EMD Oil Shale Committee

EMD Oil Shale Committee Annual Report - 2013

Alan Burnham, Chair

May 18, 2013

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.)

The Queensland government has lifted a 20-year moratorium on shale oil mining imposed in 2008 by the former Labor government. Queensland Energy Resources (QER) has operated a technology demonstration plant in Gladstone, and is considering the Stuart site of the Yarwun resource to be an important source of oil for the future.

Interior Secretary Kenneth Salazar finalized plans for oil shale and tar sands development on Bureau of Land Management (BLM) lands. The Record of Decision (ROD) and plan amendments make nearly 700,000 acres in Colorado, Utah and Wyoming available for potential oil shale leasing. Under the ROD, the BLM-managed lands will be available only for Research, Development and Demonstration (RD&D) leases, which companies could convert to commercial leases after satisfying conditions of the RD&D lease and meeting due diligence, clean air and water requirements.

The International Oil Shale Symposium (IOSS) will be held in Tallinn, Estonia, June 10-13, 2013, hosted by Enefit, with partners the Colorado School of Mines, Tallinn University of Technology and the University of Tartu. The IOSS will showcase Estonia's longstanding expertise, with a focus on energy independence, economic viability, and environmental sustainability; Field Trips will visit active facilities, including the recently completed Enefit280 Oil Plant. [International Oil Shale Symposium]

The Call for Abstracts is out for the 33rd Oil Shale Symposium, the premier global meeting for the oil shale industry, to be held October 14-16 at the Colorado School of Mines in Golden Colorado (with a Field Trip to Utah and Colorado localities and facilities October 17-18). Deadline for submittal of abstracts is June 28. The Symposium website provides information and links to registration and abstract submission web pages. [33rd Oil Shale Symposium]

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

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 opened the first new oil shale mine at Ojamaa, with reserves es-

timated at 58 million tons, and an expected 15-17 year lifetime. Eesti Energia continues hot testing of its Enefit 280 retort near Narva. New technology has also enabled Eesti Energia to increase electricity production by 30% over the last decade while decreasing sulfur emission by 66%.

In Brazil, Petrobras has continued its 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) continues to operate its demonstration plant near Gladstone, and is selling the 40 barrels per day of product into the commercial market. Now that the moratorium on oil shale development has been lifted, QER is moving ahead toward the next stage.

In the United States, Red Leaf Resources is proceeding with plans for a near full scale production test of its Ecoshale™ technology to begin heating in late 2013 or 2014. Shell is preparing for a multimineral test of sequential production of nahcolite and shale oil on one of its Research, Development and Demonstration leases. 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.

Jordan has attracted international interest in its oil shale resources. It signed agreements to explore oil shale development in 2009 (Shell International and Aqaba Petroleum for Oil Shale), in 2010 (Eesti Energia), in 2011, (Karak International Oil); in 2012 (Global Oil Shale Holdings and Whitehorn Resources), and in 2013 (Saudi Arabian Oil Co). In addition, the Attarat Power Company, a wholly-owned subsidiary of Enefit Jordan BV, announced it has received six bids for Jordan's first oil shale-fired power plant from engineering and construction companies.

In Morocco, San Leon Energy has said that results from samples from two reservoir zones confirmed that a commercial operation is possible. 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.

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 14,000 BOPD in 2012, will increase to approximately 15,000 BOPD in 2013. 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 shows modified version the plot by Dyni (2006) of mined oil shale in million tons, reflecting updates to 2010 by Alan Burnham of Genie Energy and Pierre Allix of Total. Addition of the production planned by 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, alt-

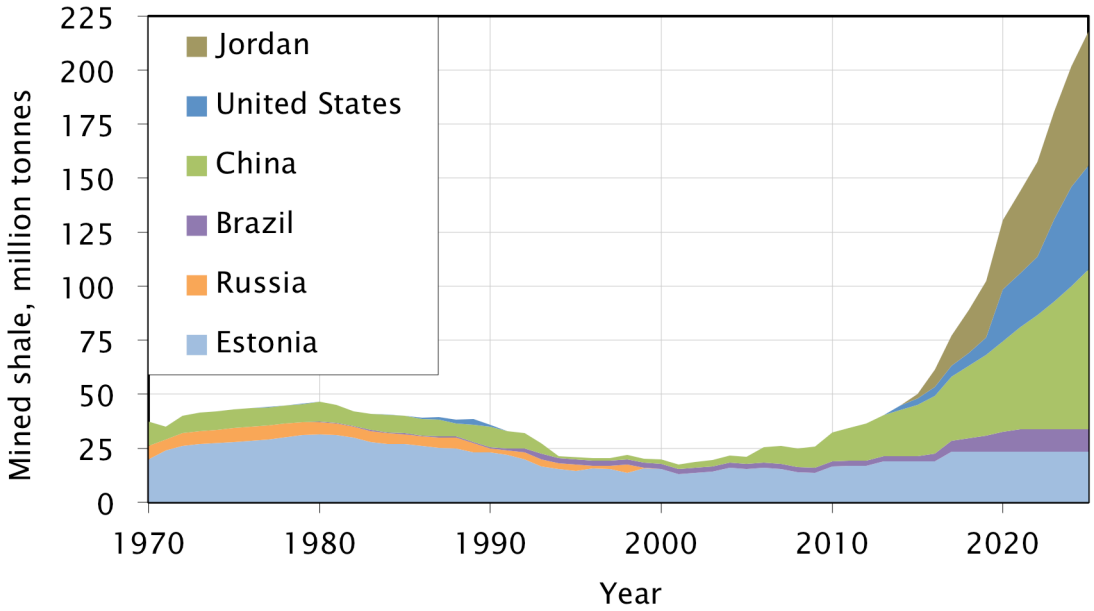

Figure 1: Historic mining production of oil shale, with extrapolation based upon proposed developments in Estonia, United States, and Jordan, and continued growth of Chinese production.

hough current RD&D leases will have to transition to production leases by that time. The indication is that if current plans stay on track (a highly uncertain assumption), 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 oil shale used for power generation vs. oil production.

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

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 U. S. Geological Survey has completed its reevaluation of oil shale resources of the Green River Formation in Colorado, Utah, and Wyoming. The results indicate 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 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 For mation. 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. It is, however, wrong to assert that oil shale production is still non-commercial, as current operations in other countries form a firm foundation

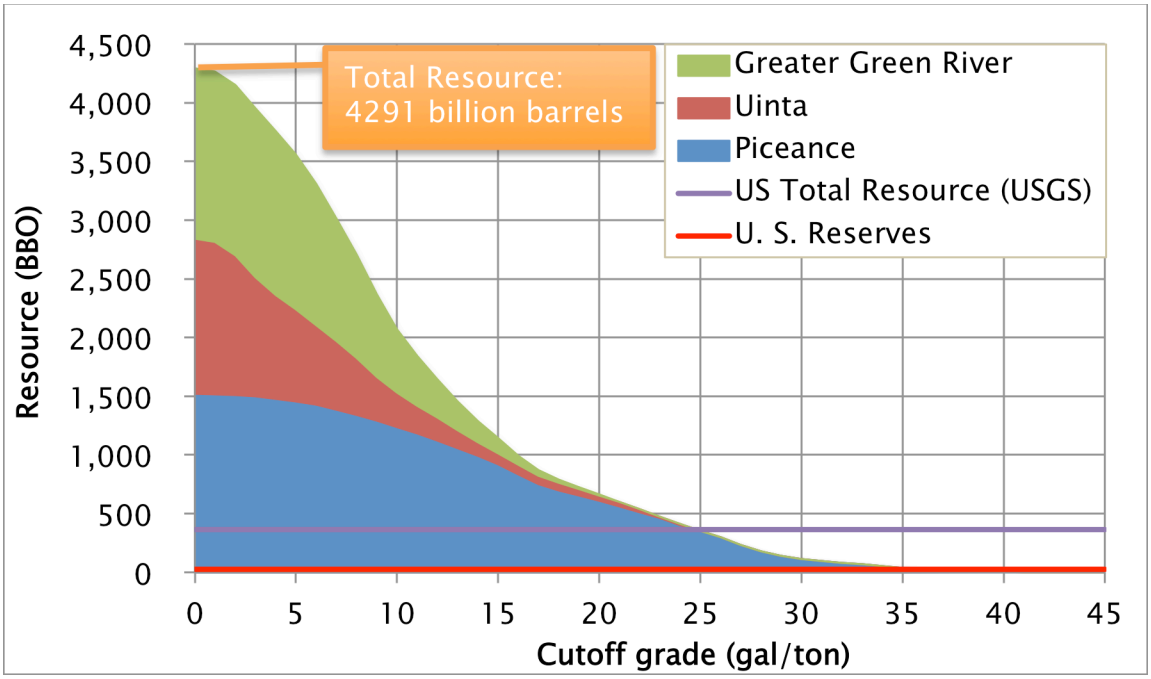

Figure 2: Oil shale resource estimates for different grades of oil shale, from U. S. Geological Survey data (presented at the 32nd Oil Shale Symposium)

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 hydrocarbon resources (Estonia, Jordan 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, Mongolia)
Shell (Colorado, Jordan)
ExxonMobil (Colorado)
Enefit (Estonia, Utah, Jordan, Morocco)
Viru Keemia Grupp (Estonia, Ukraine)
Genie Energy (Colorado, Israel, Mongolia)
Red Leaf Resources (Utah; licensees potentially in Jordan, Canada, Wyoming)
ShaleTech International/QER (Australia)
Fushun Mining Company (China)
Jordan Energy Minerals Limited/Karak International Oil (England)
Independent Energy Partners (Colorado)

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. All proceedings abstracts, presentations, and papers for the 26th through 31st Oil Shale Symposia are available at: http://www.costar-mines.org/oil_shale_symposia.html.

The program and abstracts for the 32nd Oil Shale Symposium are posted at http://mines.conference-services.net/programme.asp?conferenceID=3190&language=en-uk.

Proceedings of the 32nd Oil Shale Symposium are available for sale at:
http://csmspace.com/events/oilshale2013/proceedings32.html

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 .

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 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 (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 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). 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. The offsets are not yet clearly accepted.

Internationally, there is a lack of consistently structured resource assessments. 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.

Key Environmental and Geologic Hazards (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.

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 in August will have only one full oral session to cover 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 Annual Conference and Exhibition, May 19-22, Pittsburgh, PA

Stevensite, Oolite, and Microbialites in the Eocene Green River Formation, Sanpete Valley, Uinta Basin, Utah: P. Buchheim, S. M. Awramik

The Uteland Butte Member of the Eocene Green River Formation: An Emerging Unconventional Carbonate Tight Oil Play in the Uinta Basin, Utah: M. D. Vanden Berg, C. D. Morgan, T. C. Chidsey, P. Nielsen

A Genetic Stratigraphic Framework of the Green River Formation, Uinta Basin, Utah: The Impact of Climatic Controls on Lake Evolution: L. P. Birgenheier, P. Plink- Bjorklund, M. D. Vanden Berg, M. Rosenberg, L. Toms, J. A. Golab

Microbialite "Shrubs" of the Eocene Green River Formation: Analogs for the Cretaceous Pre-Salt Lacustrine Systems of the South Atlantic Conjugate Basins: S. M. Awramik, P. Buchheim

Sequence Stratigraphy in Mixed Lake Systems, Organic Richness and Climate — Green River Formation, Lake Uinta, Part I, Sequence Stratigraphy: K. Tanavsuu- Milkeviciene, R. Sarg, Y. Bartov

Sequence Stratigraphy in Mixed Lake Systems, Organic Richness, and Climate — Green River Formation, Lake Uinta, Part II, Organic Richness: R. Sarg, K. Tanavsuu-Milkeviciene, F. Jufang

Sequence Stratigraphy in Mixed Lake Systems, Organic Richness and Climate — Green River Formation, Lake Uinta, Part III, Mineralogy and Geochemistry: J. Boak, S. Poole, R. Sarg, K. Tanavsuu-Milkeviciene

Chemostratigraphic Subdivision and Diagenesis in the Upper Green River Formation, Southern Uinta Basin, Utah: D. Keighley, M. D. Vanden Berg, G. Yan

Emerging Oil Shale Plays in China: Q. Li, M. Chen, Y. Jin, B. Hou, F. Wang

Committee Activities

Alan Burnham has offered to serve as committee chair, but activation of his membership in AAPG has been slow.

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Mercier, T.J., Johnson, R.C., and Brownfield, M.E., 2011, *In-place oil shale resources underlying Federal lands in the Green River and Washakie Basins, southwestern Wyoming*: U.S. Geological Survey Fact Sheet 2011–3113, 2 p.

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

Appendix: Amplified Discussion of Oil Shale Commodity Activity

Highlights

The Queensland government has lifted a 20-year moratorium on shale oil mining imposed in 2008 by the former Labor government. Queensland has ~90 per cent of Australia's known oil shale reserves, capable of producing 22 billion barrels of oil. Queensland Energy Resources has operated a technology demonstration plant in Gladstone, and is considering the Stuart site of the Yarwun resource to be an important source of oil for the future.

Interior Secretary Kenneth Salazar finalized plans for oil shale and tar sands development on Bureau of Land Management (BLM) lands. The Record of Decision (ROD) and plan amendments make nearly 700,000 acres in Colorado, Utah and Wyoming available for potential oil shale leasing. Under the ROD, the BLM-managed lands will be available only for Research, Development and Demonstration (RD&D) leases, which companies could convert to commercial leases after satisfying conditions of the RD&D lease and meeting due diligence, clean air and water requirements. Salazar claims the plan maintains a strong focus on RD&D to promote new technology that may eventually lead to safe and responsible commercial development, but critics note the plan removes from consideration >90% of the richest oil shale land in Colorado, but offers hundreds of thousands of acres of low-grade, subeconomic oil shale land. They also note no other technology faces such stringent lease requirements; nor has the BLM acknowledged that commercial technology already exists, requiring only engineering design and testing to produce shale oil.

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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. Now that the moratorium on oil shale development has been lifted, QER is moving ahead toward the next stage, although reports indicate that major industrial development in the area has raised contruction costs in the near term. QER plans to move to construction and operation of a small commercial plant (3,000 BOPD) during 2014-2017, and to a second commercial plant (21,500 BOPD) in 2019-2021.

In the United States, Red Leaf Resources is proceeding with plans for a near full scale production test of its Ecoshale™ technology to begin heating in late 2013 or 2014. Commercial production at 9.500 barrels per day is the initial target following completion of that test. Shell is preparing for a multimineral test on one of its Research, Development and Development leases. This will test sequential production of nahcolite and shale oil. 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.

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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 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.

Genie Energy said today that its subsidiary, 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 the commercial potential of oil shale resources on a 34,470 km^2 area in Central Mongolia, the first such oil shale agreement in Mongolia. Genie will characterize the resource in the area and conduct a pilot test using in-situ technology on appropriate deposits. Genie may proceed to commercial development via a production sharing agreement under Mongolian law.

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 the anticipated ultimate 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

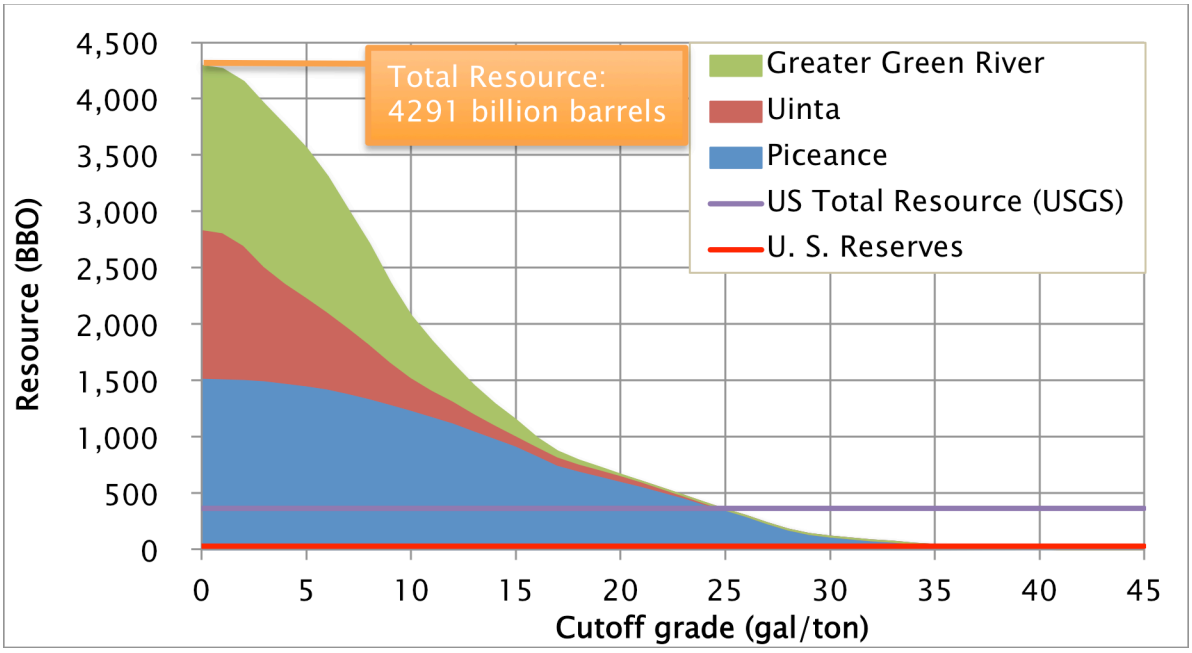

Figure 2: Oil shale resource estimates for different grades of oil shale, from U. S. Geological Survey data (presented at the 32nd Oil Shale Symposium)

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. It is, however, 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.

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.

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)

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 and conducts research on the petrophysical properties of oil shale:

- 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
- Genie Oil (partner with Total in American Oil Shale – AMSO)
- Independent Energy Partners
- Natural Soda, Inc.
- Red Leaf Resources
- Shale Tech International

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)
- 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)
- 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]

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 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 31st Oil Shale Symposia are available at: http://www.costar-mines.org/oil_shale_symposia.html.

The program and abstracts for the 32nd Oil Shale Symposium are posted at http://mines.conference-services.net/programme.asp?conferenceID=3190&language=en-uk.

Proceedings of the 32nd Oil Shale Symposium are available for sale at: http://csmspace.com/events/oilshale2013/proceedings32.html

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, 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 9,500 BOPD within about 18 months, and plans to expand that to a 30,000 BOPD facility that will start construction in 2015. 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. 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

The list continues to grow.

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 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
- Sandra Hopko, Oil shale pyrolysis chemistry
- Jessie Yeakel, geology of Green River Formation oil shale

Shell Exploration and Production Company

- Mariela Araujo – Extraction technology, thermal modeling
- Wolfgang Deeg, freeze wall development and testing
- Thomas Fowler, in situ production of oil shale
- John Hardaway, environmental restoration for in situ production
- Erik Hansen – Piceance Basin hydrology
- John Karanikas – Chief Scientist unconventional technology
- Ming Lin – Geomechanics of in situ pyrolysis
- David Montague – pyrolysis research, geomechanics, drilling
- Harry Posey - Isotope geochemistry of Green River Formation
- Etuan Zhang – In Situ oil characterization and generation

Statoil

- Kati Tanavsuu-Milkeviciene, stratigraphy and sedimentology of Green River Formation, Colorado

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
- Julio Facelli, University of Utah, Salt Lake City, UT, Cyber informatics

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, stratigraphy, and hydrogeology of oil shale, Uinta Basin
- Mike Day, Independent hydrologist, Piceance Basin hydrology
- Terry Gulliver, Norwest Corp, Oil shale geology
- Jim Finley, Telesto Solutions Inc, Green River Formation hydrology & geochemistry
- Konrad Quast, Norwest, Green River Formation geochemistry

List of International Specialists

- 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
- 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
- Richard Terres, Shell International Exploration and Production, Jordanian oil shale characterization and production
- Harold Vinegar, Israel Energy Initiative, Israel, Development of Israeli oil shale
- 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 (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). 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. 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, 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.

Socioeconomic impacts are also issues of concern. 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. 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 delivered a clear and consistent message that a range of 1-3 barrels of water per barrel of oil reasonably covers the technology likely to implemented for oil shale production, and that lower values may be achievable as industry progresses.

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 traditional, 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.

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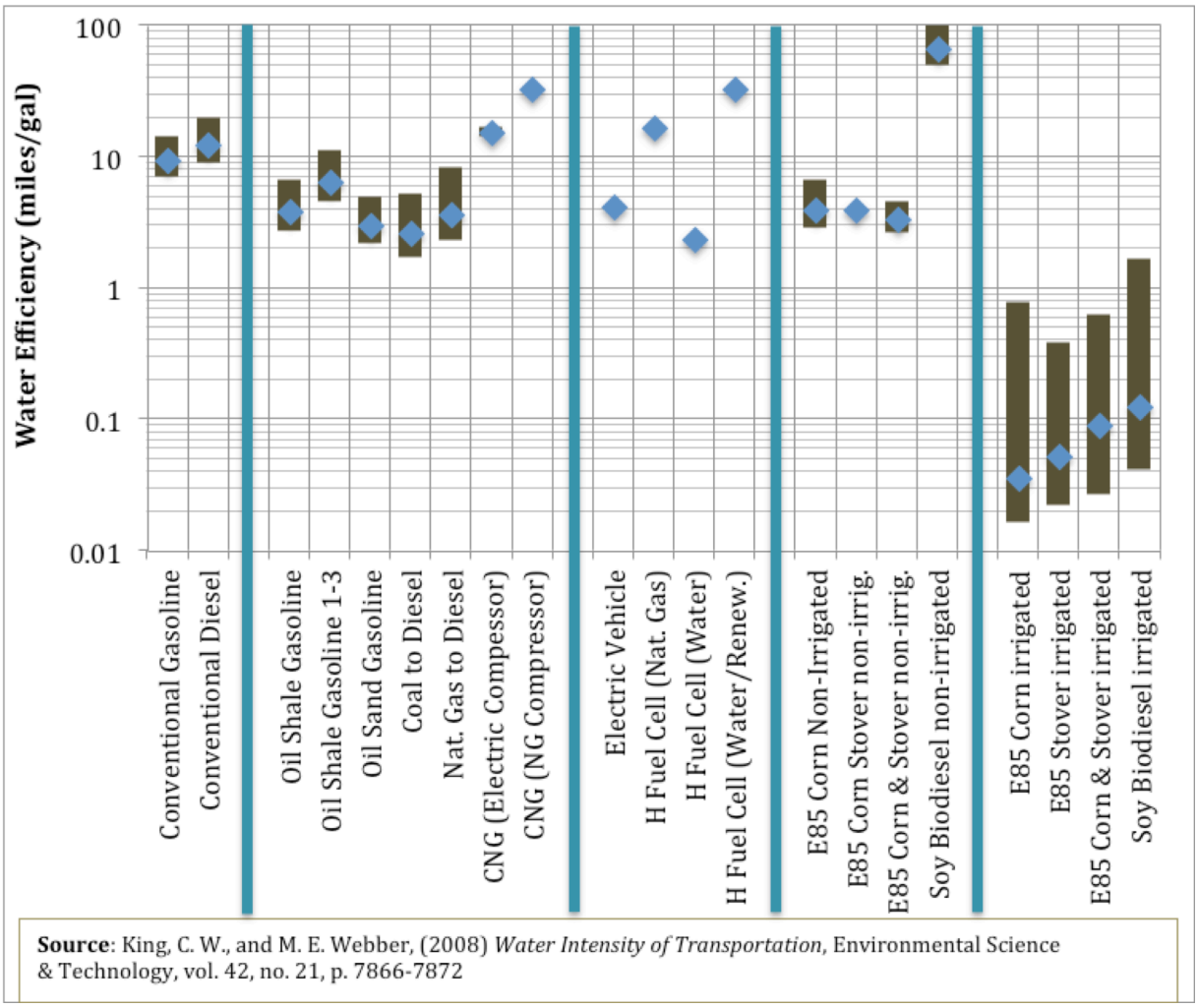

Figure 3: Water efficiency (in miles per gallon) of various conventional, unconventional, and alternative fuels. Diamond is mean value and bar represents range of estimates. An additional bar has been added to represent current industry estimates to produce shale oil of 1-3 barrels of water per barrel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

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