Oil Shale
- an alternative energy resource?

Shale oil represents a vast resource of energy. The cost of extracting the oil and the environmental consequences, however, seem to inhibit economic exploitation in the near future.
Oil shale has been used since ancient times. Like coal, it can be used directly as a fuel.

The role of oil shale in the production of energy is unknown to most people because its contribution to today’s world energy budget is minimal compared to both petroleum and coal. However, declining petroleum supplies may add to speculations whether oil shale represents an important source for the increasing world energy demands in the years ahead.

So far, the potential oil shale resources of the world have barely been touched.

**Before petroleum**

Oil shales have been exploited in several countries since the 17th century. In Sweden, alum shales (alum, short for aluminium sulfate) of Cambrian and Ordovician age were roasted as early as 1637 over wood fires to extract sulfate, which were used for colouring leather and fabrics. Later, starting at the end of the 19th century, the alum shales were used on a small scale for the production of liquid oil. These operations continued through World War II.

Oil shale deposits in France were exploited commercially as early as 1839. In Scotland, the oil industry began twenty years later, in 1859, which is the same year that Colonel Drake drilled his world famous oil well at Titusville, Pennsylvania. Large scale mining continued in Scotland during a 100-year period, until 1962. The annual production varied between 1 and 4 million tonnes of oil shale (rock volume), equivalent to only a few thousand barrels of oil per day.

Production from oil shale deposits in south-eastern Australia began in the 1860’s, coming to an end in the early 1950’s when government funding ceased. During this period some 4 million tonnes of oil shale were processed.

Canada also has several oil shale deposits, and mining took place in Nova Scotia in the 1850’s and 1860’s.

Common products made from oil shale from the early operations were kerosene and lamp oil, paraffin, fuel oil, lubricating oil and grease, naphtha, illuminating gas, and the fertilizer chemical, ammonium sulfate. With mass production of automobiles and trucks in the early 1900’s, the supposed shortage of gasoline encouraged the exploitation of oil shale deposits. Many companies were formed to develop the giant oil shale deposits of the Green River Formation in western U.S.A.

In the U.S.A. oil shale has been a leasable mineral since 1920, but no oil shale leases were issued during the period 1925-1974. The oil embargo in 1973 made it possible for the Federal Government to attract acceptable bids for two tracts of land in Colorado and Utah in the 1970’s. Both open pit and underground mining were considered. Development of large-scale mining facilities was attempted and experimental underground and above-ground retorting was carried out. However, all work has ceased and the leases have been relinquished.

Exxon bought the right to oil shale in all the leasable tracts in 1979, but decided in 1980, after an intensive multidisciplinary feasibility assessment, to pull out.

Unocal operated the last large-scale experimental mining and retorting facility from 1980 until its closure in 1991. The oil company produced 4.5 million barrels of oil (720 million Sm$^3$) from oil shale averaging less than 1 bbl of shale oil per tonne rock over the life of the project.

Oil shale is found all around the world in rocks of Cambrian to Tertiary age: e.g. Australia, Brazil, China, Estonia, Germany, Israel, Jordan, Russia, Thailand and, most important, USA. Production of shale oil, however, is limited to a few countries with Estonia being the dominant producer.
Oil shales have been known in Estonia since at least the late 18th century. Large-scale exploration for oil shale deposits and subsequent exploitation started during World War I to supply Petrograd (subsequently Leningrad, now St. Petersburg) with fuel. Since 1916 oil shale has had an enormous influence on the energy economy, particularly during the period of Soviet rule and then under the re-established Estonian Republic. During the 1950’s, oil shale was introduced as a source for electrical power generation.

From the late 1950’s to the 1970’s, massive power plants were developed. They are the largest operations based on oil shale in the world today. Estonia is currently the world’s largest producer. Up to 90% of the shale mined annually in Estonia is combusted in power plants. Energy production from Estonian kukersite oil shale has accounted for a significant portion of the world’s annual oil shale consumption. As the kukersite shale has an exceptionally high yield giving approximately one barrel of oil per tonne of shale.

A huge resource

Although information about many oil shale deposits is rudimentary, the potential world resources of shale oil are huge.

The US Geological Survey has estimated the total world resources of shale oil at 2.6 trillion barrels (410 billion Sm³). This figure might be considered a conservative estimate in view of the fact that oil shale resources of some countries are not reported and other deposits have not been fully investigated.

With an estimated resource of 2.1 trillion barrels (330 billion Sm³) of shale oil, the United States has larger resources than any other country. By far the largest known deposit is the oil shales in the western U.S.A. They contain a total estimated resource of nearly 1.5 trillion barrels of oil (240 billion Sm³). If a technology can be developed to economically recover oil from these oil shales, the potential is enormous.

Some deposits have been fairly well explored by drilling and analyses. Besides the Tertiary Green River oil shales in the U.S.A., these include the Tertiary deposits in Queensland, Australia, the Paleozoic deposits in Sweden and Estonia and the Cretaceous El-Lajjun deposit in Jordan. The remaining deposits are poorly understood and further research is required to adequately determine their resource potential.

The amount of shale oil that can be recovered from a given deposit depends upon many factors. Geothermal heating, for example, may have degraded a deposit, so that the amount of recoverable energy may be significantly reduced. Some deposits may also be buried too deep to be mined economically in the foreseeable future. Also, surface land uses may greatly restrict the availability of some oil shale deposits, especially those in the industrial western countries.

The world’s total remaining oil and gas reserves, according to the BP Statistical Review of World Energy, are estimated at 2,100 billion barrels (340 billion Sm³) of oil and gas. The coal and lignite resources of the world are even higher. It might thus be argued that oil shales represent a significant strategic energy source.

Used in power plants

The organic component of the oil shales, kerogen is typically insoluble in most common organic solvents, so temperatures in the range 350-650 °C are required to decompose the kerogen in the absence of oxygen to condensable shale oil, gas, and a solid semi-coke residue. This process is known as retorting.

Two different methods are used for shale oil production. In one, the shale is fractured...
Oil shale

Oil shale is called “the rock that burns”. The term ‘oil shale’ is a misnomer: it does not contain oil.

Oil shales are defined as fine-grained brown to black sedimentary rocks (shale, siltstones and marls) containing a large proportion of solid organic matter (kerogen) that will yield liquid or gaseous hydrocarbons upon heating and distillation. Included in most definitions of ‘oil shale’, is the potential for the profitable extraction of shale oil and combustible gas or for burning as a fuel.

The kerogen in oil shales can be converted to oil through the chemical process of pyrolysis. During pyrolysis the oil shale is heated to 500°C in the absence of air upon which and the kerogen is converted to oil and separated out, a process called “retorting”. Only oil shales expected to yield more than 40 litres of oil per tonne are of economical interest.

Oil shales may, in different contexts and cultures be called alum shale, bituminite, cannel coal, gas coal, kerosene shale or kukersite.

The solid organic matter (kerogen) has the same origin as the organic components of other fossil fuels (from plant and animal matter). It is composed chiefly of carbon, hydrogen, oxygen, and small amounts of sulfur and nitrogen and forms a complex macromolecular structure that is insoluble in common organic solvents.

Oil shales differ from mature source rocks in that the rocks have not been exposed to the same heat as when petroleum is formed (GEO 02-2004). It has simply not gone through the ‘oil window’ of heat (nature’s way of producing oil) and must therefore, in the ‘oil geologic’ have been heated to a higher temperature to yield petroleum.

and heated in situ to obtain gases and liquids through production wells drilled into the deposit. The other is by mining and crushing followed by heating in a processing plant. Finally, the waste is disposed and stabilised.

The energy subsidy to produce oil from oil shale is large. Since the oil shale has to be mined, transported, retorted, and then disposed of, at least 40% of the energy value is consumed in production. Both processes also use considerable amounts of water.

The total energy and water requirements, in combination with environmental and monetary costs, have so far made production uneconomic. During and following the oil crisis in 1973, major oil companies, working on some of the richest oil shale deposits in the world, spent huge amounts of dollars on various unsuccessful attempts to commercially extract shale oil.

As in Estonia and other countries, most of the oil shale mined today is utilized as a low-grade, high ash feedstock for production of energy, both thermal and electrical. In such power plants, the temperatures reach up to 1500°C.

More than energy

Oil shales have also been used as sources for other materials, and by-products such as alumina, ammonium sulfate, phosphate, sodium carbonate, sulfur, uranium, vanadium, and zinc can add considerable value to some oil shale deposits. In addition to hydrocarbons, some hundreds of metric tons of uranium and small amounts of vanadium were extracted from the Swedish alum shales in the 1960s. Ash waste from combustion of oil shale has been used in the cement industry.

The spent shale obtained from retorting also use in the construction industry as cement. Sweden, Germany, Estonia and China have used solid oil shale waste as a source of cement. Other potential by-products from oil shale include specialty carbon fibers, adsorbent carbons, carbon black, bricks, construction and decorative building blocks, soil additives, fertilizers, rock wool insulating materials, and glass.

Many of these by-products are still in the experimental stage, but the economic potential for manufacturing some of these seems large.

Environmental concerns

Because oil shales comprise clastic, carbonate, organic and minor sulfide fractions and also traces of some potentially toxic elements, they generate several types of environmentally harmful wastes. Combustion of oil shales releases the greenhouse gas CO2 derived from oxidation of organic matter and decomposition of carbonates. If carbonates are present in high proportions, this renders the oil shales inefficient in terms of energy per unit of CO2 emitted. Furthermore, oil shale combustion emits acidic gases (NOx and SO2) derived both from inorganic sulfides and organically bound nitrogen and sulfur.

Although the emissions of CO2, SO2 and NOx from combustion of oil shales are at the same level or lower than those from oil- or coal-based power plants with comparable capacity, the combustion of oil shales also yields particulate emissions (potentially enriched in a variety of metals, metalloids and organics) at a rate twenty to fifty times.

One factor, which makes the extraction of oil from oil shale challenging, is that spent shale occupies 20-30% percent greater volume after processing than raw shale due to a popcorn effect from the heating. This means that a 50,000 BOPD oil shale plant will produce about 7,500 cubic meters partially powdered rock waste per day in excess of that returned to the mine.

Consequently, in the vicinity of oil shale operations the environment will be altered, and costly environmental assessments of the impact on different ecological compartments has to be carried out parallel to developing the oil shale industry.
With consumption of fossil fuels allegedly outstripping discovery of new resources, it could be argued that oil shales may represent a viable energy alternative for oil-poor countries, provided they are prepared for potential conflicts with international environmental agreements intended to regulate national emissions of greenhouse gases and thus to reduce the global emissions.

However, the economic competitiveness of oil shale mining must be questioned. Interest in the oil shales of the western U.S.A. as a strategic reserve increased after the oil embargo of 1973, when the price of oil doubled, but was found to be commercially unviable in the 1980’s. If oil shale should be considered as raw material for shale oil it must contain enough organic matter to yield more energy than it requires processing the rock. The organic content needs to be 8-10 weight percent (i.e. yielding about 40-50 litres per tonne), before it can be considered a source for synthetic fuel.

Geographical, economical and political aspects will heavily influence future consumption of oil shale. From an environmental viewpoint, the most favourable remediation strategies must be followed, including continuous monitoring of gaseous and particulate emissions and their effects.

**Beyond conventional oil and gas**

Estonia is predominantly using their oil shales for production of electricity. In Queensland, Australia, oil shales are used for production of oil. More than 2.6 billion barrels (410 million Sm³) can be produced from wells, and the capacity can reach 200,000 barrels of oil per day. Brazil has a
retorting plant producing a few thousand barrels a day. In China, some 400,000 barrels of oil are retorted annually.

It is evident that the present production of petroleum products from oil shales is very limited compared to the overall resource. Today’s production of shale oil is also small compared to the oil production, which is close to 75 million barrels of oil per day.

The future development and expansion of the oil shale industry will be governed by the price of crude oil. When the price of shale oil is comparable to that of crude oil, and with an increasing number of countries experiencing declines in conventional oil production, then shale oil may find a place in the world fossil energy mix. It seems unlikely, however, that shale oil production can be expanded such that it can make a major contribution toward replacing the daily consumption of more than seventy million barrels of oil worldwide.

The energy demands of blasting, transport, crushing, heating and adding hydrogen, together with the safe disposal of huge quantities of waste material, are large. The key is the development of efficient, economic technology. Assuming that two-thirds of the remaining world oil resources will be produced in the Middle East and that two-thirds of the resources of oil shale are located in North America, where the consumption of petroleum per capita is the greatest, one may wonder about the geopolitical importance of shale oil in the future.

Gigantic generators are required to convert the combustion energy from over ten megatonnes of oil shale per year to electric power.