Oil Shale and the Environmental Cost of Production

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The world's current energy dilemma is two-fold in nature. On one hand, our increasing dependence on oil to fuel a global economy is unsustainable because the resource's inherent finiteness. At the same time, our unchecked consumption of oil and other fossil fuels has resulted in widespread pollution and threatens to cause long-term changes in global climate. Some optimists have postulated that these dual aspects will be resolved simultaneously: as we run out of efficient fossil energy, we will switch to cleaner fuels giving way to declining pollution. However, a quite different scenario may be more likely in which dwindling conventional oil supplies may drive a shift towards more abundant, lower-efficiency resources.

Oil shales are one such unconventional resource that has emerged as a possible means to supplement declining conventional oil production. While it has long been known that oil shale can yield substantial quantities of petroleum, high operating costs and adverse environmental effects, have prevented significant commercial exploitation of the resource. Recently however, rising oil prices and growing demand have made oil shale development more economically attractive, drawing renewed interest from commercial and government entities. Yet, the local and global environmental implications of oil shale development remain daunting. If we are driven to use such an inefficient resource, we will likely still pay dearly – though a degraded environment and increased potential for global climate change.

Geology of Oil Shale

The term oil shale refers to a class of fine-grained sedimentary rocks containing high concentrations of organic material, called kerogen, that can be transformed into petroleum upon extensive heating and processing. Like other hydrocarbon source-rocks, oil shales originate from accumulations of sediments and organic matter deposited in anoxic environments. As the deposits are buried by additional sediments, high temperature and pressure removes water and enables chemical reactions that transform the organic matter into kerogen. These reactions can proceed at greater temperatures to produce oil, but oil shales have not been buried to sufficient depths to allow this further conversion.

Oil shales are often confused with tar sands currently mined in Alberta; but in fact, tar sands and oil shale lie at opposite ends of the oil lifecycle. Tar sands are near the end of the oil cycle having been degraded beyond their prime by slow chemical reactions. Oil shales on the other hand, are a precursor to oil that have not yet been buried deep enough for kerogen to be converted into useful hydrocarbons.

Oil shale typically contains enough hydrocarbons to burn in raw form and can be used directly as a solid fuel. However, producing oil from kerogen requires pyrolysis, an energy intensive process in which the rock is heated to 450-550°C in the absence of oxygen. The industrial procedure used to convert oil shale into useful hydrocarbons is called "retorting."

Distribution of the resource

There is no question that the oil shale resource is both rich and vast. A conservative estimate of the worldwide oil shale resource in place is more than 2.5 trillion barrels oil equivalent, with roughly 2 trillion barrels located in the United States (Bunger and Crawford, 2004). Of the U.S. resource, the majority is located in the Green River formation (Figure 1), which holds an estimated 1.5-1.8 trillion barrels in Colorado, Utah, and Wyoming (Smith, 1980). Oil shale resources are typically distinguished by their grade or the gallons of oil which can be produced from one ton of shale. Only grades of greater than 10 gal/ton are typically included in the net resource (RAND, 2005). Within the Green River formation, some shale yields more than 60 gal/ton, but lower-grade formations are much more frequent; for comparison, the oil yield of Athabasca tar sands currently minded in Canada is roughly 22 gal/ton (Bunger and Crawford, 2004).

Of course, not all of the oil contained in the Green River oil shales is even hypothetically recoverable. At least 20% of the resource (RAND, 2005) lies under towns and other heavily regulated lands that would be off limits to large extraction operations. Recovery would be further limited by incomplete extraction and conversion losses during retorting. Considering proposed technology and geologic constraints, the RAND Corporation recently estimated and upper bound of 75% recovery and a lower bound of 50% for developed deposits, yielding a total recovery factor of 40%-60% (50-75% x 80%). This recovery factor suggests a total recoverable resource of between a half and one trillion barrels, a figure roughly equal to the entire current world oil reserves.

Getting oil from shale

Extracting oil from oil shale requires entirely different methods than conventional oil production. Oil shales contain no liquid oil in their natural state and must be retorted at very high temperatures to convert the solid kerogen to liquid hydrocarbons. Most proposed methods for producing shale oil fall into one of two categories: mining with surface retorting or in-situ retorting.

Oil shale can be mined either by either traditional underground methods or by large-scale surface mining. Surface mining is generally more efficient in thick, continuous deposits, such as the majority of the Green River Formation which ranges from 500 to 2,000 feet thick (Smith, 1980). Once the resource has been mined, the shale is transported to a retorting plant where it is intensively heated to around 500°C to produce a liquid product from the kerogen.

In-situ retorting involves heating the oil shale in place and then pumping out the liquid product after it is converted from the solid kerogen. In-situ methods are favorable when there is significant overburden which may be costly to remove in surface mining. The liquid product that is produced by either surface or in-situ retorting contains high concentrations of nitrogen and other impurities (Bunger and Crawford, 2004), and so extensive refinement is required following retorting to create a competitive grade of oil.

Historical production of oil shales

Oil shales have been commercially mined for more than a century but have been used predominately in their raw form, burned directly in electrical and industrial plants. A worldwide production history (Figure 3) shows a distinct peak in world production of ~50 million tons per year in 1980 followed by a steady decline (Dyni, 2003). Estonia has been the largest producer of oil shale since the mid-1960s but production began to decline in 1981 when a much more efficient nuclear power station came online in Leningrad (US DOE, 2004).

In general, oil shale has only been burned only in countries with dire conventional energy prospects and processed into oil only during periods of exceptionally uncertain oil supply. Estonia, which has no domestic supply of oil or coal, began processing petroleum from shale in the 1920s using surface retorting techniques, but less than 15% of the total mined product has ever been processed for oil. Currently, three commercial retorts in Estonia now produce only 5,000 bpd of shale oil. China produced more than 15,000 bpd of shale, prior to major development of the Daqing oil field in the early 1960s, but Chinese production now stands at less than 2,000 bpd (Laherrere, 2005).

In the United States, several surface retorting technologies were developed and tested on the Green River formation between 1960 and 1980. The Oil Shale Company (TOSCO) built a prototype plant in Colorado in 1964 but was forced to close in 1972 after only 270,000 bbl total production because operational costs greatly exceeded the price of imported crude (Laherrere, 2005). Interest in the oil shale resource was again prompted by the 1973 oil crisis and as the United State became a net importer of oil. Supported in part by tax credits, Unocal built a retort with a design capacity of 9,000 bpd while Exxon and TOSCO collaborated to build a retorting plant which could produce 47,000 bpd. The Unocal retort suffered major design problems, producing at under half the predicted capacity. The Exxon plant never got off the ground and was cancelled in 1982 after crude oil prices collapsed rendering the plant uneconomical (RAND, 2005).

Proposed Oil shale development

Now two decades later, rising oil prices and concerns for developing more secure sources of energy have generated renewed interest in developing oil shale resources in the United States. A current price tag of $70 per barrel and new technologies are making even the most expensive extraction operations more attractive to oil industries.

A new generation of surface retorts modeled on the state-of-the-art Alberta Taciuk Processor technology, used to extract oil from tar sands in Canada, may allow for somewhat more efficient surface retorting (Snyder, 2004). Based on expected capital, operating, and maintenance costs, the RAND corporation estimated that a 50,000 bpd surface retorting operations could be profitable with oil prices at $70-95/bbl. Another technology receiving increased attention is Shell's In-situ Conversion Process (ICP) which has been under development for the past 20 years and has been tested in several scaled-down experiments at the Mahogany Research site in Colorado. Shell's ICP involves drilling holes more than a thousand feet deep, inserting electrical heaters and heating the rock to 650-700°F for two to four years to enable kerogen conversion. In order to prevent groundwater from mixing with oil products, Shell also intends to inject coolants around the production site to create a frozen, impermeable barrier (Shell Mahogany Factsheet, 2006). Shell has estimated that these extraction methods will be economically viable as long as oil prices remain above $20-30/bbl but will delay a decision of whether to pursue commercial development until 2008 (Lavelle, 2006).

These operations and prices are by no means proven, and most doubt that commercial production of oil shale will ever be possible. Nonetheless, even the United States government has shown an increased commitment to oil shale development. In 2004, the Department of Energy initiated a major study by the Office of Naval Petroleum and Oil Shale Reserves to evaluate the strategic significance of the nation's resources. The report concluded that current technology could support a domestic oil shale industry that by 2020 would produce 2 million bpd, roughly a quarter of current US production.

In order to accommodate development, the 2005 Energy Bill mandated development of a commercial leasing program for Green River formation lands, more than two-thirds of which are held by the Bureau of Land Management. By 2007, this program may allow for parcels as large as 50,000 to be leased to by companies approved for oil shale testing and development (Sura, 2005). However, the leases will be subject to the future findings of a programmatic environmental impact statement (DOI EIS, 2006) scheduled to be completed by the summer of 2007. This report will require lawmakers to directly confront the extensive environmental costs and scant benefits of shale oil production.

Implications of Oil Shale Development

Large-scale oil shale development would carry major environmental costs that must be considered in any assessment of the resource value. Direct environmental damage would include ecosystem displacement, groundwater contamination, and air pollution, and it is likely that even the global climate would be affected due to increased greenhouse gas emissions. Furthermore, the minimal energy efficiency of shale oil extraction means that these costs will more than likely outweigh the limited resource benefits.

In terms of raw energy content, oil shale is vastly inferior to coal, firewood, and even manure. Pound for pound, oil shale contains around one-sixth the energy content of coal and only one-fourth that of recycled phone books (Udall and Andrews, 2004). Of this already nominal energy content only a portion is recovered in net because of the tremendous amount of energy required for retorting. RAND estimates that a production operation of 100,000 bpd would require a dedicated 1.2 gigawatt dedicated power plant, comparable in size to the Seabrook nuclear plant in Connecticut which serves more than 900,000 customers; production of a million barrels a day would require ten of these. Shell has reported its ICP method is expected to produce about three units of energy for every one unit of input energy (Lavelle, 2006). Even if this unproven efficiency is achieved, it would imply a 30% reduction in the total net energy available from estimated recoverable resources.

While the energy benefit of shale is minimal, the environmental implications of oil shale development would be tremendous. The most direct obvious environmental impact of an oil shale industry would be the immediate displacement of ecosystems in land under development. Surface retorting, which requires underground or surface mining would strongly alter the local ecology and current land uses. Strip mining would require some of the largest open-pit mines in the world. Around 1.5 tons of spent oil shale is produced for every one barrel of retorted oil (Albulescu and Mazzella, 1987), so a surface retorting operation of a million barrels per day would require more than half a billion tons of raw shale to be mined and disposed of each year. Furthermore, the retorting process increases the volume of the shale by 15-25 percent so that the pit or mine from which the shale was removed cannot store all of the waste product (US DOE, 2004). Both surface and underground mining would require piling this material above ground, thereby creating an unnaturally elevated landscape and likely causing decade-long displacement of preexisting flora and fauna (RAND).

This new landscape would not only be reshaped but would also become toxic and would alter both runoff patterns and groundwater quality. Spent shale has a higher salt content than raw shale and contains small concentrations of arsenic and selenium which can be mobilized by water that infiltrates tailings piles (Harney, 1983). Shell's in-situ method is often touted as a clean alternative because it does not require surface mining or waste piles, but this approach can still cause groundwater contamination. The "freeze-barrier" would only protect groundwater during production; once the kerogen has been removed the hydraulic conductivity of the remaining shale increases allowing groundwater to flow through and leach salts from the newly toxic aquifer (RAND). Because the Green River formation lies within the greater Colorado River drainage basin, any surface or groundwater contamination will not only affect the local population but will likely have a significant impact on water quality for the millions of downstream users.

In addition to likely groundwater contamination, large-scale development would also require tremendous quantities of water to be used in production operations. Water is required at various stages of the mining, retorting, and refining processes. The U.S. Water resources council estimated consumptive water use of around three barrels of water per barrel of shale oil production (Water Resources Council, 1981). Water resources from the Colorado River Bain are already very tightly regulated and are in high demand from a growing population in the arid Southwest. A recent agreement with California water districts will return roughly 8 million acre-ft/year to the Upper Basin

(Bunger and Crawford, 2004). A one million bpd oil shale industry would consume the entirety of these reallocated water rights (Sura, 2005) – water that could alternately be used to support a combination of municipal supply, irrigation, ecosystem restoration, and recreation – and would likely diminish the quality of previously available water supplies.

Local air quality may also be impaired by particulate and gas emissions from mining and retorting operations. Surface mining exposes fine-ground rubble which can be carried as fugitive dust that remains airborne for weeks and can cause serious health problems if inhaled (Idaho DEQ, 2006). Also, because shale oil contains high concentrations of nitrogen and sulfur, retorting and refining plants would also produce large quantities of nitrogen and sulfur oxides (RAND), precursors to acid rain. While many technologies have developed in recent years to control such point-source emissions, other emissions from major mining operations seem more difficult to control. Tar-sand mining in Alberta already requires some of the largest mining and transport machinery every built, and the fleets of oil shale mining machinery would undoubtedly cause a significant drop in the exceptional air quality which Colorado, Wyoming, and Utah currently enjoy.

Perhaps most troubling of all is the substantial increase in greenhouse gas emission that would follow oil shale development. The vast energy inputs required to supply heat in both surface and in-situ retorting would almost certainly be supplied by fossil fuels. In addition, high temperatures at which the shale is retorted can cause carbon dioxide to be released directly from mineral carbonates in the rock (RAND). Therefore, the total carbon dioxide output for a barrel of oil derived from shale would be far greater than for conventionally produced oil. Greenpeace estimates that from production to combustion, every barrel of shale oil will produce four to six times more carbon dioxide than conventional oil (Greenpeace, 1999). Unfortunately, as the United States has yet to commit to significant carbon dioxide emission reduction, greenhouse gas emissions from oil shale development may be one of the least strictly regulated aspects of the industry.

If oil shale development does proceed, there would be long-term implications for the future of energy use, including increased dependence on fossil fuels and a momentum towards further development. Cost effective oil shale technology is still largely unproven and will require tremendous capital investment if it is ever to be fully realized. It is foreseeable that energy companies directing large amounts of capital into oil shale will have less capital available for research into cleaner, alternative energy resources. Simultaneously, oil shale retorting will place increase demand on already stressed energy resources.

If an economically successful shale industry is established, it will likely be enduring, as it will be unfavorable to shift away from the developed resource to alternative fuels. Development costs are the greatest barrier to a large-scale oil shale industry and because no exploration costs are required after initial, capital-intensive development, the only substantial post-development costs would be for maintenance and retorting energy. Therefore, a successful oil shale industry will likely be sustained and reinforced by economic momentum, strengthening our marriage to fossil fuels in spite of environmental concerns.

Conclusions

Proposed oil shale development will likely fail on both fronts of our current energy challenge as it provides a little in the way of new fuel and will only exacerbate current environmental deterioration. Current interest in production is spurned only by our dependence on oil, not our need for energy, and there exist numerous other alternative energy technologies, such as nuclear, wind, and biofuel which may provide more efficient energy resources. Even the potential for petroleum supply from of oil shale is minimal: the most optimistic prospects of shale oil production in the United States of 2 Mbpd by 2020 would serve at most only one or two percent of global consumption rates.

Potential development must be view both in light of these poor energy benefits and in the context of severe environmental implications. Aggressively pursuing oil shale will extend our commitment to fossil fuels, and will likely cause even more significant environmental damage than current energy resources. Greenpeace recently recognized the local and global implications of the most recent attempt at large-scale oil shale development in Gladstone, Australia and successfully campaigned to help forestall further development (Greenpeace, 1999).

The future of oil shale in the United States will be largely guided by the findings of the Department of the Interior when it releases the environmental impact statement this summer. This report should recognize the limitations of oil shale and restrain any oil development to small experimental scales. At best, oil shale may be able to serve the United States as a strategic resource in times of acute and short-term oil scarcity. If oil shale development does move forward, it should continue at a cautious pace and with limited expectations in mind. Unfortunately, this resource will not be a cure our energy woes and due to the environmental implication of production we must abandon our pursuits to exploit it as such.

Figure 1: Distribution of Oil Shale in the Green River Formation (RAND, 2005)

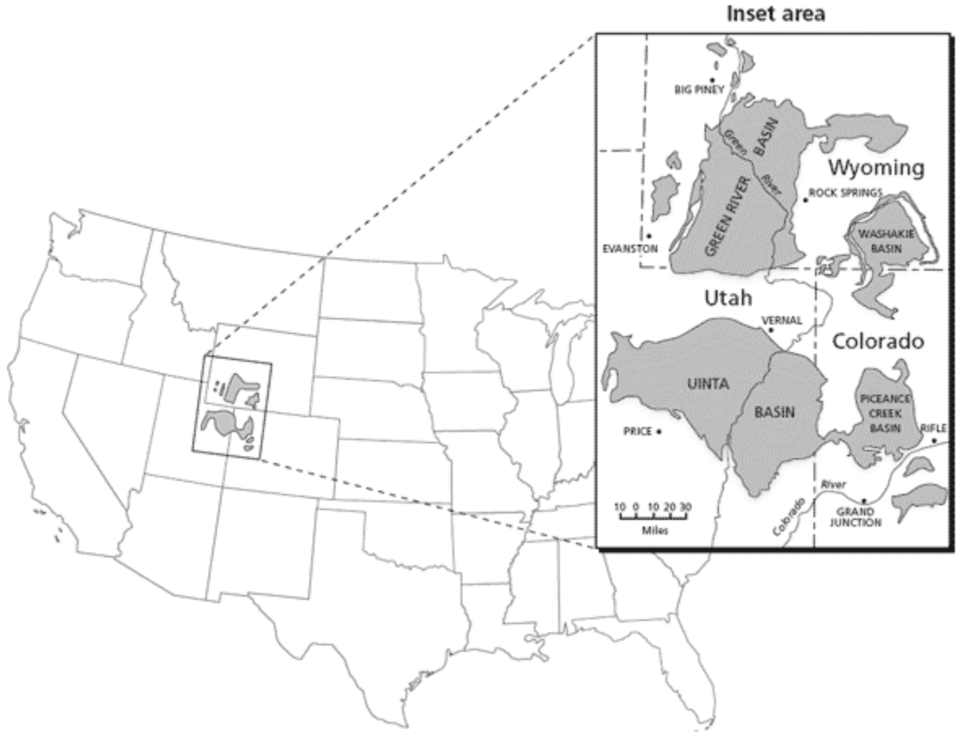
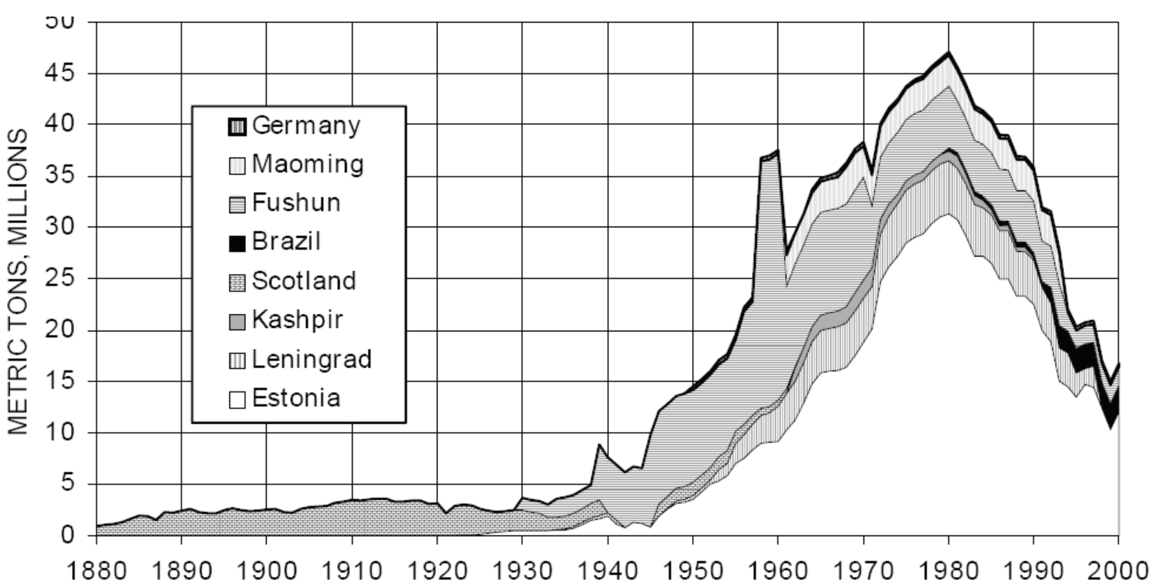


Figure 2: Oil Shale Production History (Dyni, 2003)



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