EMD Oil Shale Committee

**2016 EMD Oil Shale Committee Final Report**

**Alan K. Burnham (Chair), Stanford University**

**May 18, 2016**

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## EXECUTIVE SUMMARY


Progress on oil shale continued around the world, although many projects have been cancelled recently due to low oil prices. New production capacity was in full force in Estonia and China, and plans for production moved forward in Jordan and Utah, although at a slower pace than expected a few years ago. Some companies are re-optimizing their processes and projects to adapt to the current economic situation. The current status is still in flux, and it is too early to know whether we are seeing a repeat of the 1980s or a shorter-term correction.

Oil shale continues to be mined and retorted or burned in power plants in Estonia, China and Brazil. Production rose significantly in 2015, but future expansion is uncertain. In Estonia, Viru Keemia Grupp brought a second Petroter plant on line in Q3 of 2014 and a third unit in the Q3 of 2015,

bringing their total installed capacity to ~14,000 BOPD (barrels of oil per day). Eesti Energia (Enefit) achieved full design-capacity operation of their new Enefit280 plan in 2015, which increases their shale oil capacity to nearly 10,000 BOPD, with coproduction of ~20 MW electric power. Enefit also commissioned a new 300 MW thermal circulating fluidized-bed power plant that is capable of burning up to 50% biomass along with oil shale. Numerous Fushun and other small retort types are coming on line in China, and an Alberta Taciuk Process (ATP) unit (designed to retort fines) operated at 95% of design availability and 90% of plant design throughput near Fushun. However, despite this increased capacity, total shale oil production increased by only 2% to about 17,000 BOPD due to depressed oil prices. Nearly half that production was at Fushun. Small-scale commercial production also continues in southern Brazil by Petrobras (~4,000 BOPD), and Irati Energy Limited completed a market study by Ernst & Young and a preliminary economic assessment by Millcreek Mining Group of its plan for an 8,000 BOPD shale oil plant in southern Brazil.

In Jordan, development schedules have been adjusted due to economic conditions, but development projects continue. JOSCO, a wholly owned Shell subsidiary, has drilled and characterized 340 wells to support the selection of its final 1000 $km^2$ lease hold. It activated a small-scale in-situ pilot in September 2015 to demonstrate its technology in the resource and to calibrate its subsurface models for use in potential commercial development. Oil was pumped to the surface after a few months of heating, and heating will continue until summer 2016. Another approved project by Saudi Arabian Corporation for Oil Shale had intended to start producing shale oil in five years and increase to 30,000 BOPD by 2025, but no current schedule is available. The venture will use the Russian UTT-3000 technology, a version of a hot-burned-shale recycle process. A 30-year Power Purchase Agreement with the Attarat Power Production Company (majority owned by Eesti Energia) intends to produce electricity from oil shale using a 553 MW Foster Wheeler design and expects to close financing in 2016.

Oil shale development activities continued at a low level in Israel and Mongolia by Genie Energy using an in-situ process. The Israeli project received a significant setback due to rejection of its pilot test permit application by a local planning committee, but the company plans to appeal. Even so, the company has announced its intentions to focus in the near term on exploring for oil in the Golan Heights and recently disclosed a discovery there. In Morocco, development efforts continued by TAQA using the EcoShale process.

In Australia, Queensland Energy Resources (QER) successfully completed the operation of its demonstration plant near Gladstone in early 2014. A draft Environmental Impact Assessment has been prepared for an 8300 bbl per stream day commercial plant located at the Stuart oil shale deposit near Gladstone, Queensland. Given the current economic climate, QER identified and adopted cost savings of up to $100 million to improve project returns and position the company favorably to move forward with a commercial plant when oil prices recover. QER recently completed extensive fuel trials of both jet fuel and ultra-low sulfur diesel (ULSD) extracted from oil shale and manufactured using the Paraho retorting process. Both these QER shale derived fuels have now been accepted for commercial use.

In the U.S., Utah projects by Red Leaf and partners and Enefit American Oil (EAO) proceeded on public and private lands. In contrast, ExxonMobil and American Shale Oil LLC terminated their Colorado projects on U.S. Bureau of Land Management (BLM) Research, Development, and Demonstration (RD&D) leases. American Shale Oil LLC recently received an extension on their BLM lease, but the partners subsequently decided to discontinue funding and start site reclamation. ExxonMobil had not yet started field activities and has relinquished their RD&D site. EAO and Simple Oil LLC continued activities related to their Plan of Development and permitting for their RD&D Leases. Shell continued activities related to disposition of their Colorado oil shale assets, including plugging and abandonment and reclamation on both private lands and public leases, preferring to concentrate on Jordan. Terra Carta purchased nearly all their oil shale assets.

EAO continues to make progress getting permits for development of its private lands in Utah. The draft EIS for its industrial utilities corridor was published by the Bureau of Land Management in April 2016. EAO re-optimized its demonstration plans by switching to its smaller and already demonstrated Enefit280 design and developed an alternative conceptual plan that would include process changes allowing better heat and gas liquids recovery. They are also evaluating a possible alternative development plan that would move their plant site and transition more quickly to underground mining of richer oil shale. In 2016, Enefit contracted Millcreek Mining Group to prepare an initial review and subsequent possible reserve statement for EAO's proposed oil shale mining and mineral processing project located on the Enefit South parcel. If the screening results in EAO proceeding with the full reserve statement, this could potentially allow EAO to advance the status of a portion of its property from a measured and indicated oil shale resource to proven and probable oil shale reserve classification. This would be the first oil shale to shale oil project to achieve the reserve classification.

Red Leaf delayed its demonstration-scale project of the EcoShale® process at Seep Ridge, Utah, with partner Total with a view to improve the design to be viable in a lower crude oil price market. One design improvement under consideration is a switch from indirect to direct hot-gas heating of the capsule, which Red Leaf expects to be cheaper and more energy efficient. A refined design and economic study is now in progress. Once finalized, Red Leaf will determine whether any modifications are required for its existing permits. TomCo received temporary approval to establish a commercial operation using the EcoShale® process 15 miles from the Red Leaf operation, but that project is on hold until the demonstration test concludes.

The number of international oil shale symposia has decreased along with industrial activity. The 35th Oil Shale Symposium was held October 5-6, 2015 in Salt Lake City, Utah, with a large international participation. The International Symposium "Oil Shale 100" is currently being organized for September 20-23, 2016, in Tallinn to celebrate 100 years of oil shale activity in Estonia (http://oilshalesymposium.com/).

The AAPG Energy Minerals Division published a review of unconventional energy resources in Natural Resources Research, Volume 24, pages 443-508, 2015. This review included a short report (pp. 449-450) by Alan Burnham on oil shale resources and activities. Also in 2015, the Utah Geological Association released Publication 44, "Geology of Utah's Uinta Basin and Uinta Mountains, including a chapter on the history of Utah's oil shale industry by Gary Aho.

## Current and Projected Oil Shale Production

Current activities include both production and development projects, with active oil shale production most important in Estonia and China (each about 15 million tonnes/year), and with Brazil a distant third (2.4 million tonnes/year). A summary of recent activity in Estonia and China (Hou, 2014) is shown in Figure 1. Figure 2 puts these figures in context with historical production around the world.

A summary of various oil shale production and development projects is shown in Figure 3, and production projections up to 2030 are shown in Figure 4 (Boak, 2014). The projections in Figure 4 do not include potential in-situ projects, as that technology is still being developed. However, it does include projects that propose surface retorting technology that has not been demonstrated at a commercial (>5,000 BOPD) scale. Even so, it is plausible that a more mature surface-retorting technology could be substituted with less disruption if the proposed technology does not come to fruition. Then again, these projections do not take the recent decline of crude oil prices into account. In brief, there are many factors that make these projections optimistic.

Total global production of shale oil for 2015 is estimated to be about 46,000 BOPD, all from China, Estonia, and Brazil. Chinese production is estimated to be about 17,000 BOPD, Estonian production about 25,000 BOPD, and Brazilian production about 4,000 BOPD. Current projections show that oil shale will not be a significant part of global production (>500,000 BOPD) for at least another decade. However, projects are in line over the next several years that could increase production significantly over current levels.

**Production and Development Activities around the World**

**China** produces shale oil and electric power from oil shale mined in 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, with a billion-tonne resource recently discovered in Heilongjiang Province. The major producing and developing companies are the Fushun Mining Group, the Maoming Petrochemical Co. (owned by SINOPEC), Longkou Coal Mining Co, Longteng Energy Company, Gansu and Saniang Coal Companies, Julin Energy & Communication Corp., and Petrochina. The gas-combustion Fushun retort is the dominant technology, and the Fushun district is responsible for about half of Chinese production. A new open pit mine opened in 2014 in Fushun. New retorts are being built rapidly in China—about 130 in 2014. Most of them use lump oil shale, but some retorts are now being built to process fines. An ATP retort in Fushun tripled its operational time to 300 days, including 115 days of continuous operation between turnarounds, and has nearly reached full design capacity. Oil shale fines are also burned at various locations in fluidized beds for power production. The total oil production increased from 830,000 to 850,000 tons, which corresponds to about 17,000 bbl/day.

In **Estonia**, the three producers are Viru Keemia Grupp (VKG), Eesti Energia (internationally known as Enefit), and Kiviõli Keemiatööstus. VKG, the largest oil producer in the country, commissioned a second Petroter plant in August 2014 and a third unit in September 2015, which will raise their capacity to about 14,000 BOPD. VKG continues efforts to reduce air emissions and produce building material from spent shale. Enefit produces 80% of Estonia's electricity from oil shale and operates two Enefit140 retorts producing shale oil at a combined rate of about 4,000 BOPD. Enefit achieved design-capacity operation of its new Enefit280 retort in September 2015, which brings its total production capacity to nearly 10,000 BOPD. The Enefit280 unit also coproduces electricity.

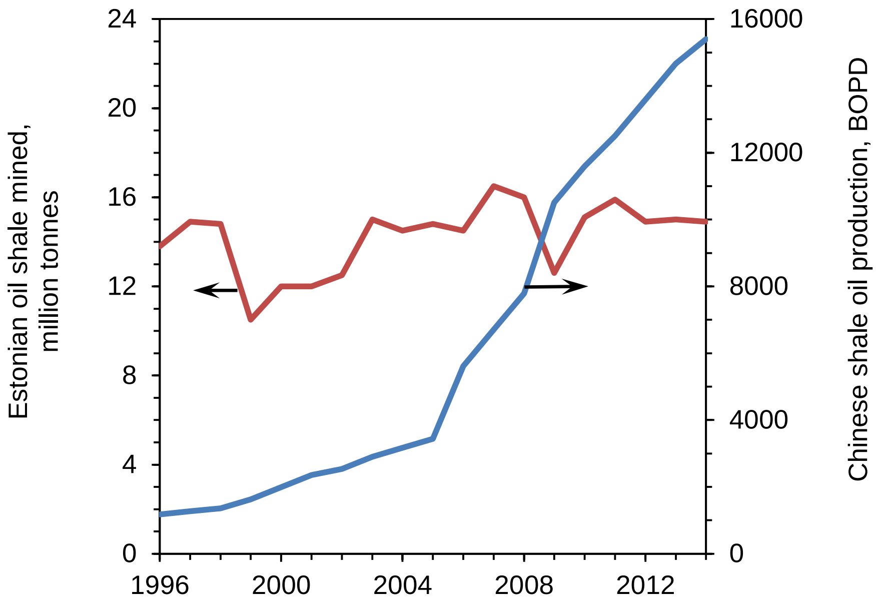


**Figure 1.** Recent history of oil shale mining in Estonia and shale oil produced in China.

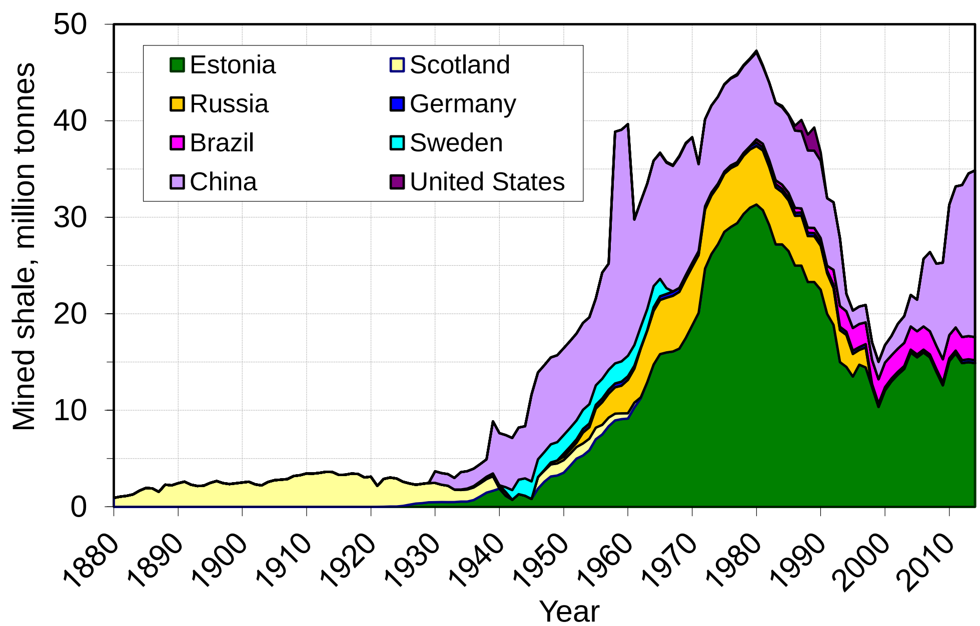


**Figure 2.** History of oil shale extraction updated from Dyni (2006) using a variety of industry and government sources.

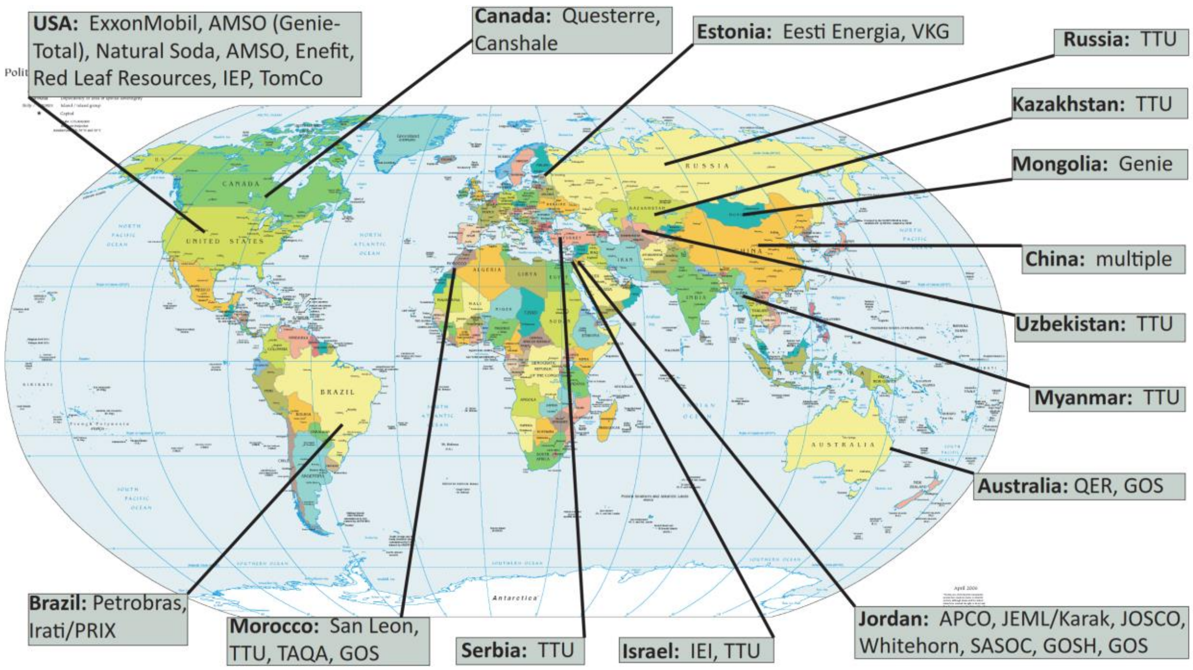


**Figure 3:** Oil shale projects around the world (Boak, 2014).

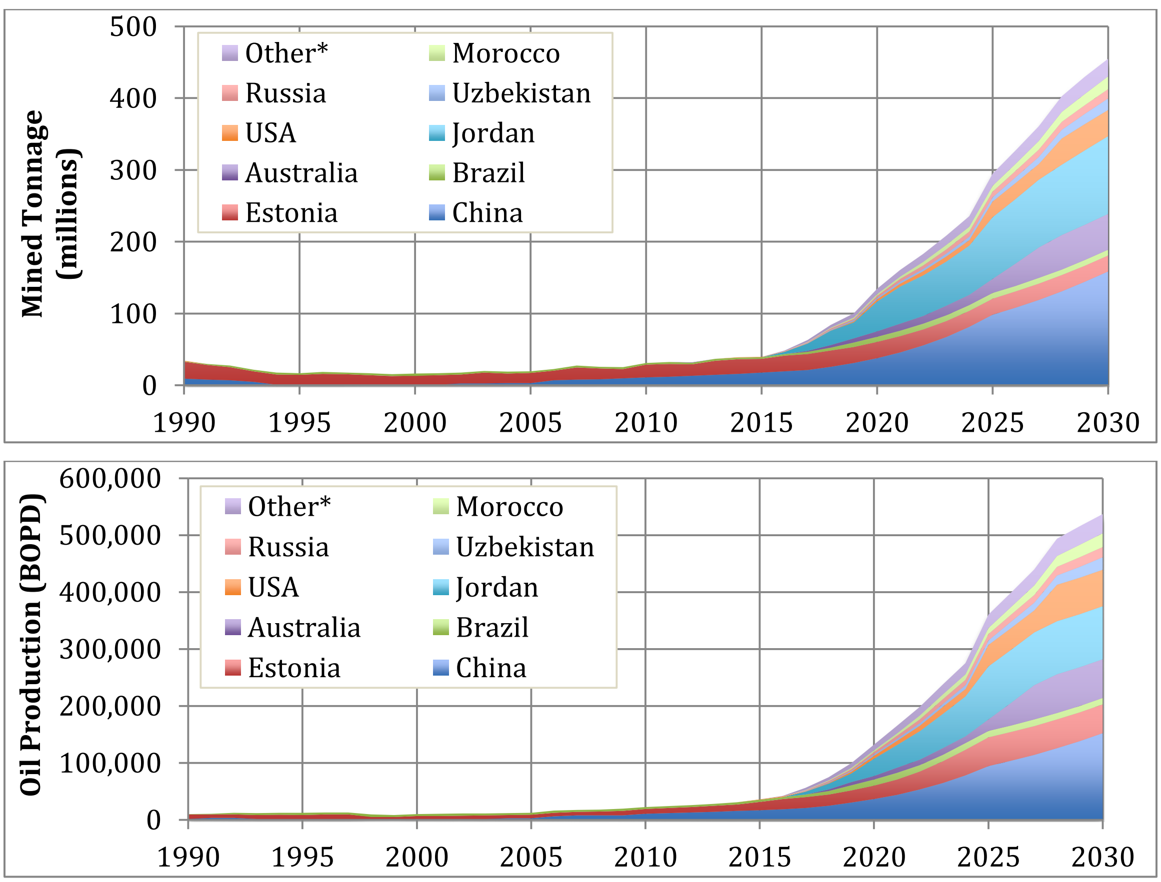


**Figure 4:** Current and projected quantities of mined oil shale and shale oil produced by pyrolysis. Much of the mined oil shale is burned directly to produce electricity.

In **Brazil**, Petrobras continues mining and retorting Irati oil shale, producing about 4,000 BOPD using the Petrosix technology, but it has no expansion plans. However, startup Irati Energy Limited, owned by Forbes & Manhattan, controls >3,100 $km^2$ in Southern Brazil, with over 2 billion barrels (bbls) of potential oil shale resources. It plans an initial start-up production of 8,000-10,000 BOPD using two Petrosix retorts. Future project expansion will use the PRIX technology, which is an incremental improvement over the Petrosix technology. It has completed its exploration phase and is looking for investment in the engineering phase based on market and economic assessments completed by Ernst & Young and Millcreek Mining Group, respectively.

**Jordan** is pursuing oil shale aggressively, although economic forces will delay its goal of producing 14% of its energy from oil shale, including all of its currently imported oil, to about 2025. It currently has numerous Concession Agreements, Memoranda of Understanding, and a Power Purchase Agreement in place. Attarat Power Company (APCO; 65% owned by Enefit) received approval from Jordan's Ministry of Environment to proceed with a Foster-Wheeler-designed 553 MW oil-shale-fired power plant. Jordan signed a Power Purchase Agreement in October 2014, and the plant is expected to be operational at the end of 2019. APCO signed an engineering, procurement and construction contract with Guangong Power International Corporation in November to build the power plant. Enefit is also negotiating a separate agreement with Jordan to construct a 40,000 BOPD shale oil plant. Jordan Oil Shale Company (JOSCO, owned by Shell) has drilled and characterized 340 wells to support the selection of its final 1,000 $km^2$ lease hold. It activated a small-scale in-situ pilot in September 2015 to demonstrate its in-situ technology in the resource and to calibrate its subsurface models for potential commercial development. Karak International and parent Jordan Energy and Mining Ltd (JEML) have completed an interim funding agreement underwritten by Sentient Group funds to pursue a shale oil production project. Karak holds a concession for the Lajjun deposit that contains approximately 300 million bbls of oil in place, where it proposes to use the ATP technology, and it also has a Memorandum of Understanding (MOU) to explore oil shale at Al Nadiyya. Another MOU has also been signed between Jordan and a consortium of China's Shandong Electric Power Construction Corp and HTJ Group and Jordan's Al-Lajjun Oil Shale Company to produce 900 MW of electric power. Jordan also signed a MOU in 2014 with China's Fushun Mining Group Co to conduct geological and geophysical studies in the Wadi Al Naadiyeh area. Jordan approved a concession in March 2013 to the Saudi Arabian Corporation for Oil Shale and a production agreement in March 2014 that is projected to produce 3,000 BOPD by 2019 and 30,000 BOPD using the Russian UTT-3000 technology. Other companies holding MOUs for shale oil production are Aqaba Petroleum for Oil Shale Co, which also proposes to use the UTT-3000 process, Global Oil Shale Holdings, which proposes to use the PRIX process, and Whitehorn Resources and Questerre, which propose to use the Red Leaf EcoShale Process.

In the **United States**, Red Leaf Resources has leases on 45,000 acres of Utah state lands and projects at both Seep Ridge and Holliday Block. They obtained the necessary permits from the State of Utah and started construction in 2014 of a 5/8$^{th}$ commercial-scale demonstration of its EcoShale® technology. However, due to the decline in oil prices, the project was halted and the process was re-optimized for the new economic environment. The current design changes from indirect to direct heating to reduce capsule construction costs, increase retorting rate, and increase thermal efficiency. Construction is expected to start in 2016 or 2017 and expected to generate ~200,000 BO in less than one year. Red Leaf settled a lawsuit in 2014 with Living Rivers in return for sharing ground water monitoring information. Meanwhile, TomCo Energy received temporary approval from the State of Utah in September 2014 for its Notice of Intention to Commence Large Mining Operations using the Red Leaf EcoShale process, but they will wait for the demonstration-scale process validation.

Enefit American Oil (EAO) has 3.5 billion bbl of in–place oil shale resources associated with both private lands and an RD&D Lease from the U. S. BLM and SITLA leases from the state of Utah, with about 2/3 on private land. It made progress on getting permits for development of its private lands in Utah. The draft EIS for its industrial utilities corridor was published in April 2016. It successfully resolved a potential environmental roadblock in 2014 by working with local officials, who created a conservation plan for a potentially rare plant (Beardtongue), culminating in USFWS deciding not to list the plants on the endangered species list. Signed just one year ago, a landmark Conservation Agreement to help protect two sensitive species of flowering plants living on or near oil shale outcrops is already showing promising signs of success. Not only have more plants been identified throughout Utah's southern Uinta Basin – and, importantly, in areas previously thought to be outside their growing range, nearly 90 percent of penstemon plants transplanted to an EAO conservation area in 2014 have survived the move, based on 2015 survey data. EAO re-optimized its demonstration plans by switching to its smaller and already demonstrated Enefit280 design and developed an alternative conceptual plan that would include process changes allowing better heat and gas liquids recovery. EAO is also evaluating a possible alternative site development plan that would transition more quickly to underground mining of richer oil shale and includes moving their plant site. In 2016, EAO contracted Millcreek Mining Group to prepare an initial review and subsequent possible reserve statement for EAO's proposed oil shale mining and mineral processing project located on the Enefit South parcel. If the screening causes EAO to proceed with the full reserve statement, this could potentially allow EAO to advance the status of a portion of its property from a measured and indicated oil shale resource to proven and probable oil shale reserve classification. This would be the first oil shale to shale oil project to achieve the reserve classification.

Further efforts in the United States occurred on the BLM RD&D Leases. Enefit used shale both from its RD&D lease holding and its private lands to demonstrate the applicability of the Enefit process to Utah oil shale through pilot testing in Germany. In Colorado, American Shale Oil LLC (AMSO), a partnership of Total and Genie Energy, encountered problems with its downhole heater in 2013. In 2015, AMSO qualified an electrical heating system for restarting its pilot test. However, economic forces caused the partners in 2016 to discontinue work and move toward site reclamation. In 2013, Shell cancelled its multi-mineral test of sequential production of nahcolite and shale oil on one of its three RD&D leases. They plan no development activities on their other two RD&D leases and are currently reclaiming both their private and public lands along with disposing of all of their Colorado holdings. Terra Carta purchased all the Shell oil shale land, minerals, and infrastructure except small areas around the Shell pilot tests. Simple Oil LLC, formerly known as Natural Soda Holdings Inc. (NSHI), and ExxonMobil received approval from BLM of their Development Plans for in-situ projects on their second-round RD&D leases awarded in 2012. Simple Oil has continued its permitting and development activities. However, ExxonMobil has relinquished its 160-acre RD&D property back to the BLM and has ceased all oil shale operations in Colorado. All work to date had been at their Colony Mine site, so no reclamation was needed on their RD&D site.

In other activities, Shale Technologies International Services LLC continues to maintain a small staff at their facilities in Rifle, CO. Great Western Energy secured leases on over 13,000 acres of Utah state lands. Meanwhile, Orion Reserves is offering to sell its 3000 acres of private Utah oil shale lands.

In **Australia**, Queensland Energy Resources (QER) successfully completed the operation of its demonstration plant near Gladstone in early 2014. A favorable environmental review of the operation was issued by the Queensland Department of Environment and Heritage Protection. The Australian Government Department of the Environment ruled in July 2014 that the development proposal will require assessment and approval under national environmental law before it can proceed. A draft Environmental Impact Assessment has been prepared for an 8300 bbl per stream day commercial plant located at the Stuart oil shale deposit near Gladstone, Queensland. Given the current economic climate, QER identified and adopted cost savings of up to $100 million to improve project returns and position the company favorably to move forward with a commercial plant when oil prices recover. QER recently completed extensive fuel trials of both jet fuel and ultra-low sulfur diesel (ULSD) extracted from oil shale and manufactured using the Paraho retorting process. These trials encompassed component rig testing in the UK for the jet fuel and both static dynamometer testing and over 70,000 kilometres of actual road testing for the ULSD. Both these QER shale derived fuels have now been accepted for commercial use. In addition, Oil Corp holds a site-specific license for using EcoShale® technology in Queensland.

In **Morocco**, San Leon Energy determined in 2012-2013 that a yield of 17 gal/ton was achievable in two reservoir zones of the Tarfaya oil shale using Enefit Technology, and it began investigating Timahdit oil shale in 2013. They reported in August 2014 that shale oil had been produced successfully using bench tests of the Enefit280 process. San Leon Energy signed a MOU with Chevron Lummus Global to examine upgrading of Timahdit shale oil. The Abu Dhabi National Energy Company (TAQA) is also currently working on the Timahdit area in order to evaluate a potential development using the EcoShale® Technology. Global Oil Shale PLC has established a fully owned subsidiary in the country and is continuing the evaluation of the Tarfaya oil shale resources by open pit mining.

**Mongolia** Petroleum Authority entered into an exclusive five-year oil shale development agreement in April 2013 with Genie Mongolia to explore and evaluate the commercial potential of oil shale resources on a 34,470 square kilometer area in Central Mongolia. Genie Mongolia has begun surface mapping and other geophysical evaluation work as well as drilling exploratory wells, and has secured permits for additional exploratory wells. Further plans depend on both technical and regulatory developments. In September 2014, Mongolia held an international investors forum, with over 300 attendees from corporations such as Rosneft, Petrochina, British Gas, Sinopec and many other companies. The Prime Minister gave an opening speech describing legal reforms intended to increase investment.

In **Israel**, the government issued directives in April 2013 for the environmental impact statement that is required as part of Israeli Energy Initiative's (IEI) pilot test permit application in the Shefla Basin. IEI, a subsidiary of Genie Energy, prepared and initially submitted its pilot application in June of 2013 to the Jerusalem District Building and Planning Committee and supplied additional information in November. In August 2014, the Israeli Environmental Protection Ministry recommended against the project. In September, the Jerusalem District Committee for Planning and Building declined to issue IEI a permit for its pilot project. IEI is currently evaluating alternatives to determine the best course of action to advance the project and develop the resource covered by the exploration license.

In **Canada**, Chapman Petroleum Engineering Ltd. completed in February 2013 an NI 51-101 Engineering Evaluation Report of Contingent Resources and Commerciality Factors for Xtra Energy's Pasquia Hills oil shale permit located in northeastern Saskatchewan, estimating about 2 billion bbls of potential oil. In December 2013, Cencor acquired a 55% working interest in a Pasquia Hills oil shale project with a resource of 1.2 billion bbls of oil. Meanwhile, Canshale is evaluating commercial feasibility of its 3 billion bbl oil shale resource near the Hudson Bay in Saskatchewan using the ATP technology. Questerre and Whitehorn have options for licenses.

**Uzbekistan** could become the first Central Asian country to produce from oil shale as part of plans by the government to address dwindling oil production and domestic fuel shortages. The national oil and gas company Uzbekneftegaz plans to develop a $600 million oil shale processing complex (mine and processing plant) with a capacity of 8 million tons per year, producing 1 million tons of shale oil annually (~17,000 BOPD). The feasibility study was planned for completion in 2015. In the first phase, one million tons per year would be processed in a solid-heat-carrier unit of a design yet to be chosen. Future expansion may include preliminary hydrotreatment, but final refining to motor fuels would take place in the existing Bukhara refinery.

**Estimated U. S. and International Resources/Reserves and Strategic Importance**

The standard reference for world resources of oil shale places them at ~3.0 trillion bbls, of which about two trillion bbls were located in the U.S.A. (Dyni, 2003).[1] The largest oil shale deposit in the world is the Green River Formation of Colorado, Utah and Wyoming. Dyni noted that the estimate was conservative because several deposits had not been adequately explored. Consequently, it is not surprising that some have proposed major upward revisions in some countries. For example, China just discovered a billion bbl resource in Heilongjiang Province. Additional updates to the projected resources of oil shale come from Israel and Jordan. Each now estimates the potential for more than 100 billion bbls of oil in place. Yuval Bartov of IEI suggested resources as high as 250 billion bbls, and JEML reports an estimated resource of 102 billion bbls for Jordan (pending peer review). Other increases are likely as more exploration and resource characterization is performed.

If one takes the largest number from recent estimates, the U.S. has the largest resource at 6 trillion bbls, China is second at 330 billion bbls, Russia third at 270 billion bbls, Israel fourth at 250 billion bbls, and Jordan and DR Congo tied for fifth at 100 billion bbls. The next four, with resources from 30 to 80 billion bbls, are Brazil, Italy, Australia, and Morocco. Estonia, which became the largest producer of shale oil this year, is 11$^{th}$ at only 16 billion bbls. These estimates should be taken with due caution, and a new assessment using consistent criteria is sorely needed.

The U.S. resource estimate depends on whether one includes formations besides the Green River Formation and whether a grade cutoff is used. The most recent evaluation of the Green River Formation in Colorado, Utah, and Wyoming (summarized in Birdwell et al., 2013) places the total resource, regardless of grade, at 4.3 trillion bbls. Colorado resources increased from the 1.0 trillion bbl previous estimate to 1.52 trillion bbls, with Utah estimated at 1.32 trillion bbls of oil in place, and Wyoming with total resources of 1.44 trillion bbls. If one includes the Eastern Devonian shales and the Phosphoria shales in the U.S. resources, one gets a total resource closer to 6 trillion bbls. While it is true that the other formations are not as rich as the Green River Formation, one should also recognize that they are as rich as resources considered in other countries and that an Eastern Oil Shale Symposium was held for 13 years in the 1980s and 90s to discuss recovery technology for those resources.

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[1] Measurements of shale oil yield by Fischer Assay, a method designed to approximate the recovery of surface retorting methods, provide the basis for most resource estimates. Recovery estimates for different processes will be different and are usually referenced to the Fischer Assay value. Most processes recover less than Fischer Assay oil, but 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.

A recent fact sheet on the resource available at various cutoff grades indicates that the marginally prospective resources (those with Fischer Assay oil yield above 15 gal/ton) in the Green River Formation are closer to 1.0 trillion bbls and are generally located in the Piceance Basin. Figure 5 shows the USGS estimates of these amounts. It should be noted that these estimates are fairly conservative and were determined on a per acre basis with grade averaged over stratigraphically defined intervals (rich and lean zones in the Piceance and Uinta Basins, more general intervals in the Greater Green River Basin). Additional analyses of the oil shale resource in the Piceance and Uinta Basins are available in other USGS Fact Sheets on issues related to in-situ development and mining (Birdwell et al., 2014, 2015). Even though the recoverable resource in the Uinta Basin looks tiny in Figure 5, it is still estimated to be tens of billions of bbls, which is larger than the US proved crude oil and condensate *reserves* (36.5 billion bbls, EIA, December 2014). A closer examination of the Uinta Basin resource was conducted by the Utah Geological Survey (Vanden Berg, 2008) yielding a range of estimates based on grade cutoffs, interval thicknesses and overburden in the upper Green River oil shale resource. It is worth noting that the >20 gal/ton resource total for the Formation of about 700 billion bbls dwarfs the proven crude oil reserves and illustrates the potential importance of future oil shale development. One caution is that the remaining undiscovered and technically recoverable crude oil resource is considerably larger than the proved reserves for a variety of reasons and is more comparable to the amount of oil recoverable from oil shale.

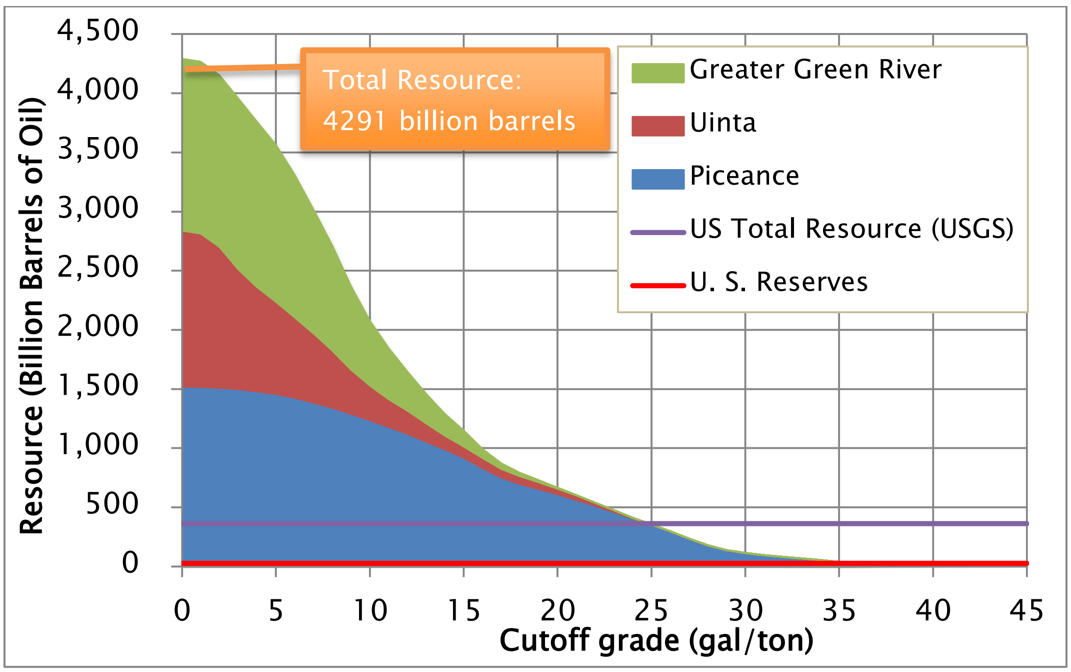



**Figure 5:** Oil Shale resource estimates for different grades of oil shale, from U.S. Geological Survey data (presented at the 32nd Oil Shale Symposium and summarized in a USGS Fact Sheet, Birdwell et al., 2013) compared to U.S. crude oil reserves.

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 in large part due to regulatory uncertainty. Technology to produce the vast quantities of oil potentially recoverable is being tested, but only two developers still have production plans, both using above ground technology in Utah. Current operations in other countries form a firm foundation for concluding that commercial technology is available for production in the U. S., but the recent drop in crude oil prices has reduced the urgency of oil shale development. In contrast, development of this resource can be very important strategically for smaller countries with lower energy demands and no other liquid hydrocarbon resources (Estonia, Jordan, and Morocco, for example). Estimates of the oil shale resource in Israel have increased dramatically in recent years, but recent discoveries of off-shore natural gas and Golan Heights oil may reduce its sense of importance to that country in the near-term.

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

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

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

**Research Focus** (Additional details in the Appendix)

Current research on oil shale is best identified through presentations at the Oil Shale Symposium that had been held each October in Golden, CO, at the Colorado School of Mines, but starting in 2015 the symposium will be rotated between multiple host cities, including Golden, Salt Lake City, and others to be determined by the organizers. Abstracts, presentations, and papers for the 26th through 32nd Oil Shale Symposia are available at: http://www.costar-mines.org/oil_shale_symposia.html .

Proceedings of the 33rd Oil Shale Symposium will be made freely available in the near future. The Program for the 33rd Oil Shale Symposium is currently available online at http://mines.conference-services.net/programme.asp?conferenceID=3736&language=en-uk

Proceedings of the 34th Oil Shale Symposium are currently available to attendees of the meeting only, but will be made freely available sometime in the future. The Program for the 34th Oil Shale Symposium is currently available online at http://mines.conference-services.net/programme.asp?conferenceID=4255&language=en-uk

Proceedings of the 35th Oil Shale Symposium will be available for sale once assembly is complete and will be available sometime in 2016. The program and abstracts for the 35th Oil Shale Symposium are posted at

http://mines.conference-services.net/programme.asp?conferenceID=4640&language=en-uk

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

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

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

Information on oil shale research conducted by the U.S. Geological Survey Energy Resources Program is available at the Oil Shale Research Homepage: http://energy.usgs.gov/OilGas/UnconventionalOilGas/OilShale.aspx .

**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 (USDOE) and U.S. Department of Interior, but such funding is negligible. Other companies may have provided smaller grants that are not widely publicized. Other private funding appears to support development at least of the Red Leaf Resources program. International funding comes from diverse sources, not all of them publicly acknowledged. It is clear that governments in Jordan and Morocco are actively supporting granting of concessions and dissemination of available data. Companies in Estonia (Eesti Energia, Viru Keemia Grupp), Brazil (Petrobras), and China (CNPC, Fushun Mining Group 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 shale oil. Especially in the USA, issues have been raised about greenhouse gas emissions and water consumption by industry.

The primary source of emissions for in situ production is power plant emissions of $CO_2$. Minimizing energy use is essential to profitability and sustainability. An Enefit presentation at the 31st Oil Shale Symposium indicated that production from their Estonian 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 using ash as a cement clinker substitute, this could reduce $CO_2$ emissions to approximately that of crude oil. Recovering waste heat from exhausted retorts would also increase energy efficient and reduce $CO_2$ emissions, and Red Leaf Resources recently proposed a change in their heating methodology to accomplish that objective among others (Lechtenberger, 2015). Bottoming cycles for power production from exhausted in situ retorts and sequestration of $CO_2$ in exhausted in situ retorts are both conceivable but not demonstrated.

In situ processes require robust heating technology, but none is fully demonstrated at present. Substantial progress has been made on electric heating cables that do not require splices between mineral-insulated cable segments. However, energy efficiency considerations are motivating work on non-electrical systems, including down-hole burners and hot circulating fluid systems such as propane, $CO_2$, and molten salts. The hot-fluid systems include demonstration of super-insulated piping systems to minimize heat loss from the surface. Geothermic fuel cells are also under development, which can switch from underground heat generation to electric power generation for export depending on the pricing in the power market.

NOSA has recently updated its estimate of water needs for an oil shale industry. Based upon 2014 input from developers such as Shell and Enefit, NOSA now estimates water usage of 0.7 to 1.2 bbls of water per bbl of shale oil (Bw/Bo) (16,000 to 29,000 acre feet per year for 500,000 bbls/day of marketable shale oil production). This is down from an average of 1.7 Bw/Bo in a 2012 estimate, which assumed a 1,500,000 BOPD industry. Further details are in the appendix.

Developing criteria and methods for consistently structured resource assessments would be a contribution to the global development of this resource, and would potentially create good will between the U. S., the European Union, and the developing countries with oil shale resources. Critical to such assessments will be careful estimation of uncertainty regarding resource estimates where data are sparse.

**Key Environmental and Socio-economic Concerns** (Additional details in the Appendix)
The critical environmental issues are how to extract, produce and upgrade shale oil in an environmentally friendly and economically sound way such that:

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

**Relevant EMD Technical Sessions and Workshops**
The primary conferences covering oil shale science and technology were the Jordan International Oil Shale Symposium, April 14-15, 2014 in Movenpick, Jordan, and the $34^{th}$ Oil Shale Symposium, October 13-15, 2014, at the Colorado School of Mines in Golden, CO. The most recent U.S Oil Shale Symposium was held in Salt Lake City, Utah, October 5-6, 2015, and its program is given in the appendix. The International Symposium "Oil Shale 100" is currently being organized for September 20-23, 2016, in Tallinn to celebrate 100 years of oil shale activity in Estonia (http://oilshalesymposium.com/).

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

### *Leading Companies in Development of Oil Shale*

Efforts by major international oil companies in the U.S. are generally led out of Houston, Texas, but AMSO still maintains a small field office in western Colorado. International oil companies with activities in oil shale include (in alphabetic order):

- Petrobras (Brazil)
- Shell (Jordan)
- Total (partner with Genie Oil in AMSO, and partner with Red Leaf Resources at Seep Ridge UT)

In addition, three other large oil companies have significant land holdings underlain by oil shale, and one major oilfield service company has acquired technology for oil shale evaluation and conducts research on the petrophysical properties of oil shale:

- Anadarko Petroleum Corporation
- ConocoPhillips
- Chevron
- Schlumberger

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

- Combustion Resources, Inc.
- Enefit American Oil
- General Synfuels International
- Genie Oil (Israel/Mongolia/partner with Total in AMSO)
- Great Western Energy (Colorado/Utah)
- Independent Energy Partners
- Simple Oil LLC
- Red Leaf Resources
- Shale Tech International
- CanShale (Canada)
- Centor Energy (Canada)
- UMATAC/ThyssenKrupp (China/Jordan/Canada)
- TomCo Energy (Utah) (EcoShale licensee)
- Anadarko (Wyoming)
- Orion Reserves (Utah lease holdings)
- Encana (has resource holdings in CO)
- Uintah Gateway/Partners – property in CO and UT, developing regional upgrader project in UT that would start with black wax then expand for shale oil.

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

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

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

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

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

### *Current Research*

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

The first is the traditional method of oil shale extraction, which has been pursued with some intermittency for more than one hundred years. Developments in this area generally relate to increasing the energy efficiency and decreasing the impact of retort operation by reducing water use and $CO_2$ emissions. The development of advanced fluidized bed reactors is a current area of research and development. In addition, research continues on the impacts of past mining and retorting, and on utilization of spent oil shale and oil shale ash from burning of oil shale in power plants. The most obvious applications involve use of spent shale and ash in cement and brick manufacture, but more advanced techniques involving extraction of various constituents from the material have been investigated. The Fushun Mining Group 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 using their In situ Conversion Process (ICP), and ExxonMobil, AMSO (a partnership of Total and Genie Oil), IEI (Israel Energy Initiatives, a Genie subsidiary) have investigated 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 products from surface retorts. 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, Utah. 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/. Red Leaf is not currently involved in supporting external research on its method, although it is working with engineering firms on process design. Its plans for a 2015 demonstration project have been delayed at least a year due to low oil prices, and the delay is being used to re-optimize the process. The company had anticipated producing 10,000 BOPD by 2017 and 30,000 BOPD sometime in the 2020s, but no new schedule information is available. If it does occur, it would be a globally significant development for oil shale.

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

Independent Energy Partners is testing its Geothermic Fuel Cell unit at the Colorado School of Mines in Golden, Colorado, in partnership with Delphi and Total. A downhole test of 30-ft module started in October 2014 and operated successfully for a month with a combined heat and power efficiency of 55%. Shale Tech International Services LLC (STIS) continues oil shale processing research at its R&D Center in Colorado with a scaled back staff. STIS provides analytical laboratory services and batch testing for client resources, as well as a technology licensing and project development program.

The Stanford-Total Enhanced Modeling of Source rocks (STEMS) project started in 2014 to address the fundamentals of oil and gas formation for in-situ oil shale production and natural petroleum formation. Research relevant to both applications is being pursued, with an increasing emphasis petroleum source rocks as time progresses.

The Grossman Group at MIT has opened an experimental research program on kerogen and is working on projects focusing on its characterization and the exploration of new applications of it as material substitute. The effort started in 2013 and is currently sponsored by Shell and Schlumberger.

*List of Specialists in the United States*

***Amec Foster Wheeler***

- Konrad Quast, Green River Formation geochemistry

***American Shale Oil LLC***

- Leo Switzer, in situ extraction technology

***Colorado School of Mines:***

- 
- John Berger, COSTAR, modeling of fracturing in oil shale
- Mark Kuchta, underground methods for in situ production of oil shale
- J. Frederick Sarg, stratigraphy and sedimentology of Green River Formation, Colorado
- Wei (Wendy) Zhou, Geographic Information Systems for oil shale water resource evaluation

***Daub & Associates, Inc.***
- Gerald J. Daub, geology of the Piceance, Uinta, and Green River Basins, hydrology, environmental, permitting, well optimization, rock mechanics, etc.

***Enefit American Oil***
- Rikki Hrenko-Browning, , oil shale development
- Ryan Clerico, environmental issues and regulatory affairs

***ExxonMobil Upstream Research Company***
- William Symington, thermal behavior of Green River Formation oil shale and technology for application of heat in situ

***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 (emeritus), 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

***Millcreek Engineering/Mining Group***
- Andrew Maxwell, oil shale properties, retorting
- Alister Horn, mining
- Greg Gold, oil shale properties, mining, retorting
- Steven Kerr, oil shale exploration and resource characterization

***Schlumberger Doll Research Center***
- Drew Pomerantz, pyrolysis of oil shale, kinetics, and characterization
- Michael Herron, mineralogic and chemical characterization of oil shale
- Malka Machlus, stratigraphy of Green River Formation oil shale
- Robert Kleinberg, characterization and pyrolysis of oil shale

***Shell Exploration and Production Company***
- Mariela Araujo, Extraction technology, thermal modeling
- Dave Burns, Heater development
- Tom Fowler, in situ production of oil shale, oil shale piloting
- John Karanikas, Chief Scientist unconventional technology
- Etuan Zhang, In situ oil characterization and generation

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

***Sage Geotech***
- Gary Aho, Rifle, CO, geology, mining, and oil shale production technology
- Ed Cooley, ERTL Inc., Rifle, CO, ex-situ oil shale processing technology
- Glenn Vawter, ATP Services LLC, oil shale extraction technology
- Bob Loucks, former VP of OXY oil shale’s Cathedral Bluffs Project C-b Tract
- Howard Earnest, former manager of AMOCO’s Rio Blanco Project C-a Tract
- Bob Faulkner, former pyro-process manager at METSO Minerals/Allis Chalmers

- Glen Sykes, underground mine development, C-b mine construction in Colorado and White River Mine development in Utah

***Shale Tech International Services LLC***
- Justin Bilyeu, ex-situ oil shale processing technology
- Larry Lukens, ex-situ oil shale technology

***U. S. Geological Survey***
- Justin Birdwell, U. S. Geological Survey, Lakewood CO, organic geochemistry of oil shale and other source rocks
- Michael Brownfield (emeritus), 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 (emeritus), 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
- Michal Hradisky, University of Utah, Salt Lake City, UT, oil shale process modeling
- Ronald Pugmire, University of Utah, Salt Lake City, UT, chemistry and kinetics of oil shale pyrolysis
- 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
- Philip Smith, Institute for Clean and Secure Energy, University of Utah, Salt Lake City, UT, chemistry and simulation of oil shale retorting processes

***Others***
- Jeremy Boak, Director, Oklahoma Geological Survey, Norman, OK, assessment of $CO_2$ emissions and water consumption by oil shale production; geologic characterization of oil shale
- Adam Brandt, Stanford University, Stanford CA, assessment of $CO_2$ emissions from oil shale production
- Alan Burnham, consultant to Total, Consulting Professor, Stanford, University, Stanford, CA, oil shale retorting technology; chemical kinetics.
- Alan Carroll, COSTAR, University of Wisconsin, Madison, WI, stratigraphy, sedimentology and geochronology of Green River Formation, Wyoming; lacustrine stratigraphy and sedimentology
- Mike Day, Independent hydrologist, Piceance Basin hydrology
- Roger Day, geology, drilling, and operations expertise in the Green River formation
- Jim Finley, Telesto Solutions Inc, Green River Formation hydrology & geochemistry
- Thomas Fletcher, Brigham Young University, Provo, UT, oil shale chemistry
- Terry Gulliver, oil shale hydrology
- John Hardaway, Environmental restoration for in situ production
- Benjamin Harding, AMEC Environmental, Boulder CO, water use for oil shale production

- Timothy Lowenstein, COSTAR, Binghamton University, Binghamton NY, chemistry and formation of evaporite minerals and spring deposits of the Green River Formation, Colorado and Wyoming
- Seth Lyman, Bingham Research Center, Utah State University, Vernal, UT, Air quality measurement and instrumentation
- Glenn Mason, Indiana University Southeast, New Albany, IN, geology of Green River Formation oil shale
- Bill Merrill, Western Water and Land, hydrology of the Green River Formation
- Jim McConaghy, Antero Engineering, Salida CO, ex-situ and in-situ oil shale extraction technology
- Judith Thomas, U. S. Geological Survey, Colorado Water Science Center, Grand Junction, CO, hydrology of Piceance Creek Basin
- Michael Vanden Berg, Utah Geological Survey, Salt Lake City, UT, geology, stratigraphy, and hydrogeology of oil shale, Uinta Basin
- Henrik Wallman, ProCo, Modeling of in situ and ex situ oil shale processing
- Glen Miller, USGS-retired, oil shale geology and mineral resources

*List of International Specialists*

***Enefit***

- Alo Kelder, ex-situ oil sale processing technology
- Indrek Aarna, ex-situ oil shale processing technology
- Tarvi Thomberg, ex-situ oil shale processing technology
- Erkki Kaisla, oil shale mining
- Oleg Nikitin, oil shale mining
- Tõnis Meriste, environmental issues
- Andres Anijalg, oil shale development (Jordan)

***Viru Keemia Grupp***

- Jaanus Purga, ex situ oil shale processing technology

***Israeli Energy Initiatives***

- Yuval Bartov, lacustrine stratigraphy, Green River Formation and Israel
- Harold Vinegar, general oil shale technology, development of Israeli oil shale

***TOTAL SA***

- Pierre Allix, geology, oil shale properties, resource evaluation, retorting processes
- Jean Deridder, oil shale project development
- Olivier Garnier, retorting processes, oil shale development, upgrading
- Samuel Lethier, ex situ oil shale process engineering
- Eric Chabal, ex situ oil shale project development
- Francoise Behar, geochemistry, oil shale kinetics
- Alexandre Lapene, process modeling and simulation

***QER***

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

***UMATAC***

- Gordon Taciuk, ex situ oil shale processing technology
- Steven Odut, ex situ oil shale processing technology
- John Barge, ex situ oil shale processing technology
- Lucas Rojek, ex situ oil shale processing technology
- Daniel Melo, ex situ oil shale processing technology

***Others***

- Omar Al-Ayed, Al-Balqa Applied University, Faculty of Engineering, Amman Jordan, properties of Jordanian oil shale and shale oil
- Mohammed Bencherifa, Organization National des Hydrocarbures et des Mines (ONHYM), Rabat, Morocco, engineering and geology of Moroccan oil shale
- Jaan Habicht, University of 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
- Väino Puura, University of Tartu, Resource assessment of oil shale
- Erik Puura, University of Tartu, ash leaching, contaminant transport and ash utilization
- Jialin Qian, China University of Petroleum, Beijing, China, Properties of oil shale in China
- Aya Schneider-Mor, Ben-Gurion University of the Negev, Beer Sheva, Israel, Geology and stratigraphy of Israeli oil shale
- Walid Sinno, San Leon Energy, London England, Development of Tarfaya oil shale
- Jyri Soone, University of Tartu, Tallinn, Estonia, Environmental effects of oil shale ash and spent shale
- Kati Tanavsuu-Milkeviciene, Statoil, stratigraphy and sedimentology of Green River Formation, Colorado
- 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 had come primarily from corporations actively pursuing oil shale development or by companies developing oil shale technology with the goal of selling technology/equipment to developers. These included Federal RD&D leaseholders (Shell, American Oil Shale/Total) and others holding land underlain by the Green River Formation (NSHI—now Simple Oil, ExxonMobil). Most of that funding has been discontinued. The Stanford-Total Enhanced Modeling of Source Rocks (STEMS) project funded by Total still continues but with an increasing emphasis on natural petroleum source rocks. U.S. Federal sources include the USDOE through its National Energy Technology Laboratory, as part of the Fossil Fuel program. However, such funding has been essentially zero for oil shale the past few years. The ACS Petroleum Research Fund is a potential source of support. Other companies may have provided smaller grants that are not widely publicized. Other private funding appears to support development at least of the Red Leaf Resources program. International funding comes from diverse sources, not all of them publicly acknowledged. It is clear that governments in Jordan and Morocco are actively supporting granting of concessions and dissemination of available data. Companies in Estonia (Enefit/Eesti Energia, Viru Keemia Grupp), Brazil (Petrobras), Canada/Germany (UMATAC/ThyssenKrupp) and China (CNPC, Fushun Mining Group 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 and less costly methods of extraction, production and upgrading of oil shale and shale oil. 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) as initially conceived. 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) as well as CAPEX. Shell has been developing their Circulating Molten Salt (CMS) heater, which is expected to reduce fuel consumption—and therefore $CO_2$ emissions—by approximately 30-40% compared to operations powered by electrical heaters. Recovering waste heat from exhausted retorts would also increase energy efficient and reduce $CO_2$ emissions, and Red Leaf Resources recently proposed a change in their heating methodology to accomplish that objective among others (Lechtenberger, 2015). AMSO has examined the potential for sequestration of $CO_2$ in exhausted in situ retorts (Burnham and Carroll, 2009). A presentation by Enefit at the 31st Oil Shale Symposium indicated that production from their Estonian 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 using ash as a cement clinker substitute, this could reduce $CO_2$ emissions to a level comparable to that of crude oil.

In the United States, understanding and mitigating the environmental effects of oil shale production across entire productive regions is clearly not the responsibility of individual leaseholders, but rather of the majority steward of the land, the Federal government. In the past, the USDOE 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 (e.g., Canadian National Instruments NI-43-101 Standards of Disclosure for Mineral Projects and NI-51-101 Standards of Disclosure for Oil and Gas Activities) would be a contribution to the global development of this resource, and would potentially create good will between the U. S., the European Union, and the developing countries with oil shale resources. Critical to such assessments will be careful estimation of the uncertainty regarding resource estimates where data are sparse.

### *Critical Environmental or Geohazard Issues and Mitigation Strategies*

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

1) The use of energy to pyrolyze the kerogen is minimized
2) The greenhouse gas emissions are reduced or compensated for by carbon trading or $CO_2$ sequestration
3) The water used in construction, operation, power generation, and reclamation is minimized and does not deplete the water resources of arid regions
4) The extraction, production and upgrading of the shale oil does not unduly affect the quality of the air, the native biological communities, or surface and ground water of the region.
5) Any Subsidence caused by mining or in-situ retorting does not cause unacceptable disruption of natural surface features or human structures

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

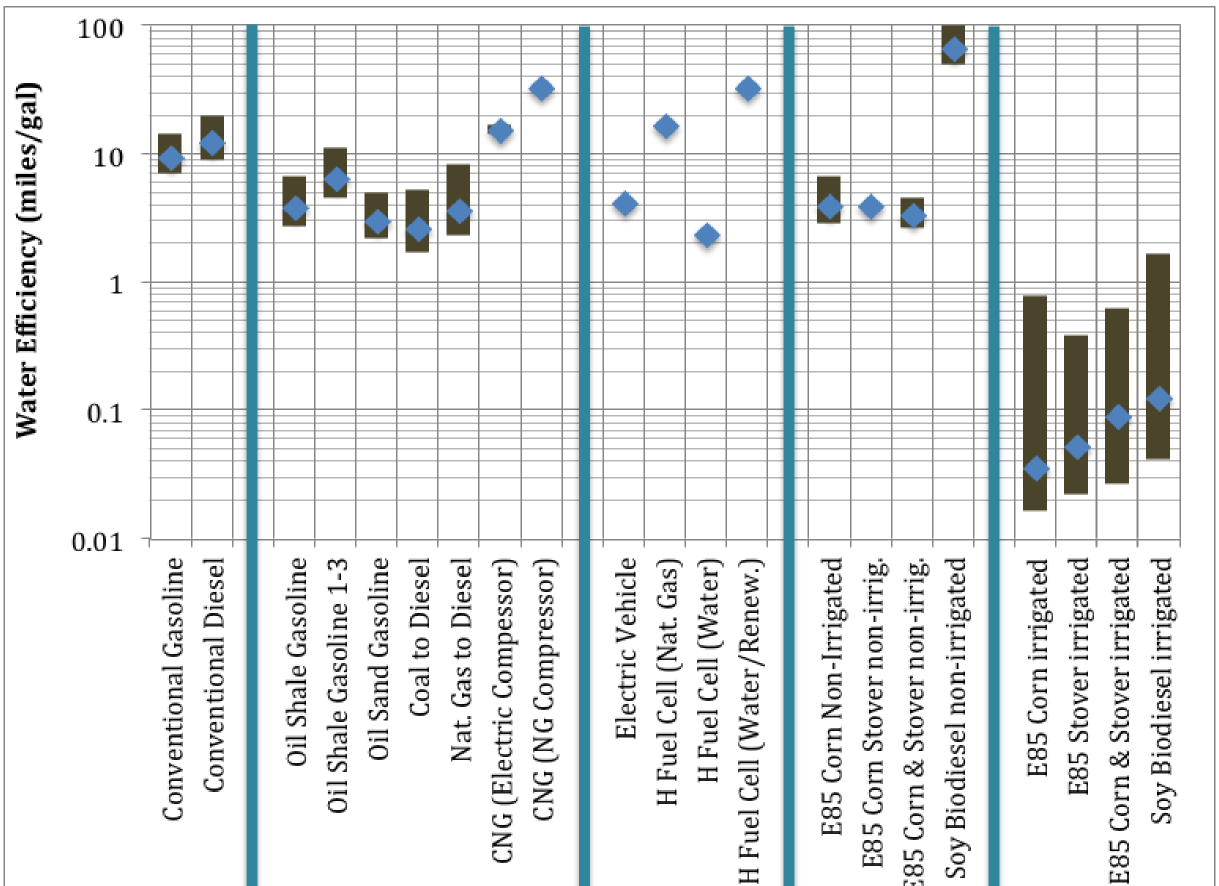
The recent offering of RD&D leases required that each of these concerns be addressed explicitly in the lease application. Numerous companies have highlighted the requirement for multiple rounds of interaction with regulatory bodies before production can begin. These interactions include at least two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

Water use has been highlighted as an important environmental issue recently, with reports from the U.S. 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, exaggerated, or from very limited studies intended to highlight pre-existing uncertainty in the water use estimates. The industry has had previously been claiming a water usage amount in the range of 1-3 barrels of water per barrel of oil to reasonably covers the technology likely to implemented for oil shale production, and that lower values may be achievable as industry progresses. The high end was for in-situ processes where aquifer remediation was required. More recently, with in-situ processing in the Piceance Basin planned only below the aquifers, this lower range is more appropriate. Water consumption, as reported in the 2013 Colorado symposium for Shell's ICP process in the zones excluding the nahcolitic interval, is approximately 0.3 bbls of water per bbl of oil production (Wani et al., Shell 2013).

The National Oil Shale Association has recently updated its estimate of water needs for an oil shale industry (Vawter, 2014). Based upon 2014 input from developers such as Shell and Enefit, NOSA now estimates water usage of 0.7 to 1.2 barrels of water per barrel of shale oil (Bw/Bo) (16,000 to 29,000 acre feet per year for 500,000 barrels per day of marketable shale oil production). This is down from an average of 1.7 Bw/Bo in a 2012 estimate. The major reductions came from more aggressive water conservation efforts and the elimination of water needed for ground water flushing after in situ retorting. Most developers now believe that a bulk of future in situ development will be carried out in areas where there is no mobile ground water, and thus ground water mitigation technology such as a freeze wall will not be necessary.

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

While still maintaining that 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




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

**Figure 6:** Water efficiency (in miles per gallon) of various conventional, unconventional, and alternative fuels. Diamond is mean value and bar represents range of estimates. An additional bar has been added to represent current industry estimates to produce shale oil of 1-3 barrels of water per barrel of oil, which is on the high side of current expectations.

vague claims of both Government and opponents that not enough is known have the distinct ring of political motivation. Figure 6 shows water consumption in miles-driven per gallon of water consumed 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 oil shale 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 biofuels. Consistency would seem to require equal Federal anxiety about biofuel production in Colorado and other states.

**Relevant EMD Technical Sessions and Workshops**

The primary conferences covering oil shale science and technology in 2014 were the Jordan International Oil Shale Symposium, April 14-15, 2014 in Movenpick, Jordan, and the 34th Oil Shale Symposium, October 13-15, 2014, at the Colorado School of Mines in Golden, CO. Detailed agendas were shown in the 2014 oil shale commodity report. The U.S. Oil Shale Symposium, which included substantial international participation, was held in Salt Lake City, October 5-9, 2015. The program follows.

| Monday, October 5, 2015 | |
|---|---|
| 7:00 - 8:00 AM | Speakers' Breakfast<br>*Grand Ballroom C, Hilton Salt Lake City Center* |
| | **Continental breakfast**<br>*Grand Ballroom B, Hilton Salt Lake City Center* |
| 8:00 AM - 7:00 PM | **Sponsor & Vendor Exhibits (see listing below)**<br>*Exhibit area and lobby* |
| 8:00 - 9:30 AM | 1. Opening Plenary<br>*Alpine Ballroom, Hilton Salt Lake City Center* |
| 9:30 - 10:00 AM | **Coffee**<br>*Exhibit area and Lobby* |
| 10:00 - 11:40 AM | 2. In-situ Processing<br>*Alpine Ballroom, Hilton Salt Lake City Center* |
| | 3. Modeling<br>*Ballroom A, Hilton Salt Lake City Center* |
| 11:40 AM- 1:00 PM | **Lunch**<br>*Ballroom C, Hilton Salt Lake City Center* |
| 1:00 - 2:40 PM | 4. Surface Processing<br>*Alpine Ballroom, Hilton Salt Lake City Center* |
| | 5. Chemistry and Geochemistry<br>*Ballroom A, Hilton Salt Lake City Center* |
| 2:40 - 3:10 PM | **Coffee**<br>*Exhibit area and Lobby* |
| 3:10 - 4:50 PM | 6. International Updates 1<br>*Alpine Ballroom, Hilton Salt Lake City Center* |
| 5:00 - 7:00 PM | Poster session and Symposium Reception<br>*Exhibit area and Lobby* |

## Tuesday, October 6, 2015

| | |
|---|---|
| 7:00 - 8:00 AM | Speakers' Breakfast<br>*Grand Ballroom C, Hilton Salt Lake City Center* |
| | **Continental Breakfast**<br>*Grand Ballroom B, Hilton Salt Lake City Center* |
| 8:00 AM - 3:00 PM | **Sponsor and Vendor Exhibits**<br>*Exhibit area and Lobby* |
| 8:00 - 9:40 AM | 7. Geology and Stratigraphy<br>*Alpine Ballroom, Hilton Salt Lake City Center* |
| 8:00 - 9:40 AM | 8. Resource Evaluation<br>*Ballroom A, Hilton Salt Lake City Center* |
| 9:40 - 10:10 AM | **Coffee**<br>*Exhibit area and Lobby* |
| 10:10 - 11:50 AM | 9. Pyrolysis<br>*Alpine Ballroom, Hilton Salt Lake City Center* |
| 10:10 - 11:50 AM | 10. Panel Discussions<br>*Ballroom A, Hilton Salt Lake City Center* |
| 11:50 AM - 1:00 PM | **Lunch**<br>*Ballroom C, Hilton Salt Lake City Center* |
| 1:00 - 2:40 PM | 11. International Updates 2<br>*Alpine Ballroom, Hilton Salt Lake City Center* |
| 2:40 - 3:10 PM | **Coffee**<br>*Exhibit area and Lobby* |
| 3:10 - 4:50 PM | 12. Closing Plenary and U.S. Updates<br>*Alpine Ballroom, Hilton Salt Lake City Center* |

## Poster Session, Monday - Tuesday, October 5-6, 2015

| | |
|---|---|
| October 5, 2015 5:00 - 7:00 PM | Poster session - see listing above<br>*Exhibit area and Lobby* |

## Sponsors and Exhibitors, Monday - Tuesday, October 5-6, 2015

**Symposium Exhibitors**

**List of Exhibitors**

## Field Trip, Wednesday - Thursday, October 7-8, 2015

| | |
|---|---|
| 7:00 AM October 7 - 7:00 PM October 8, 2015 | Oil Shale Field Trip to the Uinta Basin<br>*Field sites in Utah* |
| 7:30 AM - 7:00 PM | Day 1 Itinerary, October 7, 2015<br>*Various sites* |
| 7:30 AM - 6:30 PM | Day 2 Itinerary, October 8, 2015<br>*Various sites* |

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