EMD Oil Shale Committee

EMD Oil Shale Committee Semi-Annual Report - 2012

Kati Tanavsuu-Milkeviciene, Chair

November 19, 2012

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

Committee Activities

In the first half of the 2012-2013 business year, the Oil Shale Committee has found itself looking for a new Oil Shale Committee Chair to replace Jeremy Boak, who was elected as the Energy Minerals Division's President-Elect. Our first candidate, Dr. Kati Tanavsuu-Milkeviciene has had to withdraw because she has accepted a new position. We continue to search for a new committee chair.

The Oil Shale Committee has continued to engage in the international discussion about technical terminology regarding *oil shale* and *shale oil*. The Chair has suggested that the terms *oil-bearing shale* and *shale-hosted oil* be used for rock formations containing liquid hydrocarbons.

Oil shale related presentations and posters at AAPG meetings include:

AAPG Rocky Mountain Section Meeting, September 9-12, Grand Junction, CO

Breaking Down Barriers in Mudstone Investigations: What Oil Shale Can Tell Us about Shale-Hosted Hydrocarbons, by Jeremy Boak and J. Frederick Sarg; (2012) *AAPG Rocky Mountain Section Meeting, Grand Junction, Colorado, 9-12 September*

Climate Control on Oil Shale Organic Richness - Green River Formation, Piceance Creek Basin. J. Frederick Sarg, Jufang Feng, and Kati Tanavsuu-Milkeviciene; (2012) *AAPG Rocky Mountain Section Meeting, Grand Junction, Colorado, 9-12 September*

AAPG International Conference and Exhibit, September 16-19, Singapore

Sedimentation, Maturity and Petroleum Potential of the Oligocene Oil Shale Deposits of the Assam Basin, North-East India: A Review, by Jha, Prakash; Chaubey, Ravi S.; *AAPG International Conference & Exhibition, Singapore, 16-19 September*

Geological Characteristics and Developing -Prospecting Foreground of Oil shale in Tongchuan-Huangling District, Shaaxi, North China, by Yunlai, Bai; *AAPG International Conference & Exhibition, Singapore, 16-19 September*

Other

Evolution of an organic-rich lake basin – stratigraphy, climate and tectonics: Piceance Creek basin, Eocene Green River Formation; by Kati Tanavsuu-Milkeviciene and J. Frederick Sarg; Sedimentology Vol. 59, No. 6, pp. 1735-1768.

The analysis of tectonic controls on the shale distribution and its resource potential in lacustrine basins in East China; Wang, H. Jiang, S., Huang, C, Abstract # 1118933, AAPG Annual Conference: (Long Beach, CA, 4/22-25/2012) ABSTRACTS 2012. (Available at http://www.searchanddiscovery.com as of 3/28/2012; 1 p; Abstract only)

Microbial Carbonates from Core and Outcrop, Tertiary (Eocene) Green River Formation, Uinta Basin, Utah, by Eby, David E.; Chidsey, Jr., Thomas C.; Vanden Berg, Michael D.; Laine, Michael D.; Search and Discovery #90142 (2012) AAPG Annual Conference: (Long Beach, CA, 4/22-25/2012)

Spatial analysis and environmental impact assessment of Ordovician oil shale using ArcGIS: A case study of North Eastern Estonia, by Obinna Nzekwe; #90157 (2012) AAPG Foundation Grants-in-Aid Projects

Oil Shale Commodity Report

World Oil Shale 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 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 an update to the plot by Dyni (2006) of mined oil shale in million tons. Data gathered by Alan Burnham and Pierre Allix of AMSO/Total update the chart to 2010. Addition of the production planned by Enefit in Estonia, Enefit and JEML in Jordan, and Enefit and Red Leaf Resources in Utah out to 2025 are combined with a conservative projection of future Chinese produc-

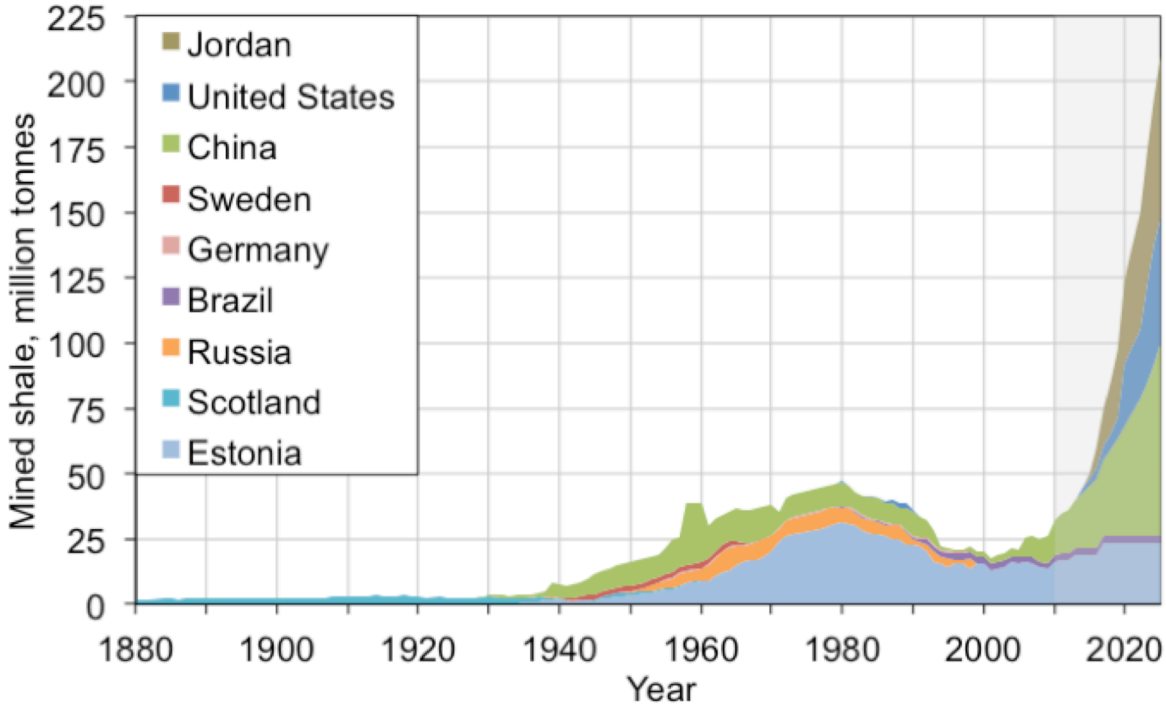

Figure 1: Historic mining production of oil shale, with extrapolation based upon proposed developments in Estonia, United States, and Jordan, and continued growth of Chinese production.

tion based upon the last fifteen years of production. No projections are made of any projects using in situ technology, although current RD&D leases will have to transition to production leases by that time.

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

Highlights

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

- The US Bureau of Land Management (BLM) published a final programmatic environmental impact statement and possible land use amendments for federally administered oil shale and tar sands acreage in Colorado, Utah, and Wyoming on November 9, 2012. The PEIS analyzed several land allocation and resource management alternatives, the US Department of the Interior agency noted. The preferred alternative makes 676,967 acres available for research and development of oil shale out of a total of 2,112,197 acres administered by BLM in the most geologically prospective area (26,259 of 307,165 acres in Colorado, 357,409 of 560,870 acres in Utah, and 293,299 of 1,244,162 acres in Wyoming), and 129,567 of about 430,000 acres in eastern Utah would be available for tar sands-related activities.
- BLM also announced awarding of two ten-year 160-acre Research, Development and Demonstration (RD&D) leases in Colorado, to ExxonMobil Exploration Company and Natural Soda Holdings, Inc., effective December 1, 2012.
- Red Leaf Resources is proceeding with their plan to begin development of their Ecoshale In-Capsule technology in Utah, with production startup in about 12-18 months. Red Leaf has obtained the backing of Total to test the process. Red Leaf estimates the surface recoverable oil resources for their Utah and Wyoming acreage are approximately 400 million barrels and 800 million barrels respectively.
- Eesti Energia has begun hot commissioning of their Enefit 280 retort system near Narva, Estonia.
- The Jordanian Oil Shale Symposium at the Dead Sea in Jordan in May 2012 highlighted developments, brought together a wide range of international developers of oil shale, and focused attention on the large deposits in the Middle East. Unfortunately, participation did not include those working to develop the large Israeli deposits that are essentially continuous with the Jordanian resource, as Israel did not even appear on the list of countries at the registration site. The Symposium website is at Jordan International Oil Shale Symposium Posters are posted there, but presentation materials are not available.
- The 32nd Oil Shale Symposium brought together approximately 270 professionals from the oil shale industry for two-and-one-half days of reviews of current status and description of ongoing research and development activities, October 15-17, 2012 at the Colorado School of Mines in Golden Colorado. A field trip took 30 attendees to oil shale development sites (ShaleTech International and Enefit American Oil) and geologic overview stops in Colorado and Utah.

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.

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 should be available for sale by the end of the AAPG Annual Convention and Exhibition in Pittsburgh.

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
- Kati Tanavsuu-Milkeviciene, stratigraphy and sedimentology of Green River Formation, Colorado
- Wei (Wendy) Zhou, Geographic Information Systems for oil shale water resource evaulation

Idaho National Laboratory

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

Los Alamos National Laboratory

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

Schlumberger Doll Research Center

- Neil Bostrom, pyrolysis of oil shale, kinetics, and characterization
- Michael Herron, mineralogic and chemical characterization of oil shale

- Malka Machlus, stratigraphy of Green River Formation oil shale

ExxonMobil Upstream Research Company

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

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

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

Focus of Recent Activity

Recent oil shale activity in the United States has centered on the development and testing of oil shale technology. The U. S. Bureau of Land Management (BLM) has recently awarded two leases from among three applications for a second round of Research Development and Demonstration (RD&D) leases. The two leases were awarded on November 9, 2012, and are effective December 1, 2012. The leases offer the same 160 acre RD&D area as the previous round. However, the lease preference area, which becomes available at fair market price after a company has shown commercial feasibility for its technology, has been reduced to 480 acres, for a total of 640 acres.

The US Bureau of Land Management (BLM) published a draft programmatic environmental impact statement and possible land use amendments for federally administered oil shale and tar sands acreage in Colorado, Utah, and Wyoming. The revised draft PEIS was released February 3, 2012. A 90-day comment period on the proposals ended May 4, 2012. Revision of the PEIS represents BLM's approach to complying with settlement agreements for several lawsuits that challenged the process of the previous PEIS and subsequent revisions to Resource Management Plans. The preferred alternative removed more than 90% of the richest deposits – especially in Colorado – from consideration, leaving only scattered acreage seemingly randomly distributed in the basin. It retained tens of thousands of acres underlain by oil shale with less than 15 gallons per ton of oil on average - land which is unlikely to be developed any time in the foreseeable future. This can hardly be characterized as a cautious and reasonable approach, as it selected one of the two most extreme options among those proposed by BLM.

BLM expected to publish a notice of proposed rulemaking to address the royalty rate and environmental protection requirements applicable to oil shale leasing, no later than 11/18/12. The proposed rules have not been released.

Shell has begun development of a test program on one of its multi-mineral RD&D leases in western Colorado. This test is intended to generate porosity by hot water leaching followed by pyrolysis of oil shale in the leached mass, utilizing natural geologic containment of the Saline Zone. Shell continues to experiment with its In situ Conversion Process (ICP), which involves electric heating of a block of rock contained by a freeze wall to protect ground water and minimize heat loss to flowing water. Shell has demonstrated all of the elements of this system on a small scale, and has completed a test freeze wall on a larger scale on private land in Colorado. They have also reported on experiments that complete the process by circulating water through the block to remove hydrocarbons not extracted through the production wells. Shell has also established baseline water chemistry of water-bearing intervals (aquifers) that expand the aquifer definitions in the Piceance

Creek Basin, based on hydrology, water chemistry, and proximity to the Saline Zone dissolution interface.

ExxonMobil continues work at its Colony site to investigate its *in situ* oil shale technology, which involves electric heating through large plate electrodes created by hydraulic fracturing from horizontal wells and injection of an electrically conductive proppant. They have demonstrated that the process can create an effective connected heating element. ExxonMobil has created a plan for a test of the *in situ* technology at the RD&D lease it has applied for on BLM land. ExxonMobil has not commented on whether the awarding of their RD&D lease will cause them to change plans for experiments at the Colony site.

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

Red Leaf Resources is preparing a revised application for its large mine permit, and anticipates production startup within eighteen months of receiving all required permits. They anticipate startup of a 9,500 barrel per day operation in 2013 or 2014.

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

Internationally, Estonia is in the process of significantly expanding its capability to produce oil from shale, while de-emphasizing the use of oil shale for combustion in power plants. Enefit, the international arm of Eesti Energia, the national energy company of Estonia, has begun aggressive development overseas, with projects in the U. S. and Jordan. The new Enefit 280 retort near Narva, Estonia underwent testing and in early and mid-2012, and started hot commissioning in October. This system will bring another 5,000 BOPD on production in the next few months. They plan to initiate production in the U. S. in 2020, and in Jordan also about 2020. Enefit also proposes to make a decision on additional production units in Estonia to be brought on line before 2020.

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

ShaleTech International and Queensland Energy Resources Ltd (QER) are continuing to operate a small demonstration retort in Queensland Australia to show the viability of the Paraho II™ technology for environmentally sound shale oil production. The demonstration plant produces about 40 barrels per day, and 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.

San Leon Energy of Dublin Ireland has stopped testing of its in situ technology in late 2011, and is evaluating the hydrologic system in anticipation of further testing. They have also received additional concession areas to begin evaluation of surface processing of oil shale using the Enefit 280™ technology.

China appears to be rapidly increasing its capacity to produce shale oil through surface retorting. Currently, it appears there are over 500 retorts of various sizes (mostly 100 metric ton/day shale, Fushun-type retorts) installed with more than 200 under construction. Total production was about 14,000 barrels per day. A significant number of the retorts are new in the last year, and may not yet be on line.

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

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

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

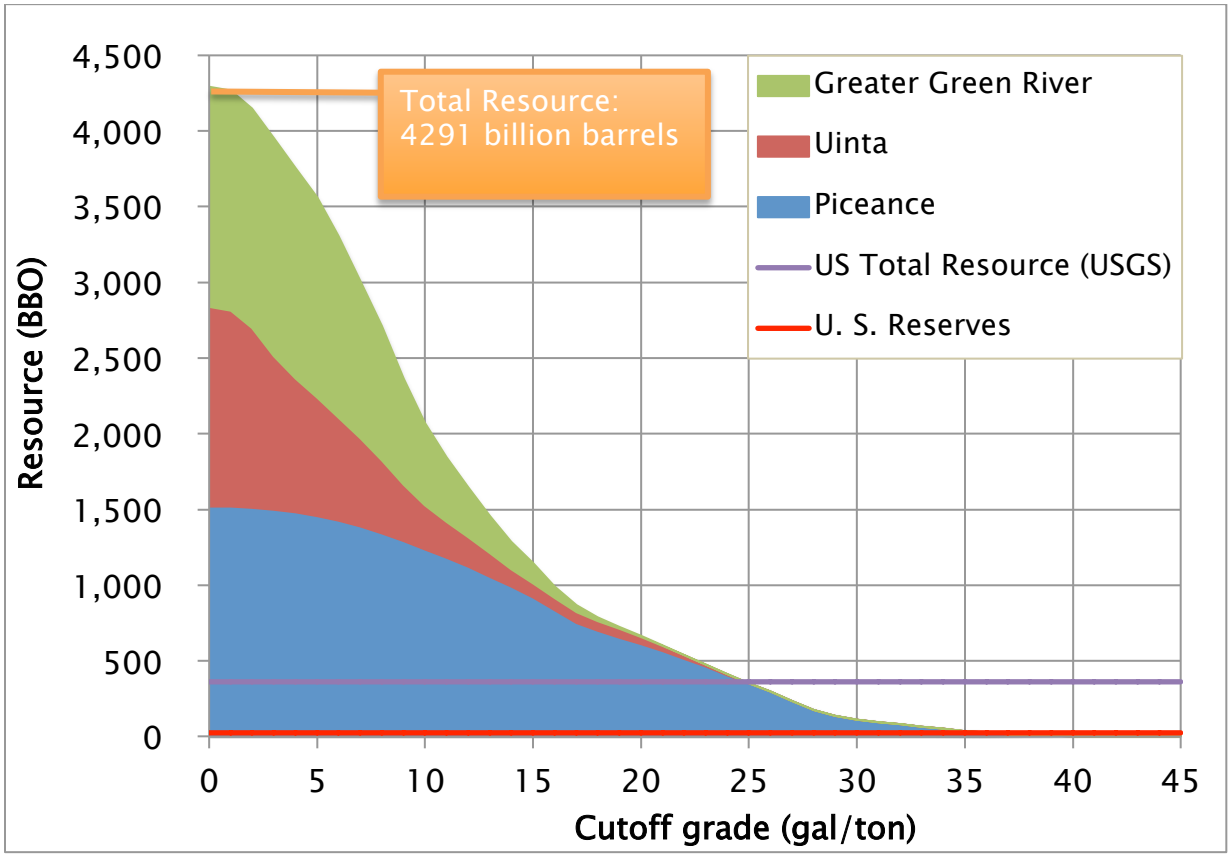

Figure 2: Oil shale resource estimates for different grades of oil shale, from U. S. Geological Survey data (presented at the 32nd Oil Shale Symposium)

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 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.

The projection shown in Figure 3 indicates that oil shale may take longer still to become a significant player in the global petroleum supply. In the figure, the growth in oil shale production is compared to the growth rates for historic U. S. oil production and for Canadian oil sand production (Boak 2009). The growth rate required to reach one million barrels per year by the 2030s is >14% compared to ~9 and ~10% for historic U. S. oil and Canadian oil sand. These results are achievable,

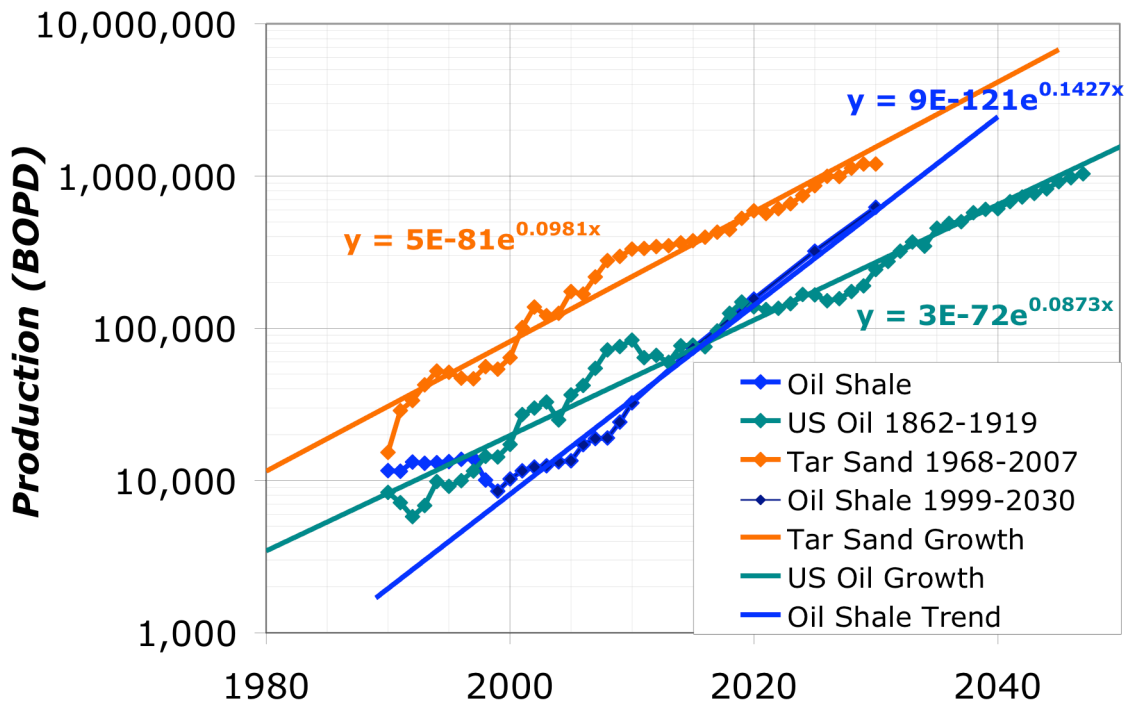

Figure 3: Projected oil shale production and historic production of U. S. crude oil and Canadian oil sands. The exponential curve fits to data indicate extended periods with growth rates of ~9% and ~10% for the U. S. and Canadian examples, and project >14% for oil shale even to reach one million barrels per day by 2035. .

but will require considerable focus and investment. Currently, shale oil production lags that shown in this projection, having only just reached the projected value for 2010.

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

Critical Technology Needs

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

ther 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

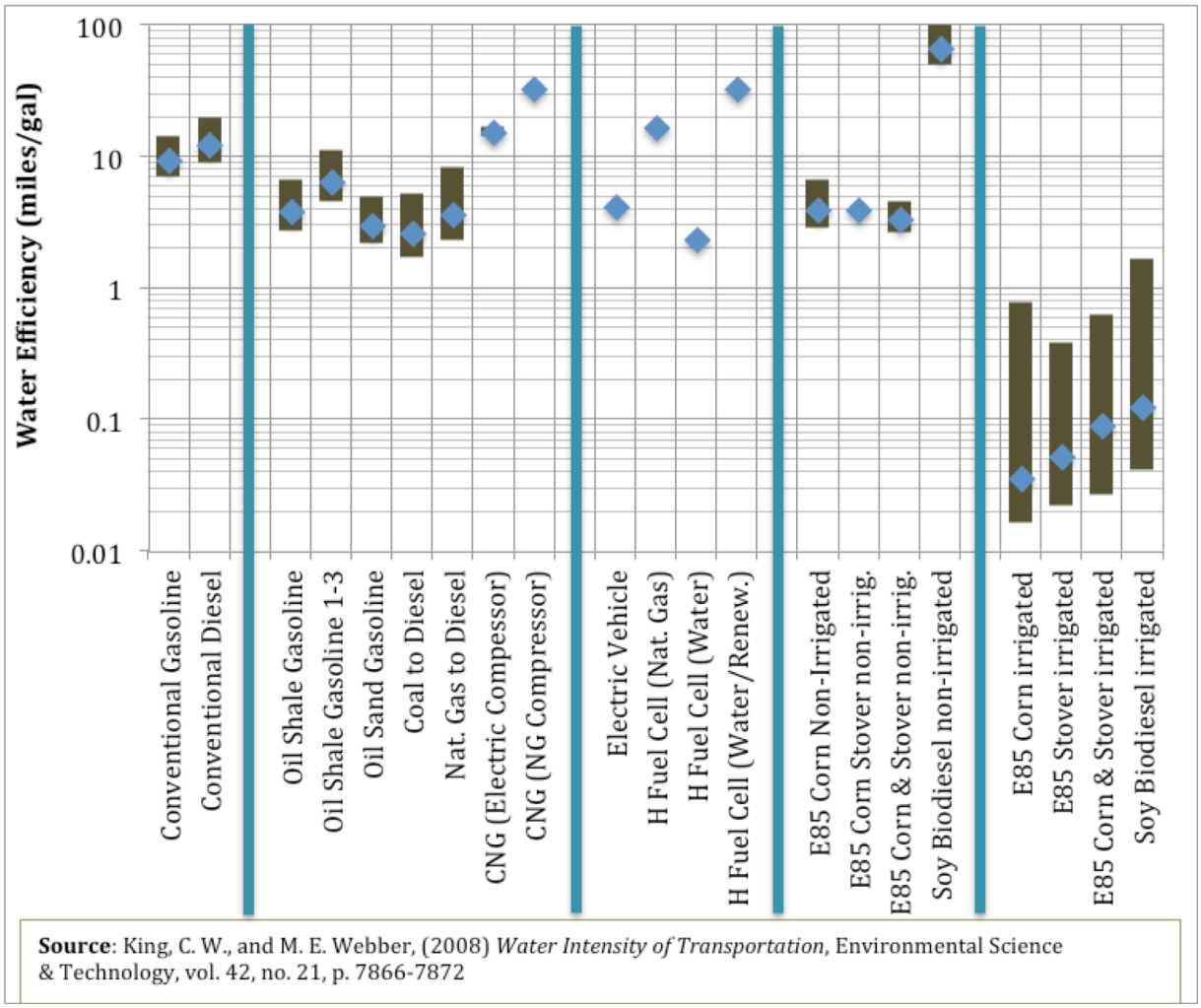

Figure 4: Water efficiency (in miles per gallon) of various conventional, unconventional, and alternative fuels. Diamond is mean value and bar represents range of estimates. An additional bar has been added to represent current industry estimates to produce shale oil of 1-3 barrels of water per barrel of oil.

vague claims of both Government and opponents that not enough is known have the distinct ring of political motivation. Figure 4 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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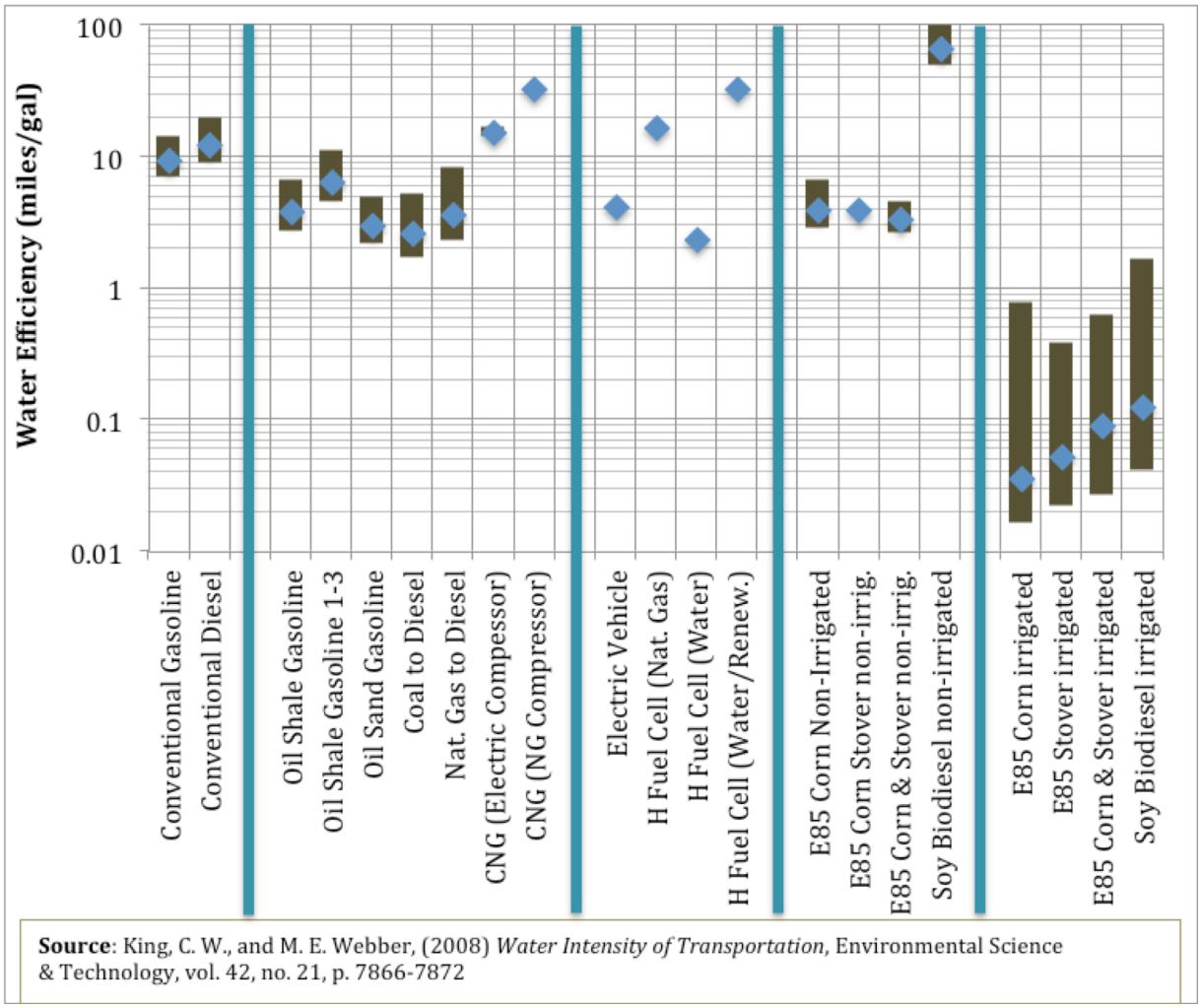

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