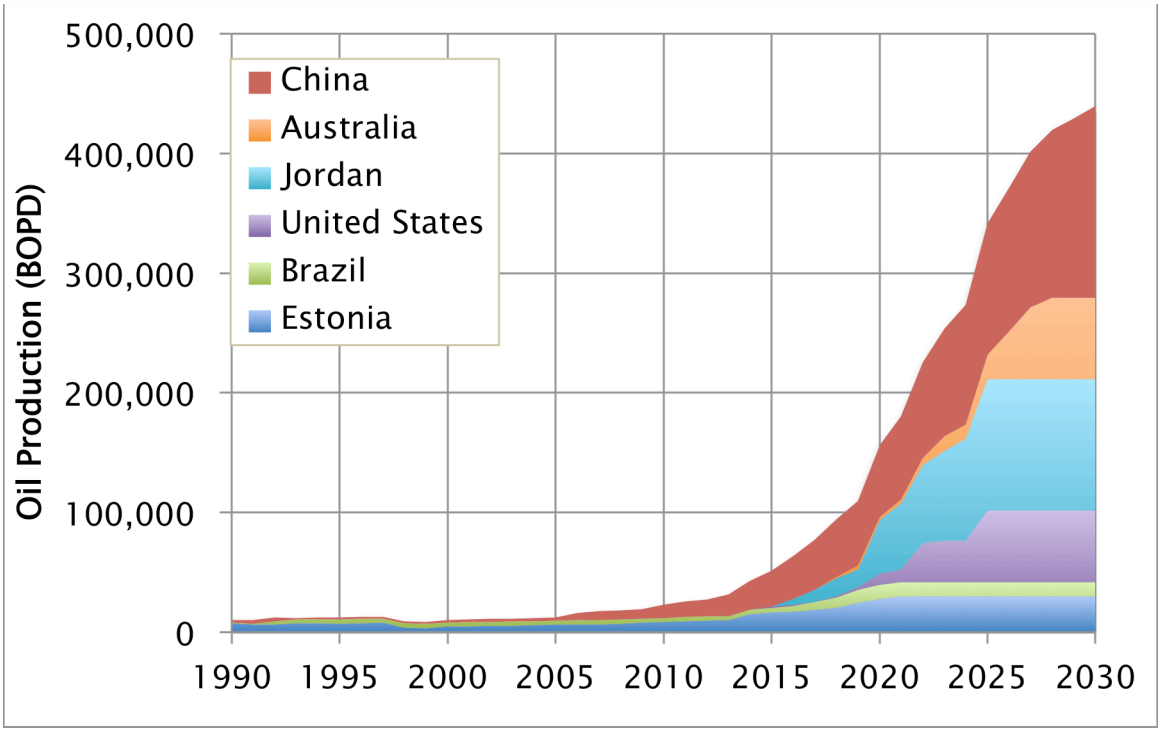


**Figure 1:** Historic mining production of oil shale, with extrapolation based upon proposed developments in Estonia, United States, and Jordan, and continued growth of Chinese production.

**Estimated U. S. and International Resources/Reserves and Strategic Importance** (Additional details in the Appendix.)

The U. S. Geological Survey has completed a reevaluation of oil shale resources of the Green River Formation in Colorado, Utah, and Wyoming (summarized in Birdwell et al, 2012). The results indi-

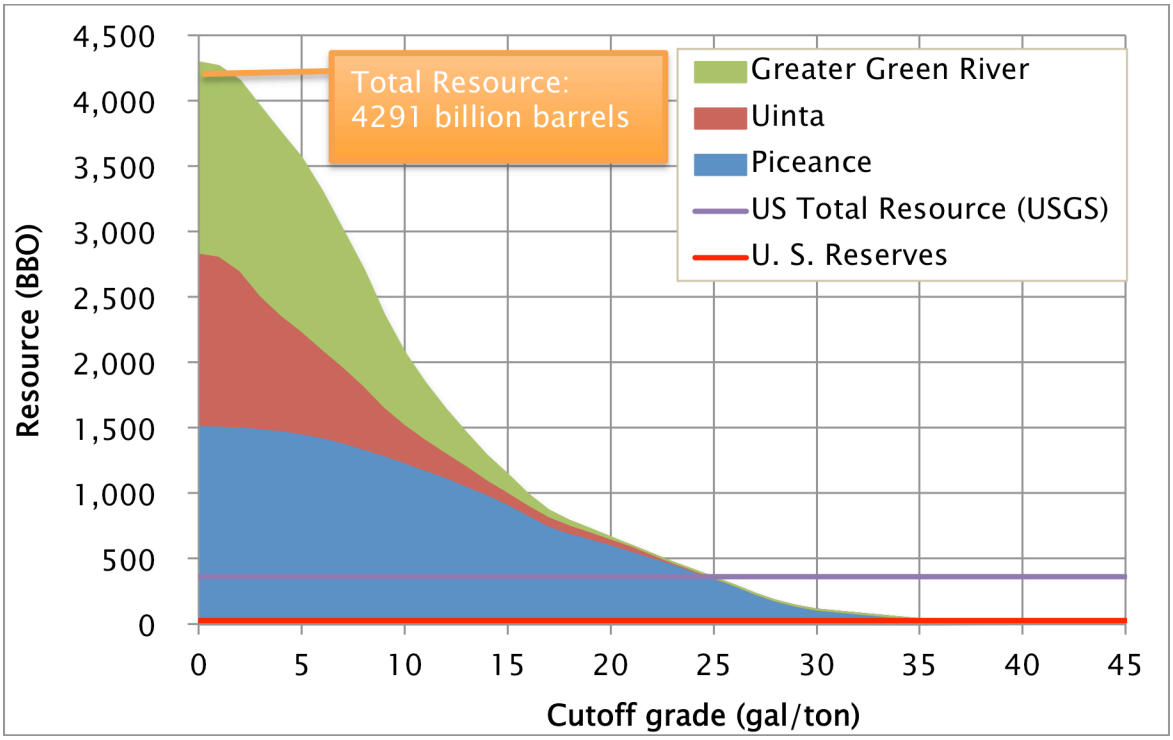


**Figure 2:** Oil shale resource estimates for different grades of oil shale, from U. S. Geological Survey data (presented at the 32nd Oil Shale Symposium)

cate Colorado resources increased from the 1.0 trillion barrel previous estimate to 1.52 trillion barrels, with Utah estimated at 1.32 trillion barrels of oil in place, and Wyoming with total resources of 1.44 trillion barrels. The total resource is estimated at 4.29 trillion barrels. A recent fact sheet on the resource available at various cutoff grades indicates that the most favorable resources (those with Fischer Assay oil yield above 15 gal/ton) are substantially smaller, and that these better resources are far more concentrated in the Piceance Basin than is evident from the total resource numbers. Figure 2 shows the USGS estimates of these amounts.

The USGS data do, however, indicate the very large potential resource in the Green River Formation. At the fifteen gallon per ton cutoff generally considered the limit of marginal resources, there is more than one trillion barrels available. At the cutoff for rich resources of 25 gallons per ton, the amount still is equal to the anticipated ultimate production from U. S. conventional oil. 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 only two developers are currently planning to produce by 2020. Current operations in other countries form a firm foundation for concluding that commercial technology is available for production in the U. S. However, especially for smaller countries with lower energy demands and no other liquid hydrocarbon resources (Estonia, Jordan, Israel and Morocco, for example) development of this resource can be very important strategically.

**Leading Companies** (Additional details in the Appendix)

The top companies at this point (with areas of development) are:

Total (Utah, Colorado, Jordan)
Shell (Jordan)
ExxonMobil (Colorado)
Natural Soda (Colorado)
Enefit (Estonia, Utah, Jordan)
Viru Keemia Grupp (Estonia, Ukraine)
Red Leaf Resources (Utah; Wyoming; licensees potentially in Jordan, Morocco, Canada)
Genie Energy (Colorado, Israel, Mongolia)
QER (Australia)/ ShaleTech International (Colorado and licensing Paraho worldwide)
Fushun Mining Company (China)
UMATAC/Thyssen Krupp (China)
Jordan Energy Minerals Limited/Karak International Oil (Jordan)
Independent Energy Partners (Colorado)
San Leon (Morocco)
CanShale (Canada)
Centor Energy (Canada)
TomCo Energy (Utah) (EcoShale licensee)
Anadarko (Wyoming)

**Research Focus and Leading Researchers** (Additional details in the Appendix)

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. Abstracts, presentations, and papers for the 26th through 32nd Oil Shale Symposia are available at: http://www.costar-mines.org/oil_shale_symposia.html .

Proceedings of the 33rd Oil Shale Symposium will be available for sale in April, once assembly is complete. The program and abstracts for the 33rd Oil Shale Symposium are posted at http://mines.conference-services.net/programme.asp?conferenceID=3190&language=en-uk .

Research at the University of Utah under USTAR and other activities in oil shale are covered in the University of Utah Unconventional Fuels Conference: http://www.icse.utah.edu/assets/archive/2013/ucf_agenda.htm .

Presentations and videos from the Estonian Oil Shale Symposium can be found at: http://oilshalesymposium.eu/ .

General information about oil shale in the United States is provided by the National Oil Shale Association (NOSA): www.oilshaleassoc.org .

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 .

**Sources of Funding**

Funding for oil shale research in the United States comes primarily from corporations actively pursuing oil shale development. U.S. Federal sources include the U.S. Department of Energy and U. S. Department of Interior, but such funding is negligible. 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.

**Critical Technology Needs** (Additional details in the Appendix)

Critical technology needs mainly concern the development of more energy efficient and environmentally friendly methods of extraction, production and upgrading of oil shale. Especially in the U. S., issues have been raised about greenhouse gas emissions and water consumption by industry.

The primary source of emissions for in situ production is power plant emissions of $CO_2$. Water consumption as reported in the 2013 Colorado symposium for Shell's ICP process (with a freeze wall) has dropped considerably to ~1.8 bbls of water per bbl of oil production with nearly all of the water consumption used for refilling the pore space upon completion of the project. Shell's ICP process in the nahcolitic interval (i.e. no freeze wall required) utilizes closer to 0.3 bbls of water per bbl of oil production (Wani, et al, Shell 2013). Minimizing energy use is essential to profitability and sustainability. AMSO has suggested sequestration of $CO_2$ in exhausted *in situ* retorts (Burnham and Carroll, 2009). An Enefit presentation 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.

The National Oil Shale Association has recently updated its estimate of water needs for an oil shale industry. Based upon 2014 input from developers such as Shell and Enefit, NOSA now estimates water usage of 0.7 to 1.2 barrels of water per barrel of shale oil (Bw/Bo) (16,000 to 29,000 acre feet per year for 500,000 barrels per day of marketable shale oil production). This is down from an average of 1.7 Bw/Bo in a 2012 estimate. Further details are in the appendix.

Developing criteria and methods for consistently structured resource 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 uncertainty regarding resource estimates where data are sparse.

**Key Environmental and Social Concerns** (Additional details in the Appendix)

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

1) Use of energy to pyrolyze the kerogen is minimized
2) Greenhouse gas emissions are reduced or compensated for by carbon trading or sequestration
3) Water used in construction, operation, power generation, and reclamation is minimized and does not deplete the water resources of arid regions
4) Extraction, production and upgrading of shale oil does not unduly affect the quality of the air, the native biological communities, or surface and ground water of the region.
5) Conduct projects in a manner that meets community expectations by keeping the public apprised of progress, being transparent, and being sensitive to changes in social dynamics

**Relevant EMD Technical Sessions, Publications, Workshops**

Oil shale related presentations were included in the 2013 programs of the Unconventional Resources Technology Conference (URTeC), held in Denver, August 12-14, the AAPG Rocky Mountain Section 62nd Annual Meeting in Salt Lake City (September 22-24), and the Geological Society of America Annual Convention in Denver (October 27-30). Much of the present focus in oil shale is in the engineering area, and results are presented at the Oil Shale Symposia mentioned in the highlights. Full listings are included in the Appendix.

## *Appendix: Amplified Discussion of Oil Shale Commodity Activity*

### Highlights from Previous Report

The International Oil Shale Symposium (IOSS) was held in Tallinn, Estonia, June 10-13, 2013, and the 33rd Oil Shale Symposium was held October 14-16 at the Colorado School of Mines in Golden CO, with a field trip to Utah and Colorado October 17-18. There was some overlap in their content but also some distinct information.

Papers presented included a summary of progress on various oil shale projects around the world as well as scientific and technical papers related to oil shale recovery technology. The Golden, CO, meeting was held during the shutdown of the US Federal Government, which prevented participation by governmental officials, including the keynote speaker.

Another significant event was the pullout of Shell Oil from oil shale activities in Colorado. This pullout is symptomatic of the situation that oil companies have limited resources to pursue multiple opportunities around the world. Shell is still proceeding with their oil shale activities in Jordan.

A particularly important paper at the 33rd Oil Shale Symposium was a study by Shell that reduced expected water usage for oil shale extraction down to less than 2 barrels of water per barrel of oil. This is accomplished by a variety of actions, including the use of air-cooling instead of water evaporation for process needs and aggressively applying the latest low water use technological advances.

A series of papers by Enefit showed progress on bringing the Enefit280 process on line in Estonia, continued efforts to permit their plant construction in Utah, and progress on their Jordan project. Design modifications to the fluidized bed combustor were shown to reduce fines generation for Green River oil shale, which suffers greater attrition of rock particles than Estonian oil shale.

Other important papers and discussions addressed the social license to operate and the difficulty of raising capital for emerging technologies. The social license discussions emphasized the importance of proactive and continuous honest discussions of activities with the public to get and maintain its support. Trying to hide problems will eventually backfire. An example of successful proactive discussions was the turnaround of public opinion in Queensland Australia by QER. The difficulty in raising capital for projects that are not self-financed by a major corporation centered around the hesitation of independent capital to fund projects that are not considered to use mature technology, but once the technology is established, the rate of funding and construction should increase if the economics are favorable.

### Active Basins, Recent Focus, and Future Growth

Production continues in three countries that have produced shale oil for decades: Brazil, China, and Estonia. New retorts are being built rapidly in China and more slowly in Estonia.

China produces shale oil from the Fushun, Huadian, Huangxian, Junggar, Maoming, and Luozigou Basins, and from the Dalianhu and Haishiwan areas. Operating oil shale retorting plants are located in Beipiao, Chaoyang, Dongning, Fushun, Huadian, Jimsar, Longkou, Luozigou, Wangqing and Yaojie. Evaluation is continuing in four other basins and a number of other areas.

In Estonia, Viru Keemia Grupp has a second Petroter plant in construction, and has just received permission to start a third retort.. They have also decided to acquire a new turn-key boiler flue gas desulphurisation plant for the Northern power plant in Kohtla-Järve, Estonia. They are also considering development of a refinery targeting diesel fuel production. Eesti Energia,internationally known as Enefit continues hot testing of its Enefit280 retort near Narva. The technological solutions used in Estonia and Jordan will be based on the experience with operating the existing Enefit140 and Enefit280 oil plants. New technology has also enabled Enefit to increase electricity production by 30% over the last decade while decreasing sulfur emission by 66%.In Brazil,

Petrobras has shown little interest in expanding its mining and retorting operation in the Irati oil shale. However, startup Irati Energy Limited will soon launch a financing effort for feasibility studies of its plan to develop an initial 8,000 barrel per day shale oil plant, and further expand its South Block oil shale resource through drilling. Irati, based in Southern Brazil, controls over 3,100 $km^2$, with potential oil shale resources over 2 billion barrels, strategically located in one of Brazil's most industrialized regions, where the regional market consumes unrefined shale oil.

In Australia, Queensland Energy Resources (QER) continues to operate its demonstration plant near Gladstone, and is selling the 40 barrels per day of product into the commercial market. QER has initiated a program to ship 35,000 liters of Ultra Low Sulfur Diesel and a campaign for 13,000 liters of aviation turbine fuel (Jet A-1) for testing and certification. Now that the moratorium on oil shale development has been lifted, QER is moving ahead towards design and construction of a commercial plant (5,000 BOPD).

In the United States, Red Leaf Resources is proceeding with plans for commercial-scale production from its Ecoshale™ technology to begin heating in late 2013 or 2014. Shell has cancelled its multi-mineral test of sequential production of nahcolite and shale oil on one of its Research, Development and Demonstration leases. Freeze Wall de-commissioning began in 2012 and is ongoing. AMSO, a partnership of Total and Genie Energy, has encountered problems with its downhole heater, and is working to resume testing as soon as possible. Enefit American Oil (EAO) has also encountered engineering issues with fine particulate matter in tests in Germany of Utah oil shale in its pilot-scale system. EAO is confident it has sufficient contingency in its design plan to evaluate and resolve the problem. ExxonMobil is developing plans for its testing in situ method on the RD&D lease it was awarded in 2012. Natural Soda continues to define its pilot demonstration on its 2012 RD&D lease tract. Independent Energy Partners is testing its Geothermic Fuel Cell unit at the Colorado School of Mines in Golden CO, in partnership with Delphi and Total. Shale Tech International Services LLC (STIS) continues to further develop the Paraho II™ Technology for ex-situ oil shale processing at its R&D Center in CO. STIS provides analytical laboratory services, batch, and pilot plant test for client resources, as well as a technology licensing and project development program. Jordan has attracted international interest in its oil shale resources. It signed agreements to explore oil shale development in 2009 with Shell International (JOSCo) and Aqaba Petroleum for Oil Shale (APCO, now Al Janoub for Oil Shale Company), in 2010 with Estonia's Eesti Energia, in 2011, with the United Kingdom's Karak International Oil; in 2012 with Canada's Global Oil Shale Holdings and Canada's Whitehorn Resources, and in 2013 with the Saudi Arabian Oil Co. Enefit Jordan has received approval from Jordan's Ministry of Environment to proceed with its oil shale fired power plant, following a review by a committee appointed by the ministry of an Environmental Impact Assessment (EIA).

In Morocco, San Leon Energy, in an update of its study of the Tarfaya Oil Shale, has said that results from samples from two reservoir zones suggest that a yield of 72 liters of oil per ton of rock is achievable. Preliminary modeling of the project confirmed that a commercial operation is possible. In August 2012, San Leon commissioned Enefit Outotec Technology (EOT) to conduct an initial study of the Tarfaya Oil Shale, with a view to pursuing surface retorting utilizing the Enefit 280 process. TAQA from Abu Dhabi is currently working on Timhadit area in order to evaluate a potential development using the ECOSHALE Technology.

In April 2013, Genie Mongolia and the Petroleum Authority of Mongolia entered into an exclusive oil shale development agreement to explore and evaluate the commercial potential of oil shale resources on a 34,470 square kilometer area in Central Mongolia. Genie Mongolia has begun surface mapping and other geophysical evaluation work as well as drilling exploratory wells, and has secured permits for additional exploratory wells. The exploratory well program is intended to identify a site suitable for a pilot test. Subsequent commercial operations are contingent upon

implementation of a regulatory framework by the government for the permitting and licensing of commercial oil shale operations.

In Israel, the government issued long delayed directives In mid-April 2013 required for preparation and submission of an environmental impact statement that is a required component of Israeli Energy Initiative's (IEI's) pilot test permit application in the Shfela Basin. IEI prepared and initially submitted its pilot application in June of 2013 to the Jerusalem District Building and Planning Committee. In November, IEI submitted additional information for its application pursuant to a request by the Committee. Once the application is accepted, the permit evaluation process is expected to take at least nine months.

In Canada, Chapman Petroleum Engineering Ltd. has completed an NI 51-101 Engineering Evaluation Report of Contingent Resources and Commerciality Factors on Xtra Energy's Pasquia Hills oil shale permit located in northeastern Saskatchewan. The report provides a Best Estimate and High Estimate of 1,878 and 2,348 billion barrels of oil (distillate product).

Uzbekistan could become the first Central Asian country to attempt to produce non-conventional hydrocarbons in oil and gas rich Central Asia as early as 2013 as part of plans by the government to address dwindling oil production and domestic fuel shortages. State oil and gas company Uzbekneftegaz is planning a $600m oil shale project to launch production.

***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. The total resource is estimated at 4.29 trillion barrels. However, a recent fact sheet on the resource available at various cutoff grades indicate that the most favorable resources (those with Fischer Assay oil yield above 15 gal/ton) are substantially smaller, and that these better resources are far more concentrated in the Piceance Basin than is evident from the total resource numbers. Figure 2 shows the USGS estimates of these amounts.

The USGS data do, however, indicate the very large potential resource in the Green River Formation. At the fifteen gallon per ton cutoff generally considered the limit of marginal resources, there is more than one trillion barrels available. At the cutoff for rich resources of 25 gallons per ton, the amount still is equal to twice the anticipated remaining production from U. S. "conventional" oil.

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 lack of estimates of the gas fraction can be of special significance, as this resource is likely to be used in the heating process, and therefore affect the external energy return of the processes.

The U. S. is the only place where extensive analysis and evaluation has been published for a large oil shale resource. However, the global estimates of Dyni are considered conservative estimates of the resource potential. Estimates of the recovery potential for U. S. oil shale were generally near 50%, but vary widely. The recent data suggests a recovery potential closer to 25%. The current Chinese estimate postdates Dyni's estimate, and significantly increases the world resources. However, China's assessment indicates that they also 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 only two developers are currently planning to produce by 2020. Even so, it is wrong to assert that oil shale production is still non-commercial, as current operations in other countries form a firm foundation for concluding that commercial technology is available for production in the U. S and elsewhere.

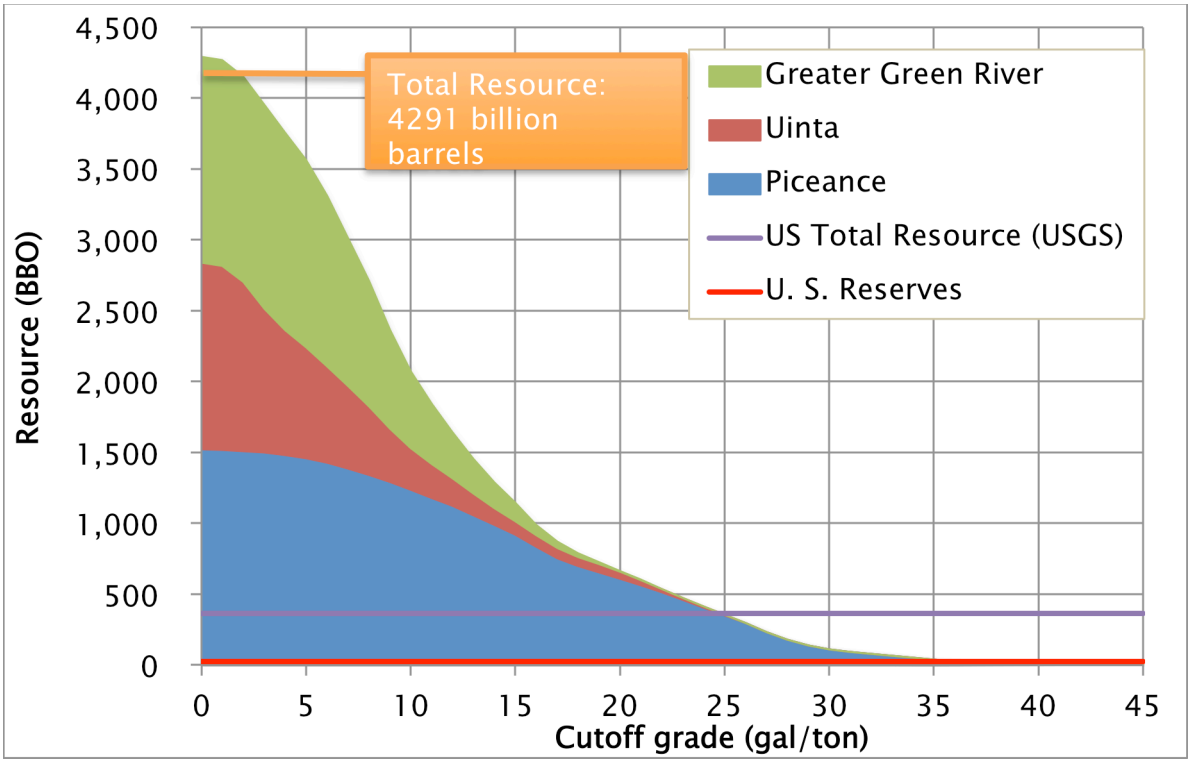


**Figure 2:** Oil shale resource estimates for different grades of oil shale, from U. S. Geological Survey data (presented at the 32nd Oil Shale Symposium)

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.

***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, and AMSO also have regional offices in western Colorado. International oil companies with activities in oil shale include (in alphabetic order):

- ExxonMobil
- Petrobras (Brazil)
- Shell

Total (partner with Genie Oil in American Shale Oil – AMSO – and partner with Red Leaf Resources in ECOSHALE)In addition, three other large oil companies have significant land holdings underlain by oil shale, and one major oilfield service company has acquired technology for oil shale evaluation and conducts research on the petrophysical properties of oil shale:

- Anadarko Petroleum Corporation
- ConocoPhillips
- Chevron
- Schlumberger

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

- Combustion Resources, Inc.
- Enefit American Oil
- EnShale Inc.
- General Synfuels International
- Genie Oil (partner with Total in American Oil Shale – AMSO)
- Independent Energy Partners
- Natural Soda, Inc.
- Red Leaf Resources
- Shale Tech International
- CanShale (Canada)
- Centor Energy (Canada)
- Taciuk/Tysen Krupp (China)
- TomCo Energy (Utah) (EcoShale licensee)
- Anadarko (Wyoming)
- Ambre Energy (trying to sell some but not all of their UT state leases)
- TomCo - UT state leases, licensee of Red Leaf Eco Shale technology,
- Encana also has resource holdings in CO
- Uintah Gateway/Partners – property in CO and UT, developing regional upgrader project in UT that would start with black wax then expand for shale oil.

International leadership is held mainly by companies producing oil shale at the present time and also currently pursuing development of oil shale:

- Eesti Energia/Enefit (Estonia)/Outotec (Finland)
- Fushun Mining Company (China)
- Queensland Energy Resources (Australia) [demonstration plant]
- Viru Keemia Grupp (Estonia)

- Altius Resources (Canada)
- Aqaba Petroleum for Oil Shale (Jordan)
- Global Oil Shale Holdings (Canada)
- Israel Energy Initiatives Limited (Israel) – owned mostly by Genie Energy
- International Corporation for Oil Shale Investment (Incosin) [MOA in Jordan]
- Jordan Energy Minerals Limited (England) [Agreement in Jordan]
- San Leon Energy (Ireland) [concession in Morocco]
- TAQA (Abu Dhabi) agreement in Morocco

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

### *Current Research*

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 energy efficiency and decreasing the impact of retort operation by reducing water use and $CO_2$ emissions. 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, AMSO (a partnership of Total and Genie Oil (a U. S. based energy company whose other operations include developing in situ oil shale production in Israel), and others are investigating different processes. In situ heating takes 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. 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 external research on its method. However, the company anticipates moving forward with production of 10,000 BOPD by 2017, and plans to expand that to a

30,000 BOPD facility that will start construction in 2020. This would be a globally significant development for oil shale.

The U. S. Geological Survey (USGS) continues to conduct research evaluating the nature and extent of oil shale resources in the United States. 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 Wisconsin, Binghamton University (New York), University of New Brunswick and other North American and international universities.

*List of Specialists in the United States*

***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
- Wei (Wendy) Zhou, Geographic Information Systems for oil shale water resource evaluation

***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***

- Drew Pomeranz, 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
- Robert Kleinberg, characterization and pyrolysis of oil shale

***ExxonMobil Upstream Research Company***

- William Symington, thermal behavior of Green River Formation oil shale and technology for application of heat in situ
- Jesse Yeakel, geology of Green River Formation oil shale
- Sartaj Ghai, in-situ extraction technology

***Shell Exploration and Production Company***

- Mariela Araujo, Extraction technology, thermal modeling
- Wolfgang Deeg, Freeze wall development and testing, oil shale piloting
- Tom Fowler, in situ production of oil shale, oil shale piloting
- Erik Hansen, Jordan and Piceance Basin hydrology
- John Karanikas, Chief Scientist unconventional technology
- Harry Posey, Isotope geochemistry of Green River Formation, oil shale regulations
- Etuan Zhang, In Situ oil characterization and generation

***American Shale Oil LLC***

- Alan Burnham, properties and kinetics of oil shale, in-situ and ex-situ retorting of oil shale
- Roger Day, geology, drilling, and operations expertise in the Green River formation
- Leo Switzer, in-situ extraction technology

***Enefit American Oil***

- Rikki Hrenko, , oil shale development
- Ryan Clerico, environmental issues and regulatory affairs

***Red Leaf Resources LLC***

- James Patten, Properties of Oil Shale, Ex Situ Retorting processes
- James Bunger, Geology, properties and kinetics, Lab and Modeling
- Les Thompson, Oil Shale Retorting Operations

***Norwest Corp***

- Greg Gold, oil shale mining and development
- Steve Kerr, geologist on Green River Formation
- Andrew Maxwell, oil shale properties, mining, retorting
- Konrad Quast, Green River Formation geochemistry

***Shale Tech InternationalServices LLC***

- Kevin Biehle, ex-situ oil shale technology and development
- Justin Bilyeu, ex-situ oil shale processing technology
- Phil Hansen, oil shale and product characterization
- Larry Lukens, ex-situ oil shale technology

***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, 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
- Jan Miller, University of Utah, Salt Lake City, UT, micro-CT scan of pre and post pyrolysis products
- John McLennan, University of Utah, Salt Lake City, UT, in-situ geomechanical properties of oil shale

***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
- Brad Bunnett, Natural Soda, Dallas TX, sodium mineral extraction from oil shale
- Alan Carroll, COSTAR, University of Wisconsin, Madison, WI, stratigraphy, sedimentology and geochronology of Green River Formation, Wyoming; lacustrine stratigraphy and sedimentology
- Ed Cooley, ERTL Inc., Rifle, CO, ex-situ oil shale processing technology
- Gerald Daub, Daub and Associates, Grand Junction CO, geology of Green River Formation
- Mike Day, Independent hydrologist, Piceance Basin hydrology
- Jim Finley, Telesto Solutions Inc, Green River Formation hydrology & geochemistry
- Thomas Fletcher, Brigham Young University, Provo, UT, oil shale chemistry
- Alan Goelzer, Jacobs Consultancy, Durham, New Hampshire, modeling of retorting and hydrogenation processe
- Terry Gulliver, Oil shale hydrology
- John Hardaway, Environmental restoration for in situ production
- 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
- Seth Lyman, Bingham Research Center, Utah State University, Vernal, UT, Air quality measurement and instrumentation
- Glenn Mason, Indiana University Southeast, New Albany, IN, geology of Green River Formation oil shale
- Bill Merrill, Western Water and Land, hydrology of the Green River Formation
- Jim McConaghy, Antero Engineering, Salida CO, ex-situ and in-situ oil shale extraction technology
- 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, stratigraphy, and hydrogeology of oil shale, Uinta Basin
- Glenn Vawter, NOSA, oil shale extraction technology
- Henrik Wallman, ProCo, Modeling of in-situ and ex-situ oil shale processing
- Glen Miller, oil shale geology and mineral resources

*List of International Specialists*

***Enefit***

- Priit Raud, ex-situ oil shale processing technology
- Pritt Ploompuu, ex-situ oil shale processing technology
- Indrek Aarna, ex-situ oil shale processing technology
- Erkki Kaisla, oil shale mining
- Oleg Nikitin, oil shale mining
- Alar Saluste, waste water treatment

***Viru Keemia Grupp***

- Janus Purga, ex-situ oil shale processing technology

***Israeli Energy Initiatives***

- Yuval Bartov, lacustrine stratigraphy, Green River Formation and Israel

- Harold Vinegar, general oil shale technology, development of Israeli oil shale

***TOTAL SA***

- Pierre Allix, Geology, properties and kinetics, resource evaluation, retorting processes,
- Bernard Corre, reservoir engineering, thermal recovery, properties and kinetics, lab and modeling
- Olivier Garnier, retorting processes, oil shale development, upgrading
- Francoise Behar, geochemistry, oil shale kinetics
- Alexandre Lapene, process modeling and simulation

***QER***

- John Parsons, ex-situ oil shale technology
- Ian Henderson, ex-situ oil shale technology
- David Cavanaugh, ex-situ oil shale technology

***UMATAC***

- Gordon Taciuk, ex-situ oil shale processing technology
- Steven Odut, ex-situ oil shale processing technology

***Others***

- Omar Al-Ayed, Al-Balqa Applied University, Faculty of Engineering, Amman Jordan, properties of Jordanian oil shale and shale oil
- Mohammed Bencherifa, Organization National des Hydrocarbures et des Mines (ONHYM), Rabat, Morocco, engineering and geology of Moroccan oil shale
- 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
- Erik Puura, Tallinn Technical University, ash leaching, contaminant transport and ash utilization
- 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
- Walid Sinno, San Leon Energy, London England, Development of Tarfaya oil shale
- Jyri Soone, Tallinn Technical University, Tallinn, Estonia, Environmental effects of oil shale ash and spent shale
- Kati Tanavsuu-Milkeviciene, Statoil, stratigraphy and sedimentology of Green River Formation, Colorado
- Richard Terres, Shell International Exploration and Production, Jordanian oil shale characterization and production
- Mahmoud Zizi, ZIZ Geoconsulting, Rabat Morocco, Geology and engineering for Moroccan oil shale

### *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 (Shell, American Oil Shale/Total) and others holding land underlain by the Green River Formation (ExxonMobil). 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 for oil shale 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 (Enefit/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.

### *Critical Technology Needs*

Critical technology needs mainly concern the development of more energy efficient and 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 largest use for a Shell-type *in situ* operation (Boak, 2008; 2012). 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). Shell has been developing their Circulating Molten Salt (CMS) heater, which is expected to reduce fuel consumption—and therefore $CO_2$ emissions—by approximately 30-40% compared to operations powered by electrical heaters. AMSO has examined the potential for sequestration of $CO_2$ in exhausted in situ retorts (Burnham and Carroll, 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. The offsets are not yet clearly accepted.

In the United States, understanding and mitigating the environmental effects 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, but can only be addressed by a Federal government interested in executing this duty.

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.
5) Any Subsidence caused by mining or in-situ retorting does not cause unacceptable disruption of natural surface features or human structures

Socioeconomic impacts are also issues of concern. It is important that projects are conducted in a manner that meets community expectations by keeping the public apprised of progress, being transparent, and being sensitive to changes in social dynamics

The recent offering of RD&D leases required that each of these concerns be addressed explicitly in the lease application. Numerous companies have highlighted the requirement for multiple rounds of interaction with regulatory bodies before production can begin. These interactions include at least two separate environmental impact assessment stages likely to focus on the same impacts, in addition to the numerous other permits that often require a public comment and review component and multiple agency coordination processes, which are often overlapping and may result in conflicting requirements from multiple agencies. 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.

Water use has been highlighted as an important environmental issue recently, with reports from the Government Accounting Office on water issues which heavily stressed a number of potential environmental impacts with little regard to whether these impacts were novel to oil shale development, or had been reasonably mitigated in the past. Many of the water numbers in the report were out of date, or from very limited studies intended to highlight pre-existing uncertainty in the water use estimates. The industry has had previously been claiming a water usage amount in the range of 1-3 barrels of water per barrel of oil to reasonably covers the technology likely to implemented for oil shale production, and that lower values may be achievable as industry progresses. The high end was for in-situ processes where aquifer remediation was required. More recently, with in-situ processing in the Piceance Basin planned only below the aquifers, this lower range is more appropriate.

The National Oil Shale Association has recently updated its estimate of water needs for an oil shale industry. Based upon 2014 input from developers such as Shell and Enefit, NOSA now estimates water usage of 0.7 to 1.2 barrels of water per barrel of shale oil (Bw/Bo) (16,000 to 29,000 acre feet per year for 500,000 barrels per day of marketable shale oil production). This is down from an average of 1.7 Bw/Bo in a 2012 estimate. The major reductions came from more aggressive water conservation efforts and the elimination of water needed for ground water flushing after in situ

retorting. Most developers now believe that a bulk of future in situ development will be carried out in areas where there is no mobile ground water, and thus ground water mitigation technology such as a freeze wall will not be necessary.

| Technology | Shale Oil B/D | Gross Bw/Bo | Net Bw/Bo | Net Acre-Ft/Yr |
|---|---|---|---|---|
| In situ | 225,000 | 0.6 – 1.3 | 0.3 – 1.0 | 3,180 - 10,600 |
| Ex situ | 200,000 | 2.4 – 2.6 | 1.4 – 1.6 | 13,200 – 15,100 |
| Modified In situ | 75,000 | 0.5 – 1.1 | 0.0 – 0.9 | 0 – 3,180 |
| *Total* | *500,000* | | *0.7 – 1.2* | *16,400 – 28,900* |

While still maintaining the water use is not defined, opponents and even the BLM have yet to provide any indication of whether or why these estimates are not adequate. In the absence of a clear statement that three barrels per barrel is too high (and a technical rationale for that assertion), the vague claims of both Government and opponents that not enough is known have the distinct ring of political motivation. Figure 3 shows water consumption in miles per gallon for a variety of tradi-

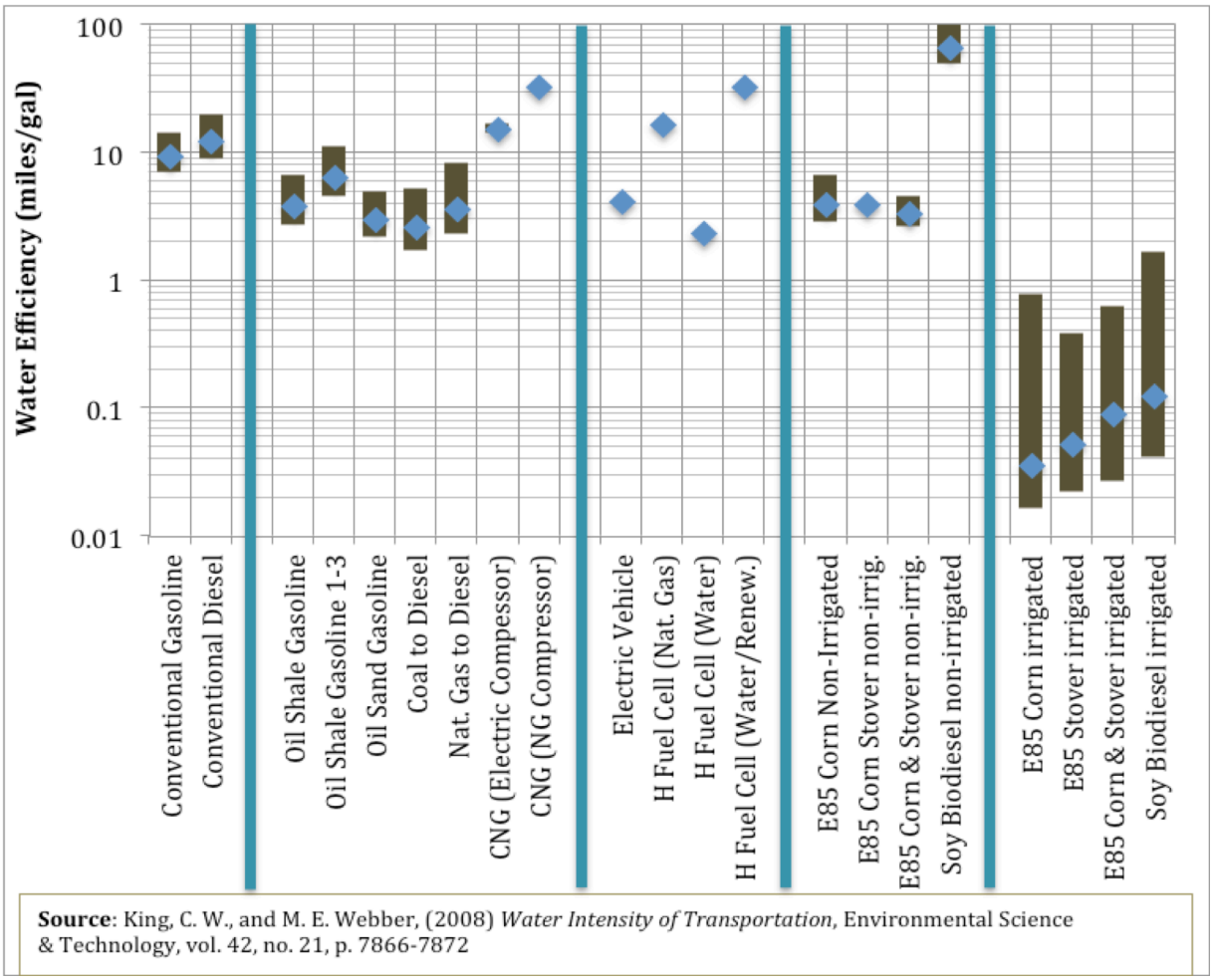


**Figure 3:** Water efficiency (in miles per gallon) of various conventional, unconventional, and alternative fuels. Diamond is mean value and bar represents range of estimates. An additional bar has been added to represent current industry estimates to produce shale oil of 1-3 barrels of water per barrel of oil, which is on the high side of current expectations.

tional, unconventional and alternative fuels. The bars indicate the range of estimated values, whereas the diamond represents the average value. An additional bar has been added to reflect up-to-date industry estimates for water consumption. From this it is clear that oil shale is comparable to most non-irrigated biofuel, and far lower in water consumption than irrigated biofuel. Consistency would seem to require equal Federal anxiety about biofuel production in Colorado.

**Relevant EMD Technical Sessions, Publications, Workshops**

Oil shale related presentations are distributed throughout the program of the Pittsburgh ACE. Much of the present focus in oil shale is in the engineering area, and results are presented at the Oil Shale Symposia mentioned in the highlights. The Unconventional Resources Technology Conference (URTEC) in Denver last August, cosponsored by the AAPG, had several talks on oil shale, heavy oil and oil sands, hydrates, and other unconventional resources beyond gas shale and oil-bearing shale.

Oil shale related presentations and posters at AAPG meetings include:

***AAPG Rocky Mountain Section 62nd Annual Meeting, September 22-24, Salt Lake City UT***

Stanley M. Awramik and H. Paul Buchheim (2013) Microbialites of the Eocene Green River Formation as Analogs to the South Atlantic Pre-Salt Carbonate Hydrocarbon Reservoirs AAPG Search and Discovery Article #90169©2013

M'bark Baddouh, Brian L. Beard, Alan R. Carroll, and Clark M. Johnson (2013) Geochemistry of Lacustrine Microbialite of the Eocene Green River Formation AAPG Search and Discovery Article #90169©2013

Birdwell, Justin E., Michael E. Brownfield, Ronald C. Johnson, Tracey J. Mercier (2013) In-Place Oil Shale Resources in the Saline Mineral and Saline-Leached Intervals, Piceance Basin, Colorado AAPG Search and Discovery Article #90169©2013 AAPG Rocky Mountain Section 62nd Annual Meeting

Boak, Jeremy and Jufang Feng (2013) Geochemistry of the Green River Formation, Piceance Creek Basin, Colorado AAPG Search and Discovery Article #90169©2013

Gierlowski-Kordesch, Elizabeth (2013) The Origin of Lacustrine Carbonates and Microbialites in Lake Basins AAPG Search and Discovery Article #90169©2013

Johnson, Ronald (2013) Structural Controls on the Development of Eocene Lake Gosiute and Lake Uinta, Southwest Wyoming, Northwest Colorado, and Eastern Utah, AAPG Search and Discovery Article #90169©2013

Jones, Evan and Piret Plink-Björklund (2013) The Response of Fluvial Systems in the Uinta Basin, Utah to Extreme Global Warming Events During the Early Eocene Climatic Optimum, AAPG Search and Discovery Article #90169©2013

Keighley, David and Michael Vanden Berg (2013) Where Have the Mahogany Oil-Shale Beds Gone? Possible Evidence of Large-Scale Slumping at Sand Wash, Uinta Basin, Utah

Keighley, David, Chris McFarlane, and Tim E. Ruble (2013) Microbial Fossils, Phosphatization, Heavy Rare Earth Element and Uranium Enrichment: Early Diagenesis of an Upper Green River Formation Oil Shale, Uinta Basin, Utah AAPG Search and Discovery Article #90169©2013

Murphy, John and Tim K. Lowenstein (2013) Preservation of Primary Lake Signatures in Carbonates of the Eocene Green River Wilkins Peak-Laney Member Transitional Zone AAPG Search and Discovery Article #90169©2013

O'Hara, T. Ryan, Kati Tänavsuu-Milkeviciene, and J. Frederick Sarg Sandstone Deposition in the Eocene Green River Formation of Eastern Uinta Basin, Evacuation Creek: Depositional Environments

and Reservoir-Scale Architecture AAPG Search and Discovery Article #90169©2013

Ruble, Tim E. and Michael D. Lewan (2013) Programmed-pyrolysis Derived Petroleum Yield Determinations Calibrated with Hydrous Pyrolysis: a Case Study of Green River Source Rocks AAPG Search and Discovery Article #90169©2013

Swierenga, Michael, J. Frederick Sarg, and Kati Tänavsuu-Milkeviciene (2013) Depositional History and Lateral Variability of a Microbial Carbonate, Three Mile Canyon and Evacuation Creek, Eastern Uinta Basin, Utah AAPG Search and Discovery Article #90169©2013

Toms, Leah, Lauren Birgenheier, and Michael Vanden Berg (2013) Temporal and Spatial Variations in Lacustrine Depositional Controls from the Middle to Upper Green River Formation, Central and Western Uinta Basin, Utah AAPG Search and Discovery Article #90169©2013

***Unconventional Resources Technology Conference (URTeC), August 12-14, 2013) Denver CO***

J. Boak, S. Poole, J. Sarg, K. Tanavsuu-Milkeviciene (2013) Evolution of Lake Uinta as Defined by Mineralogy and Geochemistry of the Green River Formation in Colorado

R. L. Kleinberg, A. Pomerantz, T. Le Doan, P. Allix, A. Burnham (2013) Insights into the Maturation Process from Physical and Chemical Analysis of Partially Pyrolyzed Green River Oil Shale

T. Le Doan, P. Allix, F. Behar, B. Corre, A. Burnham, R. L. Kleinberg, A. Pomerantz (2013) Experimental Study of Green River Oil Shale Pyrolysis

B. Nugraha, A. Pratama (2013) Study Of Ground Water Quality Effects and Relation to the In-Situ Retorting Process in Oil Shale Exploration for Environmental Improvement

S. L. Reeder, R. L. Kleinberg, M. Herron, A. Burnham, P. Allix (2013) A Multi-Measurement Core-Log Integration for Advanced Formation Evaluation of Source Rock Formations: A Green River Case Study

G. Vawter (2013) Importance of U.S. Oil Shale

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Birdwell J.E., Mercier T.J., Johnson R.C., Brownfield M.E., 2012, *In-Place Oil Shale Resources Examined by Grade in the Major Basins of the Green River Formation, Colorado, Utah, and Wyoming*: U.S. Geological Survey Fact Sheet 2012-3145, 2013.

Boak, J., 2013, *Shale Oil Production from Oil Shale: Where Do We Stand?* , Presentation at 33rd Oil Shale Symposium, Colorado School of Mines, Golden CO USA, October 14-16, 2013

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King, C. W., and M. E. Webber, 2008, *Water Intensity of Transportation*, Environmental Science & Technology, vol. 42, no. 21, p. 7866-7872

Wani, A., Schroeder, T., Meyer, C., and Fowler, T., 2013, Low Water Use Technologies – Improvements to Shell's Water Balance, 33rd Oil Shale Symposium, Colorado School of Mines, Golden CO USA