OIL SHALE

"The underground supply of oil cannot much longer be depended upon to supply the ever increasing demand,…pointing unerringly to the one permanent supply of the raw material which we have -- the deposits of oil shale. Whether we wish it to be so or not, we shall soon be forced to resort to the oil shales for our supply of oil.[1]"

-- Victor C. Alderson, ScD., President, Colorado School of Mines, in The Oil Shale Industry, 1920.

Oil shale is a common natural resource found on all of the inhabited continents. Deposits in the central and eastern areas of the U.S. underlie an area of about a quarter million square miles. However, as with many oil shale deposits throughout the world, these deposits are generally thin and irregular, yielding very little oil.

Oil shale deposits in the Western U.S. are small in comparison (17,000 square miles) but they are unusually rich and substantially thicker than most other deposits (Fig. 1). A "rich" deposit is one that yields over twenty-five gallons of crude shale oil per ton of rock. Some Western deposits have produced nearly one hundred gallons of crude shale oil per ton of rock.

These deposits provide the United States with roughly three-quarters of the world's estimated supply of recoverable oil shale resources, eighty-five percent of which are in the states of Colorado, Utah, and Wyoming. This is in dramatic contrast to the less than five percent of the world's estimated recoverable crude oil resources found in the lower 48 states. The obvious question now is, "Why isn't the United States developing a shale oil industry?"

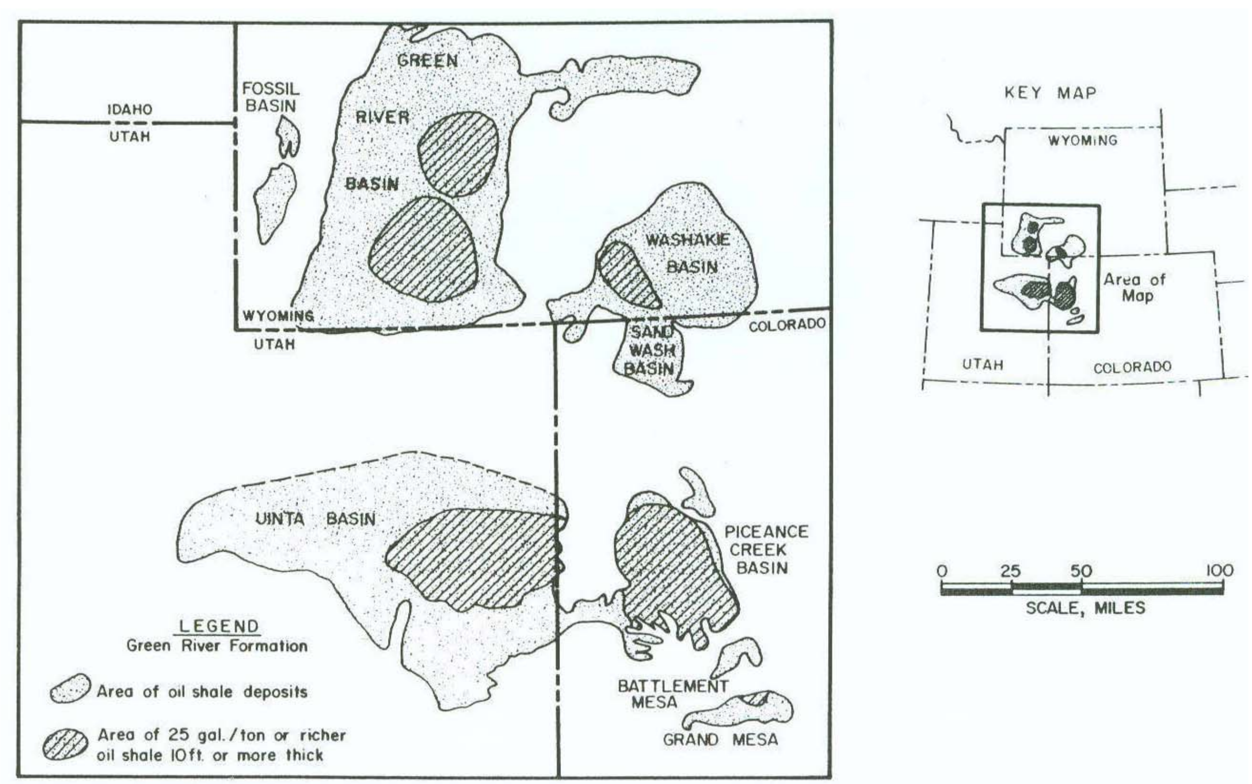

Figure 1
Oil shale deposits in the Western U.S.
Synthetic Fuels Data Handbook, Cameron Engineers, Inc., 1978, p.4

The Resource

The oil shales of the Green River Formation were deposited approximately 50 million years ago as lake sediments. The kerogen found within these deposits had an origin similar to conventional crude oil, with the exception of sufficient depth and duration of burial and the resulting temperatures and pressures to be converted to oil in a thermogenic process. As a result, the organic matter progressed only to an immature kerogen stage, rather than to mature thermogenic crude oil or natural gas.

The Green River Formation is divided into five members: Douglas Creek, Garden Gulch, Anvil Points, Parachute Creek, and Evacuation Creek (Fig. 2). The Parachute Creek Member contains the greatest amount of oil shale and it has been further divided into zones. The richest of these is the Mahogany Zone, which reaches a thickness in excess of 200 feet and averages fifty-five gallons of crude shale oil per ton of rock.

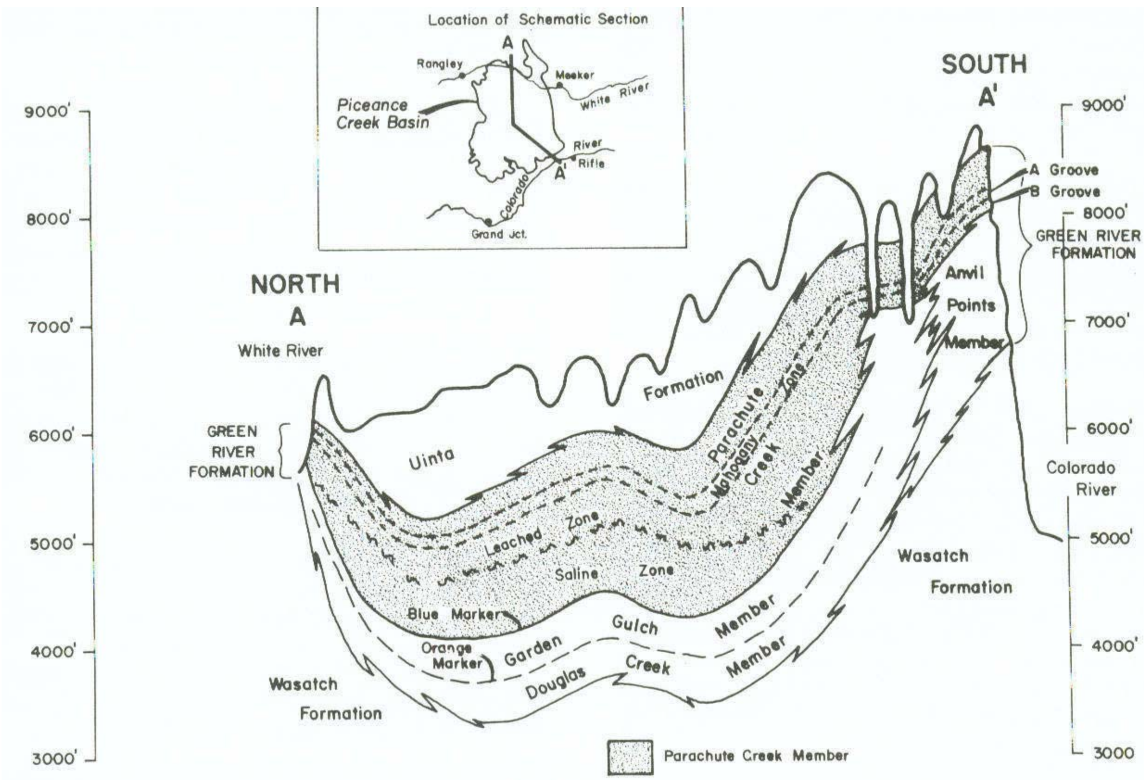

Figure 2
Oil shale members of the Green River Formation
Synthetic Fuels Data Handbook, Cameron Engineers, Inc., 1978, p.7

History

The first recorded use of shale oil occurred in Switzerland and Austria in the early 1300s. The Ute Indians were also aware of the oil shale resource as they described "a rock that burns" to settlers. While several other countries, (notably Brazil, China, Estonia, and Jordan) make use of their oil shale resources, no oil shale venture in the U.S. has been a commercial success in over a hundred years. The principal reason for this lack of success is the abundant supply of lower cost fossil fuels. In the United States, experiments in the production of shale oil have been conducted since 1850. When the first oil well was drilled in Titusville, Pennsylvania in 1859, it quickly led to the end of the fledgling domestic oil shale industry, as liquid petroleum was much more economical to produce.

Boom/Bust

The history of Western U.S. oil shale development is characterized by sudden booms brought about by energy crises, followed by equally sudden busts when a less expensive alternative became available. In 1915, it was reported that the U.S. may be running out of petroleum and the first oil shale boom was on. The boom went bust in the late 1920s when the West Texas oil fields were discovered and developed.

In 1944, interest in oil shale was renewed when the federal government realized that domestic conventional crude oil reserves would be unable to meet demand in the near future. However, nuclear energy and the discovery of enormous deposits of oil in the Middle East kept oil shale development relatively low until 1973.

In 1973, the Arab oil embargo and OPEC's escalating prices created awareness of U.S. dependence on foreign oil and a second oil shale boom resulted. This time, major oil companies began developing oil shale projects with federal subsidization. As the oil companies moved into place, so did the people. By 1980, the population in some of the small towns near the oil shale deposits had increased as much as 400%. Even with all of the new construction that occurred, there was insufficient housing and utilities to support the exploding population.

This boom, as its predecessors in the past, also ended. OPEC lost control of oil prices and it was soon apparent that even subsidized shale oil could not compete with the declining prices for conventional crude. Almost overnight, the jobs were gone, leaving a housing glut as people moved away seeking employment elsewhere. Local businesses that had expanded during the boom faced a reduced market, and many went bankrupt as loans were foreclosed. Local companies were crippled as city and county governments were faced with a substantially reduced tax base from which to service debt accrued in an effort to keep pace with anticipated growth. By the early 1990s, there were no commercial oil shale facilities operating in the U.S., with the exception of the New Paraho Corporation, which was experimenting with the development of road asphalt additives, and other applications.

Pros and Cons of Developing Oil Shale

Compared to conventional petroleum resources, shale oil has several advantages, as well a number of disadvantages, Because oil shales of the Green River Formation were formed at the bottom of a lake, the resource is continuous within the ancient shorelines. The shale oil industry is thus spared the costs and risks of exploration and drilling borne by the conventional petroleum industry.

While the exploration costs for oil shale are quite low in comparison to conventional crude oil, the recovery costs are higher. Kerogen does not flow as conventional crude oil does, nor will it easily dissolve in chemicals, and crushing does not free it from the host rock. The only way that has been found to remove kerogen from rock is to heat it. In addition, once free of the rock, the crude shale oil must be treated with hydrogen to create synthetic crude oil. Only then can it be refined into gasoline and other petroleum products similar to conventional crude oils.

Producing oil from oil shale also presents a massive materials handling challenge if it is processed in a surface retort. Assuming an average yield of one barrel of oil (42 gallons) from two and one half tons of rock, and production rates of 500,000 barrels per day, nearly 1.2 million tons of rock would be processed and disposed of on a daily basis. This is over three times the amount of material taken daily from Kennecott's Bingham Canyon Copper Mine near Salt Lake City.

The former U.S. Bureau of Mines developed a series of mining scenarios and found that even the smallest economically feasible oil shale mine (yielding approximately 50,000 bpd) would be comparable in size to the largest iron and copper mines in the world. Not only is this an expensive undertaking, but it is one fraught with potential environmental problems as well.
As a result, *in-situ* retorting, in which the oil shale is heated in place and the resulting shale oil is extracted without mining the rock, has been attempted. The impermeable nature of

undisturbed oil shale has required that the rock be fractured prior to retorting. The fracturing of rock in-place has thus far proven ineffective for in-situ retorting purposes.

A mine assisted, or "modified in-situ," process was researched and employed by Occidental Petroleum Corporation's C-b Demonstration Project prior to its closure in 1991. In the Occidental process, approximately one-fourth of the oil shale is removed from rooms within the oil shale column. The removed shale is retorted on the surface. The remaining oil shale is rubblized explosively and combustion is started from the top. Air is injected into the column to allow combustion of some of the kerogen. This provides the heat necessary to release the kerogen as shale oil, which is collected in galleries at the base of the column and pumped to the surface for processing.

While this process greatly reduces the volume of waste rock to be disposed of (by 75%), the costs of production are still substantially higher than for the production of crude oil by conventional means, and cannot compete at current market prices. Additionally, the process has its own set of environmental concerns related to hydrology, water quality, and surface damage.

Environmental Considerations

By far the most serious potential environmental and health consequences associated with oil shale development are related to waste disposal. As noted above, the amount of material mined and processed in a surface retort operation is considerable. Spent shale contains trace amounts of numerous heavy metals as well as salts. Snowmelt, rainfall, or ground water have the potential to leach toxins and salts from the spent shale into the environment unless proper waste management technology is implemented. Air quality is another environmental concern, and oil shale processing facilities must comply with the provisions of the Clean Air Act.

Federal Involvement

The Federal Government is the owner of approximately 80% of the oil shale resource in the Piceance Basin and controls the richest portions of the deposits. Much of the oil shale in Utah and Wyoming is also federally owned. In April of 1930, President Hoover signed an Executive Order withdrawing oil shale lands from the Federal Leasing Program. The order can only be lifted by the Secretary of the Interior, which has occurred only once in the past fifty years.

The U.S. government has been involved in oil shale research and development to a significant extent beginning in the 1940s when it established an experimental station at Anvil Points in western Colorado. The experimental station has since been closed and the equipment removed. In 1979, the Carter administration proposed that an independent federal entity, the Energy Security Corporation, be created with broad powers to provide assistance to the private sector to initiate large-scale synthetic fuels production.

In 1980, Congress passed the Energy Security Act, intended to promote non-petroleum energy production in order to reduce U.S. dependence on foreign oil. It evolved from the belief that a dependable energy source and natural security were inexorably linked. Among the provisions of the Act was the creation of the Synthetic Fuels Corporation (SFC) which provided financial assistance for developing synthetic fuels. The SFC was disbanded in 1986 when the price of oil dropped. It had taken two years to organize the SFC, missing the peak of the oil shale boom. Once the SFC was operational, it was nearly paralyzed by Administration and Congressional scrutiny. In six years of operation, only four projects were funded through SFC for a total of $1.7 billion.

Lacking a domestic energy crisis of substantial duration, or a dramatic increase in the world price of crude oil, the development of oil shale as an energy resource appears remote. However, as this is being written, a multinational oil company is again looking into development of the Western U.S. oil shale resource.

Shell's Mahogany Oil Shale Project

Shell Exploration and Production Company, much as other large energy companies, was involved in the oil shale boom in Colorado during the 1970s. By 1979, however, the company sold its interests in the Colony Project to ARCO, and sold other leases to Occidental and Tenneco. Shell was no longer active in Colorado's oil shale boom. However, Shell had not given up on oil shale, and by 1982 continued to experiment with technology at Red Pinnacle and other laboratories. In 1987, the company purchased the Ertl-Mahogany and Pacific tracts in Colorado. In 2000, Shell returned to Mahogany with an expanded in-situ heating technology research program that is now ongoing.

Unlike the Occidental "modified in-situ" process, which required a considerable amount of mining to create the necessary void volume for the direct combustion retorting process, Shell has developed and patented a true in-situ technology known as the "In-situ Conversion Process" (ICP). According to Shell, the ICP could potentially produce high quality transportation fuels from oil shale, oil sand, and coal in a technically, economically, and environmentally sound manner..."

The ICP process involves the drilling of holes from the surface to the oil shale zone, which may be up to 2,000 feet deep (Fig. 3). Into these holes are inserted electrical resistance heaters which gradually (over a period of months) heat the oil shale to approximately 650-700 deg. F. This heating process converts the kerogen present in the oil shale into oil and gas, with the heavier compounds being partially converted in lighter end products such as light oil (API=38) and methane. Shell claims that the products collected at the surface consist of approximately 1/3 natural gas and 2/3 light oil. Following surface processing, the products would include diesel fuel, jet fuel, and naphtha/gasoline.

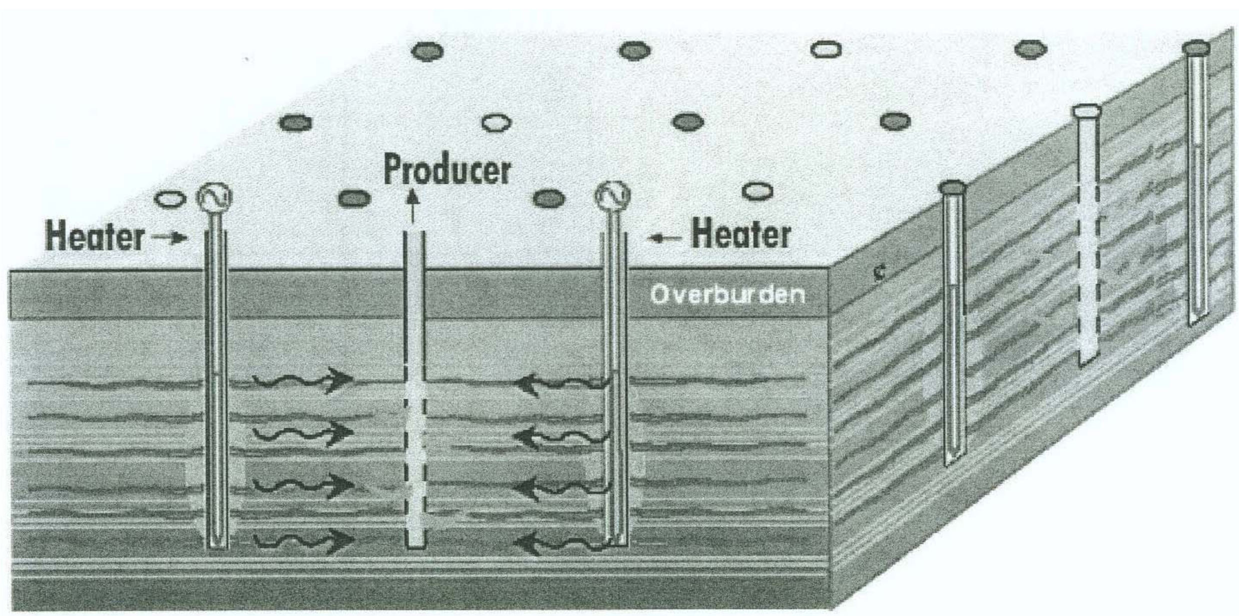

Figure 3
Shell Exploration & Production, Mahogany Research Project, Fact Sheet

Shell projects that the ICP has the potential to recover over ten times more oil and gas per acre than traditional processes (up to one million barrels per acre). It is also claimed that the process is more environmentally acceptable than other technologies, requires dramatically less water, and could be economically viable at oil prices in the $25-30/barrel range.

Shell's most recent research on the ICP has been conducted on its Mahogany property in Rio Blanco County. The first small field test was conducted in 1996-97, followed by three subsequent tests, the most recent being completed in early 2005. Based on the encouraging results of these tests, Shell is dramatically expanding its efforts with a more expansive research effort scheduled to run until 2010. The results of these tests will determine whether Shell moves forward with commercial operations.

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