

EMD Oil Shale Committee



EMD Oil Shale Committee Mid-Year Report

November 18, 2010

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Introduction

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

- Advancement by the U. S. Department of Interior's Bureau of Land Management of three Research Development and Deployment (RD&D) lease applications for oil shale to the Environmental Assessment stage, which is expected to last 4-18 months. Lease nominations came from ExxonMobil, Natural Soda (both in Colorado), and AuraSource, Inc. (in Utah)
- Announcement of plan for initial U. S. production of shale oil by Red Leaf Resources within 24 months (October 2012)
- Increase of estimates of oil shale resources in Jordan (to 102 BBO or more), Israel (to 250 BBO), and Utah (to 1,320 BBO)
- Advancement of oil shale development in Jordan with agreements in place with Eesti Energia (Estonia) and nearly in place with Jordan Energy Minerals Limited (with startup planned for 2014 at 15,000 BOPD, estimated breakeven price of \$38/barrel)
- Large increases in the number of oil shale retorts in China, potentially leading to significant increases in production over the next several years.

1. Current Global Production

Total global production of shale oil is currently about 20,000 barrels per day (BOPD). All of this production comes from mining and retorting operations in Brazil, China, and Estonia. Indications are that Chinese production, which was just over 10,000 BOPD in 2010, will increase to approximately 11,000 BOPD in 2011. It is evident that 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 by at least two fold, and potentially by four or five fold.

2. Current Resource Estimates

World resources of oil shale were previously estimated to be >3.0 trillion barrels, of which about two trillion barrels are 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 is currently reevaluating 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 in review, with preliminary values of the total resource that exceed those of Utah, and release is expected soon.

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.

These estimates are based largely on measurements of oil shale yield by Fischer Assay, a method designed to approximate the recovery of retorting methods. Most 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 account for non-condensable hydrocarbon gases potentially present in the mass fraction lost during assay. In situ processes tend to have a higher gas/liquids ratio. Thus, it is difficult to provide consistent estimates of the potential resource of oil shale available at this time.

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

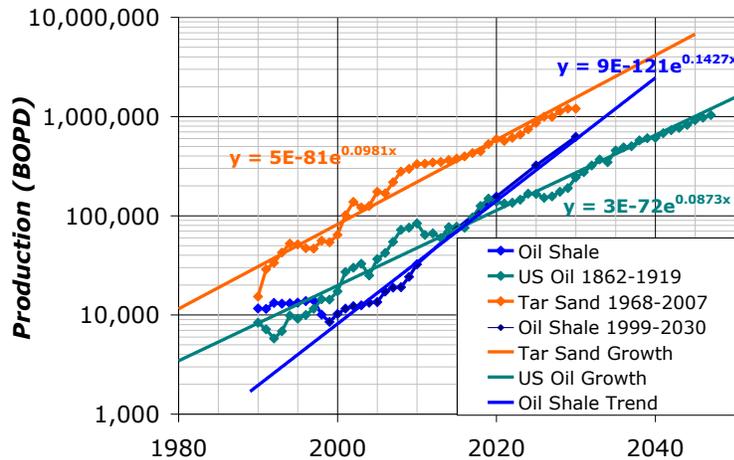


Figure 1: Projected oil shale production and historic production of U. S. crude oil and Canadian oil sands. The exponential curve fits to data indicate extended periods with growth rates of ~9% and ~10% for the U. S. and Canadian examples, and project >14% for oil shale even to reach one million barrels per day by 2035.

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

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

3. 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 is currently reviewing three applications for a second round of Research Development and Demonstration (RD&D) leases. The technical review was completed in the Spring of 2010, and in September, the BLM announced that it would advance all three leases to the next stage of environmental assessment. This step is expected to take four to eighteen months to complete. The leases offer the same 160 acre RD&D area as the previous round. However, the lease preference area, which becomes available at fair market price after a company has shown commercial feasibility for its technology, has been reduced more than 90% from 4,960 to 480 acres, for a total of 640 acres (compared to 5,120 acres previously).

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.

ExxonMobil continues work at its Colony site to investigate its ElectroFrac™ technology, which also involves electric heating, but through large plate electrodes created by hydraulic fracturing from horizontal wells and injection of an electrically conductive proppant to create what ExxonMobil itself characterizes as a “Giant Toaster”. They have now demonstrated that the process can create an effective connected heating element.

American Shale Oil (AMSO) plan to conduct a pilot test of their CCR™ (Conduction, Convection and Reflux) in situ process in 2011. The AMSO process involves heating in a sealed heater well, probably using downhole burners, to create a growing rubble-filled retort zone in which produced hydrocarbons recirculate to transfer heat upward. Production of hydrocarbons as vapor will occur through a production well located above the heating well.

Chevron has completed geologic and hydrologic characterization (and monitoring) wells at its RD&D lease in Colorado. It has been relatively quiet about development of its own technology for in situ extraction.

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 around efforts to reduce the carbon and water footprints of the systems while still maintaining a positive energy balance. OSEC, in partnership with Petrobras and Mitsui, is moving ahead with plans to develop a mining and retorting operation on its land south of Vernal, UT. They have selected a preferred development site and completed a drilling program as well as a commercial feasibility study. Their current production plan calls for building a capability for mining 30 million tons per year and producing 50,000 BPD of upgraded shale oil with an API gravity of 35 with an estimated all-in cost of \$38-44/barrel.

In addition, Red Leaf Resources Ecoshale Division has tested their in-capsule technology. Results reported at the 30th Oil Shale Symposium indicate that the company anticipates moving forward with production of 9,500 BOPD within 24 months, and plans to expand that to a 30,000 BOPD facility that will start construction in 2013. This would be a globally significant development for oil shale. Red Leaf currently estimates an energy return on investment of 11.5 to 1.

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. Jordan is actively pursuing partnerships to develop its significant resources of oil shale, partnering with Petrobras, Shell, Eesti Energia, Jordan Energy Minerals, Limited, and others to define a path toward energy independence. Petrobras and Total have been working with Morocco to develop well-characterized oil shale deposits near Timadhit. San Leon Energy of Dublin Ireland plans to begin testing of its in situ technology in 2011. Eesti Energia has recently signed an agreement with Morocco to evaluate a group of other oil shale deposits around the country.

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 which is now available. A limited number of 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.

4. Active Companies

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

- Chevron
- ExxonMobil
- Shell
- Total/American Shale Oil (AMSO)
- Petrobras (Brazil)/ Oil Shale Exploration Company (OSEC)

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

- Anadarko Petroleum Corporation
- ConocoPhillips
- Schlumberger

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

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

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

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

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

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

5. Current Research Activity

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 29th Oil Shale Symposia are available at: <http://www.ceri-mines.org/oilshaleresearch.htm>. Proceedings of the 30th Oil Shale Symposium should be available for sale by the end of the AAPG Annual Convention and Exhibition in Houston at: http://outreach.mines.edu/cont_ed/oilshale/?CMSPAGE=Outreach/cont_ed/oilshale/ .

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 has set as an objective no net waste products from oil shale production. They are working with a group at Jilin University in Changchun, which presented research results at the 30th Oil Shale Symposium.

The second method, in situ heating and extraction, is the focus of intensive research to develop a method to heat and pyrolyze kerogen-rich rocks underground and efficiently extract the resulting oil and gas from the formation. Shell has been a leader in this area, but ExxonMobil, Total/AMSO, Chevron, and others are investigating different processes. In situ heating takes much longer (on the scale of years), but as a consequence pyrolysis occurs at lower temperatures, and additional reaction at depth leads to a lighter oil with a larger gas fraction. The amount of secondary processing to meet refinery requirements is generally considered to be less than for retort products. Research on in situ processes and on processing the resulting material is ongoing at companies developing these methods, but results are generally proprietary. Symposium presentations have described general results in containment, heating, extraction, refining, and reclamation.

The third method, in-capsule extraction is the method being pursued by Red Leaf Resources of Cottonwood Heights UT. It involves mining of oil shale, encapsulation in a surface cell akin to a landfill, heating and extraction of the products, and final sealing of the exhausted retort. A recent trial has been completed and the results are favorable. The process is described in more

detail at Red Leaf's website: <http://www.redleafinc.com/>. Currently, Red Leaf is not directly involved in supporting research on its method.

6. Research Funding

Funding for oil shale research in the United States comes primarily from corporations actively pursuing oil shale development. These include Federal RD&D leaseholders (Chevron, Shell, American Oil Shale/Total) and others holding land underlain by the Green River Formation (ExxonMobil). U.S. Federal sources include the U.S. Department of Energy through its National Energy technology Laboratory, as part of the Fossil Fuel program. 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.

7. 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 CO₂, and power plant water consumption is the second largest use for a Shell-type in situ operation (Boak 2008, 2010). So minimizing energy use for these processes is essential. ExxonMobil has suggested air-cooled power plants to reduce water use, but these may increase CO₂ emissions (Thomas, 2010). AMSO has emphasized the potential for sequestration of CO₂ in exhausted in situ retorts (Burnham and Collins, 2009).

Understanding and mitigating the environmental impacts of oil shale production across entire productive regions is clearly not the responsibility of individual leaseholders, but rather of the majority steward of the land, the Federal government. In the past, the U. S. Department of Energy managed an Oil Shale Task Force charged with defining and integrating baseline characterization and monitoring needs for environmental impacts within the basins of the Green River Formation. This critical need has not been recognized by the Congress, and therefore the need is not being addressed systematically. The Interior Department, as the agency responsible for administering these lands, is the primary beneficiary of research to better define the critical environmental issues and potential mitigating actions, but neither DOI nor the Department of Energy have provided consistent, ongoing research to address these issues.

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.

8. Critical Environmental or Geohazard Issues

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 CO₂ sequestration,
- 3) the water used in construction, operation, power generation, and reclamation is minimized and does not deplete the water resources of arid regions, and
- 4) the extraction, production and upgrading of the shale oil does not unduly affect the quality of the air, the native biological communities, or surface and ground water of the region.

Socioeconomic impacts are also issues of concern. The recent offering of Research, Development, and Demonstration leases required that each of these concerns be addressed explicitly in the lease application. In addition, Shell has determined that developers must interact with 47 separate regulatory bodies before production can begin. These interactions include at least two separate environmental impact assessment stages likely to focus on the same impacts. A streamlined review process that avoids duplicative requirements would be more likely to protect the environment without discouraging development of the resource.

9. Recent and Current Conferences and Sessions

A session on environmental impacts of oil shale and oil sand development was part of the technical program of the Geological Society of America 2010 Annual Meeting in November 2010. The session drew papers only on oil shale from the U. S. Geological Survey, Idaho National Laboratory, and the Colorado School of Mines.

Planning is under way for a possible Oil Shale Symposium in Jordan in April 2011.

The premier international meeting on oil shale is the Oil Shale Symposium hosted by the Colorado School of Mines in October. The 30th Oil Shale Symposium occurred October 18-22, 2010, which also included a field trip to western Colorado and Eastern Utah. The 31st Oil Shale Symposium will occur October 17-21, 2011 in Golden, with a field trip probably to both Colorado and Utah.

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Appendix 1: Preliminary List of Specialists in the United States

| Name | Organization | Research Area |
|--------------------|--|--|
| Gary Aho | Oil Shale Exploration Company (OSEC), Rifle CO | Oil shale production technology |
| Mike Batzle | Center for Rock Abuse, Colorado School of Mines | Physical properties of oil shale |
| Jeremy Boak | Center for Oil Shale Technology and Research (COSTAR), Colorado School of Mines, Golden CO | Assessment of CO ₂ emissions and water consumption by oil shale production; geologic characterization of oil shale. |
| John Berger | COSTAR, Colorado School of Mines, Golden CO | Modeling of fracturing in oil shale |
| Justin Birdwell | U. S. Geological Survey, Lakewood CO | Organic geochemistry of oil shale and other source rocks |
| Lauren Birgenheier | Energy Geosciences Institute, University of Utah, Salt Lake City UT | Stratigraphy of oil shale |
| Neil Bostrom | Schlumberger-Doll Research, Cambridge, MA | Pyrolysis of oil shale, kinetics, and characterization |
| Adam Brandt | Stanford University, Stanford CA | Assessment of CO ₂ emissions from oil shale production |
| Michael Brownfield | U. S. Geological Survey, Lakewood CO | Geology, stratigraphy, sedimentology and resource evaluation of Green River Formation oil shale |
| 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 |
| Kadri Dagdalen | Colorado School of Mines, Golden CO | Underground methods for in situ production of oil shale |
| Gerald Daub | Daub and Associates, Grand Junction CO | Geology of Green River Formation |
| Milind Deo | Institute for Clean and Secure Energy, University of Utah, Salt Lake City, UT | Chemistry and simulation of oil shale retorting processes |
| John Dyni | U. S. Geological Survey (ret.), Lakewood CO | Geology and resource evaluation of oil shale |
| Benjamin Harding | AMEC Environmental, Boulder CO | Water use for oil shale production |
| Michael Herron | Schlumberger-Doll Research, Cambridge MA | Mineralogical and chemical characterization of oil shale |
| Hai Huang | Idaho National Laboratory, Idaho Falls, ID | Geomechanical behavior of oil shale |
| Ronald Johnson | U. S. Geological Survey, Lakewood CO | Geology, stratigraphy sedimentology and resource evaluation of Green River Formation oil shale |
| Mark Kuchta | Colorado School of Mines, Golden CO | Underground methods for in situ production of oil shale |
| Daniel Levitt | Los Alamos National Laboratory, Los Alamos NM | Hydrology of oil shale deposits |
| Michael Lewan | U. S. Geological Survey, Lakewood CO | Organic geochemistry of oil shale and other source rocks |
| Timothy Lowenstein | Binghamton University, Binghamton NY | Chemistry and formation of evaporite minerals and spring deposits of the |

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|----------------------------|---|---|
| | | Green River Formation, Colorado and Wyoming |
| Jonathan Mace | Los Alamos National Laboratory, Los Alamos NM | Explosives application to fracturing of oil shale |
| Malka Machlus | Schlumberger-Doll Research, Cambridge MA | Stratigraphy of Green River Formation oil shale |
| Glenn Mason | Indiana University Southeast, New Albany, IN | Geology of Green River Formation oil shale |
| Earl Mattson | Idaho National Laboratory, Idaho Falls, ID | Hydrology of oil shale deposits and water consumption patterns for oil shale production |
| Bill McKinzie | Shell, Houston TX | In situ conversion processes for oil shale |
| Carl Palmer | Idaho National Laboratory, Idaho Falls, ID | Mineralogical and chemical effects of pyrolysis on oil shale |
| Donatella Pasqualini | Los Alamos National Laboratory, Los Alamos, NM | Energy systems analysis for Western Energy Corridor |
| Ron Pugmire | University of Utah, Salt Lake City, UT | Chemistry and kinetics of oil shale pyrolysis |
| J. Frederick Sarg | Colorado School of Mines, Golden CO | Stratigraphy and sedimentology of Green River Formation, Colorado |
| Philip Smith | Institute for Clean and Secure Energy, University of Utah, Salt Lake City, UT | Chemistry and simulation of oil shale retorting processes |
| Kati Tanavsuu-Milkeviciene | Colorado School of Mines, Golden CO | Stratigraphy and sedimentology of Green River Formation, Colorado |
| Judith Thomas | U. S. Geological Survey, Colorado Water Science Center, Grand Junction, CO | Hydrology of Piceance Creek Basin |
| Michael Vanden Berg | Utah Geological Survey, Salt Lake City, UT | Geology and stratigraphy of oil shale, Utah |
| Jessie Yeakel | ExxonMobil Upstream Research, Houston, TX | Geology of Green River Formation oil shale |
| Wei (Wendy) Zhou | Colorado School of Mines, Golden CO | Geographic Information Systems for oil shale water resource evaluation |

List of International Specialists (The current list is preliminary and incomplete.)

| Name | Organization | Research Area |
|---------------------|--|---|
| 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 |

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| Zhaojun Liu | Jilin University, Changchun, China | Geology, stratigraphy, and resource evaluation of Chinese oil shale |
| Tsevi Minster | Geological Survey of Israel, Jerusalem, Israel | Resource characterization for Israeli oil shale |
| Vaino Puura | Tallinn Technical University | Resource assessment of oil shale |
| Jialin Qian | China University of Petroleum, Beijing, China | Properties of oil shale in China |
| Aya Schneider-Mor | Ben-Gurion University of the Negev, Beer Sheva, Israel | Geology and stratigraphy of Israeli oil shale |
| Jyri Soone | Tallinn Technical University, Tallinn, Estonia | Environmental effects of oil shale ash and spent shale |
| Mahmoud Zizi | ZIZ Geoconsulting, Rabat Morocco | Geology and engineering for Moroccan oil shale |

