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WESTERN OIL SHALE DEVELOPMENT: A TECHNOLOGY ASSESSMENT EXECUTIVE

Executive Summary

Western Oil Shale Development: A Technology Assessment

November 1981

Prepared for the
U.S. Department of Energy
Assistant Secretary for Environmental Protection, Safety, and Emergency Preparedness
under Contract DE-AC06-76RLO 1830

DOE Project Manager: G. J. Rotariu

Pacific Northwest Laboratory
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Richland, Washington 99352

FOREWORD

The U.S. Department of Energy (DOE), Office of the Assistant Secretary for Environmental Protection, Safety, and Emergency Preparedness (EP), Office of Environmental Assessments, has been conducting technology assessments of the evolving energy technologies. The purpose of these is to evaluate in as quantitative a manner as possible the potential environmental, health, and socioeconomic impacts of each technology as it moves towards commercialization. The assessments identify where further information is needed, provide an analysis of potential environmental, health, and socioeconomic consequences of each technology, and define research and development (R&D) needed to ensure environmentally acceptable commercialization.

This is the final report of the Western Oil Shale Development Technology Assessment. We would like to express our appreciation to Drs. Darryl Hessel and Ira Levy of the Pacific Northwest Laboratory for their efforts in coordinating the work, to Dr. Hessel and Mr. Gabor Strasser for preparing this report, and to the entire team of participants listed in the Appendix for conducting and reporting the major technical studies.

Dr. George J. Rotariu
Oil Shale Technology Assessment Project Manager
Technology Assessments Division

CONTENTS

1.0 INTRODUCTION

This technology assessment was initiated in the summer of 1979 under the authority of the U.S. Department of Energy (DOE), Office of the Assistant Secretary for Environmental Protection, Safety, and Emergency Preparedness (EP), Office of Environmental Assessments.

The project was undertaken to examine shale oil as a prospective domestic energy source, within the context of environmental constraints, available natural and economic resources, and the characteristics of existing and emerging technology. During the course of this study, energy policy has evolved from an active federal role in fostering commercialization of synthetic fuels technology to a federal role which fosters supply-side economics and permits free market forces to dictate the pace and type of energy technologies that need to be developed. Under either policy, intense interest in oil shale is determined by the following facts:

(1) Oil shale is one of our most abundant potential sources of liquid fuel. The U.S. has immense deposits of oil shale, equivalent to over two trillion barrels of oil, of which about 400 billion barrels derive from high-grade deposits (30+ gallons of oil per ton) in the West that are viewed as recoverable. At a use rate of 17 million barrels of oil per day, 400 billion barrels of oil are equivalent to over 40 years of U.S. liquid fuel consumption, even with a 50% recovery loss adjustment.

(2) Oil exploration and development are proceeding actively with private industrial or combined government and private support.

(3) The technical feasibility, economic viability, and environmental acceptability of commercial shale oil production are poorly understood;

This technology assessment integrates and synthesizes the relevant data concerning the issues in item (3), particularly the environmental aspects.

2.0 OBJECTIVES

The general goal of this technology assessment was to present the prospects of shale oil within the context of 1) environmental constraints, 2) available natural and economic resources, and 3) the characteristics of existing and emerging technology.

The objectives were:

1. to review shale oil technologies objectively as a means of supplying domestically produced fuels within environmental, social, economic, and legal/institutional constraints;
2. using available data, analyses, and experienced judgment, to examine the major points of uncertainty regarding potential impacts of oil shale development;
3. to resolve issues where data and analyses are compelling or where conclusions can be reached on judgmental grounds;
4. to specify issues which cannot be resolved on the bases of the data, analyses, and experienced judgment currently available; and
5. when appropriate and feasible, to suggest ways for the removal of existing uncertainties that stand in the way of resolving outstanding issues.

3.0 APPROACH

Oil shale development, like all new developing technologies, has many uncertainties. At this early stage of technological development, data on technical performance and environmental emissions are scarce and generally believed by scientists and governmental officials to be unreliable. Under these circumstances, it is not surprising that interested industrial participants, public officials, and representatives of various interest groups have expressed a wide range of opinions on the prospects for and consequences of shale oil production.

In light of these circumstances, this assessment has proceeded through several stages: issues have been identified and described; tentative conclusions have been drawn and examined; and results have been reported. These stages have involved a) a small group of investigators who have functioned principally as integrators of information, b) two panels composed of representatives of private and governmental organizations interested in oil shale development, and c) a group of scientists and consultants endeavoring to conduct a series of technical supporting studies focused on quantitative, critical studies of the technological state-of-the-art and a broad range of environmental factors.

The panel members (identified in the Appendix) were selected for their scientific expertise, experience with oil shale, and/or interest in eventual decisions on commercial application of shale oil production processes. Included were a Technology Panel of five individuals involved in developing and applying processes for producing shale oil, and an Impact Panel of seven individuals concerned with potential environmental, health and safety, social, economic, legal, or institutional constraints and impacts of shale oil production. These panels clarified issues and developed information supporting their respective positions. The panel members applied their experience and judgment, developed through involvement with the fledgling oil shale industry, to some of those issues that at the time of the meetings could not be resolved through technical analyses alone. The panels contributed to the assessment mainly at the initial stage of issue identification and description.

Three scenarios were developed for illustrative purposes; the technical studies were conducted only on the highest production combination. The low-production scenario is an example of slow development with production projected to reach 41,050 barrels per day by 1990. Only three plants are included. Additional production capacity will require a reduction of uncertainties either through commercial operating experience or through government incentives, such as price supports. The medium- and high-production scenarios assume that the technologies will be successfully demonstrated and that the government will provide the necessary financial incentives. Production is then projected to reach, respectively, 189,000 or almost 300,000 barrels per day by 1990, depending on the extent to which the technologies are proven and on the incentives offered. This is still relatively low compared to the stated expectations of some firms who project millions of barrels per day from oil shale.

An attempt was made to consider the shale oil production technologies as described in the high scenario. This effort was expected to lead to recognition of most of the potentially significant impacts of a mature shale oil production industry. Impacts of media (air, surface water, ground water, and land), ecological systems and agriculture, human (primarily occupational) health and safety, social and economic systems, and legal/institutional systems were considered.

As the study progressed, it became apparent that the conduct of a rigorous, quantitative, systematic analysis was constrained by the absence of adequate data on existing conditions, by the state of development of shale oil production technologies, and by the absence of quantitative analytical models appropriate for application under the conditions in the oil shale region.

For these reasons, most of the results of this study comprise an overview of existing knowledge rather than a quantitative analysis of projected conditions from a shale oil industry. The study integrators and the participants in the technical supporting studies were forced by these circumstances to rely heavily upon other relevant studies and ongoing events for information useful in assessing oil shale development. Nevertheless, where it was possible to develop appropriate analytical techniques or models and where useful projections of impacts could be made, this was done. (For example, a new ecological impact model was developed.) Such efforts were based on the 300,000 barrel per day scenario.

The findings in this report are derived from the combined results of the panel meetings of May 1979, the technical supporting studies, and the continuing review of other related studies and events.

4.0 SUMMARY OF ISSUES AND FINDINGS

There are three major arguments supporting the exploration and possible development of a commercial oil shale industry in the United States:

1. Liquid Fuels Availability: There is a global liquid fuels problem, notwithstanding fluctuations such as the oil glut of 1981.
2. Immense Shale Deposits: There are immense oil shale deposits in the U.S. which have the potential of supplying all our needs for liquid fuels at the current rate of consumption for a time period approaching half a century.
3. Recoverability Piloted: It has been demonstrated that oil shale can be retrieved from the ground, retorted, and refined to required specifications. Modified in-situ (MIS) retorting techniques have also been demonstrated, although they have not yet been shown to be efficient in recovering oil.

While the above arguments appear persuasive by themselves, numerous problems temper their promising message. These include recovery rates, technical feasibilities, economic viabilities, and environmental acceptabilities. Many of these problems are identified in this chapter, and they are discussed more fully in chapters 3.0 through 11.0.

4.1 PRACTICAL RATES OF RECOVERY

Based on existing and projected technologies (without major new developments) maximum production rates are not likely to exceed one million barrels per day. Principal constraints are (1) effects on air quality, especially violation of current prevention of significant deterioration (PSD) limits, and (2) readily available surface water supplies.

This rate of recovery represents only about 5% of the USA need for liquid fuels. Although much higher rates of recovery have been discussed lately, these have not yet been analyzed in terms of the actual working technologies and processes, nor in terms of their potential environmental economic, social, and political consequences.

4.2 TECHNOLOGICAL ASPECTS

Over the last forty years, industry has developed a range of oil shale retorting technologies. Important among the surface retorting technologies are TOSCO II, Lurgi, Paraho, Union B, and Superior. Occidental Oil Shale, Incorporated, has developed a modified in-situ process with some success. The Rio Blanco Oil Shale Company has also been experimenting with an MIS process. In general, the above-ground retorting technologies are much closer to commercial readiness than are the MIS processes. However, most of the information about all of these technologies is based on bench- or pilot-scale operating experience, not commercial operating experience. Until full-scale modules (approximately 5,000 to 10,000 barrels per day) are built and are in operation, many uncertainties will remain. Uncertainties about the technical feasibility of a profitable and environmentally acceptable industry are likely to slow development.

In addition to the technologies already mentioned, the following backup or emerging technologies also exist: Illinois Institute of Technology Institute's Radio-Frequency; Raytheon's Radio-Frequency; Chevron's Fluidized-Bed; Equity's Pure In-Situ; Union's Solid Gas Retort (SGR); Institute of Gas Technology's Hytort; Multi-Mineral's Integrated In-Situ; Marathon's Steam Retort; and Horizontal Technology's Recycling Chemical Solvent Process.

The oil shale industry, as it emerges, will employ a variety of technologies adapted to the specific characteristics of the shale deposits in different geographic locations. This report uses a mix of processes for its 300,000 barrels per day scenario. In reality, the industry in the 1990s may use fewer technologies, and plants may be larger than those shown. The processes actually used will almost certainly differ somewhat from those discussed, and they may even include processes that have not yet emerged or that are hybrids of other processes. The technologies presented are nevertheless representative of the shale oil technologies likely to comprise an industry in the near future.

4.3 AVAILABILITY OF NATURAL AND ECONOMIC RESOURCES

4.3.1 Oil Shale

U.S. reserves of oil shale are immense. Estimates of the total size of deposits vary with the oil shale yield considered economically recoverable, which in turn is a function of the price of competitive energy sources. This reserve is in any case far larger than U.S. reserves of oil and gas. Most experts estimate that over 400 billion barrels are economically recoverable. Eighty percent of this lies in northwestern Colorado.

Development of this resource may be limited by environmental standards. Lengthy permitting processes could delay start-up of commercial facilities on Federal land by almost 10 years, and on private land, by 7 years.

Land ownership patterns are another substantial barrier to development. First, about 85% of all oil shale reserves are on Federal land. The title to much of this land is questionable due to unpatented mining claims made under the Mining Act of 1872. Leasing by industry is limited to tracts of no more than 5,120 acres each by the 1920 Mineral Leasing Act. This is only enough for one commercial-scale plant, so developers cannot benefit from their experiences in further developments on the same tracts. Privately owned tracts of oil shale land are often small and non-contiguous, and they may have lower grade shale than the Federal tracts. There are twenty-eight private blocks of land that are considered capable of supporting a 50,000 barrel per day plant.

4.3.2 Water

Surface water supplies in the Upper Colorado River Basin appear to be adequate to support a 500,000 to 1,000,000 barrel per day oil shale industry. This water would come from the White River, the Upper Colorado River Main Stem, and tributaries local to the Piceance Creek Basin; it might be supplemented by water from underground aquifers.

The availability of an adequate water supply is linked to several factors. First, although a large part of the water in the Upper Colorado is not currently used, if all decrees (claims made under water rights laws but not consummated) were actually used, there would be a major water shortage. Second, competition from other future users, such as agriculture and other energy activities, will limit that amount of water allocated to oil shale. Third, water shortages in the Lower Colorado Basin may force amendments to the law allocating water between the Upper and Lower Colorado Basin. Use of ground water may be limited by ground-water allocation laws, ground-water quality, and possible impacts on surface water. Most authorities on the subject conclude that while water is physically available to support an industry even much larger than 1,000,000 barrels of oil per day, competition will become a significant factor about the year 2000, when usage is expected to reach 1,000,000 barrels per day.

4.3.3 Other Resources

The availability of labor, transportation, equipment and materials, and financing could inhibit oil shale development. A moderate rate of development, for example, the scenario created for this study, 300,000 barrels per day by 1990, would place heavy demands on all four of these resources.

This oil shale scenario would require a work force in the state of Colorado of 7,540 in 1985 and 10,250 in 1990. The population of the four-county oil shale region in 1979 was only 109,739 people, so it is unlikely that a sufficient work force could be hired locally. Local labor would be taken away from other economic activities of regional importance, especially agriculture. However, a sufficient work force could be brought into the region. While skilled and semi-skilled labor can be obtained, professional employees will be at a premium. Engineering firms capable of building an oil shale plant may be overtaxed.

Energy development has already had a significant impact on the transportation system of the oil shale region. Further development is likely to exacerbate the problem. Increased truck traffic could cause severely congested roads. Impacts would be mitigated by building pipelines to transport the product.

Certain types of equipment required for oil shale development--compressors, heaters, boilers, shell and tube exchangers, pumps, and draglines--may be in short supply. This could limit the rate of oil shale development and increase the cost.

Developing an oil shale industry will require very large capital investments. Since the technologies have not been commercially demonstrated, will require long construction times, and will produce little fuel relative to their cost, industry and the financial community may be reluctant to make the large expenditures required.

4.4 ENVIRONMENTAL ACCEPTABILITY

4.4.1 Air Quality

Air quality is generally considered to be that aspect of the environment most likely to constrain oil shale development. Potentially significant air quality problems include:

- impacts of toxic substances, especially polycyclic organic compounds and trace metals, on human health;
- effects of photochemical oxidants on human health, vegetation, and atmospheric visibility;
- inadvertent weather changes; and
- degradation of regional visibility due to particulate emissions and the production of secondary aerosols.

Air quality in the oil shale region is at present excellent. However, occasionally, ambient air concentrations of nonmethane hydrocarbons and particulates exceed standards. These problems appear to have natural causes, and EPA has indicated that they will not preclude oil shale development, provided that oil shale facilities meet emission and PSD standards.

Prevention of Significant Deterioration (PSD) regulations are most likely to constrain development. A study conducted for EPA estimates that the PSD limit for the Class I Flat Tops Wilderness Area may place an upper bound of 400,000 barrels per day on the oil shale industry. A 300,000 barrel per day industry might also use an estimated 20% to 38% of the PSD Class II SO_2 allowance and 28% to 54% of the particulate allowance for the Piceance Creek Basin, based on preliminary calculations. Estimates of these limits and impacts are highly uncertain, however, due to shortages of data on existing conditions, inadequate atmospheric models, lack of experience with commercial-scale shale oil production processes and current efforts to change the federal air quality laws.

An oil shale industry will add to the carbon dioxide (CO_2) concentration in the world's atmosphere since the gas is released during both fuel production and fuel use. CO_2 concentrations have already been increasing for some time due to the use of fossil fuels. However, the impact of oil shale's contribution will be trivial at the level of the 300,000 barrels per day scenario.

4.4.2 Solid Waste

Shale oil development will produce large quantities of spent shale, approximately 1 ton for each barrel of shale oil. In-situ processes will leave this spent shale underground. However, surface retorting may produce large volumes of spent shale requiring disposal. A 300,000 barrel per day industry, including 165,000 barrels produced by surface retorting, will require the surface disposal of 120,000 metric tons of spent shale each day, assuming that 60% of the spent shale is returned to the mines.

In addition to the physical and economic problems associated with disposal of such large volumes of waste, spent shale can cause fugitive dust emissions and potentially cause degradiation of surface and ground water. Specific impacts are related to the composition of the retorted shale. This is variable and a function of the composition of the raw shale, the size of the particles, and the retorting process used. Although spent shales from several experimental facilities have been studied in some detail, further study using materials representative of commercial-scale operations is required before the impacts of an oil shale industry can be completely and accurately assessed.

Water-soluble salts, organic materials, and trace elements in spent shale could impact both surface and ground-water quality through the uncontrolled release of leachates. In sufficient concentrations, some of these components would be toxic to wildlife, domestic livestock, and human health. Since the Colorado River is used for both drinking and irrigation in seven states and Mexico, potential toxic contamination and increased salinity are matters of concern.

Studies of leachates from spent shale show increased concentrations of a variety of substances, including organic carbon, So_4, S_2O_3, Cl, Na, K, B, Mo, F, and Li. However, many of these compounds and elements are removed in the initial leachates. As the shale weathers, significant changes in the composition of the leachates occur. After one year, the pH and levels of reduced sulfur species decrease in the leachates; however, arsenic, molybdenum, boron, and fluoride continue to leach. Even following significant weathering, lithium, sodium, potassium, calcium, and strontium are released in higher concentrations from spent shale than from soil.

Potential water contamination from spent shale may be prevented or substantially reduced by properly engineered disposal. A maximum of 60% of the shale may be returned to underground mines. The remainder must be disposed of on the ground surface, in canyons, hollows, or mesa-top landfill sites. Careful construction of these piles with impermeable liners and retaining dams is expected to be effective. The piles could be stabilized in the short run by compaction with water and over the long run by a combination of engineering methods and revegetation.

One major factor affecting the ability to predict potential impacts of solid waste disposal is the general lack of commercial experience with shale retorting. Actual operating experience is needed to evaluate long-term impacts associated with the physical and chemical stability of spent shale piles and the internal hydrologic regime affecting leachate production and movement. Field experience will allow us to test the effectiveness of proposed solid waste management methods in physically stabilizing the piles and in reducing leaching.

An additional source of uncertainty is future environmental regulation of spent shale. At present, spent shale disposal procedures are regulated by state laws and by stipulations in lease agreements between the U.S. Geological Survey and the holders of oil shale leases on federal lands. Future federal laws for oil shale may be similar to regulations governing coal mining. If oil shale were to be placed under the hazardous waste provisions of the Federal Resource Conservation and Recovery Act, disposal costs would increase by 35 to 100 percent.

4.4.3 Ground Water

Potential damage to ground-water systems, and directly or indirectly to surface-water systems, is one of the most significant environmental issues associated with a prospective oil shale industry. Surface retorting may cause damage if leachates from raw and spent shale piles reach ground-water aquifers or if retention dams overflow (due to a low-probability flood), discharging leachate into surface waters. Leaching of spent shale disposed of in underground mines could affect ground-water quality. In-situ retorting will have a larger impact on ground-water quality than will surface retorting. Dewatering of retorts can create many problems, and subsequent reinvasion of abandoned MIS retorts may lead to contamination of ground-water supplies. A major contribution to this study has been the conclusion that this contamination can be a much more serious problem than heretofore believed.

The severity of impacts to ground water is at present unknown. The natural conditions that will affect the type and extent of the potential contamination are not well known or understood. A greater knowledge of geohydrological conditions in the Piceance Creek Basin and adequate field data are particularly needed.

Since the oil shale formations serve as aquifers in most locations where MIS retorts are anticipated, extensive dewatering of the aquifers will be necessary. This will result in drawdown of the water table and will produce large volumes of saline water which must be disposed of. After completion of MIS retorting, reinvasion of the area by ground water may not occur fully for hundreds of years. This is likely to reduce dramatically the flows in local surface streams, and it may delay field verification of controls for and impacts from abandoned MIS retorts. Extensive dewatering will also alter the quality of local ground water and reduce the flow of fresh water in wells, even though the water withdrawn in dewatering is the saline water from the deeper formations.

Over long time periods, the water in aquifers receiving leachate from numerous MIS retorts would approach the chemical composition of the leachates themselves. There is evidence that oil shale formations on the periphery of the Basin may be naturally dry, and thus require no dewatering. Flooding and leaching of abandoned retorts would, therefore, not occur in these formations. Dry formations are relatively unlikely in the Piceance Creek Basin which is at the center of the structural basin. Water quality studies suggest that the flow in some surface streams may be either entirely or partially dependent on ground-water conditions in the bedrock aquifers, those most affected by MIS retorting. Thus, ground-water contamination could lead to surface-water degradation. Alluvial aquifers, a major source of the area's water supply, may be much less affected by oil shale development than the deep aquifers, unless dewatering eliminates or reduces base flow in these formations. The degree to which surface flows and alluvial waters are affected by the deeper aquifers is not clear.

Innovative environmental control technologies may also limit the negative impacts of oil shale development, although none of these technologies have been tested nor proven to be technically or economically feasible on a commercial scale. Damages from dewatering activities may be mitigated by reinjection of the withdrawn waters downflow from the mining and retorting locations. Backflooding and leaching of abandoned, burned out MIS retorts may be avoided by preventing the entrance of water by grouting the retorts or by other techniques. Another alternative is to remove the potentially leachable chemical species from the retorts by intentional leaching followed by treatment of the leachates. It is also possible that otherwise leachable materials might be isolated permanently in an unleachable form through control of retorting conditions. Contamination of alluvial ground water through leaching from surface piles of spent or raw shale may be prevented through the use of impermeable liners under the piles and through other techniques of pile construction.

4.4.4 Surface Water Quality

Potential changes in the quality of surface water resulting from oil shale development are of great importance. The streams local to the Piceance Creek Basin are only of limited value for fishing, but they are used extensively for irrigation of crops. The Colorado River and its major tributaries, the White and Green Rivers, into which water from the oil shale region drains, are depended upon as major sources of water for all uses in a large arid area covering several western states and Mexico.

The major existing problems in the Colorado River Basin are general shortage of water (Lower Basin, especially) and salinity. The virgin flow is highly seasonal, peaking from April through July due to snowmelt. At other times, the natural flow is largely from ground-water sources. The basin is, therefore, highly regulated with many reservoirs to store peak flows. Salinity is a natural condition due to the nature of rocks in some of the stream beds and ground-water aquifers. It is also the result of extensive irrigation and fertilization of croplands.

Since reductions in stream flow tend to cause quality changes by reducing the amount of water available to dilute pollutants, flow changes are important factors in this water quality analysis.

The 300,000 barrel per day scenario used in this assessment would require about 26% of the average annual virgin flow of the White River Basin. An industry of 1.3 million barrels per day, by comparison, would require about 60% of the natural flow. In either case most of this water would have to be stored from the peak flows of the spring months. Demands on the Upper Main Stem of the Colorado River would be trivial as compared to the natural flow and other uses.

Ground water may also be used by a shale oil industry. It exists in plentiful supply, but its use is constrained by natural quality problems and by institutional issues. Any use of ground water will reduce demands on surface water.

Ground water will be pumped from aquifers to facilitate mining and modified in-situ (MIS) retorting, irrespective of decisions made on water supply. If this "dewatering" water is discharged into Piceance and Yellow Creeks, and if the flow in alluvial aquifers and surface streams is not greatly affected by dewatering of the deep aquifers, then the discharges will swell flows in these creeks from an estimated 2 times natural annual flows in Piceance Creek to 18 to 24 times in Yellow Creek. An analysis of the quality impacts of discharging untreated dewatering water into Piceance and Yellow Creeks indicates that major increases could occur in the concentrations of sodium, boron, and fluoride. Total dissolved solids in the White River near the mouth of Yellow Creek would increase by up to 123 mg/l, bringing the concentration to 591 mg/l.

Dewatering would likely reduce or eliminate the base flow of Piceance and Yellow Creeks. One possible solution might be to reinject the water into the aquifers downflow from the mining activity. Another might be to augment stream flows by discharging the treated or untreated dewatering flow directly into the surface streams. There is some evidence that dewatering the deep aquifers, thus reducing saline groundwater flows into Piceance and Yellow Creeks, would result in quality improvements in the White River.

A variety of waste waters would be created by a shale oil industry. However, since the oil shale region is an area that is typically water short, energy development, agricultural use, and other demands will make water increasingly difficult to obtain. Accordingly, it will be beneficial to the shale oil industry to conserve water, treating and reusing it wherever possible. Because extensive treatment would be required before waste waters could be discharged to surface streams, the cost of treating them to a quality adequate for reuse will be less than the cost of discharging them.

The most difficult waste water to treat is "retort" water, which forms in the retort during pyrolysis of the shale. It contains a complex mixture of trace elements and organic substances, and adequate treatment techniques have not been developed to date. Almost no treatment research has been conducted on surface retort waters, because it was previously anticipated that these waters would not require treatment; they are produced in small volumes and were slated for hot spent shale moisturization. However, a recent ruling by the State of Colorado will require the removal of organics from these waters, and recent concern about the escape of gases, including NH_3, may require the removal of dissolved gases. Recent indications are that distillation may be required for treatment of retort water, even though it is a very expensive process.

Surface runoff may be a problem for the industry. The most serious concerns relate to runoff from surface piles of spent or raw shale and from the plant area.

Pile designs proposed by the industry incorporate dikes, drainage channels, and retention dams to prevent runoff from surrounding areas from entering piles and to preclude runoff from spent or raw shale piles from reaching natural surface waters. They also incroproate pile linings, possibly compacted spent shale, to retard or eliminate percolation of leachates into ground-water aquifers. With revegetation, there is expectation that no leachates will reach the bottom of the piles and that any surface runoff will approach the characteristics of runoff from natural land surfaces. For these reasons, most studies assume that surface piles will not result in contamination of surface waters.

There is, of course, the possibility of accidental spills of chemicals, shale oil, or waste fluids at production sites or in transportation corridors. The Federal Water Pollution Control Act requires each person storing minimum quantities of oil or hazardous substances to prepare and maintain a spill prevention control and countermeasure plan. This plan must describe the facility's strategy for preventing oil or hazardous substance spills from reaching navigable waters.

Clearly, accurate predictions of effects of modified in-situ (MIS) retort leaching are beyond the limits of current knowledge. However, the work done to date makes it apparent that some contamination of surface streams would be likely if effective preventative measures are not developed and implemented. Several approaches to prevention have been suggested, but none have been tested nor shown to be technically or financially feasible.

4.4.5 Ecology

One of the most adverse environmental impacts on land features would occur during the construction phase of an oil shale industry. Erosion which is already common to the area because of the weather extremes, including thunderstorms, would be aggravated during construction. However, revegetation of the disturbed areas is an important method for reducing the impacts.

Air pollution emissions of hydrocarbons, SO_2, NO_2 and particulates are of potential concern regarding impacts to vegetation. Other compounds which are considered possible pollutants are ammonia, chlorine, volatile trace metals, phenols and other organic compounds. Secondary photochemical reactions may further result in production of plant toxicants. However, the dosages of the pollutants necessary to induce acute, short-term, vegetation injury are high and the projected range of average daily pollutant levels in the basin are rather low. Hence the probability of acute injury is minimal. However, the chronic injury resulting from long-term, low-level exposure may be significant. On the other hand, some field studies have shown that low-levels of SO_2 in the atmosphere can be one way of removing a sulfur deficiency and thereby enhancing plant growth.

Most of the area affected by shale oil mining has a unique combination of natural and cultural conditions that promote good upland habitat, which is ecologically fragile. The desert flora is particularly susceptible to man-induced changes in available water and run-off patterns and this in turn impacts animal life. It is generally conceded that mule deer, elk, pronghorn antelope, and sage grouse would decline in numbers as a result of an oil shale industry and the resulting increased human population.

Greatest impacts will occur at the local level of influence. The major factors here will be the operating procedures, disposal of residues, and the actual mine sites. Nearly all species of wildlife are expected to decline because of loss of habitat and from all forms of human activity. Many mammals and bird species are expected to be reduced by 25 to 50% within 3 to 10 years. These reduced populations include mountain lions, bobcats, elk, black bear, skunks, porcupines, coyotes, weasels, badgers, mule deer, wild horses, golden eagles, bald eagles, sage grouse, mourning doves, owls, woodpeckers, turkey vultures, nighthawks, and hummingbirds.

Intermediate impacts will be caused primarily by downstream water pollution. Species inhabiting riparian communities will consequently be most affected. Mammal species, such as muskrats and raccoons, and waterfowl and shorebirds will undergo moderate to high declines. Maintenance of riparian habitats might mitigate the above declines as would development of compensatory tracts of lands.

The extended impacts will come primarily from the expected influx of residents due to the available job market. Mammal and avian species will undergo moderate to high declines as a result. New (human) community developments are expected to cause major problems for waterfowl, great blue heron, chukar, and beaver.

A mature, producing oil shale industry could also be detrimental to the local livestock industry because of reduced water supplies for cattle. However, this livestock reduction, if followed by reduced predator control, might help increase the populations of coyote, bobcat, black bear, mountain lion, and golden eagle.

In all, it seems likely that beaver, mountain lion, elk, and sage grouse will be eliminated from the shale oil region by a mature shale oil industry. It is likely that only beaver and elk would be reestablished after operations cease.

4.4.6 Health and Safety

There are little available data on the potential health effects of a U.S. oil shale industry. Evidence drawn largely from foreign oil shale experience indicates several possible health effects from occupational exposures. Further studies should be undertaken during the early development of the industry.

In general, synthetic oils appear to have a carcinogenic potential. Studies of oil shale workers in Scotland have shown evidence of an increased incidence of skin cancer. However, these data stem largely from a period when industrial and personal hygiene were less sophisticated than today. Experimental studies have shown that, while shale oil is more mutagenic and carcinogenic than most natural petroleums, it appears to be less so than many coal-derived liquid fuels. Hydrotreating appears to reduce these effects of crude shale oil. Middle distillate shale oils, however, appear to be less carcinogenic than either the crude or the hydrotreated crude shale oils, even though the middle distillates appear to exhibit more systemic toxicity. In the future, experimental studies will determine which components of shale oil are biologically active.

Historical evidence indicates that the incidence of respiratory illness in oil shale workers is greater than that in the general population, although still relatively low. Shale mining, crushing, and disposal create dust particles of a size known to be deposited and retained in the lungs for long periods of time. Studies of Estonian oil shale workers have shown an excess of chronic bronchitis, mild pneumonoconiosis, emphysema, and upper respiratory illness. However, raw and spent shale dusts in lungs have not been shown to be carcinogenic. Questions related to fibrogenic or obstructive lung disease require further study. Experiments in which animals have been exposed to highly concentrated aerosols have produced evidence of fibrotic changes. MIS retorting, where workers will be preparing some retorts while others are burning, may present an inhalation hazard that will need to be more fully defined, since workers may be exposed simultaneously to shale dust, diesel exhaust, and retorting offgases.

Neither the exact nature nor the pervasiveness of the relevant, applicable occupational hazards can be ascertained, based on our very limited experience. Application of available industrial hygiene procedures and equipment and of existing environmental controls may provide adequate protection. Actual commercial-scale experience is necessary before this problem can be understood adequately.

Shale oil production could possibly expose the general public to toxic or genetic effects through contamination of water and air. Ground- or surface-water contamination by biologically active materials is probable, and strong control technology efforts will be required. However, existing water clean-up techniques may be sufficient to avoid contamination of water supplies. This can only be determined as industry scales up.

4.4.7 Socioeconomics

Historically, energy development in the sparsely populated areas of the west has caused severe socioeconomic impacts due to the influx of large numbers of newcomers. The development of oil shale will generate large and rapid population growth. The projected growth may be as severe as that which produced the widely documented boom towns of the 1970s. Accommodating this large population growth will present enormous challenges to existing communities.

Impacts due to oil shale development, however, may be partially reduced by the fact that a very large operating work force as well as construction work force will be required. There will be only a small decline in the total number of oil shale employees after the construction phase ends. Thus, the oil shale region will not experience the "bust" that usually follows a "boom".

The construction and operation work force requirements of a 300,000 barrel per day oil shale industry nearly equal the total existing labor force in Rio Blanco and Garfield Counties. There are no large urban areas in the region in which the existing infrastructure and support systems could readily absorb the anticipated population impact. The largest community, Grand Junction, already suffers from growth rates that strain existing support systems.

The worst impacts include the inadequacy or lack of public facilities and services, housing, and integration of immigrants into the community; the disruption and destruction of existing social and political structure; the degradation of the quality of life of both the indigenous population and the immigrant population; and severe inflation, especially affecting the cost of land and housing.

Most of these impacts can be mitigated by careful planning for community growth. Measures for mitigation must take into consideration such factors as administrative capacity of local governments, local and state statutory requirements, and the political climate. Implementing plans for mitigation may be difficult because there is no mechanism to coordinate such a program among federal, state and local governments, industry, and private agencies. Local government officials, in particular, aggressively assert the need to include local governments in the planning and management of the multi-state resource development.

The inadequacy of public facilities and services may be alleviated by external financial assistance. Many communities in northwestern

Colorado have already expanded public facilities, specifically water treatment plants, sewer systems, and schools through state and federal financial assistance. Excess capacity in these facilities is expected to reduce disruption of services and to alleviate the immediate impacts of rapid population growth. A major issue is the question of who should pay for additional municipal facilities. Community residents have expressed the belief that they should not have to pay for the facilities and services required by the immigrant population; industry officials have maintained that the government should pay for the roads leading to oil shale sites; and the state government has expressed the view that the federal government should provide assistance for impact mitigation of oil shale development because that development serves a national need.

This issue is further complicated by the fact that the tax base created by an oil shale industry may not coincide with political jurisdictions where socioeconomic impacts are severe. For example, Mesa county officials are concerned that although no oil shale facilities will be built in Mesa County, severe secondary impacts will be felt in Grand Junction.

In order to be successful, programs designed to mitigate social impacts must begin soon--before development occurs and newcomers arrive. This implies that communities must fund new facilities before their tax base has increased. Even if this were financially feasible, the uncertainties regarding the future of the oil shale industry make prior planning seem less urgent and more difficult.

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