Oil Shale

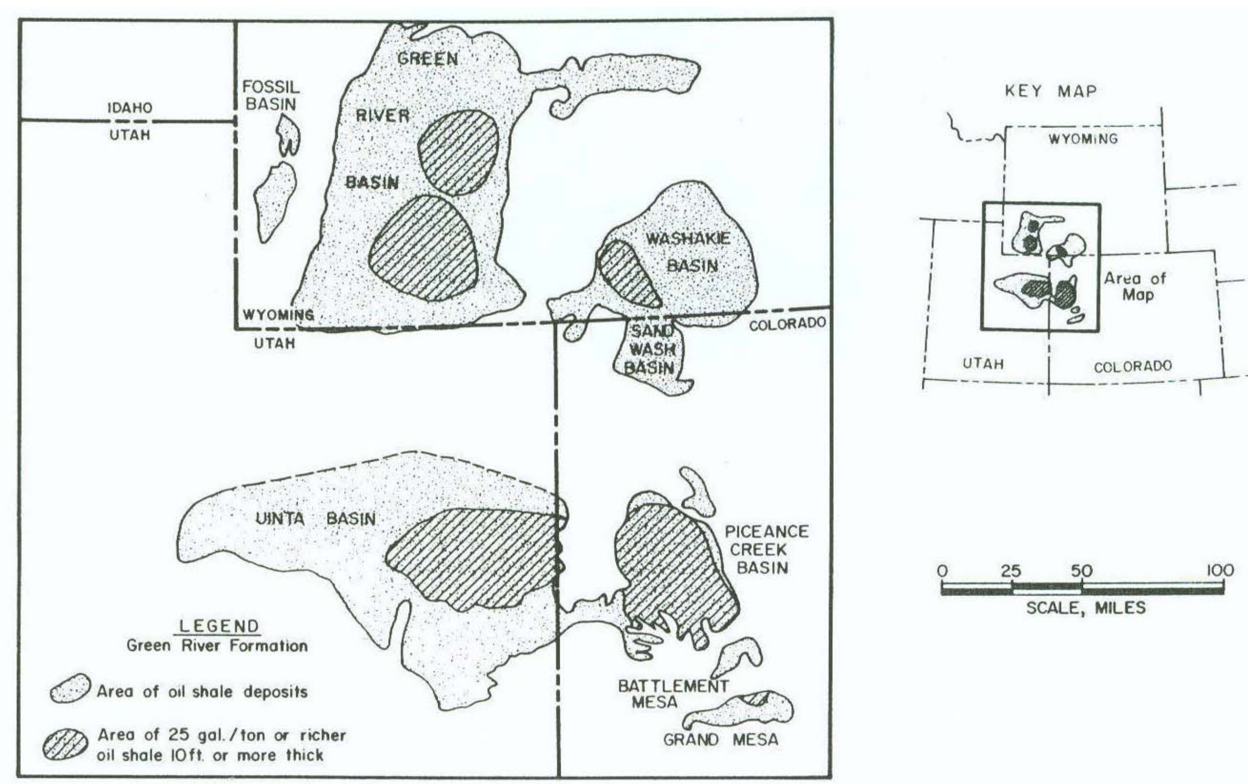
"The underground supply of oil cannot much longer be depended upon to supply the ever increasing demand,…pointing unerringly to the one permanent supply of the raw material which we have -- the deposits of oil shale. Whether we wish it to be so or not, we shall soon be forced to resort to the oil shales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

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

Oil shale is a rock that contains kerogen – a complex organic substance that does not dissolve in solvents but does break down when retorted (heated) to form crude shale oil, combustible gases, and a solid char. Oil shale is a common natural resource and is found on all of the inhabited continents. Most of the deposits are thin and irregular and yield little oil. This is true of the oil shale in the central and eastern areas of the U.S., which underlies about a quarter million square miles of surface.

Western oil shale areas are much smaller (only 17,000 square miles) but the deposits are very thick and unusually rich. A "rich" oil shale is one that yields more than twenty-five gallons of crude shale oil per ton of rock. Some oil shale from Colorado has yielded nearly one hundred gallons per ton.

The United States contains roughly three-quarters of the world's recoverable oil shale resources. Eighty-five percent of those rocks are in the Green River Formation in Colorado, Utah, and Wyoming. In contrast, less than five percent of the world's recoverable crude oil is found in the lower 48 states. If availability and quality were the only considerations, one would expect the United States to have a major shale oil industry, but this is not the case.

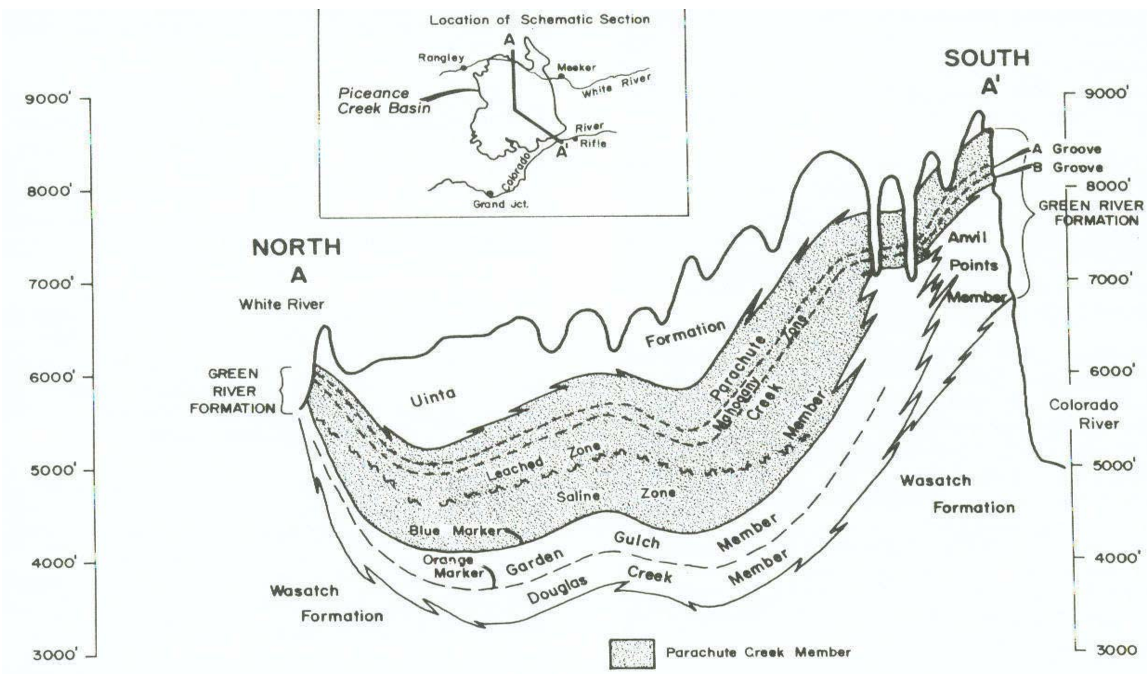


Oil shale deposits in the Western United States.
Source: Synthetic Fuels Data Handbook, Cameron Engineers, Inc., 1978.

The Resource

The oil shales of the Green River Formation began approximately 50 million years ago when organic debris (such as algae) and mineral sediments settled to the beds of two large lakes. Heat, pressure, and time molded the sediments into rock and started transforming the organic matter into crude petroleum. However the oil shale was not buried deeply enough for long enough (and therefore not exposed to sufficiently high temperatures and pressures) to complete the conversion process. The organic matter progressed only to an immature kerogen stage. In a way, retorting continues the natural thermogenic conversion of kerogen to oil and gas, but at a much faster pace.

The Green River Formation is divided into five members. The richest member is the Parachute Creek Member, and its richest zone is the Mahogany Zone, which is up to 200 feet thick and yields an average of fifty-five gallons of crude shale oil per ton of rock. The Mahogany Zone is visible as a ledge in the cliffs that overlook the Colorado River west of Rifle.



Oil shale members of the Green River Formation

Source: Synthetic Fuels Data Handbook, Cameron Engineers, Inc., 1978.

History

The first recorded use of shale oil was in Switzerland and Austria in the early 1300s. The Ute Indians were aware of the properties of oil shale, which they described as “a rock that burns” to settlers. While Brazil, China, and Estonia have substantial industries, no oil shale venture in the United States has been a commercial success in over a hundred years. The principal reason 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 oil shale development in the western states 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. would soon run out of petroleum, and the first oil shale boom was on. The boom busted in the late 1920s when the West Texas oil fields were developed.

In 1944, interest in oil shale was renewed when the federal government realized that domestic reserves of crude oil would not be able to satisfy future demand. A federal oil shale research program was initiated, and many energy companies began acquiring oil shale lands and developing extraction processes. However, the rise of nuclear energy and the discovery of enormous oil reserves in the Middle East kept energy prices (and oil shale development) at a low level.

In 1973, the Arab oil embargo reduced oil supplies and escalated prices, creating anxiety about the U.S. dependence on foreign oil. A new oil shale boom resulted in the leasing of four tracts of federal oil shale land in Colorado and Utah. Oil prices soared again in 1979 when the Shah of Iran was deposed and crude supplies were disrupted. This time, major oil companies began developing their own oil shale projects, with substantial federal support. The projects brought in people, and by 1980, the population of some of the small towns in western Colorado had increased by 400%. Despite a rush of new construction, housing stocks and infrastructure could not accommodate the exploding population.

Then oil supplies were restored, and oil prices declined rapidly. It soon became apparent that even subsidized shale oil could not compete with conventional crude. Projects were cancelled and jobs disappeared, leaving a housing glut as people moved away to seek employment elsewhere. Many businesses that had expanded during the boom went bankrupt as loans were foreclosed. Local governments were faced with a substantially reduced tax base from which to service the debt they had accumulated to keep pace with 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 developing asphalt additives for road paving and other applications at its small facility near Rifle.

In 2007, the stretch of I-70 between Glenwood Springs and Grand Junction is once again a beehive of energy-related activity. However this time the driving force is natural gas development. Overlaid on this bustle and boom is a low level of oil shale work, principally at the R&D level and carried out on some private lands and on small tracts of leased federal land.

Pros and Cons of Developing Oil Shale

Exploration risk is very small with Green River oil shale. One can stand on the shoulder of I-70, look up to the north, and see oil shale gleaming in the middle distance. The oil shale beds are continuous with the well-known shorelines of the ancient lakes, so a resource assessment is not too complicated either. Outcrop samples, a few coreholes, and some seismic data usually suffice. There is no need for drilling platforms or divers or hurricane protection, although helicopters can be helpful.

While exploration costs are low, shale oil recovery costs are high. Kerogen does not flow from its host rock as conventional crude oil does from sand; nor does it easily dissolve in chemicals; nor can it be liberated by crushing the rock. The only way that has been found so far to exploit the kerogen is to apply lots of heat. Then the crude shale oil must be treated with hydrogen to create a stable synthetic crude oil. Then the synthetic crude can be refined into gasoline and other petroleum products similar to those obtained from conventional crude.

Oil shale also presents a massive materials handling challenge if it is to beprocessed in aboveground retorts. An industry making 500,000 barrels of crude shale oil per day would have to move more than one million tons of rock each day. This is nearly three times the amount of material taken daily from Kennecott's huge Bingham Canyon copper mine near Salt Lake City. After retorting is complete, a similar amount of material, in the form of retorted or spent shale, would have to be disposed of, either in a mined-out area or in surface impoundments.

The U.S. Bureau of Mines calculated that even the smallest economically feasible oil shale mine (yielding about 50,000 barrels of crude shale oil per day) would be similar in size to the world's largest iron and copper mines. Mining operations of this scale are very expensive and are fraught with environmental challenges as well.

Retorting is also technically challenging. Hundred of unique retorting processes have been developed over the past century or so. Some (such as the Petrosix retort in Brazil, the Fushun retorts in China, the ATP retort from Alberta, and the Kiviter and Galoter retorts used in Estonia) have been employed at near-commercial size for years. Others (such as the Tosco, Lurgi-Ruhrgas, and Unocal retorts) were tested at substantial scale in the 1970s and 1980s but are not currently being developed. The Paraho retort is unique in this portfolio of aboveground retorts. No commercial scale Paraho was ever built. However smaller units have operated, almost continuously, since the 1970s.

Paraho's 250 t/d Semiworks Unit, Anvil Points, Colorado, ca. 1979

Paraho's evolution began in the 1960s at the Anvil Points Experimental Station of the U.S. Bureau of Mines near Rifle, Colorado, and continued into the 1970s when a consortium of 17 companies leased Anvil Points and constructed a 24 ton per day pilot plant and a 240 ton per day semi-works unit. In 1976, Paraho started the production of 100,000 barrels of shale oil for testing as military fuel, and in 1991 the New Paraho Corporation announced it would manufacture an asphalt additive from oil shale. Paraho's semi-works plant was torn down when the Anvil Points station was decommissioned, but the pilot plant was maintained and is now producing experimental quantities of fuel from Australian oil shale.

In situ retorting can avoid at least some of the mining burden encountered with aboveground processing. *In situ* retorting is an alternative approach in which the oil shale is heated underground and the shale oil is drawn to the surface through wells. Using hot gases to heat oil shale *in situ* has been tried several times over the past forty years, but with little success. Undisturbed oil shale generally has little permeability, and the rock must be artificially fractured to allow the hot gases to penetrate and the shale oil to depart. Attempts to create and sustain fractures have thus far not been satisfactory. Research work is continuing, however, and three companies are currently developing in situ processes on federal lands in Colorado.

A compromise approach - mine assisted or Modified *In-Situ* retorting - was tested in the 1980s on both federal lease tracts in Colorado. In the MIS process, approximately one-fourth of the oil shale in an underground column is removed by mining. The remaining oil shale is shattered with explosives to form a cylindrical chamber filled with oil shale rubble. The oil shale on the top is set on fire. The fire is sustained by blowing air through the burning rubble. Hot combustion gases pass down through the rubble and gradually heat the lower portions to retorting temperatures. Kerogen decomposes to form shale oil, which is collected in galleries at the base of the chamber and pumped to the surface. The mined oil shale is also carried to the surface, where it is processed in aboveground retorts.

Modified *in-situ* greatly reduces the amount of rock that must be handled. However controlling the size of the rubbled oil shale proved difficult, and production costs were still substantially higher than the costs of recovering conventional crude oil. There are also serious environmental concerns related to hydrology, groundwater quality, and surface subsidence.

The headframes “Hammer Hilton” and “Hammer Hilton Annex” rise above Federal Lease Tract C-b ca. 1983

Environmental Considerations

All approaches to oil shale exploitation – aboveground retorting, *in situ*, and modified *in situ* - must address substantial environmental and health and safety concerns. The regulatory structure is already in place, and the projects will have to comply with the Clean Water Act, the Clean Air Act, and the numerous other federal and state regulations that govern the adverse effects of industrial operations. Some research, development, and testing may be required to ensure compliance with the regulations, because no large-scale industry exists to provide a data base.

The most serious environmental concerns are associated with the management and disposal of solid waste, especially the rock that remains after shale oil has been extracted.

As noted, commercial-scale aboveground retorting operations will generate huge quantities of retorted and spent shale, which will contain soluble salts, organic compounds, and trace concentrations of numerous heavy metals. Regardless of where the wastes are disposed, they must be protected from leaching by snowmelt, rainfall, and ground water, because leached salts and toxins could contaminate both aquifers and surface streams.

In the case of *in situ* and modified *in situ* operations, the retorted shale will be left underground, out of sight and out of reach but potentially exposed to groundwater infiltration and leaching. If infiltration occurs, it could be very difficult to confine the contamination because there will be little access to the affected areas.

Air quality will also be threatened by fugitive dust, acidic gases, and combustion products from retorts, heaters, and electrical generators. This concern also affects all approaches to shale oil extraction, as does the potential for surface subsidence.

Federal Involvement

The Federal government owns approximately 80% of the oil shale in Colorado’s Piceance Basin, including the richest portions of the deposits. Much of the oil shale in Utah and Wyoming is also federally owned. An executive order signed by President Hoover prohibits the leasing of federal oil shale lands. The ban can only be lifted by the Secretary of the Interior. That has occurred only twice since 1930 - once in the early 1970s when the Federal Prototype Oil Shale Leasing Program was established; and once after the Energy Policy Act of 2005 required leasing of oil shale lands for experimental purposes.

Although the government’s leasing initiatives have been limited, the government has been involved with oil shale for many years and in many ways. Its R&D role began in the 1940s when the U.S. Bureau of Mines established the Anvil Points station. On that site was developed the room-and-pillar method for underground mining of oil shale, the Gas Combustion aboveground retort, and early versions of the Paraho and Petrosix retorts. In 1979, the Carter administration proposed that an independent federal entity, the Energy Security Corporation, be created with broad powers to encourage 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. It provided for the creation of the Synthetic Fuels Corporation (SFC) which was to offer financial assistance to developers of synthetic fuels. Organizing the SFC took two years, during which time the oil shale boom passed its peak. Once the SFC was operational, it was nearly paralyzed by scrutiny from the Administration and the Congress. In six years of operation, the SFC funded only four projects for a total of $1.7 billion. The SFC was disbanded in 1986.

The Prototype Leasing Program has lapsed, and the four tracts that were leased have returned to federal control and been reclaimed. The EPACT leasing program is just getting underway. So far, leases have been issued to the following companies for test work in Colorado.

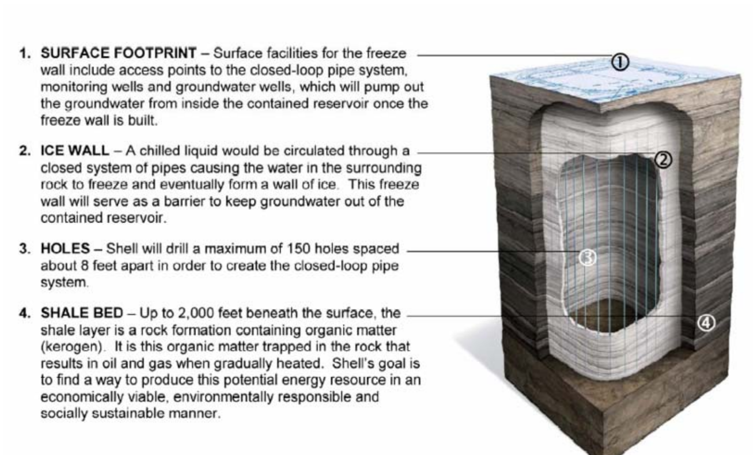
- Chevron USA, Inc. proposes to test its *in situ* technology, which consists of drilling two holes into the oil shale formation, linking the bottoms of the holes by fracturing the formation with carbon dioxide gas under pressure, using propellents or explosives to rubble the oil shale above the fracture, and then heating the oil shale interval to retorting temperatures with a heat-carrying fluid, such as additional hot carbon dioxide.

- EGL Resources, Inc. will develop its proprietary *in situ* system, which involves drilling boreholes from the surface into the oil shale zone, deviating the boreholes to the horizontal direction, and then deviating them again to return to the surface. A hot fluid will be injected into each hole, passed through the oil shale formation to heat it, and returned to the surface for reheating. Initially, natural gas or propane will supply the heat. After retorting temperatures are reached, gas produced by kerogen decomposition might be used.

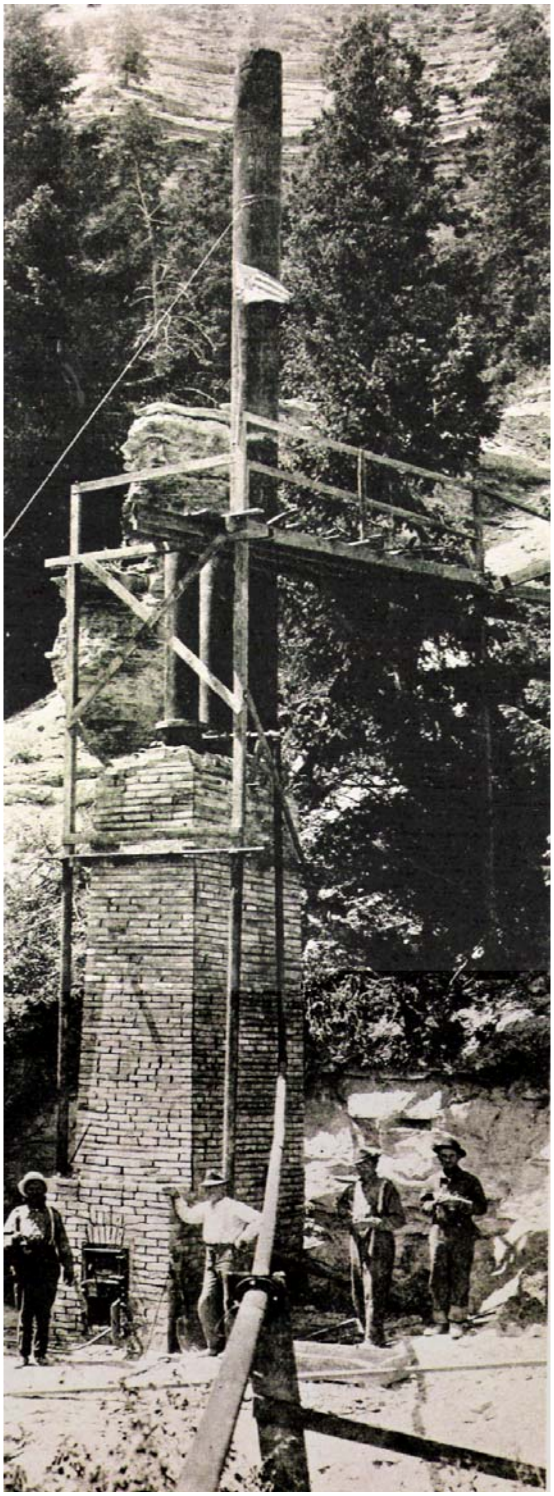
- Shell Frontier Oil & Gas, Inc. plans to use three lease tracts to work on its In-situ Conversion Process (ICP). On the first site, Shell will continue the development work begun on its privately owned Mahogany site. On the second, Shell will test combining the ICP with the recovery of nahcolite, a valuable sodium mineral that co-occurs with the oil shale. On the third, Shell will develop advanced heating equipment to use in the ICP.

Shell's process (Fig. 3) involves drilling holes into the oil shale zone, inserting electrical resistance heaters, and, over a period of several months, heating the entire zone to retorting temperatures. The oil and gas are drawn to the surface for processing.

Shell uses an innovative freeze-wall technology to exclude groundwater from the zone to be retorted. A ring of boreholes is drilled around the zone, and a refrigerated liquid is circulated through the holes. The refrigerant freezes the water between the boreholes and forms a barrier wall. Water within that wall is pumped out, and heating commences. The freeze wall must be maintained until all the oil shale is retorted.



Shell's ICP Oil Shale Concept
Source - USBLM EIA for the Shell lease



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