CHAPTER 4

Background

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CHAPTER 4

Background

Introduction

The United States has obtained energy for human comfort, security, and productivity from a variety of sources over the past 200 years. The availability of energy was instrumental in its transformation from a largely agricultural society until the late 18th century to a major industrial power in the 20th.

During all of the 18th century and early 19th, human muscles and those of beasts of burden did most of the useful work. Throughout this period, wood was the primary fuel, supplemented by relatively small amounts of coal, coal oil, whale oil, mechanical energy from falling water, and kerosene derived from natural petroleum seeps. By the middle of the 19th century, coal had become the chief fuel and dominated the Nation's energy supply system for about a hundred years. Petroleum-based fuels and natural gas entered the picture after 1859, the year in which the first commercial oil well was drilled in Pennsylvania. The use of petroleum grew rapidly. It was further accelerated by the arrival of the automobile age in the early 1900's. Natural gas, which was originally burned or vented as a waste product from oil wells, became a major fuel for domestic, commercial, and industrial heating by the end of World War II.

By the middle of the 20th century, oil and gas had become the leading sources of energy in the United States, having displaced coal because of their convenience. In 1972, according to the Department of Energy (DOE), the Nation's economy consumed approximately 72 Quads of energy from primary sources, * of which approximately 46 percent was obtained from petroleum, 32 percent from natural gas, and 17 percent from coal. Relatively small amounts were supplied by hydroelectric dams, nuclear powerplants, geothermal sources, biomass, and other energy resources. Wood, once the principal energy source for the Nation, was used largely by some lumber mills and wood-processing facilities.

*One Quad equals 1 quadrillion (101 Btu. A primary energy source is one that may be converted to another form prior to end use. Coal burned for power genera t ion is an example.

The Need for a New Energy Supply System

In 1973, Arab oil exporting nations instituted an embargo against the United States and other nations that supported Israel. Reduced petroleum availability was followed by a recession that lasted through 1974 and into 1975. As a consequence, energy consumption declined slightly, bottoming out at about 71 Quads in 1975. By 1976, energy demand had returned to its 1973 level of about 74.5 Quads/yr. It has continued to rise, although somewhat less rapidly than prior to the embargo.

In 1978, approximately 78 Quads of energy were consumed in the United States—the equivalent of 13.4 billion bbl of fuel oil. Energy supply patterns had altered slightly since 1972. In 1978, petroleum supplied about 48 percent of the energy, natural gas about 25 percent, and coal about 18 percent. Geothermal and biomass use had increased substantially, but these resources, together with nuclear and hydropower, still provided only about 9 percent of the Nation's energy.

It is likely that energy consumption will continue to rise until conservation strategies are adopted by all sectors of the economy. If historical growth trends for energy consumption are followed, the annual energy consumption will reach 135 Quads by the year 2000-the equivalent of over 23 billion bbl of fuel oil per year or nearly twice the 1978 consumption. Actual consumption should be considerably lower, because energy demand is now growing more slowly than in the past. Conservation should slow it down further.

Several implications may be drawn from this discussion. First, the United States consumes enormous amounts of energy. (The 1978 consumption was equivalent to over 2,500 gal of fuel oil per citizen per year,) Second, energy demand will continue to rise in the near future. Third, the Nation runs on fossil fuel, with petroleum satisfying nearly 50 percent of the total energy demand.

This last implication is crucial because it appears that the United States no longer has adequate petroleum reserves of its own. New petroleum discoveries peaked in the 1950's. Domestic oil production followed suit in about 1970, except for the fields in Alaska and on the Continental Shelf. Domestic discoveries are increasing, at present, because of higher oil prices, but it is unlikely that sufficient U.S. reserves exist to provide secure supplies beyond the end of the 20th century. Because of the inability of domestic petroleum development to keep pace with growing demands for liquid fuels, the United States has become increasingly dependent on imported oil. In 1978, the United States imported nearly 24 percent of its total energy supply and nearly 45 percent of its requirement for crude oil and refined petroleum products. A barrel of imported petroleum now costs five to six times as much as it did in 1972.

The short-term reliability of imported oil supplies is very uncertain, as exemplified by disruptions arising from the Suez crisis of 1956, the Arab-Israeli War of 1967, the Arab oil embargos of 1973 and 1974, and the present Iranian situation. Long-term reliability is also questionable because worldwide oil production is expected to peak within the next few decades and to decline rapidly thereafter. Eventually, it may be impossible to import oil at any price.

Growing reliance on increasingly scarce and expensive energy imports has had many adverse effects. Some of the economic impacts (such as balance-of-payments deficits) can be quantified with some degree of precision. Other, less tangible effects (such as threats to national security and the social and economic impacts of supply disruptions), although more difficult to quantify may prove to be much more significant. It has become apparent that an energy supply system needs to be evolved that is more appropriate to the Nation's present and projected needs and internal resources. Just as wood was displaced by coal, coal by domestic petroleum and gas, and domestic petroleum by imported oil, it appears that imported energy must be replaced by new sources of domestic energy.

An initial step in developing a new energy supply system should involve formulating a comprehensive policy that reduces demand through conservation, increases availability from domestic resources, and restricts imports. Conservation must be an important element of any such policy. However, there are limits to the savings that can be accomplished through conservation. Thus, it appears that it will be necessary to develop new energy resources. Potential sources include additional reserves of conventional oil and gas, enhanced oil recovery, expanded coal development, solar-thermal and photovoltaics, wind energy, tidal energy, ocean thermal gradients, increased nuclear fission for power generation, nuclear fusion, biomass combustion, and the recovery of synthetic liquid and gaseous fuels by the conversion of coal, tar sands, biomass, and oil shale. The challenge is to derive optimal combinations of these sources which, when coupled with conservation and restricted imports, will provide sufficient energy for future economic growth and development, while simultaneously protecting the Nation's physical and social environments.

The Purpose and Organization of This Chapter

As noted in the Introduction to this report, this assessment is concerned with only one of the Nation's energy supply opportunities, oil shale—specifically with deposits in the Green River formation of Colorado, Utah, and Wyoming. Although the oil shale literature is extensive, the information is inadequate concerning certain environmental, socioeconomic, technological, and financial aspects of oil shale development. However, the assessment's overall analysis has been facilitated by the extensive body of background information acquired during the Nation's long but sporadic involvement with oil shale as an energy resource. The purpose of this chapter is to organize this background information into a supporting framework for the detailed analyses found in subsequent chapters. The following subjects are discussed:

- the location and extent of the oil shale resources of the United States and foreign nations;
- the characteristics of the resource region in Colorado, Utah, and Wyoming, including brief descriptions of the geography, the geology, the climate, and the physical and social environments;
- the potential applications for materials derived from the Green River oil shales, including oil, fuel gases, minerals, and spent shale; and
- the history and status of development efforts in the United States and other countries, with emphasis on the efforts currently underway in the Green River formation.

Oil Shale Resources

The Genesis of Oil Shale

Oil shale is a sedimentary rock that contains organic matter, which although not appreciably soluble in conventional petroleum solvents can be converted to soluble liquids by heating. Oil shale was formed in the distant past by the simultaneous deposition of mineral silt and organic debris on lakebeds and sea bottoms. As the raw materials accumulated, heat and pressure transformed them into a stable mixture of inorganic minerals and solidified organic sludge. The formation processes that yielded petroleum, tar sands, and coal were conceptually similar, but differed with respect to key physical and chemical conditions. In oil shale, these conditions resulted in the formation of chemical bonds between individual organic molecules. The large size of the molecules formed by this bonding prevents them from dissolving in normal solvents. When heated in processes known as pyrolysis and destructive distillation, the bonds rupture forming smaller liquid or gaseous molecules. These can then be separated from the inorganic matrix, which remains behind as the spent shale waste product.

Photo credit Department of the Interior

Oil shale sample showing layers of organic composition

Worldwide Deposits

Oil shale deposits have been found on all of the inhabited continents. The extent of the worldwide resources cannot be accurately determined, but it appears to be very large indeed. In 1965, the U.S. Geological Survey

(USGS) estimated that the world's oil shale deposits comprised over 4 quadrillion tons, having a total potential shale oil yield of over 2 quadrillion bbl. If all of this oil were extracted and distributed among the world's residents, each person would receive about 600,000 bbl. However, the spent shale waste would cover the entire surface of the world, land areas and oceans included, to a depth of about 10 ft.

The deposits in Asia contain the largest amount of potential shale oil resources, over 700 trillion bbl; Africa is second, with nearly 500 trillion bbl; North America contains over 300 trillion bbl; South America (principally Brazil) about 250 trillion bbl; Europe has about 170 trillion bbl; and Australia and New Zealand together have only about 120 trillion bbl.

Many of the world's deposits have been subjected to commercial-scale development at various times in the past. Those in Scotland, France, Germany, Australia, Sweden, Spain, and South Africa are of historical interest because of the industries that once flourished in those countries. The deposits in Estonia, Manchuria, Brazil, and Morocco are of current interest because they are the sites of present or projected commercial development.

Deposits in the United States

Overview

The oil shale deposits in the United States are shown in figure 12, and their theoretical shale oil yields are given in table 13. The deposits in the Green River formation in Colorado, Utah, and Wyoming are particularly noteworthy because they contain the largest concentration of potential shale oil in the world. Because deposits in the Central and Eastern United States underlie a larger area, they appear more impressive on maps than do those of the Green River. However, they contain less than half the oil shale in the Green River formation, and do not yield as much oil on a unit basis because of a lower proportion of hydrogen to carbon in their organic component.

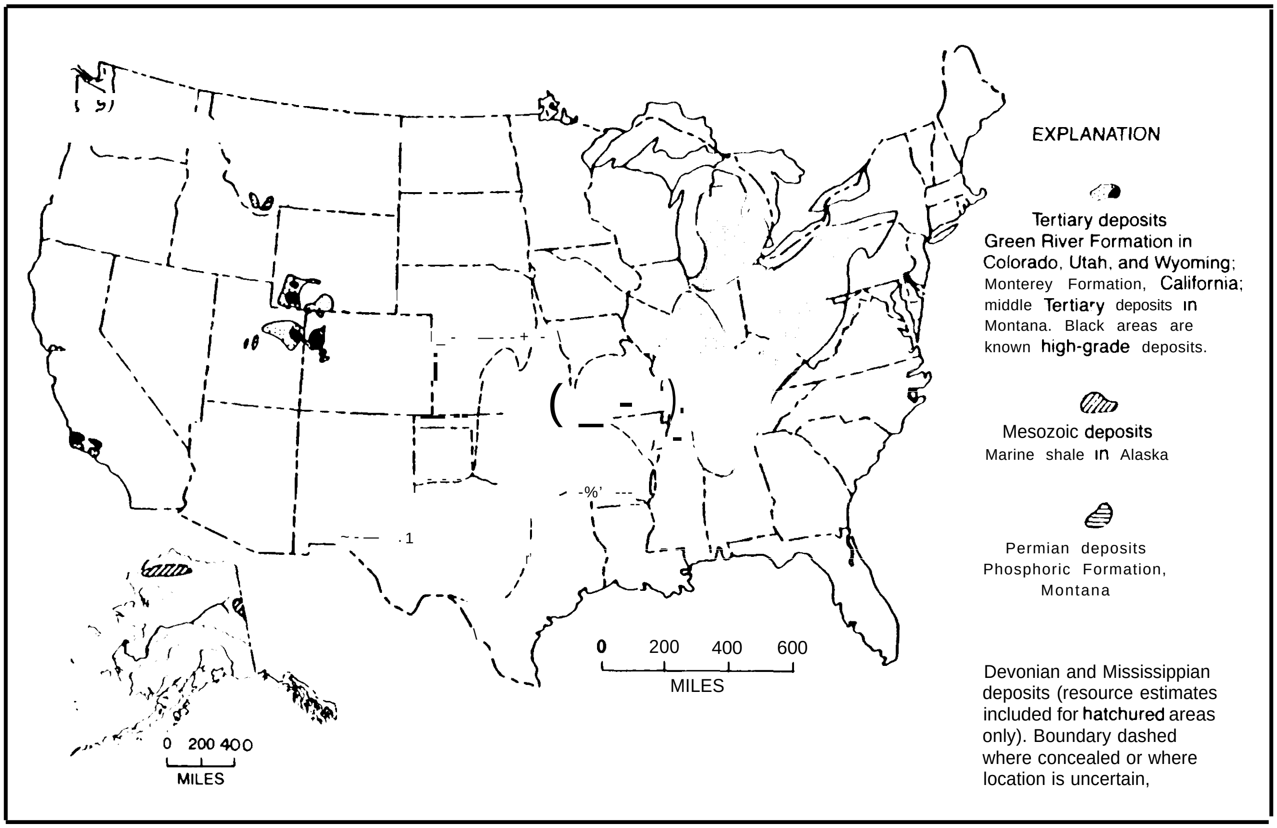
Some of the eastern shales have attracted interest because of the natural gas resources locked within the shale formations. DOE is presently supporting a research and development (R&D) program to evaluate the potential of eastern shales for producing this fuel, with special attention given to stimulating gas production from the Devonian shales that occur in and around eastern Ohio and the western part of West Virginia. The Antrim shales in southern Michigan are also being investigated as potential sources of synthetic pipeline gas, which would be obtained by underground gasification methods. DOE is also investigating the Chattanooga oil shales in Tennessee and Kentucky. In addition to their organic component these shales contain low-grade uranium and thorium ores. But they do not appear to have much commercial potential because the beds are thin and unfavorably located, and ore concentrations are very low.

The Green River Formation

The Green River formation is a geologic entity underlying some 34,000 mi^2 of terrain in northwestern Colorado, southwestern Wyoming, and northeastern Utah. (See figure 13.) The formation has been divided into several distinct geologic basins. The Green River, Great Divide, and Washakie basins occur primarily in Wyoming. Together with the Sand Wash basin in northern Colorado, these basins underlie about 14,000 mi^2. About 35 million years ago they were occupied by a single large and long-lasting freshwater lake.

The Uinta basin in northeastern Utah and northwestern Colorado and the Piceance basin in Colorado underlie about 20,000 mi^2 of terrain, and were once occupied by a second freshwater lake. Most of Colorado's Piceance basin lies north of the Colorado River, but it includes oil shale deposits within Battlement Mesa and Grand Mesa on the south side of the river. Colorado oil shale also occurs in the Sand Wash basin, which is north of the Piceance basin near the Wyoming border.

Figure 12.—Oil Shale Deposits of the United States



SOURCE D C Duncan and V E Swanson, *Organic-Rich Shales of the United States arrd World Land Areas,* U S Geological Survey Circular 523, 1965

Table 13.–Potential Shale Oil in Place in the Oil Shale Deposits of the United States (billions of barrels)

	Range of shale oil yields, gallons per ton		
Location	5- 10[a]	10- 25[a]	25- 100[a]
Colorado, Utah, and Wyoming (the Green River formation)	4,000	2,800	1,200
Central and Eastern States (Includes Antrim, Chattanooga, Devonian, and other shales)	2,000	1,000	(?)
Alaska	Large	200	250
Other deposits	134,000	22,500	(7)
Total	140,000+	26,000	2,000(?)

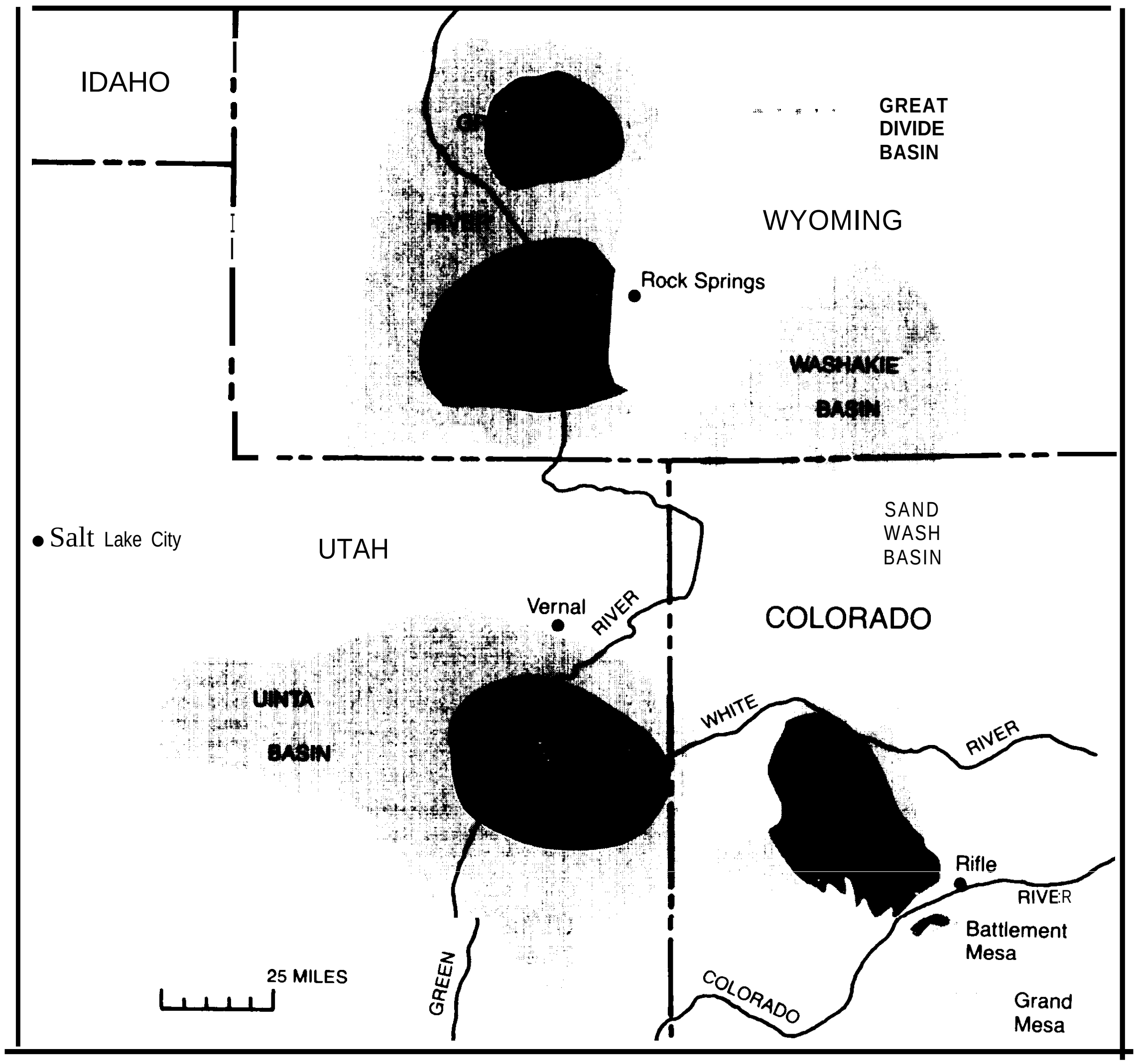
[a]Order of magnitude estimate Includes known deposits extrapolation and interpolation of known deposits and anticipated deposits

Data from D C Duncan and V E Swanson *Organic-Rich Shales of the United States and World Land Areas* U S Geological Survey Circular 523 1965

Oil shale resources have been found under some 17,000 mi^2, or 11 million acres, of the basins of the Green River formation. The principal deposits are found in the Piceance, Uinta, Green River, and Washakie basins. These areas, and in particular the Piceance basin, are among the most intensely explored geologic regions in the United States. The U.S. Bureau of Mines (USBM), USGS, and private industry have drilled hundreds of exploratory coreholes into the basin rocks. The earliest of USBM's efforts took place during World War H. As a result, there is a considerable body of geological information about some areas of the deposits. Other deposits, particularly near the fringes of the Uinta basin and the basins in Wyoming, are still largely unexplored.

To comprehend the potential value of the oil shale in the Green River formation, it is necessary to distinguish among deposits, resources, and reserves. A deposit is simply a natural accumulation. A resource is a naturally occurring substance with properties

Figure 13.—Oil Shale Deposits of the Green River Formation



EXPLANATION

Area underlain by the Green River Formation in which the oil shale is unappraised or low grade.

Area underlain by oil shale more than 10 feet thick, which yields 25 gallons or more oil per ton of shale.

SOURCE D C Duncan and V E Swanson, *Organic-Rich Shales of the United States and Wodd Land Areas,* U S Geological Survey Circular 523, 1965

that can be put to use. A reserve is the equivalent of money in the bank. All of the rocks in the Green River formation occur in deposits. Some of the deposits are also resources because they contain sufficient oil shale, which when properly manipulated can yield useful fuels to warrant being considered for commercial development. However, if the cost of extracting fuels from the resource is greater than the value of the fuels obtained, the resource is not a reserve. Reserves exist only when the resource can be extracted and processed to yield products that can be marketed at a profit.

The total oil shale deposits of the Green River formation contain, in place, * the equivalent of over 8 trillion bbl of crude shale oil, including all rocks that would yield from 5 to 100 gal/ton of oil on destructive distillation. However, many of these deposits are too thin, too deeply buried, or too low in oil yield to be included in a survey of oil shale resources, because it would not be economically feasible to develop them.

In table 14, the quality of the Green River shale is evaluated according to thickness and potential oil yield. Only deposits that yield at least 15 gal/ton and are at least 15 ft thick are considered even marginally attractive. This group includes shales containing as much as 1.4 trillion bbl of shale oil in place. The high-grade shales are further defined as shale beds that are at least 100 ft thick that would yield at least 30 gal/ton. Their in-place oil content is an additional 0.4 trillion bbl, for a total shale oil resource of about 1.8 trillion bbl, in place.

The extent of the oil shale reserves cannot be determined at present. Resources can be regarded as reserves only when processes for developing them appear to be economically feasible. This has yet to be demonstrated for oil shale processes. However, several attempts have been made to delineate particular Green River resources that would present a greater potential for profitable extraction. In 1972, the National Petroleum Council (NPC) used published geological data to classify the shale beds according to thickness and richness, accessibility to underground mining, and the extent to which they had been explored. A summary of the results appears in table 15. Data are presented for four classes of oil shale resources. Classes 1 and 2 were considered economically attractive for existing aboveground recovery technologies. They include only the more favorably located and better defined shale beds, which are at least 30 ft thick and would yield at least 30 gal/ton. These two classes contain about 130 billion bbl of shale oil, in place. The shales in class 3 might also be economically attractive, but they are less well-defined, and their unfavorable locations could hinder commercial development. Class 3 shales contain about 186 billion bbl. The bulk of the Green River resources are in class 4, which includes lower grade, poorly defined, and unfavorably located deposits. Class 4 shales contain nearly 1.5 trillion bbl. Some of the deposits in classes 3 and 4 may be suitable only for in situ processing.

The total estimate shown in table 15 (about 1.8 trillion bbl) agrees well with the total shown in table 14. However, the higher quality resources in the first three classes contain only 315 billion bbl, which is about 2 percent of the total estimated. The potential yield of these deposits can be estimated by taking into consideration the inevitable losses that would occur during mining and processing. Conventional underground mining methods can recover from 60 to 70 percent of the oil shale in a mining zone; large-scale aboveground mining can recover about 90 percent. Processing the mined ore in aboveground retorts recovers approximately 90 to 100 percent of the oil that would be recovered if the shale were dis-

*The term "in place" is used to indicate the quantity of oil that would be created if the shale were retorted. As noted, oil shale deposits contain essentially no oil as such.

Table 14.–Potential Shale Oil in Place in the Green River Formation: Colorado, Utah, and Wyoming (billions of barrels)

Nature of the deposit	Colorado	Utah	Wyoming	Total
At least 100 ft thick with oil yields averaging at least 30 gal/ton	355	50	13	418
At least 15 ft thick with oil yields averaging at least 15 gal/ton, excluding the deposits shown above	840	270	290	1,400
Totals (rounded)	1,200	320	300	1,820

SOURCE W C Culbertson and J K Pitman 011 Shale in *United States Mineral Resources* U S Geological Survey Professional Paper 8?0 1973 pp 497503

Table 15.–Potential Shale Oil Resources of the Green River Formation (billions of barrels)

Location	Resource class[a] 1	2	3	4	Total
Piceance basin (Colorado)	34	83	167	916	1,200
Uinta basin (Utah and Colorado)	–	12	15	294	321
Wyoming basins	–	–	4	256	260
Totals	34	95	186	1,466	1,781

a 1 Deposits at least 30 ft thick and averaging 35 gal/ton
2 Deposits sat least 30 ft thick and averaging 30 gal/ton
3 Deposits similar to classes 1 and 2 but less well defined and not as favorabley located
4 Poorly defined deposits ranging down to 15 gal/ton

SOURCE An Initial Appraisal by the 011 Shale Task Group 1971-1985 *U S Energy Outlook—An Interim Report*, The National Petroleum Council, Washington D C 1972

tilled under carefully controlled laboratory conditions. If it is assumed that about 60 percent of the oil in the shale deposits could be recovered, the resources in classes 1 through 3 could yield 189 billion bbl of crude shale oil.

The projected yield of 189 billion bbl of shale oil is only a small fraction of the total potential yield estimated—1.8 trillion bbl. It is very small compared with the total in-place shale oil content of the Green River deposits (some 8 trillion bbl). To put the figure in a meaningful perspective, the United States consumed about 6.5 billion bbl of crude petroleum in 1978, of which about 2.8 billion bbl of crude oil and refined products were imported. At the 1978 consumption levels, the higher quality Green River resources have the potential to supply all of the Nation's crude oil needs for 29 years or to replace imports for nearly 68 years. Looked at another way, the resources in the first three classes could sustain a l-million-bbl/d shale oil industry for over 500 years. The class 1 resources in Colorado's Piceance basin alone could supply it for nearly 56 years.

With existing data, a preliminary evaluation of the Green River resources can be made with respect to their promise of commercial development, but the actual reserve value is still highly uncertain. It is likely that some of the deposits could not be developed without unacceptably damaging the environment. It is also possible that some favorably located resources could not be developed because of particular geotechnical characteristics (such as highly fractured ore zones or the presence of excessive amounts of ground water) that were not considered in NPC's analysis. In any case, the economic aspects of development are not well-understood because large-scale technologies have not as yet been built and operated. As previously observed, the key criterion in estimating reserves is economic feasibility.

If all the above factors were given careful consideration, it is possible that actual reserves would be very small. On the other hand, it is also possible that an evaluation of the potential of known resources for in situ processing along with additional exploration and research, could increase the reserve estimate. There are deficiencies in the NPC estimate that largely reflect the current status of technical and geological knowledge. For example, over 75 percent of the Uinta basin deposits were placed in class 4 because they have not been as thoroughly explored as those of the Piceance basin. The analysis also downgraded deposits that are not well-suited to mining and aboveground retorting but might be ideal for underground processing. If the survey were revised in the light of present knowledge, it is possible that the reserve estimate would be substantially increased.

Description of the Oil Shale Resource Region

Location

The oil shale deposits of the Green River formation underlie about 17,000 mi^2 of terrain in northwestern Colorado, northeastern Utah, and southwestern Wyoming. * Major settlements in the area and major tributaries that drain the region's watershed into the Colorado River system are shown in figure 14.

Topography and Geology

At the time of their deposition, the oil shale basins probably resembled the fairly uniform topography of continuous lakebeds. Tectonic upheavals have since elevated them, and substantial erosion by wind and water have altered their terrain. Today, most of the oil shale region is very rugged country. The topography of both the Uinta and Piceance basins is typified by rolling plateaus, cliffs, and canyons. The elevation ranges from approximately 4,300 ft above sea level along the Green River in the Uinta basin to more than 9,000 ft at a point near the southeastern edge of the Piceance basin. This irregular topography strongly influences such characteristics as climate, air motion and dispersion patterns, and the duration of the growing season.

The various mountain systems surrounding the area of the Green River formation are shown in figure 15, and the general topographic relief of the Piceance basin north of the Colorado River in figure 16. This figure does not show Battlement Mesa and Grand Mesa, which lie to the south of the Colorado River. These are part of the Piceance structural basin, but the characteristics of their oil shale resources are not well known.

The main part of the Piceance basin is bounded by the White River on the north, by the Grand Hogback on the east, by the Roan Cliffs on the south, and by Douglas Creek and the Cathedral Bluffs on the west. Within the basin are topographically high areas such as the Roan Plateau, which is relatively flat but severely eroded by stream courses.

*This area is slightly larger than Vermont and New Hampshire combined.

The southern escarpments (steep cliffs) that overlook the valleys of the Colorado and Green Rivers are the most spectacular features of both the Piceance and Uinta basins. At several locations these sheer cliffs rise to heights of 4,000 ft above the adjacent river valleys. They are nearly continuous for a distance of some ZOO miles from the intersection of the Roan Cliffs with the Grand Hogback near Rifle along the Cathedral Bluffs on the western side of the Piceance basin, to the intersection of the Book Cliffs with the Wasatch Plateau at the western tip of the Uinta basin.

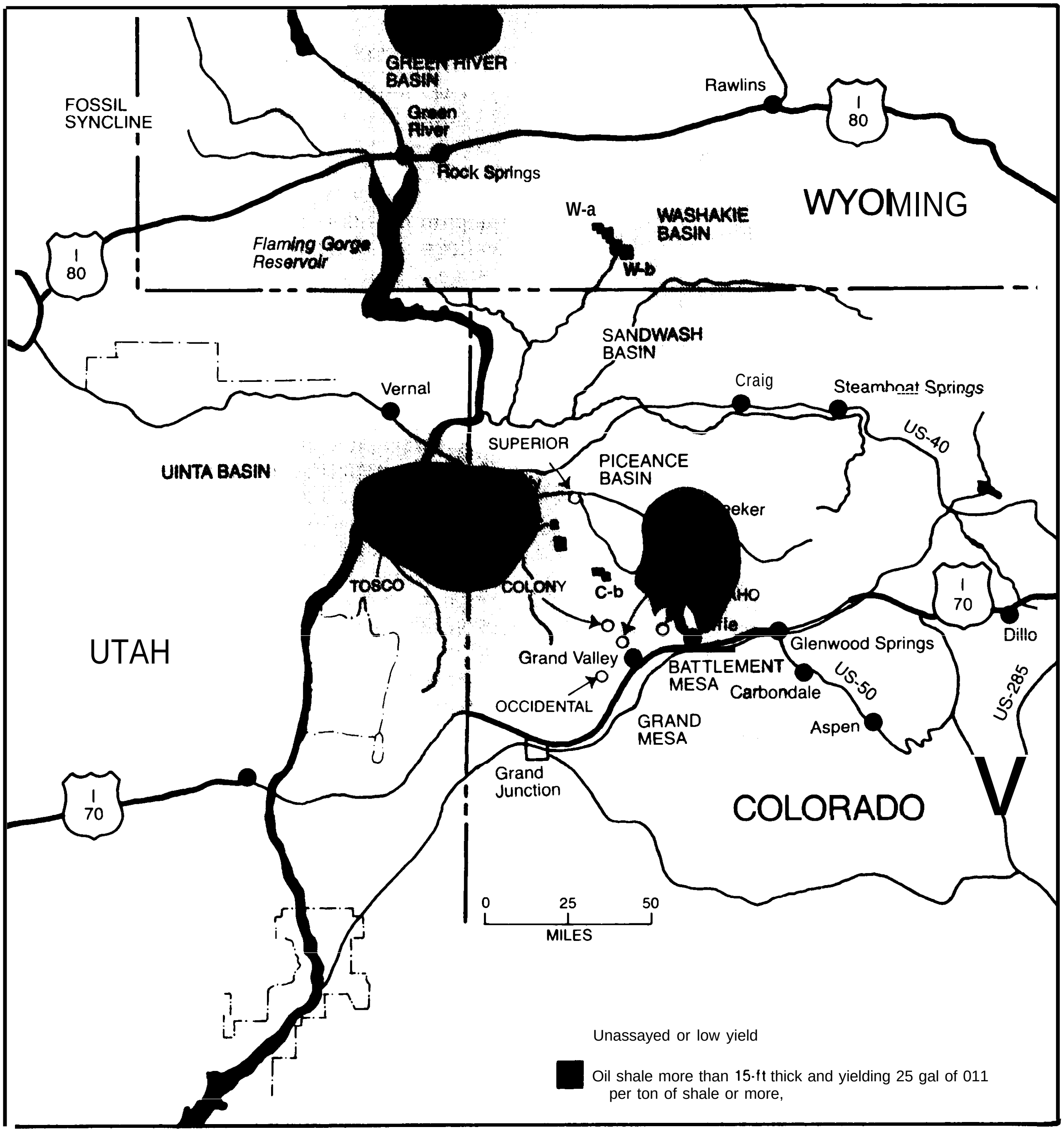
Escarpments along tributary canyons are similarly impressive. The topography along one stretch of Parachute Creek in the Piceance basin is depicted in figure 17. * At the location shown, the maximum elevation is approximately 8,100 ft above sea level at the ridge of the escarpment, and the minimum elevation is about 6,100 ft in the adjacent bed of Parachute Creek. The topography in other tributary canyons is similar. For example, the Roan Creek Valley (near the southern edge of the Piceance basin) is more than 30 miles long and from 2,000 to 3,000 ft deep. The Federal oil shale lease tracts are located in less eroded areas of the basin, and their topographic relief is much less dramatic. On tract C-a, for example, the average difference in elevation between valley floors and nearby ridge tops is only about 300 to 600 ft.

Figure 18 is an idealized cross section of the Piceance basin that shows the stratigraphic relationships between the various structural members of the Green River formation, the overlying Uinta formation, and the underlying Wasatch formation.** The bound-

*The Parachute Creek valley was the site of two oil shale development projects in the 1950's and 1960's, and additional projects are currently being considered for the same locations.

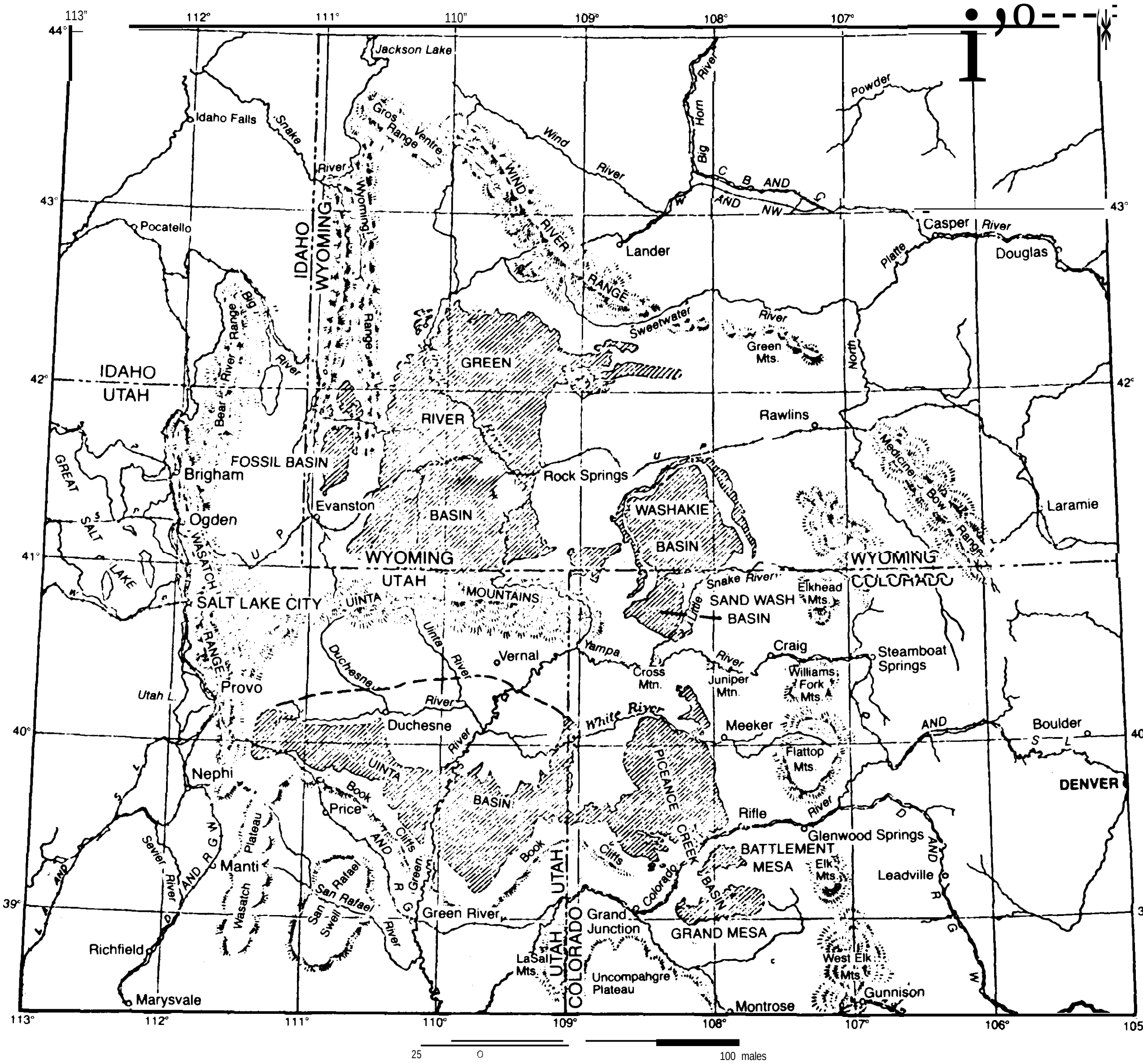
**The Uinta formation was previously called the Evacuation Creek member of the Green River formation in this area. See: C. W. Keighin, "Resource Appraisal of Oil Shale in the Green River Formation, Piceance Creek Basin, Colorado, " Quarterly of the *Colorado School of* Mines, vol. 70, No. 3, July 1975, pp. 57-68.

Figure 14.—The Oil Shale Resource Region of the Green River Formation: Colorado, Utah, and Wyoming



SOURCE. E DiSante, "A Look at 011 Shale–What's It All About, " *Shale Country Magazine,* VOI 1, No 1, January 1975, p 7

Figure 15.—Major Mountain Systems in the Vicinity of the Green River Formation

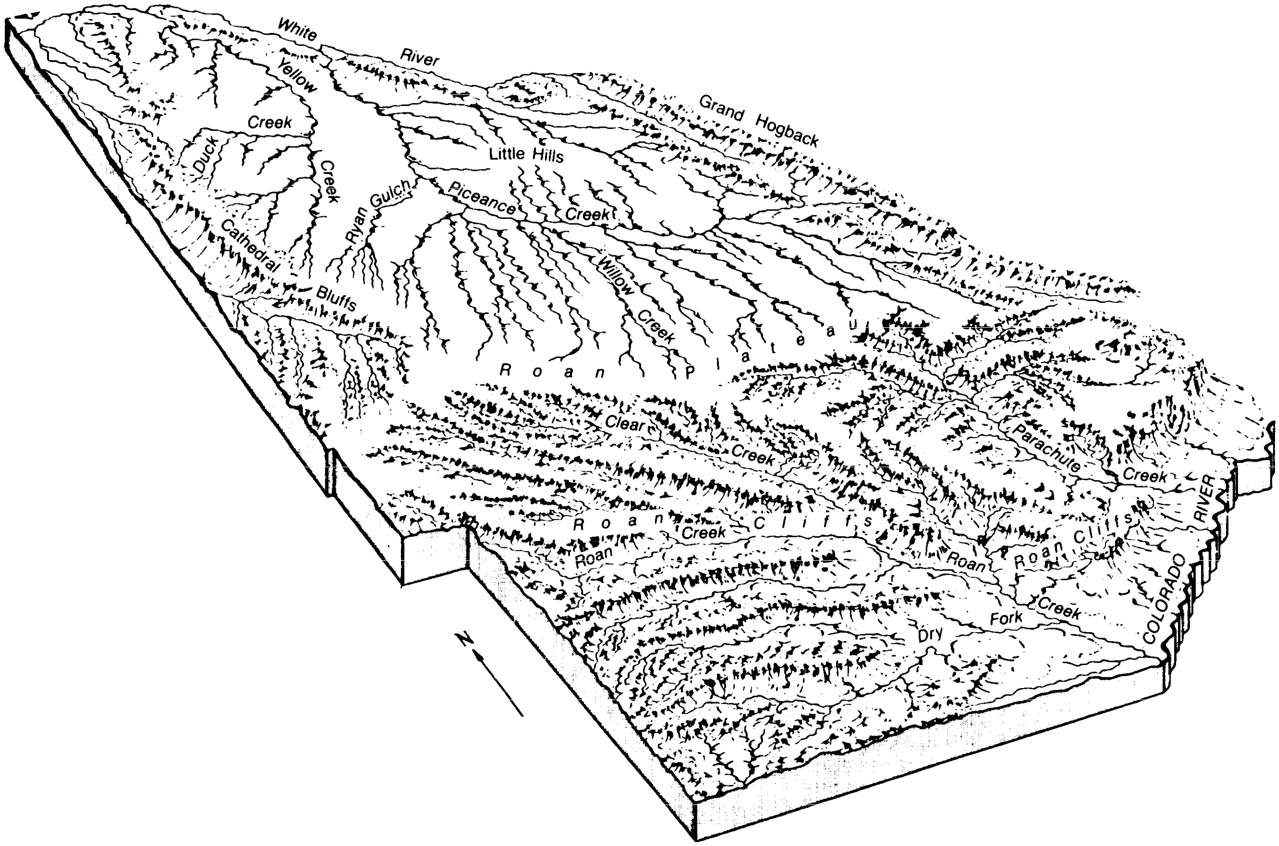


SOURCE U S Department of the Interior, *Final Environmental Statement for the Prototype Oil Shale Leasing Program,* GPO stock No *2400-00785,* 1973. p II-2

aries of these members, which are visible along Parachute Creek, were shown in figure 17. The Green River formation is about 3,000 ft thick near the center of the basin.

The top strata of the section comprise the Uinta formation, which underlies the surfaces of high plateaus in the Piceance basin. The Uinta is largely barren sandstone and siltstone with some interbedded oil shale. Below the Uinta, at a depth of 500 to 1,000 ft, is the Parachute Creek member of the Green River formation, which is almost entirely oil shale marlstone with occasional beds of volcanic material (tuff) and sandstone. Near the basin's depositional center, the Parachute Creek member contains scattered deposits of the minerals dawsonite, nahcolite, and halite. Dawsonite, which contains aluminum, is occasionally found in thin layers between the oil

Figure 16.—Topographic Relief of the Piceance Basin, Colo.



SOURCE Golder Associates, Inc., *Water Management in Oil Shale Mining*, September 1977, NTIS No PB-276 086, p 73

shale beds. More commonly it occurs as microscopic crystals disseminated throughout the oil shale. Nahcolite is sodium bicarbonate. It is a source of soda ash, a raw material for glassmaking, and may also be used to remove sulfur dioxide from stack gases. Halite is sodium chloride, from which table salt is made. The Parachute Creek member also includes the Mahogany Zone, which contains oil shale yielding up to 70 gal/ton. Below the Mahogany Zone, near the center of the basin, is a region from which soluble sodium salts have been leached out by the ground water flows and which now contains saline ground water. Near the bottom of the Parachute Creek member is the “saline zone, ” which contains high concentrations of nahcolite and other sodium salts that have not been leached.

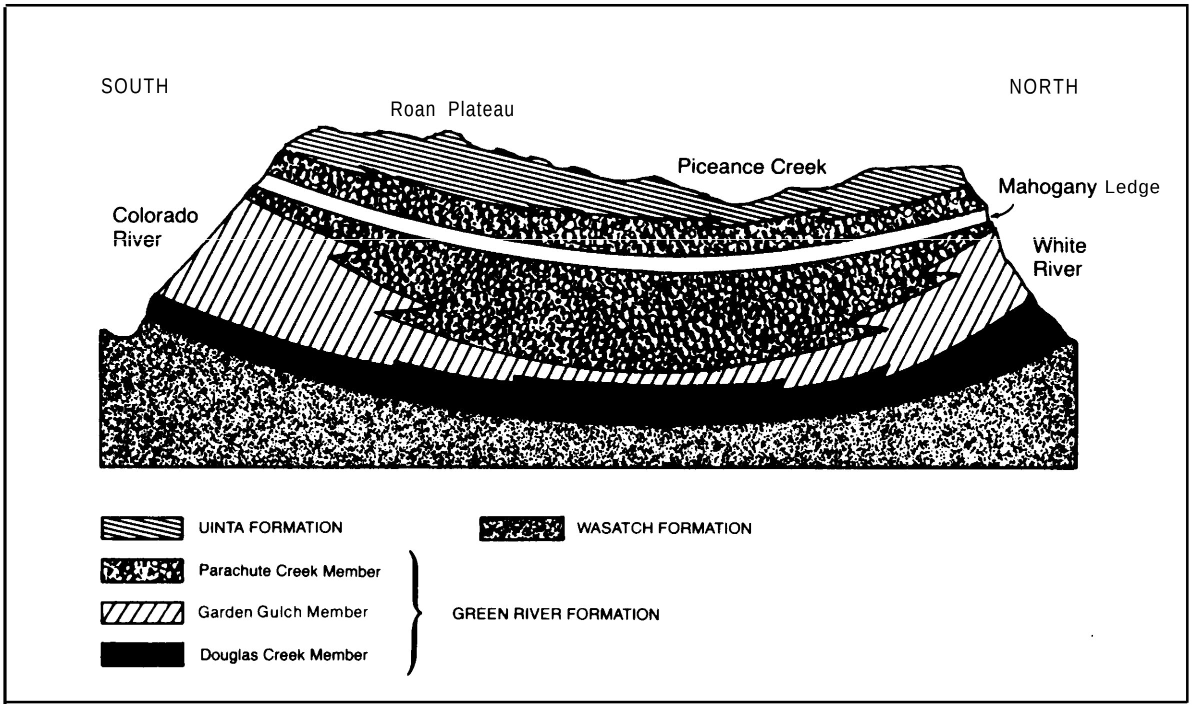
The lower extremities of the Garden Gulch and Douglas Creek members, which underlie the Parachute Creek member, roughly coincide with the bottom of the ancient lake on which the raw materials for the Green River oil shales accumulated. The upper 200 to 300 ft of the Garden Gulch member contain clay beds and deposits of shale having an appreciable organic content. ’ The Garden Gulch shales are true shales in that their primary inorganic components are aluminum-containing illite clays, unlike the oil shales of Parachute Creek, which are primarily composed of dolomite (calcium and magnesium carbonate) rocks. Below the Douglas Creek member is the Wasatch formation, which is largely barren sandstone and mudstone. The Wasatch rocks generally form valley floors throughout much of the Piceance basin. They

Figure 17.— Stratigraphy and Landform Units Along Parachute Creek, Piceance Basin, Colo.

LANDFORM UNITS	**STRATIGRAPHY**
I—CLIFFS (ESCARPMENT)	UINTA FORMATION
2—MID-SLOPES	GREEN RIVER FORMATION
3—SLIP AND ROCKFALL TERRAIN (TALUS)	Tgp--PARACHUTE CREEK MEMBER
4—WASATCH FOOTSLOPES	Tgg—GARDEN GULCH MEMBER
5-ALLUVIAL FAN	Tgd—DOUGLAS CREEK MEMBER
6-CHANNEL LAND	WASATCH FORMATION

SOURCE Bureau of Land Management, *Draft Environmental Statement for Proposed Development of Oil Shale Resources by the Colony Development Operation In Colorado* U S Department of the Interior, 1975 p III-101

Figure 18.— Idealized Cross Section of the Piceance Basin, Colo.



SOURCE Bureau of Land Management, *Draft Environmental Statement for Proposed Development of Oil Shale Resources by the Colony Development Operation in Colorado,* U S. Department of the Interior, 1975, p 111.13

do not contain any oil shale of commercial interest.

Variations in the properties of the various strata have had significant effects on the topographic relief of the region. The Uinta formation sandstones cover the oil shale deposits over much of the Piceance basin. Over the past several million years, outcrops of the Uinta rocks have weathered considerably. The organic-rich oil shale zones of the underlying Parachute Creek member, however, have been much more resistant to weathering. The Mahogany Zone of the Parachute Creek member is an outstanding example. It is from 10 to 225 ft thick, contains oil shale that has, in general, a high organic content, and underlies an area of more than 1,200 mi^2 in the Piceance basin. It also extends into the neighboring Uinta basin. * Oil shale beds immediately above and below the Mahogany Zone are lower in organic content and less resistant to weathering. Where the zone outcrops along tributary canyons, its richer shales have resisted erosion, but the leaner surrounding shales have not. Consequently, the outcropping fringe of the zone is often highly visible as an overhanging prominence known as the Mahogany Ledge, which appears in most areas as a dark band along the escarpment, as shown near the top of figure 17.

Gradual deterioration of the ledge has resulted in rockfalls and the formation of talus (debris) slopes between the bottom of the ledge and the river valley below. Such slopes were indicated in figure 17 as slip and rockfall terrain. They are steep and unstable, particularly if naturally or artificially undercut. Because talus slopes are naturally unstable and lack sufficient permanent topsoil, they do not provide favorable growing conditions for most types of vegetation. However, varying amounts and kinds of vegetation can grow on some slopes depending on their aspect and

*Green River oil shale has a laminar appearance because of variations in the organic content of adjacent strata. Polished sections of the richer beds resemble mahogany wood. Most oil shale projects in the near term will be focused on the rich shales of the Mahogany Zone. The other potential source of rich oil shale, the Garden Gulch member, is probably too deep for near-term commercial development.

the available moisture. The north-facing slopes generally have fairly abundant vegetation; the south-facing slopes much less.

Climate and Meteorology

Climate

The climate of the oil shale region is classified on the whole as semiarid to arid. Annual precipitation varies from approximately 7 inches in the Wyoming plains to approximately 24 inches in the high plateaus of the Piceance basin. Most of this occurs as snowfall, Snowpack, which commonly exceeds 30 inches on protected slopes, provides surface runoff during the spring. Summer and fall are usually dry, but there are short, heavy thunderstorms occasionally during the late summer months. These can cause flash flooding in low-lying areas, Relative humidity is generally low to moderate, with high evaporation rates throughout the region. Because of the region's abundant sunshine, most valley floors and south-facing slopes are usually not covered with snow during winter,

Average temperatures are generally moderate, but maximum daytime temperatures can reach 100° F (38° C) at lower elevations during midsummer, and winter temperatures may drop to – 40° F (–40° C) at higher elevations. The number of frost-free days varies from 50 at higher elevations to 125 at lower elevations. The limited rainfall and low relative humidity coupled with the short growing season restrict the agricultural use of tillable areas. Some forage crops are produced along the tributary valleys within the basins, but most food crops are grown outside of the basin along major rivers where adequate irrigation water is available.

Meteorology

The meteorology of the oil shale region in Colorado is typified by year-round gradient winds from the west that are interrupted only by the passage of frontal systems. Migratory low-pressure systems are frequently deflected around the entire region by the Sierra Nevadas to the west and the Rocky Mountains to the east, Stagnant high-pressure cells sometimes persist for days over the basins, their passage blocked by the surrounding high mountains. Adjacent mountain ranges also contribute to the region's dry climate. Moist air from the Gulf of Mexico is blocked by the Rocky Mountains, while moist air from the Pacific is blocked by the Sierra Nevadas. Flows from both directions lose most of their moisture before reaching the oil shale area. The frequent presence of dry, high-pressure air cells over the basins causes an abundance of clear sunny days with light winds and large differences between daytime and nighttime temperatures.

Air Patterns

Localized wind patterns and other meteorological conditions are very sensitive to topography and elevation. For example, in the Piceance basin, shielding by the Cathedral Bluffs, the gentle downward slope of the basin to the northeast quadrant and the existence of deep gullies, effectively channel surface wind flows and decouple them from the prevailing gradient winds. The shielding effect is provided by the sheer escarpment of the Cathedral Bluffs and Roan Cliffs along the southern and western edges of the basin. When prevailing winds encounter the bluffs they must rise approximately 3,000 ft to clear the upper ridges. The rising air increases in speed and generates turbulent eddies whose duration is enhanced by the downward slope of the basin's upper surface. The shielding of the escarpments combined with the basin's downslope minimizes the effect of gradient winds on surface wind patterns except along very high ridges and plateaus. Airflows in the Colorado River valley, in tributary canyons, and along the valleys and low hills atop the Roan Plateau are almost entirely determined by local topography. They follow a drainage-wind pattern and are nearly independent of the behavior of prevailing gradient winds aloft.

The Mountain-Valley Breeze System

The predominance of drainage-wind patterns is exemplified by the mountain-valley breeze system that has been observed on both Federal oil shale lease tracts in Colorado. The phenomenon is characterized by gentle down-valley air flows beginning around sunset and prevailing for about 10 hours in winter, followed by gentle up-valley flows starting at midmorning. On clear nights, when the upper atmosphere is stable, layers of dense, cold air form near ground level. Any cold air that enters the valley along adjacent slopes will tend to flow downslope into the stagnant cold layer. In the early morning, sunlight gradually warms the surrounding slopes. The cold air then disperses and flows upslope to become entrained in the prevailing gradient winds. At various times during the day and night, circular flow patterns and eddies may prevail within the valley, but they will not carry air from the valley unless gradient winds along the upper ridges are quite strong.’

Thermal Inversions and Their Implications

The mountain-valley breeze system often causes a layer of cold stagnant air to form below a layer of warm air—a thermal inversion. Such inversions exacerbate air pollution problems. There is little air transport out of the cold layer, and pollutants emitted near ground level will tend to accumulate there. Inversions are usually broken by surface heating during the daylight hours, but under certain adverse conditions they may prevail for several days. Valleys with broad floors are especially susceptible, particularly after a snowfall. Snow cover reflects sunlight and inhibits the warming of the stagnant layer during the day, thus reducing the upward flow of warm air that is essential to disruption of the inversion. At night, the exposed snow surface enhances the downward flow of air from the valley ridges, thus increasing the thickness of the inversion layer.

Studies have shown that Grand Junction, Colo., which is located outside of the oil shale basins, experiences one of the highest inversion frequencies in the United States. The inversions occur most frequently during the winter and persist over 50 percent of the time in the fall and winter months. Inversions might be expected to occur less frequently on the slopes and plateaus of the Piceance basin. However, it has been predicted that inversion episodes lasting from 3 to 6 days could occur at least once a year over the entire region.[3] Recent investigations performed on the Federal lease tracts have concluded that the pollutant dispersion potential of the basin is good when contaminated air is released above the higher plateaus, and relatively poor when fumes are released into the valleys. The same studies have predicted that trapping inversions, * such as are associated with the mountain-valley breeze system, should seldom persist longer than 24 hours.

Plants and Animals

The Green River formation underlies a large area. Its soil characteristics show considerable variation over this area. In combination with climate, meteorology, and topography, soil characteristics largely determine the types of plant communities that can be supported. These, in turn, influence the diverse animal species that feed directly or indirectly on them.

Plants

The vegetation of the region is highly diverse, and its makeup is strongly affected by elevation. Most of the broader stream valleys in the region contain fertile alluvial (floodplain) soils that support relatively luxuriant growths of cottonwood, shrubs, and other species. In contrast, the surfaces of steep slopes and some upper plateaus are bare rocks and ledges with little or no soil development. Vegetation is often absent or at best quite sparse in such areas, especially in some plateaus in Utah and Wyoming and in the Piceance basin where the saline rocks of the

*A trapping inversion is one that traps contaminated air regardless of the temperature at which the contaminants are released from their source.

Garden Gulch member are exposed, Some gently sloping upland areas contain thin and poorly developed soils with occasional localized strips of alluvium. Plant cover in these locations varies from very sparse in the poorer areas to relatively abundant over the alluvial deposits. In general, the extent of vegetation is strongly influenced by aspect. South-facing slopes have much less vegetation because their greater exposure to sunlight accelerates the evaporation of critical moisture.

In the high plains of southwestern Wyoming, soils are usually thin and dry, and vegetation is predominantly saltbrush-greasewood and related shrubs. There are limited areas of Douglas fir forests and mountain mahogany woodlands in the northern fringes of the Green River and Washakie basins. Soils are somewhat thicker in the Uinta basin, but the arid climate inhibits plant growth except along the valleys of the major rivers, Saltbrush-greasewood and other shrubs dominate, but there are occasional stands of mountain mahogany, oak shrub, pine, and fir.

In the Piceance basin, shrublands and woodlands also dominate, and forestlands are sparse. Shrubland plants consist primarily of mixed shrubs on moist soils at higher elevations and sagebrush, which dominates in all dry soils. Woodlands occur in thinner soils at lower elevations, and are dominated by pinyon pine and juniper, except where grazing and other disruptions have allowed intrusions of brushes and grasses. Forests are primarily cottonwood along streams at lower elevations, and Douglas fir and aspen on northern and eastern slopes at higher elevations,

Overall, plant life in the Green River formation area is less abundant than in other regions that have ample rainfall and less rugged terrain. However, the area contains diverse plant communities that are well adapted to their environment. Some of the communities in the Piceance basin were studied by the developers of Federal lease tracts C-a and C-b as part of the baseline-monitoring function required for the preparation of detailed development plans. The baseline studies included a census of existing plant species and a determination of the structural characteristics and successional status of plant communities. The results of these studies provide an indication of the diversity of plant life in the vicinity of proposed oil shale development sites.

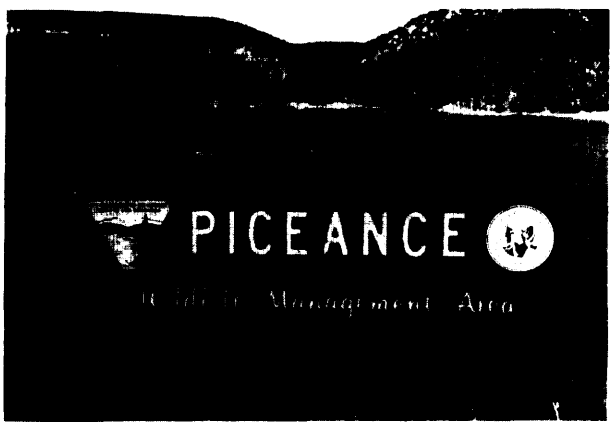
The plants identified on tract C-a included 5 types of trees, 36 shrub species, and 168 herbaceous species, of which 44 were classified as grass or grass-like. One of the plants, dragon milkvetch, is on the Smithsonian Institution's list of endangered plant species. However, the species is not considered threatened in Colorado.' On tract C-b, 37 types of trees, shrubs, and vines were identified, together with 137 species of herbs. Vegetation community types included pinyon-juniper woodlands and rangelands, upland and valley sagebrush, Douglas fir forests and aspen woodlands, mixed mountain shrublands, marshes, riparian areas, agricultural fields, mountain grasslands and communities dominated by bunchgrass, Great Basin wild rye, rabbitbush, greasewood, and annual wild plants. No threatened or endangered plant species were found on tract C-b or on tracts U-a and U-b,[5] Colony Development{ has reported the presence of two endangered plant species (yellow columbine and milkvetch) and one threatened plant species (sullivantia) along the valley of Parachute Creek.[6]

Animals

Many types of mammals, cold-blooded vertebrates, birds, invertebrates, and aquatic systems exist throughout the oil shale regions. The diversity of vertebrates is among the highest in the United States, a result of the highly diversified habitats of woodland, grassy shrubland, and high desert that characterize the area. In Colorado's Piceance basin, for example, more than **300** species of birds, reptiles, mammals, and amphibians have been found or are believed to exist. Similar numbers of animal species have been reported in other geologic basins of the Green River formation. ' Because of the relatively low rainfall, wildlife of the region are highly dependent on the stream systems and the riparian habitats of their environs.

COLORADO'S PICEANCE BASIN

The Piceance basin is Colorado's most important mule deer range. It is the principal wintering ground for the White River herd, the largest nonmigratory deer herd in North America. Its size has been estimated at approximately 100,000 head.[8] The northeast corner of the basin normally supports the highest deer concentrations in winter, and the entire basin is considered to be a deer range in the summer. Antelope are also found there, but are primarily restricted to the northern edge. Limited numbers of elk live in the general area of the basin and especially on the upper plateaus. A few mountain lions roam over it, largely in pursuit of migrating deer herds and sheep flocks, and a few black bear are found at higher elevations in the southern part. Coyotes and bobcats are regarded as abundant, but there has been no detailed census of these predators. There may be as many as 150 to 200 cottontail rabbits per square mile, and both snowshoe hares and pine squirrels are found in the Douglas fir forests of the high plateaus. Other mammals present include yellow-bellied marmots, prairie dogs, ground squirrels, porcupines, chipmunks, red foxes, raccoons, badgers, and skunks, and from 150 to 250 wild horses range throughout the entire area. The avian species found in this basin include sage grouse, partridge (stocked), pheasants, mallards and other ducks, mourning doves, pigeons, golden and bald eagles, and many other species of migratory waterfowl, shorebirds, songbirds, hawks, eagles, and vultures. Fish species include trout, suckers, and minnews.[8]



Phofo credit *OTA staff*

UTAH'S UINTA BASIN

Utah's Uinta basin is more primitive and isolated than the Piceance basin. It has been described as an ideal natural faunal habitat. ’() Parts of the basin are utilized by mule deer herds as winter feeding areas, and small numbers of elk are also present in restricted areas. Transplanted antelope have become established and appear to be flourishing. Bears have been reported in the area but are considered scarce. Mountain lions also range over the basin, but their numbers are unknown. Other mammal species include coyotes, porcupine, bobcat, muskrat, beaver, mink, rabbits and hares, and others. The Bureau of Land Management (BLM) has estimated that about 130 head of wild horse inhabit Utah's oil shale lands. Most bird species found in the Piceance basin are also found in the Uinta basin. Fish live in the clear headwaiters of various tributaries but are less abundant in the heavily silted lower reaches of most rivers and streams.[11]

WYOMING'S BASINS

Over 300 animal species have been identified in Wyoming's Green River and Washakie basins. Of the larger mammals, elk and moose are believed to inhabit the parts of Wyoming that encompass the oil shale regions. Relatively few elk and moose live in the oil shale basins per se, but black bear and lions have been observed. The basins also contain important antelope ranges and habitats. Sizable numbers of wild horses live in the Washakie basin and winter in the highlands where prevailing winds sweep the heavy snowfalls from grazing areas. Several species of grouse, ptarmigan, partridge, wild turkey, pheasant, ducks, and geese have also been observed in the general vicinity of the oil shale lands. Tributaries support several trout varieties including the Colorado River cutthroat, and some of the better trout habitats are located within the oil shale area. 12

ENDANGERED SPECIES

In compiling an inventory of animal species, the tract C-a lessees recorded sightings of both peregrine falcons, listed as an endangered species by the U.S. Department of the Interior (DOI), and prairie falcons, a fully protected species, The number of peregrine falcons was estimated at from one to four. No falcon nesting sites were found in the 170 mi^2 survey area. It is unlikely that falcons would nest within the tract boundaries because of the absence of large cliff faces (their preferred nesting location) and the scarcity of water. Approximately 30 greater sandhill cranes, endangered species in Colorado, were observed in the study area, but no nesting sites were discovered within a 20-mile radius of the tract. The tract and its environs may serve as staging and foraging areas for the birds during their annual migrations, but the area does not contain any important crane habitats. [13]

The environmental reconnaissance on tract C-b did not reveal any rare, endangered, threatened, or protected animal species. However, a prairie falcon was sighted outside of the tract boundaries.[14] Environmental surveys for Colony Development revealed no endangered or threatened species within the tract boundaries.[15] BLM's environmental statement for the Colony program lists several species of concern that might be present in the general area. These include the southern bald eagle, the prairie and peregrine falcons, the humpback chub, the Colorado squawfish, the Colorado cutthroat trout, the bonytail sucker, the black-footed ferret, and the ferruginous hawk. [16]

Air and Water Quality and Economic Base

Regional air and water quality, and their potential alterations because of oil shale development, are discussed in chapter 8. The region's economic base, and the impacts it might experience during the development of an oil shale industry, are discussed in chapter 10.

Air Quality

In general, air quality is excellent throughout most of the region because of the region's rural character and lack of industrialization and urban development. Ambient concentrations of sulfur dioxide, nitrogen oxides, hydrogen sulfide, and carbon monoxide are very low compared with more densely populated areas in the three oil shale States. In both the Piceance and Uinta basins, however, there are occasionally high ambient concentrations of nonmethane hydrocarbons, particulate, and ozone, The hydrocarbons are apparently emitted in aerosol form by sagebrush and other vegetation, because their concentrations vary with the growing seasons for these plants. Windstorms and passing automobile traffic on unpaved roads both contribute to high particulate concentrations. Haze is occasionally observed in the valley of the Colorado River and in the canyons of its tributaries. It has not been determined whether this haze is caused by photochemical smog or by a combination of suspended particulate and local humidity. In general, the area is free from man-induced odors. [17]

Air quality problems may be encountered in the future because of the region's peculiar meteorological conditions. As discussed previously, the predominance of the mountain-valley breeze system coupled with high altitudes and the effects of surrounding mountain ranges on gradient winds aloft, leads to frequent thermal inversions, especially during winter. To date, such inversions have been offensive only near the larger population centers outside of the oil shale basins, such as Grand Junction. However, inversion-related air pollution is likely to become more severe as the region develops, regardless of whether such growth is associated with the creation of an oil shale industry or expansions in other activities. The potential for inversions may preclude siting processing plants in canyons and other low-lying areas, thus, limiting them to higher areas such as the Roan Plateau of the Piceance basin.

Water Quality

Water quality in the region is highly variable. It is good to excellent in most of the upstream reaches of major tributaries such as the Colorado River, but significantly poorer in the downstream reaches. The gradual deterioration is caused by discharges from numerous point and nonpoint sources. About half of the increase in salinity is related to the discharge of naturally saline streams into the river system. The rest is generally related to the concentration of human activities, such as urban areas, mineral development sites, and irrigated farmlands.

A twentyfold increase in salinity has been noted in the Colorado River between its headwaiters and Imperial Dam in Arizona.[18] Salinity is of special concern because the Colorado River system is important to the entire Southwest. Irrigated agriculture causes most of the human-related salinity effects through salt loading (picking up soluble salts from field soils) and salt concentration (the evaporation and transpiration of relatively pure water in irrigation canals and fields).

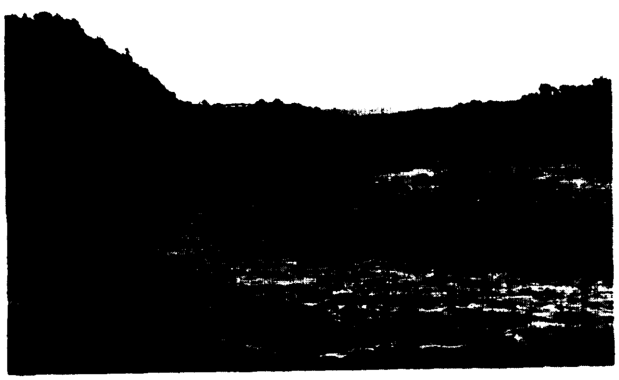


Photo credit OTA staff

White River near Meeker, Colo.

Surface streams within the oil shale basins also show wide variations in water quality. In Piceance Creek, for example, the concentration of dissolved solids range from less than 400 mg/1 in the upper reaches to over 5,000 mg/1 at the discharge point into the White River.[f] Dissolved solids in Yellow Creek in the Piceance basin range from about 700 to 3,000 mg/1. Water quality deteriorates in the downstream direction because of natural surface runoff, agricultural return flows, and the discharge of saline ground water from aquifers in the Green River and Uinta formations. As described in chapters 8 and 9, ground water quality in the aquifers of the Piceance basin varies enormously, from a low of less than 250 mg/1 in the purer waters of the upper aquifer above the Mahogany Zone to over 63,000 mg/1 in the highly saline brines of the lower aquifer in the northern portions of the basin. In general, the ground water from all the aquifers in the Piceance basin does not satisfy the drinking-water standards of the U.S. Public Health Service. There are particular problems with respect to dissolved solids, fluoride, and barium concentrations.[20]

The quality of surface streams and ground water in the Uinta basin shows similar extreme variability. The concentration of total dissolved solids in the Uinta basin ground water aquifers range from 350 mg/1 (which is considered potable water) to 72,000 mg/1 (which is considered brine). In the Wyoming oil shale basins, surface streams have dissolved solids concentrations from 150 to 855 mg/1, while concentrations in ground water range from about 450 to 7,000 mg/l.[21]

Population

The population density over the entire oil shale resource region is low, averaging about 3 persons per square mile. The densities in many areas are even lower. For example, when the oil shale resources of a 2,500 mi^2 area of the Uinta basin were mapped in 1967, 250 people lived in the entire area, with 200 of them living in the town of Bonanza. The average population density of the area was therefore about 0.1 persons per square mile.[22]

The population of the entire Green River formation region is approximately 120,000. About 62 percent live in Colorado, 17 percent in Utah, and 21 percent in Wyoming. The major communities are Grand Junction, Rifle, Meeker, Craig, and Rangely in Colorado; Vernal in Utah; and Green River and Rock Springs in Wyoming, Grand Junction, the largest Colorado town, has a population of approximately 24,000, Vernal 'has about 6,200, and Rock Springs about 28,000, The region's present economy is based on agriculture (crop raising and sheep and cattle ranching), minerals production (oil, gas, uranium, trona, and coal), and tourism and recreation,[23,24,25]

Oil Shale Products and Their Potential Applications

The Nature of Oil Shale

Green River oil shale is not a shale nor does it contain appreciable amounts of liquid oil. The shale portion is actually a marlstone, and its principal constituents are dolomite, calcite, and quartz. In contrast, true shales are composed largely of silicate clays. They have a finely stratified or laminated structure and tend to fracture along individual bedding planes. Oil shale also has a stratified appearance and tends to fracture in a similar matter, particularly when organic matter is present in low concentrations. These properties led early investigators to believe that the Green River oil shales were true shales. However, the appearance and fracture properties of Green River shale arise from variations in the concentrations of organic matter it contains, and not to any great extent from the characteristics of the inorganic component,

Most of the organic component is a solid material called kerogen, from the Greek words for waxmaking, that is insoluble in most standard petroleum solvents. About 10 percent of the organic component is a solid substance called bitumen that can be dissolved in certain solvents.

Kerogen is composed of carbon and hydrogen molecules cross-linked together by sulfur and oxygen atoms to form relatively large three-dimensional macromolecules with molecular weights of about 3,000. These macromolecules are embedded within the finer grained inorganic or mineral matrix of the oil shale rock. This organic continuous phase gives kerogen-rich oil shale most of its physical strength and stability. When the organic matrix is removed from very rich oil shale, the mineral residue has little cohesive strength and is easily crushed to a fine powder,

Kerogen Pyrolysis

When kerogen is heated above 400” F (200° C), chemical bonds between and within the individual organic molecules are ruptured, forming smaller molecules. Most of these can be readily isolated from the mineral material as liquid and gaseous products. Some of the organic coproducts of kerogen decomposition remain trapped within the inorganic material as a coke-like residue.

A chemical change produced by heat is called pyrolysis, This process can also be called destructive distillation, when an organic substance is broken down by heat and the products are distilled off, leaving a residue. When pyrolysis is carried out in a vessel called a retort, the process is called retorting. Oil shale retorts may vary in size from laboratory-size Fischer assay* units used to estimate the potential oil yield of oil shale rocks, to commercial-sized vessels that can process 10,000 tons of raw oil shale per day, to in situ retorts containing several hundred thousand tons of rock.

When kerogen is pyrolyzed, three combustible products are formed: vaporized oil, which can be condensed by cooling; a gaseous mixture containing hydrogen, oxides of carbon, hydrogen sulfide, and hydrocarbon

*In a Fischer assay, small samples of crushed oil shale are heated to 9320 F (500° C] under carefully controlled conditions. The oil yield by this method is the standard measure of oil shale quality.

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gases such as methane; and a coke-like solid residue that remains behind in the retort.

The relative proportions of oil, gases, and coke largely depend on the pyrolysis temperature and atmospheric conditions in the retort, and to a lesser extent on the organic content of the raw shale. The product yields from a typical Green River oil shale pyrolyzed at 932° F (500° C) according to the standard Fischer assay technique are summarized in table 16. As indicated, the raw shale contained about 17 percent organic matter by weight and yielded about 27 gal/ton. Oil was the largest decomposition product. It comprised 63 percent of the organic matter originally present in the shale, Noncondensible gases comprised 15 percent, and the carbon residue about 13 percent. The balance of hydrogen and oxygen content of the organic matter was transformed to water vapor by the pyrolysis process.

Table 16.–Composition and Pyrolysis Products of Typical Colorado Oil Shale[a]

Mineral constituents

Mineral	Weight percent of minerals
Dolomite	32
Calcite	16
Quartz	15
Illite	19
Low-albite	10
Adularia	6
Pyrite	1
Acalcime	1
Total	100

Ultimate analysis of organic constituent

Element	Weight percent of organics
Carbon	765
Hydrogen	103
Nitrogen	25
Sulfur	1.2
Oxygen	9.5
Total	1000

Yields from Fischer assay **Pyrolysis**

Decomposition product	Weight percent of organic constituent in raw shale	Weight percent of total raw shale
Oil	63	10,4
Noncondensable gas	15	2.5
Fixed-carbon residue	13	2.2
Water vapor	9	1.4
Total	100	16,5

[a]Pyrolyzed by the standard Fischer assay procedure at 932° F 011 yield = ?6 7 gal/ton

SOURCE T A Sladek Recent Trends in 011 Shale–Pad 1 History Nature and Reserves *Mineral Industries f3u/e/in* vol 17 No 6 November 1974 pp 4-5

Each of the three main products of kerogen decomposition is a potential source of energy. Crude shale oil can be burned directly as a fuel or it can be refined to produce fuels similar to those obtained from conventional petroleum crude oils. As discussed in chapter 6, the physical and chemical properties of crude shale oil differ from those of conventional crude, thus presenting some refining challenges. However, shale oil can yield high-quality finished fuels such as gasoline and jet fuel.

The composition and properties of the off-gas from kerogen pyrolysis vary tremendously with the nature of the pyrolysis process. Gas from the Fischer retort typically has a heating value comparable to that of natural gas. Such high-quality gas could be used as plant fuel in the oil shale facility, or it could be pipelined to other areas for commercial or industrial applications. In contrast, gases from commercial directly heated retorts are highly diluted with carbon dioxide (from combustion and from the decomposition of carbonate minerals) and nitrogen. They have only about one-tenth the heating value of natural gas. Such gases could be useful within the oil shale facility but they could not be transported economically over any significant distance, nor could they be upgraded to higher heating values at reasonable cost. Surplus retort gases could become valuable by-products if they were burned for power generation. Some developers plan to do this.

The coke residue is also a potential source of energy, but it is a very poor solid fuel compared with coal or with the raw shale itself. (A typical shale coke from the Fischer retort has a heating value of about 250 Btu/lb; most quality coals have heating values of about 12,000 Btu/lb.) Transportation of the coke residue for offsite combustion would not be practical because of its high content of inert mineral matter. Any energy values will have to be recovered within the oil shale facility either by burning the residue in the retorts or by converting its carbonaceous component to fuel gas. If the latter approach is followed, the gas may be consumed within the plant, upgraded for external sale, or burned onsite for power generation.

As indicated in table 16, inorganic minerals comprise approximately 80 percent of raw Green River oil shale. These minerals remain as part of the coke residue after the oil and gas products are removed. The properties of this retorted or spent shale vary with the type of retorting procedure used. Indirectly heated retorts produce a carbonaceous spent shale, while directly heated retorts produce a shale that is essentially stripped of carbon. The indirectly heated TOSCO II retort, for example, produces a spent shale resembling black talcum powder. The directly heated Union "A" retort produces a gray decarbonized spent shale resembling coal ash and clinkers.

Spent shale will be produced in enormous quantities by an oil shale industry of any significant size. Some potential uses exist for the spent shale produced by aboveground retorts. With in situ processing, the spent shale remains underground, and the only option for byproduct recovery is by means of a leaching process. Spent shale on the surface could be converted to cement or building materials, but the output from a single commercial-size facility will far exceed the market demand for such material. Nearly all of the spent shale will have to be disposed of as a waste material, and such disposal will have to be done either on or very near the plantsite. Spent shale disposal is the source of much of the environmental controversy surrounding oil shale development as discussed in chapter 8.

Associated Minerals

In addition to kerogen, some deposits in the Green River formation contain several sodium-bearing minerals that could be commercially valuabIe. These include nahcolite, dawsonite, and trona. Nahcolite (sodium bicarbonate) is chemically identical to commercial baking soda. As mentioned previously, it occurs in scattered deposits near the depositional center of the Piceance basin and is found in high concentrations near the bottom of the Parachute Creek member. Nahcolite may be processed to yield soda ash, a common raw material for glass production, and its ability to adsorb sulfurous gases may be of use in scrubbing sulfur compounds from powerplant stack gases.

Dawsonite (dihydroxy sodium aluminum carbonate) is a potential source of alumina, which can be converted to aluminum. As indicated previously, dawsonite is found as disseminated crystals and crystalline planes in the Parachute Creek member. Occurrences of both nahcolite and dawsonite are very extensive in this basin. A survey of mineral resources in the basin by USGS estimated that 1 mi^2 of terrain in the soda-mineral region overlies 1 billion bbl of potential shale oil in place, 130 million tons of nahcolite with a potential soda ash yield of 82 million tons, and sufficient dawsonite to produce 42 million tons of alumina. By comparison, the bauxite deposits in the rest of the United States contain the equivalent of only about 30 million tons of alumina.[26]

Trona is a hydrated mixture of sodium carbonate and sodium bicarbonate. It is also a source of soda ash for glass production, and is presently being mined for this purpose in Sweetwater County, Wyo. Unlike nahcolite and dawsonite, trona does not always occur in intimate association with oil shale, and its commercial development could take place either with or without the related development of hydrocarbon resources. The existing facilities in Sweetwater County do not recover shale oil. Projected plans for multiminerals operations, such as those of Superior Oil and the Multi Minerals Corp., call for the simultaneous production of shale oil, soda ash, and alumina.[27 28]

Both of these projects depend on acquiring access to Federal land through land exchanges or leasing. No privately owned tracts contain sufficient quantities of dawsonite and nahcolite for their development to be economically attractive. Some sodium leases have been issued for oil shale land, but these exclude the development of the associated oil shale.

The History of Oil Shale Development

Useful hydrocarbons have been extracted from oil shale for many years. In the 14th century, Austrian and Swiss oil shales were pyrolyzed to yield "petro oleum, " or "rock oil. " This was subsequently processed to yield an ointment called Icthyol, a name derived from the Greek words for fish-oil, in reference to the fossilized fish remains frequently encountered in the marine oil shales of central Europe.[29] In 1694, England issued patent No. 33 for a retorting process that was claimed to produce "oyle from a kinde of stone. "[30]

In 1859, the first commercial oil well was drilled in Pennsylvania. Prior to that year, at least 50 commercial plants existed along the Atlantic seaboard of the United States for extracting fuel oil from oil shales.]' Also in 1859, the first commercial oil shale retort began operating in Scotland. It started an industry that lasted for over 100 years.

In 1874, workers on the transcontinental rail line found that rocks picked up from excavations along the Green River in Wyoming ignited when used to protect campfires from the night winds. The March 1874 issue of Scientific American noted that the railroad superintendent :[32]

> . . . has caused analyses and experiments to be made with this substance which proves to be a shale rock rich in mineral oils. The oil can be produced in abundant quantities, say 35 gallons to the ton of rock. The oil thus obtained is of excellent quality.

The rocks of interest were pieces of oil shale from the Green River formation.

The use of oil shale as a fuel resource thus predates the large-scale use of conventional petroleum by several centuries. In the past 150 years, commercial industries have existed in Scotland, France, Germany, Spain, South Africa, Australia, and the United States. At present, industries exist or are being started in Estonia, the People's Republic of China, Brazil, and perhaps the United States. The following section describes the history of foreign and U.S. development efforts and defines the status of present industries around the world.

Scotland

Scottish oil shales occur in seams from 4 to 14 ft thick yielding approximately 22 gal/ton. Reserves were originally estimated to contain about 600 million bbl. The first retorting plant was built in 1859. Its economic viability was immediately threatened by the rapid development of conventional petroleum that followed the drilling of the first commercial oil well. The production of shale oil and valuable byproducts such as waxes, ammonia, pyridines, * ammonium sulfate, and building materials enabled the Scottish industry to survive for over 100 years despite the high cost of the oil in comparison with conventional crude oil. At its peak, the industry involved about 140 different companies and processed about 3.3 million ton/yr of oil shale. In 1919, the companies were consolidated into a single corporation that subsequently became a subsidiary of the predecessor of British Petroleum. The industry was subsidized by the British Government with tax credits and other incentives, but competition from cheap petroleum forced the last plant to close in 1962.

Sweden

Typical Swedish oil shales are about 50 ft thick and yield from 6 to 15 gal/ton. The total resource is estimated to be about 2.5 billion bbl of shale oil in place. The Swedish oil shale industry began in the 1920's, with the largest operations near the city of Kvarntorp. These facilities featured two types of aboveground retorts and a unique type of in situ process in which the deposits were pyrolyzed with electric heaters. The industry reached a maximum capacity of 2 million tons of oil shale per year (6,000 ton/d) and produced as much as

*Nitrogen-containing organic solvents also used to synthesize other useful products.

550,000 bbl/yr of crude shale oil. Because of the limited quantity of high-quality reserves, and price competition from petroleum crude, the industry ceased operation in 1966.

France

French resources total about 500 million bbl of shale oil in place. They are of medium quality and yield from 10 to 24 gal/ton. They are more properly called bituminous shales, rather than oil shales, because they contain inclusions of asphaltic compounds. The French industry began in 1840 and continued intermittently until 1957. Its maximum throughput was 0,5 million ton/yr of shale, attained in 1950. For most of its existence, the industry was protected from competition with foreign oil by excise taxes and import duties.

Spain

The best Spanish resources yield from 30 to 36 gal/ton. Reserves have been estimated at about 280 million bbl of oil in place. The Spanish industry began in 1922 using retorts similar to those that had been developed in Scotland. Maximum throughput for these units was 220 ton/d, reached in 1947. In 1955, new retorts from Scotland were installed. In 1960, the enlarged industry processed 1 million tons, supplying more than half of Spain's requirement of lubricating oil, Obsolete processing technology and high operating costs forced the industry to cease operation in 1966.

Germany

German resources are estimated to contain only about 2 million bbl of shale oil in place. Oil yields average only 12 gal/ton. German shales were developed as early as 1857, and several retorts were operated in the 1930's. A major development effort was initiated during World War II in response to wartime fuel shortages. The German industry used two types of aboveground retorts and one in situ process. A plant with about 30 Lurgi above--ground retorts was operated from 1947 to 1949. In 1961, a plant was built in the town of Dotterhausen that burns finely crushed oil shale in a fluidized-bed combustor. The heat of combustion is used for power generation, and the spent shale product is used to make cement. The plant is the only active oil shale facility in West Germany.

South Africa

Very rich deposits are found in South Africa. Oil yields reach 100 gal/ton, with an average of 55 gal/ton, and the deposits are located just beneath coalbeds. South African shale oil production began in 1935, and the industry attained a maximum throughput of 800 ton/d in the 1950's, with a corresponding shale oil production of 800 bbl/d. The industry was located in the country's interior, and although it was not directly subsidized by the government, its economic viability was enhanced by the high cost of transporting competing petroleum from the seacoast ports to interior markets in the vicinity of the plants. The richer deposits were eventually depleted, and the industry ceased operations in 1962,

Australia

Oil shale deposits are found throughout Australia. Those of New South Wales and Tasmania have been developed commercially. Total reserves are estimated at 270 million bbl of shale oil in place. Most of the deposits are very rich, with oil yields as high as 180 gal/ton. Shale oil production in New South Wales began in 1862, and by 1892, about 100,000 tons of shale were being processed each year. The Australian Government began subsidizing the industry in 1917, but production ceased in 1925. Production of Tasmanian shale oil began in 1910 and ceased in 1935. In the interim, about 41,000 tons of oil shale were processed, and 85,000 bbl of shale oil were produced.

Production was resumed in New South Wales early in World War II under the direction of the Australian Government. By 1947, annual throughput reached 330,000 tons, and about 100,000 bbl of shale-derived gasoline were produced annually. The production was equivalent to about 3 percent of Australia's gasoline consumption. The plant was closed in 1952 because of resource depletion, high operating costs, and competition from conventional petroleum.

United States

As indicated previously, the U.S. oil shale industry was an important part of the Nation's energy economy before the first oil well was drilled. At least 50 commercial plants for extraction of fuel oil from eastern oil shales existed prior to 1859. The industry disap peared shortly after commercial petroleum production began.

Between 1915 and 1920, supplies of domestic crude fell below demand, and oil imports increased, especially from new oilfields in Mexico. USGS indicated at that time that the United States had only a 9-year reserve of petroleum in the ground and that the outlook for new discoveries was not good. At about the same time, USGS announced that large fuel resources were contained in the oil shales of the Green River formation. When combined with predictions of forthcoming fuel shortages, the announcement triggered an oil shale boom. Some 30,000 mining claims were filed on Federal lands, and about 200 companies were formed to develop the resource. Retort development programs were initiated at several locations, and at least 25 retorting processes were advanced to the pilot-plant stage. Total shale oil production was negligible, but interest was at an all-time high. The boom ended abruptly with the discovery of large oilfields in eastern Texas. Oil prices dropped to a few cents per barrel, and interest in oil shale development essentially disappeared.

Little R&D was conducted in the United States until World War II. In 1944, out of concern for the hazards of imported energy, Congress passed the Synthetic Liquid Fuels Act, which authorized USBM to establish a liquid fuel supply from domestic oil shale. USBM began a comprehensive R&D program that has continued to the present day, although oversight authority was transferred to the Energy Research and Development Administration in 1974 and to its successor, DOE, in 1978.

One of USBM's most significant early acts was the establishment of a research facility at Anvil Points on the Naval Oil Shale Reserve near Rifle, Colo. Between 1944 and 1956, the Anvil Points facility was used for mining studies that led to the application of the room-and-pillar technique of underground mining. The gas combustion retort, the predecessor of modern directly heated retorts, was also developed during this period. In 1964, the facility was leased by the Colorado School of Mines Research Foundation, and was the site of a 4-year development program in which the gas combustion retort was evaluated and improved by a consortium of six major oil companies: Mobil, Humble, Continental, Pan American, Phillips, and Sinclair.

In 1973, the facility was leased by Development Engineering, Inc. (DEI), which operated it for 5 years during which the Paraho retorting process was developed. This is an improved version of the gas combustion retort. DEI then used the facility to produce over 100,000 bbl of shale oil for refining studies, and has recently proposed to use Anvil Points for further development work, including the construction and operation of a commercial-size module of the Paraho retort.

Between 1963 and 1968, DOI evolved a leasing proposal that was intended to encourage private development of the Federal oil shale lands in the Green River formation. The program failed to attract private participation. However, it gave rise to the current Federal Prototype Oil Shale Leasing Program, which was conceived in 1969 and promulgated in 1974 with the sale of leases to four tracts in Colorado and Utah. The histories of these leasing programs are presented in volume II of this report. The status of development efforts on the Federal lease tracts is described in the last section of this chapter.

In addition to these activities on Federal lands, private companies have also engaged in exploration and R&D programs on their own lands, The companies that have been most heavily involved are: Union Oil, Occidental Petroleum and its subsidiary Occidental Oil Shale, Inc.; Superior Oil Co.; and the Colony Development Operation group, which has included Tosco, Atlantic Richfield, Cleveland Cliffs Iron Co., and Ashland Oil Co. The activities of these companies, and others that are presently involved in oil shale development, are summarized in the following section, together with a status report on the industries in other countries.

Status of Foreign Oil Shale Industries

Morocco

Oil shale is found in Morocco at Timahdit, in the Middle Atlas mountains, and at Tarfaya, on the Atlantic coast in the southern part of the country. Other, smaller deposits have also been found. Most of the development efforts involve the Timahdit deposits, which contain an estimated 4 billion to 9 billion bbl of shale oil in a seam that is as much as 350 ft thick. The Moroccan Government is actively investigating aboveground retorting, direct combustion of oil shale for power generation, and modified in situ processing technologies.

Soviet Union

The principal reserves of the U.S.S.R. are in the Baltic Basin, with additional deposits in the Ukranian S.S.R. and the Central Asian Republics. The latter resources have been little explored and are not being developed; most development activity is centered on the "kukersite" oil shales in the Baltic basin. The total Baltic resource is estimated to be about 21 billion tons, with about 11.3 billion tons regarded as having commercial potential. About 8.4 billion tons occur in the Estonian S. S. R., with about 2.9 billion tons in the Leningrad area. The Estonian shales occur in beds about 10 ft thick and are buried beneath 30 to 130 ft of overburden. They are of good quality, yielding about 50 gal/ton.

The Estonian deposits were first developed in the 1920's after the State achieved independence from Finland. In 1939, about 1.7 million tons were processed. About 60 percent of the shale was retorted to obtain fuel oil; the rest was burned directly for process heat and power generation. During World War II, the area was occupied by Germany, and the shale oil produced during this period was refined to obtain illuminating oil and bunker fuel oil for the German navy. When the Estonian S.S.R. was created, the German-built plants were expanded to provide fuel gas for the cities of Tallinn and Leningrad. Shale oil and petrochemicals were also produced, but most of the shale mined was burned as a boiler fuel for power generation.

In 1970, about 14 million tons were mined. The present goal is to expand production to 54 million ton/yr. About 75 percent of the present production is burned under boilers to supply about 90 percent of Estonia's electrical needs. The rest is retorted to produce fuel oil, gasoline, fuel gas, and chemicals.

The Soviet industry is estimated to have mined about 560 million tons of kukersite between 1945 and 1975. As noted, only one-fourth of the mined shale is retorted. If all of the shale had been converted to oil, the average production rate would have been about 67,000 bbl/d, slightly more than would be produced by a single commercial-scale oil shale facility in the United States. The present target of 54 million ton/yr is equivalent to about 200,000 bbl/d.

Two types of large-scale retorts are used: the Kiviter gas generator which is similar to the gas combustion and Paraho directly heated retorts; and the Galoter retort which uses spent shale as a heat carrier and is remarkably similar to the TOSCO II indirectly heated design. At present, the largest Kiviter retort has a capacity of about 1,000 ton/d, about one-tenth the size of retorts planned for U.S. plants. The largest Galoter unit has a capacity of about 500 ton/d. A 3,30()-ton/d unit is under construction. *

People's Republic of China

Oil shale is found near Fushun in Manchura, and near Maoming in the Province of Kwantung. The Manchuria deposits occur in 450-ft-thick seams and overlie thick coal seams. The shale is mined by open pit methods, together with the coal, Oil yields average only about 15 gal/ton. The deposits were first developed by the Japanese when they invaded Manchuria during World War II. About 1.3 million bbl of shale oil were recovered during the war through use of retorts similar to the gas combustion design. Most of the oil was refined into fuel oil for the Japanese navy. During the Korean war, production was expanded to about 50,000 bbl/d. Byproducts included chemical fertilizer from the nitrogen in the shale oil and cement from the spent shale. Additional shale was mined, mixed with coal, and burned directly for power generation.

During the past decade, the capacity of the Manchuria industry has remained fairly constant, but six retorting plants have been built in the Kwantung Province. The total production from the Chinese plants is unknown, but it is unlikely to be more than about 50,000 to 70,000 bbl/d. About two-thirds of the oil is refined, the rest is burned directly for power generation.

Brazil

Brazil has very large deposits which could contain as much as 3 trillion bbl of potential shale oil. The largest deposits of commercial interest are those of the Irati formation, which begins in the State of Sao Paulo and extends southward in an S-shaped curve for a distance of about 1,000 miles to the border with Uruguay. Irati shale yields about 20 gal/ton on retorting, which is comparable to a medium grade of Green River shale.

Small retorts have been used intermittently in Brazil since 1862. Early operations produced illuminating gases for home use. Retorting was discontinued in 1946 but resumed in the 1950's under control of the national government. In 1970, a 2,200-ton/d" demonstration retorting plant was completed at Sao Mateus do Sul in the State of Parana. The plant has operated on an experimental basis. The Petrosix retorting process is used. It was developed by the engineering staff of Petrobras, the national oil company, with the assistance of Cameron Engineers, a U.S. engineering firm. Little information has been released about the demonstration but, given the properties of the Irati shale and assuming high oil recoveries from the retort, the plant could produce about 1,000 bbl/d of shale oil, eve. a million cubic feet of high-Btu gas per day, and about 15 ton/d of elemental sulfur.

At present, Petrobras is attempting to raise about $1.5 billion to build a commercial-size plant with a capacity of about 45,000 bbl/d. The plant would be sited near the present demonstration facility. About 20 Petrosix retorts would be used. Current plans call for a 25,000-bbl/d operation by 1983, with subsequent expansion to full capacity by 1985. The deposits in the immediate vicinity of the plantsite could supply the full-size facility for about 30 years. Two additional plants of similar size are contemplated for the State of Rio Grande do Sul, which is south of the demonstration plant.

Brazil's enduring interest in oil shale development is related to its oil-import problem. It consumes about a million barrels of crude oil per day, of which about 960,000 bbl/d are imported. The net drain of the national economy is about $11 billion per year, which contributes to a net deficit in the balance of international payments of about $1.55 billion. It is difficult to track the effect of this deficit in an economy with a 60-percent annual inflation rate, but the currency drain to purchase im-

*For additional information on retorting technologies see ch. 5.

ported oil is estimated to be equivalent to about 6 percent of the nation's gross national product (GNP). If the United States spent the same proportion of its GNP on imported oil, about 15 million bbl/d would be imported, or nearly twice the present rate.

Status of U.S. Oil Shale Projects

The characteristics and status of 11 projects that are at least at the stage of field testing in the Green River shales are summarized in table 17. The list does not include several relatively new projects (such as Multi Mineral Corp. 's project for extraction of oil, nahcolite, and alumina from deeply buried deposits in the Piceance basin) or projects that are being conducted in the eastern shales. It also does not include the numerous theoretical investigations and laboratory-scale experiments that are being conducted by Federal and State agencies and private companies.

Two of the projects—Rio Blanco and Cathedral Bluffs—are actively proceeding towards commercial-scale operations on Federal lease tracts in Colorado. The White River project is also on a Federal lease tract, but it is inactive at present because of legal uncertainties.* Tosco's Sand Wash project is Proceeding towards commercialization at a relatively leisurely pace to maintain compliance with the due-diligence provisions of the Utah leases. Three projects—Logan Wash, Geokinetics, and BX—are of an experimental nature and are being partially funded by DOE. The four other projects—Colony, Union, Superior, and Paraho—are aimed towards ultimate commercial-scale operations but are inactive at present for a variety of reasons, principally economic.

*The Rio Blanco, Cathedral Bluffs, and White River projects are parts of the Federal Prototype Oil Shale Leasing Program, which is discussed in vol. II of this report.

Table 17.–Status of Major U.S. Oil Shale Projects

Project	Location	Proposed technology	Production target (barrels per day)	Status summary
Rio Blanco Oil Shale Co.: Gulf, Standard of Indiana	Federal lease tract C-a, Colorado	MIS[a] and Lurgi-Ruhrgas aboveground retorts	76,000 (1987)	Shaft sinking for MIS module development. Designing Lurgi-Ruhrgas module, PSD[b] permit obtained for 1,000 bbl/d.
Cathedral Bluffs 011 Shale project: Occidental Oil Shale: Tenneco	Federal lease tract C-b; Colorado	Occidental MIS	57,000 (1986)	Shaft sinking for MIS module development, Process development work being done at Logan Wash, PSD permit obtained for 5,000 bbl/d.
White River Shale project: Sundeco; Philips; SOHIO	Federal lease tracts U-a and U-b; Utah	Paraho aboveground retorts	100,000	Inactive because of litigation between Utah, the Federal Government, and private claimants over landownership
Colony Development Opera-tion: ARCO; Tosco	Colony Dow West property ;Colorado	TOSCO II aboveground retorts	46,000	Inactive pending improved economic conditions. PSD permit obtained for 46,000 bbl/d.
Long Ridge project: Union 011 of California	Union property; Colorado	Union "B" aboveground retort	9,000	Inactive pending improved economic conditions. PSD permit obtained for 9,000 bbl/d.
Superior Oil Co.	Superior property; Colorado	Superior aboveground retort	11,500 plus nahcolite, soda ash, and alumina	Inactive pending BLM approval of land exchange proposal. PSD permit obtained for 11,500 bbl/d.
Sand Wash project: Tosco	State-leased land; Utah	TOSCO II aboveground retorts	50,000	Site evaluation and feasibility studies underway. Lease terms require $8 million investment by 1985,
Paraho Development Corp.	Anvil Points: Colorado	Paraho aboveground retorts	7,000	Inactive following completion of pilot plant and semiworks testing. Seeking Federal and private funding for a modular demonstration program,
Logan Wash project, Occi-dental Oil Shale: DOE	D. A. Shale property; Colorado	Occidental MIS	500	Two commercial-size MIS retorts planned for 1980 m support of the tract C-b project. PSD permit obtained for 1,000 bbl/d,
Geokinetics, Inc., DOE	State-leased land, Utah	Horizontal-burn true in situ	2,000 (1982)	Continuation of field experiments, About 5,000 bbl have been produced to date.
BX 0il Shale project Equity 0il Co. ; DOE	Equity property; Colorado	True in situ retorting with superheated steam (Equity process)	Unknown	Steam injection begun and will continue for about 2 years. Oil production expected in 1980. Production rate has not been predicted

[a]Modified in situ processing
[b]Prevention of significant deterioration—an air quality permit that must be obtained before construction can begin (See ch 8)

SOURCE Off Ice of Technology Assessment

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