Report of the Committee on Environment and Public Planning

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Development of Oil Shale in the Green River Formation

FOREWORD

State and Federal legislators and administrators have little time to become adequately informed about the implications of the many necessary decisions that relate to energy resources versus possible effects on the environment. Under prodding from H. Guyford Stever, Director of the National Science Foundation and Scientific Advisor to the President, and from several State and Federal legislators, the Council of the Geological Society of America asked the Society's Committee on Environment and Public Policy to prepare two concise Information Papers on relevant subjects for distribution to GSA members and to public officials who have use for the information. Accordingly, this paper on "Development of Oil Shale in the Green River Formation" and another on the "Environmental Impact of Conversion from Gas or Oil to Coal for Fuel" have been prepared by panels of invited participants and are being distributed for your information and comment. The members of the Society will decide whether more of these Information Papers should be prepared under the auspices of the committee; therefore, the Council would appreciate your reaction. Additional copies of this paper are available from the Executive Secretary, Geological Society of America, 3300 Penrose Place, Boulder, Colorado 80301.
ABSTRACT

In the last two decades, U.S. petroleum demand has increased at a rate greater than that of domestic production. Concern has been expressed on the future of the Nation's energy supply if reliance must be placed entirely on increasing imports from foreign sources of questionable dependability. A domestic energy source that is under serious consideration to augment present supply is oil shale.

The Green River Formation in Colorado, Utah, and Wyoming represents a potential resource containing about 2 trillion barrels of oil in shale that averages 15 gallons per ton or more than 400 billion barrels in 30-gallon-per-ton shale. This report considers the technological and environmental aspects of developing this resource for use by the people of the United States.

INTRODUCTION

Federal land having oil shale in the Green River Formation of Colorado and Utah was leased in early 1974 for development under a prototype leasing plan prepared by the United States Department of the Interior. (Land offered for lease in Wyoming did not attract any bidders.) In addition to this Federal action, there are strong indications that oil-shale lands owned in fee will be brought into production by 1980. The recent activity is the culmination of sporadic interest in oil shale over the past 60 years by both governmental and private industry and stems from an announced policy by the Federal Government to reduce the country's increasing dependence on energy materials from foreign sources and the rising cost of energy, both of which have improved the economics for shale-oil production.

Mineral extraction (trona, coal, bitumens, oil, and gas) from the Green River Formation and its underlying rocks is nothing new. However, owing to the widespread occurrence of the oil shale, concern has been expressed by some governmental agencies and segments of the public that oil-shale development would result in severe or irreparable environmental damage to an undeveloped region that is sparsely populated and ill-equipped to cope with a large population influx.

This brief report on the status of the mining and processing methods and the setting in which activity would take place should give a better understanding of the basic policy questions that must be resolved if shale oil is to become a significant contributor to our energy supply. Selected references are included.

GEOLOGIC AND GEOGRAPHIC SETTING

Oil shale is a sedimentary rock with a diverse mineral content. It contains solid organic matter that will yield little or no oil through the use of petroleum solvents but will yield varying amounts of oil if heated. Oil shale is associated with sedimentary rocks that range in age from Cambrian through Tertiary. Most countries of the world have oil-shale deposits, but they are far from uniform in thickness, grade, and areal extent. Much of the eastern and the midcontinent part of the United States is underlain by thin low-grade deposits of oil shale. The remainder of the country contains scattered deposits of oil shale of varying thickness, value, and extent.

The principal oil-shale deposits of potential commercial interest in the United States occur in the Green River Formation of Eocene age. Underlying an area of 25,000 square miles in Colorado, Utah, and Wyoming (Fig. 1), this formation includes rich oil shale—that is, shale deposits which are at least 10 feet thick and which average 25 gallons of oil per ton of shale—that represents about 600 billion barrels of oil shale. Of this higher grade shale, more than 480 billion barrels of shale oil (more than 80 percent of the Green River oil-shale deposits) occur in the Piceance Creek Basin of northwestern Colorado, and 90 billion barrels of shale oil occur in the Uinta Basin of Utah. The Wyoming basins are lightly explored but are thought to contain 30 billion barrels in 25-gallon-per-ton grade shale.

The Green River oil shale was deposited 50 million years ago in two large lakes: Gosiute Lake in the present Green River-Washakie Basin and Lake Uinta in the present Uinta-Piceance Creek Basin. After deposition of the Green River beds, the region was warped into several large structural basins and later was elevated several thousand feet above sea level. Subsequently, streams eroded much of the formation from the structurally high areas, exposing the oil shale in a series of cliffs and ledges around the periphery of the basins.

The oil-shale areas of Colorado, Utah, and Wyoming are sparsely settled. The region is part of the high Colorado Plateau province of the upper Colorado River basin and the high plains of the Wyoming Basin. The terrain varies from dissected, wooded plateaus bounded by prominent oil-shale cliffs, to sparsely vegetated plains with low escarpments, commonly exposing the ledge- and cliff-forming oil shale. The region is drained by the upper tributaries of the Colorado River. The basins shown in Figure 1 are relatively simple structural downwarps. (Dips range between 0.5° and 5° except in the areas bordering the Uinta uplift where dips may approach 90°.) Several subsidiary folds are superposed on the major structural downwarps and several well-developed joint patterns probably formed as a result of the folding and appear to control the drainage pattern in much of the area. Faulting is rare and, where it occurs, is very high angle normal faulting. In the Piceance Creek Basin, essentially all of the faults occur as northwest-trending grabens with displacements of generally less than 100 feet.

In general, the richer oil shale is in the middle third of the Green River Formation. The rich oil shale in Wyoming is usually thin, and the beds are widely separated stratigraphically by low-grade or barren material. Around the margins of the Piceance Creek Basin and in Utah, the rich oil shale is restricted to a single zone known as the mahogany zone. In the north-central part of the Piceance Creek Basin, the mahogany and underlying zones that contain rich oil shale attain a thickness of approximately 2,000 feet.

Some of the more prominent northwest-trending fractures in the Uinta Basin are filled with solid bitumens. These have had a variety of commercial uses through the years but most recently have been refined into petroleum products. In the western part of the Uinta Basin, some saline minerals are associated with the oil shale; however, not much is known about association or mineral distribution.

Oil shale in the middle of the Green River Formation in the Green River Basin, Wyoming, is interbedded with thick beds of trona, a sodium carbonate-sodium bicarbonate salt.
The oil shale associated with the trona is thin and only moderately rich; however, the trona beds are thick and quite pure and are now being extensively mined for use in the manufacture of soda ash.

A several-hundred-square-mile area surrounding the depositional center of the Piceance Creek Basin contains a thick sequence of saline minerals including nahcolite (sodium bicarbonate) and dawsonite (sodium aluminum carbonate). About 50 square miles of this area also contains halite interbedded with the nahcolite. Nahcolite may be used in the manufacture of soda ash or it may be used effectively in bag filters in the stack of a coal-fired electricity-generating plant to clean sulfur and nitrogen oxides from stack gases. Dawsonite has a value as a potential source of aluminum or it may be used in sanitizing domestic liquid waste. Resources of both nahcolite and dawsonite are large. In places, sections of oil shale more than 700 feet thick contain an average of 25 percent nahcolite and more than 10 percent dawsonite.

The Water Resources Division of the U.S. Geological Survey has determined that the plentiful ground water of the Piceance Creek Basin is contained in an upper and a lower aquifer separated by the mahogany zone. Above the mahogany zone, most of the water is present in interstices between sand grains and in fractures. In general, the water in the upper aquifer contains less than 1,000 milligrams per liter dissolved solids. Below the mahogany zone, mainly in the north-central part of the Piceance Creek Basin, ground water moving through joints and fractures has leached saline minerals interbedded with the oil shale. This leached zone ranges from a few hundred to more than 1,000 feet in thickness and contains water that ranges from slightly saline to more than twice the salinity of sea water. The volume of water in the leached zone is estimated at as much as 25 million acre-feet. Little is known about the hydrologic character of the oil-shale areas of Wyoming and Utah.

SURFACE-WATER RESOURCES

Water resources of the oil-shale regions of Colorado, Utah, and Wyoming are complex and varied. Surface-water supplies are mostly available from the area's large rivers—the Green, the White, and the Colorado—most of which originate as rainfall and snowmelt from the higher elevations.

Surface-water supplies within the Piceance Creek Basin are small. The average discharge of individual streams does not exceed 40 cubic feet per second and that flow is highly variable. Direct flow of the streams in the Piceance Creek Basin is overappropriated, and water for a mature industry would ultimately need to be imported from the White and Colorado Rivers that border the basin in order to obtain a full supply.

Streams draining the oil-shale land in the Green River and Washakie Basins receive very little precipitation each year and flow only intermittently.

The Green River is the principal surface-water resource of the Green River Basin. Water supplies may be made available from the existing Fontenelle and Flaming Gorge Reservoirs.

Streams in the Uinta Basin, which are within the area of the oil-shale deposits, drain relatively low elevation watersheds that receive small amounts of precipitation each year;
The Green River oil-shale area is in a semiarid to arid region. Annual precipitation varies from 7 to 24 inches. Much of the precipitation is in the form of snow that falls between December and April. Intense summer showers are common. Temperatures are generally mild except in the winter months when they may drop to —40°F. Frost-free periods vary from 30 days in the high elevations to 1 25 in the lower elevations.

SOILS

Soils of the Green River oil-shale region are extremely complex and variable. Upland areas commonly contain steep slopes, bare rock cliffs, and ledges with little soil development. Large areas of gently sloping uplands contain thin, poorly developed soils that intermingle with moderately deep soils in alluvial valleys and swales. The soils map (Fig. 2) depicts locations of major soil associations.

VEGETATION

The oil-shale region has a complex pattern of diverse plant communities. The area's extreme variations in climate and soils produce vegetative types from the desert to the subalpine zones. Natural plant communities have also been modified by man's activities.

The oil-shale region can readily be divided into seven major vegetative types: saltbush, greasewood, pinyon-juniper, sagebrush, mountain shrub, aspen, and conifers. They generally occur in relation to elevation with saltbush at the lowest elevations and conifers at the highest.

In the Piceance Creek Basin, 90 percent of the total area supports three vegetative types: pinyon-juniper, sagebrush, and mountain shrub. In the Uinta Basin, the saltbush type accounts for 75 percent of the vegetation. The sagebrush type covers 70 percent of the Washakie Basin.

WILDLIFE

Many species of wildlife inhabit the Green River oil-shale region. These include seven species of big game, three species of small game, 27 species of migratory waterfowl and shorebirds, six species of upland game birds, five species of fur bearers, 21 species of nongame mammals, 200 species of birds, six species of upland game birds, five species of fur bearers, 21 species of nongame mammals, 200 species of birds, and 24 species of raptors.

The mule deer is the most abundant big game animal. It is very important to the economy of the region.

Sport fishing in the Green River oil-shale region is quite limited because of the semiarid climate. Excellent sport fishing is available in areas adjacent to the oil-shale region in the watersheds of the Colorado, Green, and White Rivers.

Several species of endangered or threatened wildlife may exist in the region, including the black-footed ferret, American peregrine falcon, humpback chub, Colorado River squawfish, spotted bat, and prairie falcon.

LAND OWNERSHIP

About 72 percent of the land underlain by the high-grade oil shale in the Green River Formation is public land administered by the U.S. Department of the Interior.

In southwestern Wyoming, about 50 percent of the oil-shale land is privately owned. The State owns around 10 percent, and the remainder is in the public domain.

In Utah, about 80 percent of the oil-shale land is owned by the Federal Government and approximately 15 percent is owned by the State. The remainder is in private ownership. The State of Utah has applied to the Federal Government for selection (transfer to State ownership) of approximately 150,000 acres of oil-shale land now owned by the Federal Government.

In Colorado, the Federal Government owns about 80 percent of the oil-shale land. The remainder is privately held or has a clouded title.

MINING AND PROCESSING TECHNOLOGY

Development in the technology of mining and processing these shale deposits has been erratic over the years, apparently in response to the pressures exerted by uncertain foreign relations and market conditions. Oil may be produced from oil shale by either aboveground or in situ processing. For aboveground processing the oil shale must be mined, crushed, and heated. The oil must be recovered and the residual spent shale disposed of in an acceptable manner. For in situ processing, the organic material must also be pyrolyzed using adequate permeability and surface area for the flow of process fluids. The oil from either process may require some treatment before transportation.

Underground Mining

Although there was much interest in Green River oil shale from 1916 to 1927, the first real research into mining was done by the U.S. Bureau of Mines from 1944 to 1956. The bureau, entering via adits into the upper (mahogany ledge) shale beds, developed a modified room-and-pillar mining system. This system, with few changes, has been used by all but one shale mining operation in the Green River Formation to date.

Studies indicate that a 65 to 70 percent recovery can be expected from room-and-pillar mines, with mining heights of 30 to 90 feet and overburden depths of 600 to 1,000 feet. Additional pillars along outcrops, around shafts or adits, and as panels for backfilling may reduce recovery below 60 percent.

Underground mining can probably be done with high-tonnage extraction using a modification of the system developed by the Bureau of Mines. However, roof falls and other support problems encountered in all of the large-volume mines indicate that each individual underground mining operation should be designed using the best available rock mechanics techniques to provide for maximum safety and resource utilization. Even with this additional research, it is doubtful whether total resource extraction will exceed 60 percent.

Openpit Mining

No openpit mining of the Green River Formation has ever been done. However, this mining method is one that is proposed for Colorado Tract C-a by the leaseholders.

Openpit mining would provide nearly 100 percent recovery of all valuable resources. This is in contrast to lesser recovery for known underground mining methods that do not disturb the surface.

The technology of very large openpit mines has been demonstrated by copper mines where recovery of more than
ASSOCIATIONS OF GREAT GROUPS OF SOILS

A. Light Colored Soils of the Arid Region
1. Haplargids, Camborthids, Torriorthents, Torrifluvents
2. Haplargids, Camborthids, Torriorthents, Torriorthents*
3. Haplargids, Camborthids, Haplustolls, Argiustolls, Torripsamments
4. Haplargids, Camborthids, Calciorthids, Haplustolls, Torrifluvents
5. Haplargids, Camborthids, Calciorthids, Haplustolls, Torriorthents*
6. Haplargids, Camborthids, Torriorthents
7. Haplargids, Torriorthents, Natrargids, Natrustolls

B. Moderately Dark Colored Soils of the Semi-Arid Region
1. Haplargids, Camborthids, Haplustolls, Argiustolls, Torrifluvents
2. Haplargids, Camborthids, Haplustolls, Argiustolls, Torriorthents*
3. Haplargids, Camborthids, Haplustolls, Argiustolls, Torriorthents*
4. Haplargids, Camborthids, Torriorthents, Torrifluvents
5. Haplargids, Camborthids, Torriorthents, Haplustolls
6. Haplargids, Camborthids, Torriorthents

C. Dark Colored Soils of the Semi-Arid Region
1. Argiustolls, Haploborolls, Camborthids, Haplustolls, Torrifluvents
2. Argiustolls, Haplustolls, Torriorthents*
3. Argiustolls, Haplustolls, Torriorthents*

D. Dark Colored Soils of the Sub-Humid Region
1. Argiborolls, Haploborolls, Ustorthents
2. Argiborolls, Haploborolls, Ustorthents
3. Argiborolls, Haploborolls, Ustorthents
4. Argiborolls, Haploborolls, Ustorthents
5. Argiborolls, Haploborolls, Ustorthents

E. Soils of the Cool to Cold, Sub-Humid and Humid Forest Region
1. Eutroboralf, Rockland
2. Eutroboralf, Haploborolls, Ustorthents
3. Eutroboralf, Ustorthents

F. Saline and Sodic Soils
1. Natrargids, Natrustolls, Torrifluvents

G. Immature Soils on Unconsolidated Upland Materials and Aeolian Sands
1. Torripsamments, Camborthids, Haplargids, Haplustolls, Argiustolls
2. Torripsamments, Camborthids, Haplargids

H. Immature Shallow Soils on Consolidated Upland Materials and Miscellaneous Land Types
1. Torriorthents, Badlands, Torripsamments
2. Torriorthents, Haplargids, Camborthids
3. Ustorthents, Argiborolls, Haploborolls
4. Torriorthents, Torripsamments, Haplargids, Camborthids
5. Rockland

* includes Lithic Subgroups
** includes High-Lime Soils
one million tons per day of ore and overburden lias occurred. If use of lower grade shale or more complete extraction is determined to be economic, current openpit mining technology is immediately applicable to meet production goals.

In Situ Processing

In situ extraction of oil may be an alternative to mining but is in the early stages of development. Little has been published, although some reports have been released by both the government and industry.

In situ processing may be accomplished by passing retorting gases and produced liquids either vertically or horizontally through fractured shale. Application of the vertical retorting system requires a method for obtaining a cavity filled with broken shale. Two methods are considered most promising: (1) mining sufficient shale from the lower part of a room to provide the desired porosity when the shale above the mined portion is fractured by explosives and collapsed into it, and (2) use of nuclear explosive to create an underground cavity into which the overlying shale collapses. The first alternative is being tested in a field experiment, but the second is presently only a concept that would be applicable to rather thick oil shale intervals with adequate overburden.

The horizontal sweep approach is somewhat similar to thermal recovery methods in petroleum reservoirs. However, since oil shale deposits frequently have very low permeability, creating appropriate fractures is a primary requirement. Applications of this general concept have been attempted at various times during the past 20 years, but the only currently active field project is that being conducted by the U.S. Bureau of Mines.

Aboveground Processing

Although many aboveground retorting systems have been tried in the last 60 years or so, only three have been tested on a large scale with modern equipment so that an indication as to their potential applicability is available. These, which are shown schematically in Figure 3, are the gas-combustion, Union Oil Company of California, and TOSCO retorting systems that have been tested in pilot plants having capacities as much as 1,000 tons per day. In contrast, individual units in a commercial operation are generally considered to be in the 5,000 to 10,000 tons-per-day range.

The gas combustion retort was originally developed in the early 1950s by the U.S. Bureau of Mines. Further development of the process was conducted during the mid-1960s by a six-company group. The most recent work on this process involves testing of the Paraho retort, a patented modification of the original system, in a program sponsored by 17 companies.

The Union Oil Company of California process was tested on pilot scale in 1957 and 1958. The plant had a capacity of about 1,000 tons per day. It was announced after completion of the tests that the process had been successful and that it could be commercialized in the proper economic cli-

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Figure 3. Schematic representations of three oil-shale retorting processes.
mate. The amount of developmental work that has been done on the process since 1958 is not known.

The most recent development work has been on the TOSCO II process. A pilot plant designed for about 1,000 tons per day was operated at various times over a period of several years ending early in 1972. The most recent announcement concerning the process is that engineering design of a commercial plant is in progress and will be completed in the fall of 1974. If construction of a commercial plant is started at that time, production might be expected in about 1978.

OIL-SHALE PRODUCTS

The fuels and chemicals normally produced from petroleum can also be obtained from shale oil utilizing adaptations of petroleum technology. Green River Formation oil will normally have a high nitrogen content and have a high pour point. Hence, it may be advisable to upgrade the product near the retorting site. The extent of upgrading selected will be strongly influenced by the availability of capital, manpower, water, and other requirements of the process.

ENVIRONMENTAL CONSIDERATIONS

Physical

Oil-shale development will produce both direct and indirect changes in the environment. Many of these changes will be of local significance, and others will be of an expanding nature and have cumulative impact. These major regional changes will conflict with uses of the other physical resources of the areas involved. Impacts will occur to the land itself, water resources and air quality, fish and wildlife habitats, grazing and agricultural activities, recreation and aesthetic values, and the existing social and economic patterns. The environmental impacts must be assessed for their anticipated direct, indirect, and cumulative effects including impacts in areas required for support facilities such as highways, railroads, airports, power lines, plants, pipelines, townsites, and related facilities.

Major impact on the land itself will involve disposal of the shale residue after the oil has been extracted. The oil extraction process increases the bulk volume by 20 to 30 percent, depending on the volume of saline minerals and whether they are recovered. Two options have been considered for processed shale disposal—surface or underground. Because the waste volume exceeds the extracted volume, some surface disposal will be required in the underground disposal option. Provision must also be made to prevent the leaching of water-soluble minerals from the surface and underground spent shale areas and subsequent contamination of the existing water system.

In the production of 100,000 barrels of shale oil per day, approximately 20 billion cubic feet of spent shale residue will be produced during 20 years. Assuming that 50 percent of this material will be disposed of on the surface, the spent shale from an operation of this magnitude could fill a space 5 to 10 miles long, 2,000 feet wide, and 200 feet deep. This will have a substantial visual impact and provision must be made for contouring the spent shale disposal area to blend with the present landscape. Furthermore, the spent shale areas must be revegetated to minimize the visual impact and provide food for livestock and wildlife. Present technology is generally adequate to assure successful revegetation of most disturbed areas through natural plant establishment and succession, reseeding of native species, or establishment of introduced plant communities.

Federal agencies including the U.S. Forest Service, Soil Conservation Service, Agricultural Research Service, and the Bureau of Land Management have been successfully re-vegetating disturbed range lands for many years.

Demonstration plots have been established to show that spent shale from several processes will support vegetation if the material is leached, mulched, fertilized, and irrigated. Top dressing with topsoil, and mixing soil and waste material appear to have possibilities. A sizeable volume of water is required to leach the spent shale and to irrigate new plantings.

The problem of maintaining air quality in accordance with established standards does not appear to present unique problems. However, this will require special equipment and base data. Continued monitoring of area conditions will be necessary to insure all processors meet legal requirements for clean air quality.

The potential water problems may be divided into two broad categories: consumptive water needs and nonpotable water disposal. It is estimated that about 3 barrels of water are consumed for every barrel of oil produced. An operation producing 100,000 barrels of oil per day will require 12,000 to 18,000 acre-feet of water per year. Associated urban development could increase this to 13,000 to 20,000 acre-feet per year. It is anticipated that substantial quantities of water will be encountered in mining of the oil shale in the northcentral part of the Piceance Creek Basin. Most of the water lies in and below the leached zone and dewatering will be required before mining and in situ processing. Although hydrologic conditions vary both laterally and vertically, as much as 18,000 acre-feet per year may be produced in dewatering a mine for an operation producing 100,000 barrels of oil per day. This water may be used to meet processing needs. Excess amounts of saline water will have to be disposed of by reinjection, evaporation, or transportation of the water to an operation with a water deficit.

Human

Development of oil shale will create many direct and indirect effects to the environment in which people live, work, and play. The magnitude of effects will depend on the degree and rate of development. Some assumptions may be made based on present projections by government and industry:

The present population of the region is approximately 119,000, of which 44,000 are employed. It is estimated that over 4,500 new permanent jobs will be created by 1981 for a production capacity of 100,000 barrels per day. If production readies one million barrels per day, population related to the shale oil industry would grow by about 114,800, or nearly double the present population.

Needs for public services will increase substantially.

Total taxes and public revenues should increase by about $307 million per year by 1981 and $759 million by 1985. However, there will be lag between the time when expenditures for public construction are needed and the time when tax revenues become available.

The predominantly rural oil-shale region will be changed
with oil-shale development. Changes will occur not only in the physical environment, but will also occur in the community structures and organizations, in the economic and political systems of the area, and in the social structures and life-styles of all the people involved. Crime rates will increase, recreation patterns will change to more sophisticated urbanized styles, and unemployment rates should decrease.

It may be expected that resentment will develop between some local people who wish to escape the pressures of urban living and the newcomers who will create a more urban environment. On the other hand, some of the local people look forward to the economic benefits and the employment opportunities that will be available to young people.

SELECTED REFERENCES


