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Introduction

I started my first oil shale project in the fall of 1967, at the Colorado School of Mines, as part of my master's program in the Department of Chemical and Petroleum Refining Engineering. I set out to measure thermal conductivity factors for oil shale in the Green River formation, the huge geological entity that underlies much of northwestern Colorado, northeastern Utah, and southwestern Wyoming. My work was sponsored by Sinclair Oil Company, which wanted to simulate the transmission of heat through beds of oil shale at their property overlooking the Parachute Valley in Colorado. Sinclair's field tests in the 1950s were somewhat successful, and they were encouraged by high oil prices (almost $3 per barrel and holding) to try again. Sinclair called its process "underground retorting" or "retorting in place." The currently popular phrase *in situ* was provided later, by Latin scholars.

After graduate school, I worked in a steel mill and then on oil shale, coal conversion and tar sands processing, fuel alcohol from corn, oil shale, resource recovery from municipal waste, management of scrap tires and other special wastes, domestic independent power projects, waste-to-energy facilities, recycling and solid waste composting, international power projects, gas-to-liquids technology, recovery of energy from agricultural residues, hybrid power plants, and oil shale.

In 2007 and 2008, I was principal investigator and director of the Jordan Oil Shale Technical Assistance project. My colleagues and I conducted a feasibility study for development of the oil shale resources in The Hashemite Kingdom of Jordan and prepared a strategic plan for their commercialization. Work included reviewing the mining and processing technologies and industries under development in other countries and updating cost engineering studies from the 1970s to allow forecasting of the product prices required to support an oil shale industry in Jordan. The client was Jordan's Ministry of Energy and Mineral Resources. The prime contractor was Behre Dolbear and Company (USA) Inc. Funds came from the U.S. Trade and Development Agency, a branch of the Department of Commerce.

In 2008 and 2009, I was engaged by the European Union to support the Euro-Mediterranean Energy Market Integration Project, or MED EMIP. My job was to develop a concept paper for creation of an oil shale council for the countries of Turkey, Syria, Jordan, Egypt, and Morocco. All of these countries have oil shale deposits and not much else in the way of indigenous fossil fuels. The council would allow them to share their experience, influence, and expertise and develop their resources in an orderly and beneficial manner. My work again included reviewing the status of oil shale technologies and projects in the Middle East, North Africa, and other regions and assessing the significance of that work for the council's members. The project was successful in that an Oil Shale Cooperation Center was established in Amman in April of 2010. The future of that center is unclear, given the social unrest in its member countries.

I would now like to describe what I learned about oil shale projects around the world and to highlight some of the implications of that work for the emerging oil shale industry in the United States.

Oil Shale Projects in Other Countries

People's Republic of China

In Liaoning Province, the Fushun Mining Group plant uses a large number of small retorts to make about 2 million barrels of oil per year from lump oil shale, plus bricks and cement from the ash. Installation of a large retort to handle fine oil shale was completed in 2010. The plant uses the Alberta Taciuk Process (ATP) technology which was developed for soil cleaning in Canada. FMG has announced plans to expand their capacity by 3 million barrels per year.

In Jilin Province, Jilin Energy & Communication Corporation produces 12 MW of electricity by burning oil shale in fluidized bed boilers. Jilin Energy is developing a plant that will use Petrosix retorts to produce 1.5 million barrels per year of shale oil, 100 MW of electricity, and cement. Six other companies produce shale oil in Jilin Province. Quantities are relatively small. And Royal Dutch Shell has established a joint venture to evaluate the potential of Shell's *in-situ* conversion process in the province.

SINOPEC has proposed to build an oil shale power plant in Guangdong province. A retorting plant has been proposed for Heinan Province. In Heilongjiang Province, PetroChina is building a plant that will make about 700,000 barrels of shale oil per year, and a larger plant has been proposed by China National Coal Company and Harbin Coal Chemical Company. Several other minerals companies have proposed oil shale projects, some involving co-processing of oil shale and coal.

Estonia

Serious development of Estonia's resources began after World War I, and today more than 12 million tonnes of oil shale is mined per year. More than 85% is burned to generate electric power. Retorting plants produce 1.6 million barrels of shale oil per year, mostly in descendents of the Kiviter and UTT retorts that were developed when Estonia was part of the Soviet empire. One of the big players is Viru Keemia Grupp AS (VKG), which operates a power station and two shale oil plants which process lump oil shale in Kiviter retorts. In December 2009, VKG commissioned a Petroter retort (a descendent of the UTT process) which produces 730,000 barrels of shale oil per year plus fuel gas and steam. VKG has a permit to pursue oil shale development in Ukraine.

The other big player is Eesti Energia AS, the national power utility. Eesti Energia operates the Narva Oil Factory, which produces about 950,000 barrels of shale oil per year in two TSK140 retorts. These process fine oil shale and are also descendents of the UTT retorts developed in Soviet times. In 2009, Eesti Energia announced plans to expand its retorting capacity by more than 2 million barrels per year by 2012. Production of fuel gas, steam, and electricity will also rise. In 2008, Eesti Energia and Finnish minerals processing company Outotec formed a joint company – Enefit – to develop oil shale processes and projects, especially in other countries. Enefit's subsidiary Oil Shale Energy Jordan is developing a retorting plant and a large power station in Jordan. Enefit American Oil has acquired the Oil Shale Exploration Company project in Utah, which could, in time, produce 57,000 barrels of shale oil per day.

The Hashemite Kingdom Jordan

Jordan's deposits are located 60 to 90 miles south of Amman. They are large, have medium yield, and might be extracted with low-cost surface mining. The oil shale and the shale oil are very high in sulfur, which complicates combustion and retorting and makes refining difficult and expensive. These defects could be offset by selling the sulfur recovered during refining, because sulfur is a valuable commodity. In January 2000, sulfur sold for $3 per long ton along the west coast of the USA; in January 2011, the price was $180 per long ton.

The Kingdom has no other significant resources of fossil fuel, and the government is committed to oil shale development. Since November 2005, the government has executed memoranda of understanding (MOUs):

- With Jordan Cement Factories Company to manufacture cement from oil shale in the El Lajjun deposit
- With Royal Dutch Shell to evaluate applying Shell's *in-situ* process to deeply buried oil shale in central and southern Jordan
- With Eesti Energia to evaluate using Enefit retorts to make at least 37,000 barrels per day of shale oil and its boilers to generate at least 440 MW of electricity
- With Jordan Energy and Mining Ltd. to investigate shale oil production using the ATP technology
- With the International Corporation for Oil Shale Investment to evaluate retorting of oil shale from the El Lajjun resource in successors to the fine-shale and coarse-shale retorts developed in Estonia during the Soviet era
- With Brazil's national oil company Petrobras to examine application of the Petrosix retorting technology. The global energy company Total S.A. is participating.
- With Russian firm Inter Rao and Jordan's Aqaba Petroleum to examine using Russian technology for oil shale mining and shale oil extraction

- With the International Company for Oil Shale Investment to evaluate development of the Attarat Umm Ghudran resource.

The agreements cover both *in situ* retorting and aboveground processing in a diverse selection of retorts, with a range of potential production capacities, in several of Jordan's oil shale areas. One agreement could produce a major power generating facility capable of meeting most of Jordan's electrical demand, and one agreement provides for recovery of a valuable byproduct – Portland cement. With these agreements, Jordan is well positioned to become a major producer of shale oil. However there are restraints. In addition to the usual issue areas – economic feasibility, land disturbance, waste management, water requirements, and environmental, social, and cultural concerns – there is competition for access to the rock, some of which may contain uranium.

Australia

Australia has very large oil shale resources, principally in Queensland, and had oil shale industries of substantial size between 1865 and 1952. In June 1997, the Stuart Project was begun near the town of Gladstone in Queensland as a joint venture between Suncor Inc. of Canada and the affiliated Australian companies Southern Pacific Petroleum (SPP) and Central Pacific Minerals (CPM). Suncor subsequently departed, and SPP absorbed CPM. A demonstration plant using an ATP retort was constructed. The plant operated intermittently from 2000 to 2004, despite resistance from environmental, tourism, and fishing groups. Although the project had significant accomplishments, it had ongoing technical problems because dryer was too small. In February 2004, Queensland Energy Resources Ltd. acquired most of SPP's assets, and Stuart was suspended. In August 2008, QERL announced that it was abandoning the ATP technology in favor of the Paraho II technology. The ATP plant was dismantled.

QER processed 8,000 tonnes of Australian oil shale in the Paraho pilot plants maintained by Shale Technology International in Rifle, Colorado. In October 2009, QERL completed a feasibility study and began a campaign to restart Stuart with Paraho retorts. The first phase of that development was completed in August 2011, with commissioning of a small processing plant containing a single Paraho retort and its cadre of ancillary equipment, on the Stuart site. The plant can process about 2.5 metric tons of oil shale per hour (vs. the 250 tonnes per hour capacity of the ATP retort). When it is fully operational, the plant will manufacture ultra-low-sulfur diesel fuel, jet fuel, fuel oil, and synthetic crude oil.

Demonstration of the Paraho retorting process is particularly significant for oil shale initiatives in the American West. Reasons include:

- Paraho is American technology, developed in Colorado to use oil shale from the Green River formation.

- Paraho's history extends back nearly 70 years to the Synthetic Liquid Fuels Act of 1944, by which the U.S. Congress, in its wisdom, involved the Federal Government in development of the western oil shale resources. The Act led to a long series of pioneering tests on oil shale mining and retorting at Anvil Points in Colorado. The Gas Combustion retort was developed there. Its successor was the Paraho retort.

- The Paraho retort was developed with emphasis on energy self-sufficiency and water conservation. These requirements are important in the remote, arid west.

- Some of Paraho's operating principles were embodied in the Petrosix retort and have been thoroughly tested in Brazil with the difficult Irati oil shale and with other unforgiving materials, such as scrap tires.

- The QER project will rise on the site of a failed oil shale project which failed, in part, because of environmental controversy. QER is aware of the challenges in this area and seems to be dealing with them constructively. Similar controversy is likely to accompany any oil shale project in the U.S.

Others

Although **Brazil** is not expanding its domestic oil shale industry, the national oil company Petrobras is involved in projects in Jordan, the U.S.A., Morocco, and China. **Turkey** imports more than 90% of its fuel oil and gas and has considered developing its oil shale to reduce that dependence. There are some interesting opportunities (oil shale in one small deposit yields up to 3 barrels of oil per ton), but only a few deposits have been investigated in significant detail. **Morocco** has executed an MOU with Petrobras and Total to evaluate aboveground retorting of oil shale from the Tarfaya and Timhadit deposits and an MOU with San Leon Energy to investigate *in situ* development of portions of Tarfaya. **Syria** exports oil, but production is declining and the country is looking to its gas and oil shale deposits to maintain energy revenues. In 2009, Syria signed an MOU with Jordan to exchange expertise in producing electricity from oil shale. Before the Arab Spring of 2011, **Egypt** was examining the feasibility of developing its oil shale to conserve the country's economically important oil and natural gas. Resource surveys and limited field exploration studies are underway in **Canada**, **Thailand**, and other places. The Holcim Cement plant in Dotternhausen, **Germany**, continues to make cement from oil shale. Tests continue on the alum oil shale in **Sweden** to determine feasibility of recovering oil, uranium, nickel, molybdenum, and vanadium.

Significance for Oil Shale Development in the USA

Oil shale activities in other countries are very relevant to the future of an oil shale industry in the United States. Like the U.S., nearly all of the other countries that are working on oil shale consume much more oil than they produce. A few (Jordan, Morocco, Turkey) have essentially no indigenous liquid fuel production and are totally dependent on imports, with the attendant economic dislocations and security concerns. Many have sensitive physical environments that could be damaged by poorly controlled and inadequately regulated mining and processing facilities. Many are water-poor and cannot divert water to supply oil shale plants and their associated populations without depriving other people and activities, especially agriculture. Many have small populations and economies and would have difficulty raising billions of dollars to pay for integrated oil shale plants, despite their potential economic benefits in the long term.

Oil shale projects in other countries are also relevant to the U.S. because they will advance understanding of the processing technologies and reduce risks associated with their deployment. A very important benefit of the projects will be validation of high-level engineering designs and cost estimates. Although plants in the current and proposed industries are relatively small compared with what might be supported by the Green River oil shales, they are large enough to address many of the unknowns that must be confronted by promoters of a commercial industry. This is especially important for the retorting facilities, which are expensive to build and operate. In 2006, China's Fushun Mining Group estimated it cost $18.46 to deliver a barrel of shale oil, with 75% of the cost associated with retorting, 23% with transportation, and less than 1% with mining. A failed retort could bring an entire plant down, and it could be very expensive to repair or replace.

The growing body of operating experience and information will greatly reduce the risks associated with a commercialization phase. This progress will facilitate financing and permitting of a facility, which will ultimately mean lower product costs. These advancements are important regardless of where oil shale technology is deployed next, and especially if it is deployed in the U.S.A.

In short, the challenges faced by oil shale proponents in other countries are similar to those encountered in the United States: how to develop a practical, efficient, beneficial industry while protecting the environment and avoiding unacceptable social dislocations. It hasn't been easy over there; it won't be easy here.