Oil Shale: A Huge Resource of Low-Grade Fuel

The rich oil shale deposits on the western slope of the Rocky Mountains constitute a potential source of fuel several times as great as the identified reserves of U.S. oil, and processes for extracting synthetic crude oil from the thick seams of brown-black rock have been ready to go for 15 years. Technologically, the production of synthetic crude oil from shale is a simple process. When the shale is crushed and heated to 480°C, raw shale oil is released. Because it does not require special mineral preparation, high pressures, or difficult catalytic procedures, the process of oil shale recovery is easier than either coal gasification or coal liquefaction. Until October 1973, the principal limitation to oil shale recovery was its price, which was projected by the National Petroleum Council to be about $5.50 per barrel.

Now that the price of domestic crude oil is at least $7 per barrel, oil shale appears to be economically viable. But "it's not simply a question of raising the price of conventional oil high enough and shale oil will automatically appear—although much of the material on the subject blithely makes this assumption," according to James E. Akins, U.S. Ambassador to Saudi Arabia and formerly chief State Department advisor on fuels and energy. "There are severe ecological and mining problems in extracting shale oil which cannot and must not be ignored." Under the close scrutiny that energy alternatives have received since the October 1973 boycott, it is clear that shortages of water will probably limit shale oil production to a few percent of the U.S. petroleum consumption, no matter what the crude oil price.

Water Shortage Limits Development

According to studies by the Department of the Interior and the Atomic Energy Commission, that limit will probably be 1 million barrels per day, a figure that pales beside the daily U.S. oil consumption, which is 18 million barrels. Not even oil shale enthusiasts seem to be proposing that shale oil can be squeezed out of the rock at a rate much higher than 1 million barrels per day, because 3 barrels of water will be required for each barrel of oil produced with the existing technology. The production rate could perhaps be doubled if in situ technology—the release of oil by cracking and burning the shale in place underground—were perfected, because water otherwise used to dispose of spent shale above ground could be saved. But in situ technologies have not been proved to be workable yet.

The actual amount of shale oil extracted will also depend heavily on government policies. The Department of the Interior, which controls 80 percent of the rich shale lands, is currently leasing six small (5120-acre) tracts for development. Estimates of the shale oil production from these tracts as well as from private lands range from a high of 300,000 barrels per day by 1980 to a low of 100,000 or 250,000 barrels per day by 1985. Private oil shale developers argue that production will not nearly reach 1 million barrels per day, even with an expanded leasing program, unless the government provides substantial economic incentives, such as guaranteed loans, rapid amortization of plants, import restrictions, or a price floor.

Oil shale is found in many areas of the contiguous 48 states and in Alaska, but almost all the shale that is rich enough to yield more than 15 gallons of oil per ton is in one geological formation, along the Green River in Colorado, Wyoming, and Utah (Fig. 1). About 1800 billion barrels of shale oil are buried in the three-state region, but almost all the prime shales, with at least 30 gallons of oil per ton in seams 30 feet or more thick, are in the Piceance Creek basin in Colorado. Those are estimated at 117 billion barrels, about double the 52 billion barrels of oil that is identified and recoverable. Much of the high quality shale is in a formation called the Mahogany Zone, which is about 70 feet thick, and can be seen on the exposed faces of the canyon walls. The zone is a deposit from the sedimentation of Lake Uinta, a freshwater lake that covered the area during the Tertiary period. The burnable component of so-called oil shale, which is actually a marlstone rock, is an organic polymer called kerogen. Large quantities of nahcolite, $NaHCO_3$, and dawsonite, $NaAl(OH)_2CO_3$, are also found in parts of the Piceance basin, and they contribute to the natural alkalinity of the shale.

The people of western Colorado have heard recurring rumors that oil shale developers would start mining the region since before World War I. Oil shale was mined in Scotland for about 100 years after 1860, and 25 million tons of shale are now mined each year in Estonia, more than half for burning at mine-mouth generating stations rather than for conversion to oil. In 1957 the Union Oil Company of California tested a pilot plant that was built on privately held land along Parachute Creek, south of the major deposits in the Piceance Creek basin, which is predominantly federally owned. The Union plant successfully extracted oil from 300 to 1000 tons of shale per day, and was closed in 1958 because market prices for crude oil were too low to make the operation profitable. Union recently announced plans to build a full-size plant by 1979 that will produce 50,000 barrels per day with an improved version of the earlier process. The original version employs a large piston to continually pump rock upward through a retort where hot gases release shale oil; the oil drains out the bottom and spent shale is forced out the top in the form of large chunks or clinkers.

Also along Parachute Creek, only about 75 miles from the well-known ski center of Aspen, the Colony Development Corporation* owns 8000 acres of shale land, and has spent up to $55 million for research with a pilot plant that has processed 1000 tons of shale per day. The Colony operation is the source of much of the information currently available about the environmental effects of shale recovery, particularly in the environmental impact statement filed by the Department of the Interior for its oil shale leasing program. In the Colony process, ceramic balls are heated and then mixed with finely crushed oil shale to break down the kerogen to shale oil. Heat transfer is very efficient because two solids are in contact rather than a gas and a solid, and the yield of shale oil is virtually 100 percent. Colony has

* Colony is a joint venture by the Atlantic Richfield Company, the Oil Shale Corporation (TOSCO), Ashland Oil and Refining, and Shell Oil Company.

nearly completed the design of a large plant, to produce 50,000 barrels per day, which is scheduled to begin operation in 1977. Colony will almost certainly be the first company to market shale oil commercially.

Although strip mining has been suggested, the most likely method of removing shale from the Piceance basin is underground mining, since the overburden above the shale zone is generally at least 1000 feet thick. In the western portion of the basin, where tract C-a was leased, the overburden is considerably less, so that tract is a possible candidate for strip mining. A 100,000-barrel-per-day operation is projected. But for most of the region strip mining would be too expensive, so the shale will probably be removed by carving out underground rooms in the Mahogany Zone, leaving behind pillars of shale to hold up the roof. Since the height of the mine ceiling, determined by the shale zone thickness, will be 50 to 70 feet, an underground shale mine could accommodate very large equipment, such as trucks and front loaders. According to a study recently prepared by the Cleveland Cliffs Iron Company, the operation would be very similar to one in a large surface mine.

The alternative to mining would be in situ conversion of shale to oil, but true in situ processes appear to require at least 15 more years of development, if they ultimately prove feasible, in spite of much private and government research. The problem is to create enough void space in the shale, which is quite impermeable in its natural state, so that a flame front will burn evenly through a large underground region. The Bureau of Mines has tested hydraulic fracturing followed by chemical explosives. After the shale is ignited, air is pumped into the region at high pressure to sustain burning, and the resulting shale oil is pumped out. Although this process was promising in shallow shale beds, it has not yet worked in deeper zones.

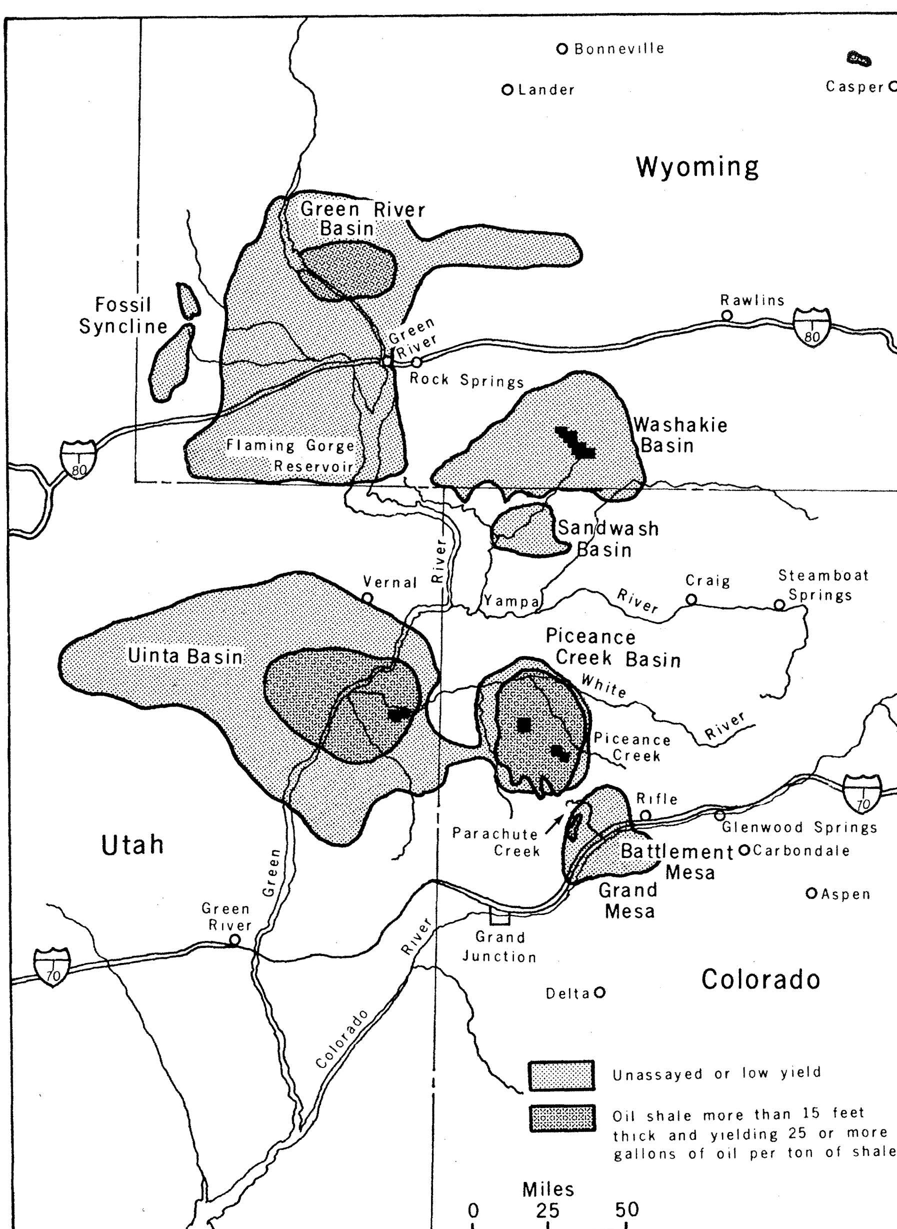

Fig. 1. The major U.S. oil shale deposits. Most of the high-grade ore is found in the Piceance Creek basin in western Colorado. Black areas indicate tracts of federal land leased for private development.

A hybrid process, often called in situ, has been proposed by the research arm of the Occidental Petroleum Corporation. Up to the point of igniting the shale, the Occidental process requires conventional underground mining. A stope mining technique is used to tunnel into the shale, hollow out a low room, and then blast down the ceiling. Then the room is sealed off and ignited. Shale oil is drained out through a trough previously cut in the floor. From 20 to 35 percent of the shale would have to be removed from the mine to make the tunnels and rooms, and that shale would be processed above ground with the same problems of any shale extraction operation. Under ground, the main uncertainties about the Occidental process are how large the rooms can be, how uniform the broken shale will be, and whether the process will work in shale that is susceptible to groundwater. Once ignited, a room would need to burn for several months to extract all the shale oil.

Occidental has successfully produced shale oil from a room 30 feet square and 70 feet high, and is now lighting a second room the same size. The yield is much lower than in aboveground processing. Experiments that simulated the Occidental in situ retorting with a large steel retort of the Bureau of Mines at Laramie, Wyoming, obtained a maximum of 60 percent shale oil recovery. After testing a third small room, Occidental is proposing to mine a much larger room, about 250 feet high, to test the process on a commercial scale. To extract 30,000 barrels per day would require completing at least one such room each week, according to knowledgeable observers. Even if all four test rooms are successful, Occidental would probably require at least 4 years to begin commercial operation, in the opinion of Gerald Dinneen, director of the Bureau of Mines station at Laramie. Others, particularly competitors, predict that 10 years will be required for development.

Unless a true in situ process can be found, oil shale development will require a mining effort that can only be called gargantuan. Oil shale has less energy value per ton than practically any substance that has been used for commercial fuel. Even for the high-grade deposits, about 1.5 tons of shale will be required to produce each barrel of oil. With coal, only about 0.5 ton would be needed to produce a barrel of synthetic crude oil, if the technology for coal liquefaction were available. To get 1 million barrels of oil per day from shale would require mining, transporting, crushing, and retorting 1.5 million tons of oil shale, then disposing of 1.3 million tons of residue. Altogether, 2.8 million tons of material would be handled each day, or about 1 billion tons per year. Last year, the total coal production in the United States was 570 million tons. Even if the Occidental in situ process were used, about 250 million tons of rock would be minded and moved each year. In order to obtain 3 million barrels of oil per day from shale, these figures would have to be trebled. In the course of 3 months, as James Akins likes to note for perspective, the tonnage would be equivalent to the weight of earth and rocks excavated in constructing the Panama Canal. "This does not mean that extraction of oil from shale is impossible," says Akins, "It is just that it is very difficult."

Because of the low energy value of shale, which necessitates such massive mining, and the aridity of the region where shale naturally occurs, its development will inevitably alter the environment and has the potential for extensive damage. The growth of a mature oil shale industry could present problems with the disposal of spent shale, revegetation of affected areas, disturbance of natural habitats, increase in the salinity of the Colorado River, and release of dust and sulfur dioxide to the air. A true in situ process would eliminate some problems, but by no means all. According to Charles Prien, at the University of Denver, Denver, Colorado, in situ methods may just hide the environmental problems underground. Specifically, there are two major aquifers for return of water to the Piceance Creek—which eventually flows into the Colorado River. In the northern half of the basin, one aquifer is above the shale zone and one is below. Prien points out that in some areas of the basin mining could create communication between these two aquifers, and that water passing through the spent shale could leach salts out of it. He thinks that the problem could probably be better controlled in the course of conventional mining than by in situ methods. In the following discussion of environmental effects, conventional underground mining is assumed.

Environmental Changes

After processing, most companies plan to dispose of waste shale above ground, probably in nearby canyons, rather than store it back underground in the mines at a higher cost. Spent shale from the original Union Oil Company process is composed of large chunks at least 10 cm across, shale from a Bureau of Mines process is about 1 cm in average size, and spent shale from the TOSCO process is a fine powder about 0.07 mm in size. Characteristics such as permeability and alkalinity also vary significantly, so the shale disposal problems with one process may be different from the problems with another. The spent shale from a 50,000-barrel-per-day plant will fill a typical canyon in the region, such as Davis Gulch where Colony will dispose of its shale, to a depth of 250 feet in 7 years, leaving about 700 acres of bare shale exposed on top. To minimize the volume, each layer of shale will be compacted as the pile is built up, and the pile will be stable against sliding if the slope is less than 3:1, according to Colony. However, tests by John C. Ward at Colorado State University, Fort Collins, have shown that snowfall destroys the compaction of spent shale to a depth of at least 2 feet. So sliding could occur if the spent shale isn't protected with topsoil and vegetation, according to Ward.

How readily the native grasses and shrubs can grow on spent shale is a question that will largely determine the environmental effects of the shale industry. Of course, the aesthetic appeal of a canyon cannot be regained by growing grass on the false floor, but the success of revegetating spent shale will affect the quantity of salts leached out of the shale by rain and snowfall, and the reduction of the wildlife population in the area, as well as the stability of the pile against erosion. The Piceance basin is the winter range for one of the largest herds of migratory deer in the world, 30,000 to 60,000 mule deer, and is the home of at least a dozen nests of golden eagles. The Department of the Interior estimates that a mature shale industry would disturb 80,000 acres of land over 30 years.

Spent shale must be heavily watered to remove salts before most grasses will grow. The spent shale from the TOSCO process has a significant alkalinity (*p*H about 9) and contains essentially no nitrogen or phosphorus. In many small test plots, Colony has gotten at least three native grasses to grow profusely, after watering heavily for the first year, using commercial fertilizer, and mulching. Two native shrubs have also grown, but so far none of the woody species used as browse by deer. Colony does not readily distribute data on how much watering was necessary to achieve this. The annual rainfall in the Piceance Creek region is only 12 to 15 inches per year, and one of the major unanswered questions is whether vegetation growing on shale can survive several dry seasons. A test plot of spent shale from the Union Oil process grew grasses naturally, however, according to Harry Johnson at the Interior Department. Tests on a plot of TOSCO spent shale by Ward showed that after 41 inches of water had been applied, with no fertilizer or mulch, only tiny weeds appeared 2 years later. Ultimately, it may be necessary—and cheaper—to cover spent shale with topsoil than to revegetate it. Besides a shortage of natural water, the industry faces another problem for artificial seeding of shale piles: where can you buy four-winged saltbush seeds?

The residents of the Rocky Mountain region and the Far West could also experience a problem with increased salinity in the Colorado River. A mature shale industry (1 million barrels per day) would deplete the quantity of fresh water flowing into the Colorado enough that the salinity at Hoover Dam would increase by 1.5 percent, according to the Department of the Interior. But many observers think that the 1.5 percent effect could be dwarfed by the contributions of salts added to the Colorado River from saline underground aquifers and by leaching of spent shale. The environmental impact statement for prototype leasing did not try to estimate such salt loading, which has been estimated to increase the salinity at Hoover Dam as much as 50 percent.

There is no doubt that the runoff from bare shale is extremely salt-laden. Ward found that the concentration of dissolved inorganic solids to be as high as 5000 mg/liter, about five times the salinity of the Colorado River in the region. Colony plans to install a catch basin at the toe of the shale embankment to keep the runoff from reaching Parachute Creek and thence the Colorado. To evaporate water fast enough so that it didn't overflow, such a basin would have to be quite large. Further increases in the salinity of the Colorado River might require considerable expenditures for desalinization downstream, where there is heavy demand for municipal and agricultural water.

Besides the potential for polluting the Colorado River, an oil shale industry could pollute the air with dust from mining, crushing, and disposal operations, and with sulfur dioxide emission from the retorting process. Some local impact on plants would occur, and there is considerable doubt whether shale operations could meet the recent court ruling that air quality not be degraded when it is purer than environmental standards.

Environmental degradation is certain to occur with a mature oil shale industry, and there is the potential for a very serious impact, according to Harry Johnson, although only local degradation will occur with the prototype program. All parties, including the environmental groups, agree that not enough is known from small test plots to assess the environmental damage to be expected on a larger scale, and the Department of the Interior intends to monitor the prototype program closely and use the information to decide about expanding the industry.

Since most of the rich oil shale is on federal lands, the industry cannot grow to 1 million barrels per day without additional public land leasing. Critics of the prototype leasing operation argue, however, that 5120-acre leases were certainly not needed to determine the environmental effects, that there are many loopholes in the stipulation that all affected lands should be rehabilitated, and that the enforcement provisions are inadequate.

Perhaps one of the most important concerns is that the shale industry will grow up, prove unsuccessful, and be abandoned, leaving the western slope of the Rockies in somewhat the same condition as Appalachia. There is no doubt that a 1 million-barrel-per-day oil shale industry would alter the character of the region. The industry would bring in 115,000 people, more than double the population that now lives in the counties where oil shale is found. Towns would have to expand their municipal services, mobile home settlements would be wheeled in, and many rural aspects of life in the region would disappear. If the industry failed, it could leave the region environmentally desolated and economically broke.

Although oil shale is a bounteous reserve compared to oil, it is clear that it cannot be extracted from the earth without paying a far greater environmental cost. Even so, the rate at which oil can be fired out of shale will be more dependent on the water reserves than on shale reserves. Even the estimated ceiling of 1 million barrels per day may be high, because much of the available water in the region has reportedly been cornered for surface coal mining. One would think that the major reason for urgently developing shale oil would be to utilize its portability as a liquid fuel. But, more likely than not, the first use of raw shale oil will be to burn it, in place of sulfureous coal, for generating electricity in the far Southwest.—WILLIAM D. METZ

Book Reviews

Beginning Grammar

A First Language. The Early Stages. ROGER BROWN. Harvard University Press, Cambridge, Mass., 1973. xx, 438 pp., illus. $15.

Blown by the winds of the changing *Zeitgeist*, the study of language development has shifted direction several times during the last 80-odd years. A promising start was made before World War I, but this, along with the mentalistic psychology it assumed, was displaced by the behaviorist revolutions in both psychology and linguistics. The early work was forgotten. In the middle 1950's, alongside a revival of interest in the higher mental processes, there was a resumption of communication between the disciplines, and psycholinguistics was first named and then came into being. The *Zeitgeist* change in psychology was followed—and massively fueled—by the paradigm change in linguistics to Chomsky's generative grammar. The formalisms of generative grammar provided a valuable tool of analysis for a number of longitudinal studies of early syntactic development, the first wave of which began in the late 1950's. Roger Brown is one of the pioneers of this work, and his book presents a scholarly and extraordinarily rich discussion of all the issues that have arisen.

The book is divided into a long introduction and two chapters, each itself the length of a small book. The first and longer chapter is devoted to stage I, which begins with the first appearance of word combinations and lasts for some months, during which the basic word order and main constituents of simple sentences are acquired. The other chapter provides a thoughtful discussion of original data on the next stage of development. Because the major problems that exercise the field concern stage I, my review will focus on the first chapter. In it Brown presents a detailed stocktaking of 15 years of work, drawing on observations of three children who were his own subjects and of other children described in the open literature and unpublished sources, including several children who were acquiring languages other than English.

The first wave of the research Brown describes was conditioned by the state of linguistics at the time, which placed the research focus on syntax, semantic structure being regarded as a murky subject that had better not influence a syntactic description. Children's utter-