

THE ENVIRONMENTAL ASPECT OF DEVELOPING INDIANA OIL SHALE

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ABSTRACT

Indiana oil shale deposits contain as much energy as Indiana coal. New technologies make it possible for developers to provide a finished product at prices competitive with natural petroleum products. The environmental consequences of producing oil shale differ considerably from traditional oil production.

This paper discusses the potential impacts, available data and necessary research for developing oil shale in Indiana. We review the extent of potential of the resource, the information available about land, water, and air in the resource area and develop several technologically based scenarios of impact. We then propose baseline and regulatory monitoring programs as well as applied research programs necessary to develop oil shale in Indiana in an environmentally clean manner as possible. Finally, we will speculate on the probability that oil shale will be developed, and if so, under what conditions.

1. INTRODUCTION

This paper deals with technologies not yet formed in a world in which the economic and political forces may vary considerably in the future and which uncertainty about the environmental background information rules. We attempt to explore the environmental aspects of a future development of Indiana Oil Shale. Thus, it more closely resembles a technology assessment than a scientific report of experiments already completed. Yet, given the lag time for environmental programs in the United States, we think our paper suggests a course of action which one should begin now to proceed in an orderly and environmentally acceptable way.

Usually, when we begin to develop a new resource, we have some notion on how large the reserves of that resource are. In this case we have a good notion of the extent of mineable oil shale from studies done by the Indiana Geological Survey. The size of the reserves, on the other hand, depend upon the economics of oil and the technology of oil shale extraction. These, in turn, depend upon an interactive relationship with the political climate, and with the environmental constraints (Figure 1). Because the economics, technology, politics and environmental constraints all affect each and are thus all interdependent, changes to any of these from outside stimuli or from each other will change the estimate of reserve. Simply put, if for some reason

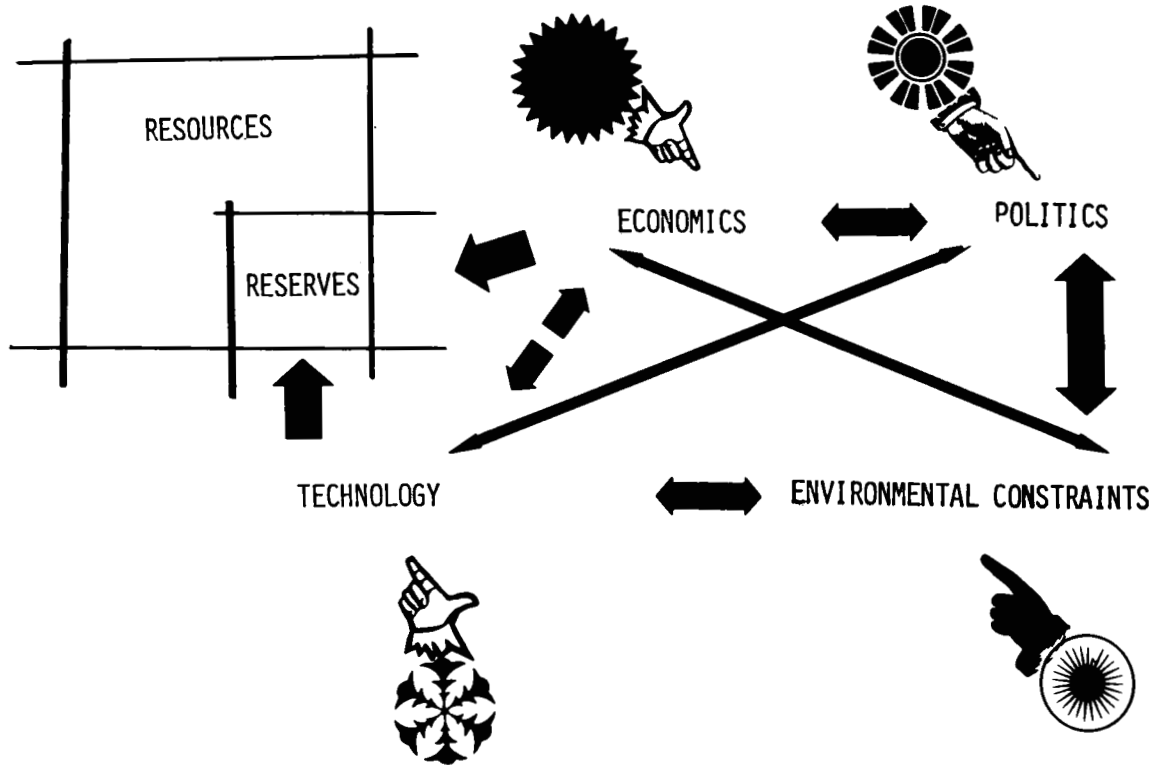


FIG. 1. CONCEPTUAL MODEL-RESEARCH

imported oil becomes very expensive or, if for some reason the U.S. decides to develop domestic reserves or, if for some reason someone develops an ultra-cheap technology which does not pollute the environment, the size of the reserves would grow immensely. So we view this as a dynamic self adjusting model placing these variables in perspective.

2. THE NATURE OF THE EASTERN OIL SHALE

Figure 2 shows the distribution of shale bearing formations in the United States. In the west, we see the small area where most oil shale research and development have taken place in the past. In the east, the map shows a large area of shale bearing formations, much lies too deep for feasible mining at present.

In southeastern Indiana, oil shale outcrops in beds 60 - 170 feet thick in an area twice the size of the state of Delaware. However, the richest and most accessible lies in a band from Indianapolis to Louisville. This shale occurs in beds up to 120 feet thick with 2 - 20 feet of overburden. This shale has been known since early work in 1837. The Indiana Geological Survey and others have described it in many publications (Hassenmueller and Woodward, 1981). Oil shale in Indiana, named the New Albany shale, outcrops in the southeastern portion of the state (Figure 3). It then thickens and dips in a southwesterly direction toward Illinois. It may be as much as 337 feet thick in southern Posey County in southwestern Indiana. However, it is several thousand feet down. The New Albany shale is nearly impermeable except where fractures occur. It lies in several beds of which the Henryville bed, the uppermost, contains several trace elements, particularly zinc, cadmium, molybdenum, and vanadium, and to a lesser degree lead, nickel and copper. Directly below the Henryville bed is the Falling Run bed which is higher in uranium (as much as 100 parts per million) and presumably rare earths. The Henryville shale naturally outcrops in several places and in Jackson County, Indiana, has on occasion burnt from natural causes.

Eastern shale differs in a number of important ways from western shales (Table 1). Of importance to our analysis are several characteristics of eastern shale, namely the high level of sulfur content, the acidic leachate and the somewhat lower yield of synthetic crude per ton (according to the Fischer assay).

Indiana Oil Shale deposits which lie near the surface contain as much energy as Indiana coal. If developers processed only 25% of Indiana shale, the potential will exceed 110 billion barrels, approximately 7 times the Prudhoe Reserves. Several developers propose technologies for the extraction of product from oil shale that yield higher than the Fischer assay. If these technologies prove feasible, the amount of energy available in Indiana shale will rise correspondingly. Because of the different nature of eastern shale and the much different nature of the environment in Indiana, we anticipate quite different environmental problems.

In general, we have considerable information about the nature of the resource, several optional technologies have been suggested, and we lack most of the necessary information on the environmental background. As a result, this paper will talk primarily about the availability of data (Figure 4). We shall proceed to review the potential consequences of air pollutants, water use and water pollutants, land use and the socioeconomic effects. Lastly, we shall comment on the potential for actual development

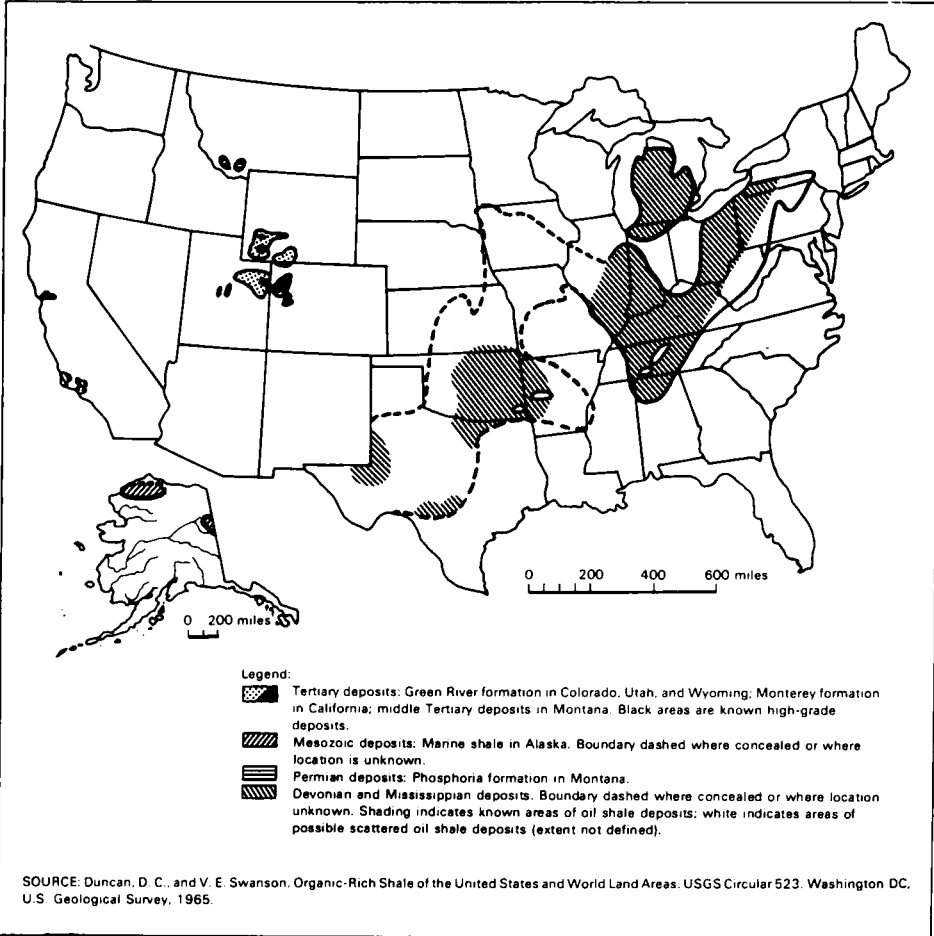


Figure 2. Principal Oil Shale Deposits in the United States.

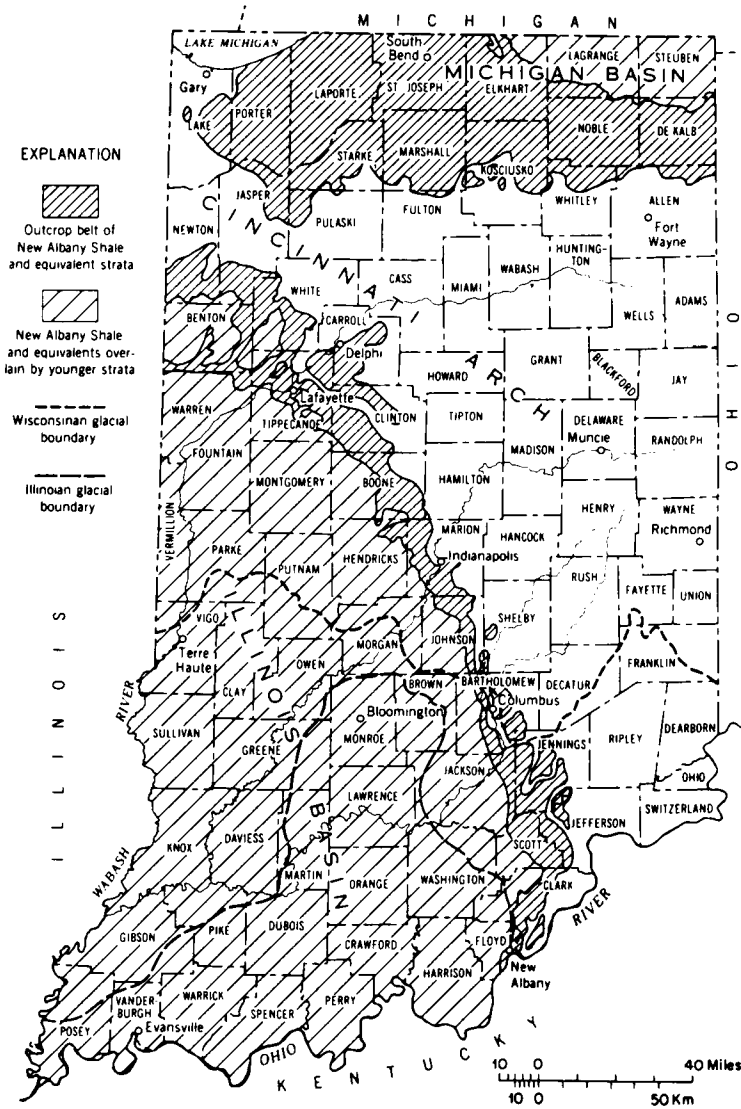


Figure 3 Map of Indiana showing distribution of the New Albany Shale and equivalent strata. Geology modified from Indiana Geological Survey 1 x 2 Regional Geologic Map Series.

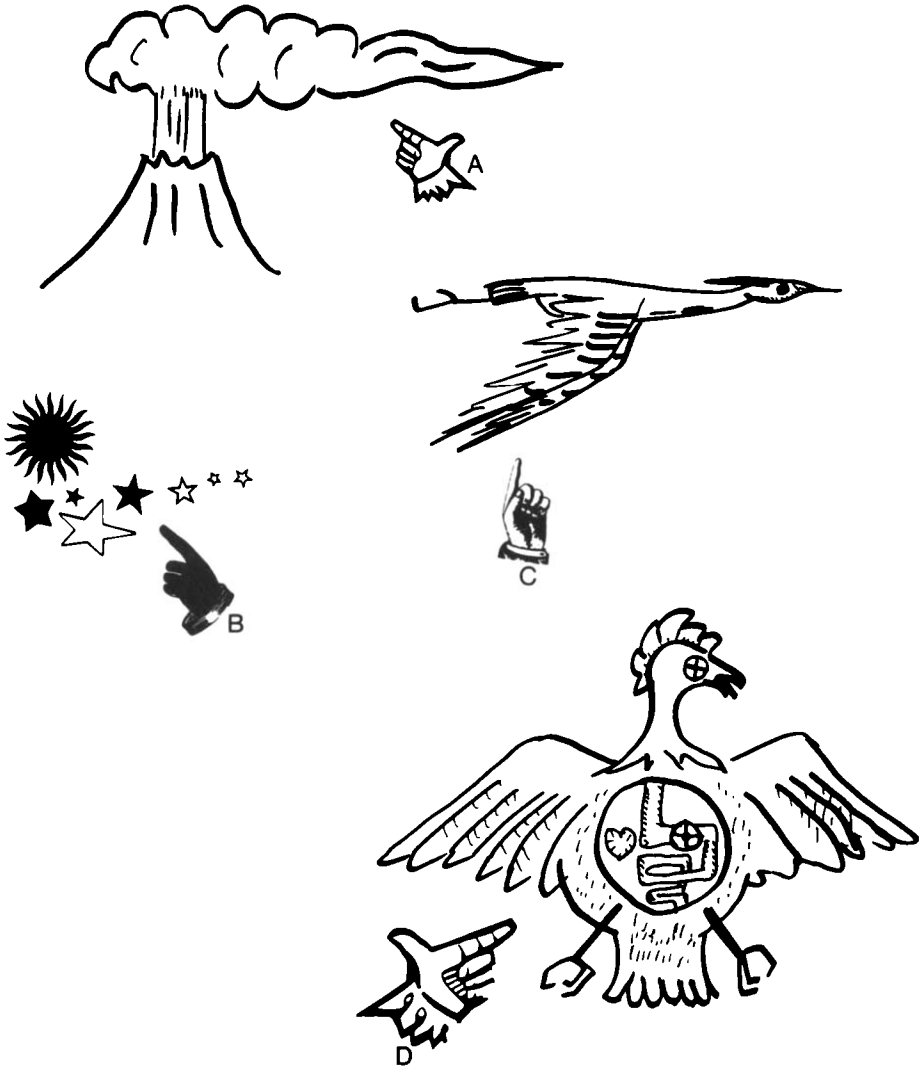


FIG. 4. DATA BASE

Table 1. Differences Between Western and Eastern Oil Shale Resources

Western	Eastern
Kerogenaceous marlstone	True oil shale
High carbonate, low sulphur content	Low carbonate, high sulphur (pyrite) content
Carbonates produce cementateous property in spent shale (low permeability)	Less cementateous property
Produces alkaline leachate	Produces acidic leachate
Arid climate and vegetation	Temporal, humid climate and vegetation
Little precipitation, high evapotranspiration	Moderate precipitation and evapotranspiration
Process wastewaters recycled	Process wastewaters possibly treated and discharged
High hydrogen-carbon ratio	Low hydrogen-carbon ratio
Natural yield of 25-35 gallons per ton	Natural yield of 10-15 gallons per ton, before retorting with hydrogen

3. AIR

Two problems confuse our predictions about air pollution impact as a result of a developing Indiana shale industry. First, no one now processes eastern oil shale on a commercial level. Stone and Webster Engineering Company (1) have developed a process they propose using, but their experiments have all been in their Brazilian development and no reports are yet publicly available. Midwestern Energy Resources Corporation is experimenting with a rotary kiln technology from Allis Chalmers, but again no commercial tests have been made. Thus, we have difficulty estimating emissions from these technologies. Bates (2) estimated potential air emissions of criteria pollutants from the technologies then under experiment (Table 2). He assumed a retort of 50,000 barrels per day, running at 50% efficiency, with an oil yield of about 10 gallons per ton. Table 2 describes some of the calculated air emissions of criteria pollutants using western shale under these conditions. We suspect that it will be some time before anyone builds a facility in the east to process 50,000 barrels per day, and when they do it will be a different technology. Similarly, the technology suggested for eastern shale will yield considerably more than 10 gallons per ton. Bates' numbers, taken from Western projects, probably exceed our expectations in the east for the next five or six years. Table 3 gives the potential air emissions from various extant oil shale technologies (3) The table shows the potential unabated emission rates. Various air pollution technologies can reduce the sulfur dioxide emissions and

perhaps the others as well. Again, these technologies differ considerably from those proposed for eastern shale. In summary, considerable evidence exists that air emissions will contain both criteria pollutants and others, no matter what the retort technology.

Table 2. Potential Air Emissions of Criteria Pollutants
(Adapted from Bates 1981)

	<u>Tons/Year</u>
Particulates	2920-5840
Sulfur Oxides	360-2920
Nitrogen Oxides	4380-7300
Hydrocarbons	180-1100

Assumptions:

1. 50,000 bbls/day
2. 50% efficiency
3. Oil yield - 10 gal/T

Table 3. Potential Air Emissions from Extant Oil Shale Technologies
(Adapted from Fruchler, J. S., et al. 1983)

Project ²	³ Potential Unabated Rates			
	SO ₂ (kg/bbl)	NH ₃ (kg/bbl)	HC(kg/hr)	CO ₂ (kg/bbl)
Occidental	11.1	-	101	415
Rio Blanco	51.7	.68	-	525
Geokinetics	7.5	-	-	-
Paraho	2.1	.76	89	154
Union B	2.8	.045	-	72
TOSCO II	6.4	2.8	316	49

1 = Retorts vary within project

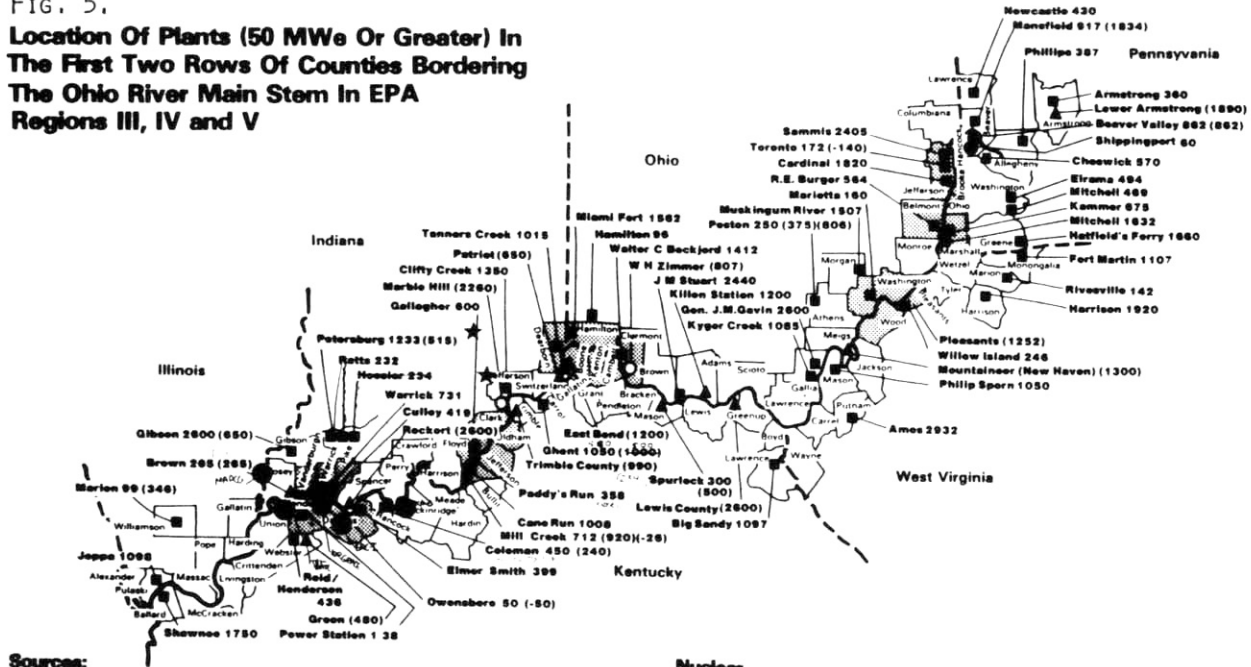
2 = Other reported pollutants include PAH's, Hg, NO_x, As

3 = Some controls are possible

Much of the area near and downwind of western oil shale developments contains pristine air pollution conditions. Such is not the case in the east. Similarly, the region downwind of the western development has few people. Again, this is not the case in the east. While the oil shale region of Indiana is sparsely populated, it lies between three major cities: Indianapolis, Cincinnati and Louisville. It also lies downwind from a large number of air pollution sources, particularly those which produce sulfur dioxide (Figure 5). Few regularly maintained monitoring devices for any pollutant occur in the oil shale area. Table 4 summarizes the available air pollution data for the

FIG. 5.

Location Of Plants (50 MWe Or Greater) In The First Two Rows Of Counties Bordering The Ohio River Main Stem In EPA Regions III, IV and V



Sources:

- (1) Steven D. Jansen, Electrical Generating Unit Inventory, Nov. 1978. Energy Resource Center, Chicago Ill. University of Illinois at Chicago Circle, Prepared for Ohio River Basin Energy Study (ORBES)
- (2) ECAR Region Site Inventory 7/18/79, Owen Lentz, Executive Manager

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Nuclear
 ● In service
 ○ Under construction or planned through 1986
Coal
 ■ In service
 ▲ Under construction or planned through 1986
 ▨ SWSA

○ Numbers following plant name indicate total MWe capacity corrected to 1979 where information available. Additions under construction or planned are in parenthesis. Retirements are preceded by a minus sign. Because of constant change these numbers may not represent current status

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southern portion of Indiana for the SO_2 , NO_2 , O_3 , HC. No direct measure of ambient air pollution in the oil shale area exists, nor do any meteorological stations which describe the wind patterns occur in the region. Because the oil shale region stretches from the Ohio River Basin northward and because wind conditions and particularly inversion conditions vary throughout the region, local meteorological stations would improve the data base considerably. In a recent paper by Loucks (unpublished MS) says that studies of tree ring data and growth data of vegetation indicate significant levels of criteria pollutants in the region. While inadequate data exist to characterize the ambient pollutants in the region, indirect evidence reinforces the theory that ambient air conditions are highly polluted.

Table 4. Availability of Air Pollution Monitoring Data in the Oil Shale Region of Indiana 1976-1981

	Number of Stations	Number of Years, all stations at EPA evaluation criteria	Stations with 2 or more years	Number Violations
SO_2	18	38	10	3 (1)
Particulates	18	42	12	24 (2)
NO_2	3	7	2	0
Ozone	1	2	1	20 (3)
HC	0	0	0	0

1 = 24 hour primary

2 = 15 Annual Average, 9 24 hour primary

3 = 1 hour average

4. WATER

We must proceed similarly in our discussion of potential effects to water in the oil shale region of the state. Here, however, the problem becomes more complex because oil shale development will affect both water quantity and water quality. We can summarize water quality data by saying that few surface water stations are regularly monitored throughout the region and none for ground water quality. Bates and Thoem (5) suggest that development will affect both surface and ground water.

Below we will discuss the available evidence that oil shale development will pollute; second, that it will use the available water resources; and third, we will look at the available data in the region. Water pollution may occur either as a result of discharges into the surface water or the leaking of leachate materials of the spent shale into the ground water. Table 5 adapts O'Shaughnessy *et al* (4) and Bates and Thoem (5) data on several potential water pollutants in waste water. Because of the varying technologies, both of oil shale retorting and of water treatment, the numbers vary quite radically in many cases. We expect lower pH from eastern shale and higher sulfates. Note that this chart does not describe trace metals. There will, however, be potential transfer of trace metals either in the waste waters or from the leachates, depending upon the technology. These trace metals include oxides of sulfur, chlorides, carbonates, aluminum, boron, cadmium, fluorine, lead,

molybdenum, vanadium, and zinc. Retorting the Henryville and the Falling Run shale will release nickel, copper, zinc, as well as uranium. Until we know more detail about the technology, we can only assume that these materials will show up either as scrubber residues in waste water, waste piles or in leachate systems from the spent shale.

Table 5. Wastewater Characteristics of filtered Retort (0.4 micron) Wastewater (Adapted from O'Shaughnessey et al 1982 and Bates and Thoem 1980.)

	<u>mg/l</u>
pH	8.5-9.6
TDS	6,197-15,900
TDC	2,500-9,500
COD	6,200-10,840
BOD	3300
Ammonia N	1,800-3,247
Arsenic	0.4-6.875
Cyanide	2.6-20.8
Sulfate	1,600-1,715
Sulfide	<0.5-222

We know somewhat more about water quantity problems. All of the known technologies of oil shale retorting use water to a greater or lesser extent. Known oil shale processing technologies use approximately 5 to 15 million gallons per day for a 50,000 barrel per day facility. New technologies may use less water, but produce considerable waste water as we have discussed above. While the eastern United States is generally more humid than the west, the particular region of the state, because of the underlying impermeable shale becomes droughty in summer. The data on ground water are derived from very few records. The surface water from streamflow statistics for 51 gauging stations, few which have current or complete data.

The data on ground water are derived from very few records. Little ground water exists except in alluvial fields along the major waterways. On our map, that would be the east fork of the White River, and of course, the Ohio River. There are no available data about seasonal change in ground water. Similarly, there are no available data about ground water quality. There are several reservoirs throughout the southern portion of Indiana. These do not provide enough excess water for a large oil shale development. We can only conclude that either individual developers or the state must provide an adequate water facility for such a development, probably moving water from the Ohio River Basin into the oil shale region. Currently Indiana state law forbids inter-basin transfers. The Ohio River does not flow strongly in summer and drops to minimum navigational levels. Thus, large scale removal for shale retorting conflicts with shipping interests on the River.

5. LAND USE

Land use problems for eastern shale differ from those of western shale for a variety of reasons. Unlike the west, Indiana is primarily an agriculture state. Over 50% of the farms in the oil shale region are rated as prime agriculture lands by the U.S. Soil Conservation Service. In addition, a number of public land holdings used for recreation and wildlife occur within the region. Thus, we must consider not only the potential acreage of land mined for oil shale, but the probability that reclamation will return that land to its former use. Johnson (1) discussed reclamation experiments on Stone and Webster's Petrobas project in Brazil. They proposed an Indiana project which would build a 50,000 barrel per day retort with a yield of approximately 16 gallons per ton. Assuming they use the top 60 feet of the shale bed and leave the remainder as an impermeable seal to reduce ground water pollution and that this 60 feet includes 50 feet of shale and 10 feet of overburden, we calculate they will require approximately 400 acres per year. Table 6 gives the calculations for a 50,000 barrel per day project and compares those numbers to a variety of other acreage figures. Some developers have calculated that Indiana oil shale could easily support a total industry of a half million barrels per day. If so, we simply multiply the calculations on Table 6 by 10 and calculate 4000 acres per year affected by oil shale. The table also includes, for comparison, the current leases held by potential oil shale developers equalling 45,000 acres, the amount of acreage occurring in Indiana strip mines are 90,000 acres. For those in the midwest that have some feeling for our land use, the Hoosier National Forest, is approximately 200,000 acres. In southern Indiana there are currently 150,000 acres in oil and gas leases as yet undeveloped. And after 10 years of hard struggle, environmentalists set aside a 13,000 acre wilderness area. In short, the area potentially affected is a relatively significant piece of the state.

Table 6. Land Use Considerations

Theoretically:

A 50,000 bbl/day retort with a yield of 16 gals/T (Petrobas)
 = 131,000 - 154,000 T/day = 48 - 56 X 10⁶T/year
 = 400 Ac/year 60 feet deep (10' overburden x 50' shale)

Current Leases = 45,000 Ac for Oil Shale Companies

Indiana Strip Mines _ 90,000 Ac

Hoosier National Forest _ 200,000 Ac

Oil and Gas Leases in Southern Indiana _ 150,000 Ac

Deam Wilderness _ 13,000 Ac

No studies suggest that spent shale will ever return to prime agricultural use. Most developers plan on backfilling their process wastes into the surface mined area. These wastes include overburden, waste lean shales, spent shale, raw finds, finds and processed wastes. These wastes pose serious problems because of their: (1) chemical composition; (2) physical properties; and (3) volume.

Shale wastes contain organic carbon, various cations, anions and trace metals, such as aluminum, boron, cadmium, fluorides, lead, molybdenum, vanadium, zinc, iron, and uranium. Indiana shale wastes, depending upon the technology, may also contain considerable sulfate.

The Indiana Geological Survey has proposed that developers use only the top half of the seam. This not only includes the richest oil shale, but leaves the bottom half 50 or 60 feet *in situ* as an impermeable layer reducing the potential for ground water pollution. Thus, the stripped areas not only provide a convenient place for the placement, but a relative good seal for the pollutants derived from the leachates of these materials. We do not as yet know how good.

A problem develops in that spent shale, as a result of retorting, expands like popcorn. Depending on the technology, various experts predict anywhere from 20 to 50% expansion by volume. This means that spent shale will not fit entirely in the holes from which it came. Some considerable material will be left stacked about the landscape. By the same token, depending upon the transportation system, it may sit in piles for potential secondary recovery of some of the metals or for other purposes. Under these conditions, the spent shale will leach. The leachates contain a variety of materials as we have discussed earlier. Figure 6 shows the expansion of spent shale under various conditions. Figure B shows the expansion if the top 50 feet is mined, giving approximately a 20% expansion. Generally, this will occupy the space formerly filled by overburden. If the expansion is as high as 50% and all 100 feet of the shale were mined, it would extend 50 feet higher than the ground surface. The reclaimer must then cover this with soil. Little extra available soil exists in that region of Indiana to augment the thin overburden.

We know of no current research on reclamation of these piles of eastern spent shale. Two primary environmental concerns include the degradation of surface and ground water quality as a result of leaching through these wastes and phytotoxicity and stability on the reclaimed area. The Petrobas project shows reclamation from Brazil. This project used, at least in part, Indiana shale upon which they planted a variety of plants which grow in tropical regions. Of these, they planted mimosa, eucalyptus, Carolina pine and several other tropical tree species. Some reclamation attempts were made using matte, a form of tea. Johnson reports the success of this study. We point out that Brazil has somewhat different climate and soil conditions from those found in Indiana.

6. SOCIOECONOMIC

Indiana shale development would affect local socioeconomic patterns quite differently than western developments affected their local patterns. Because the Green River area of Colorado is distant from large labor markets, the area would receive a large and sudden semi-permanent influx of workers and their families. The area has few large towns or services available. The influx would cause a "boom town" similar to those at Gillette, Wyoming and Colstrip,

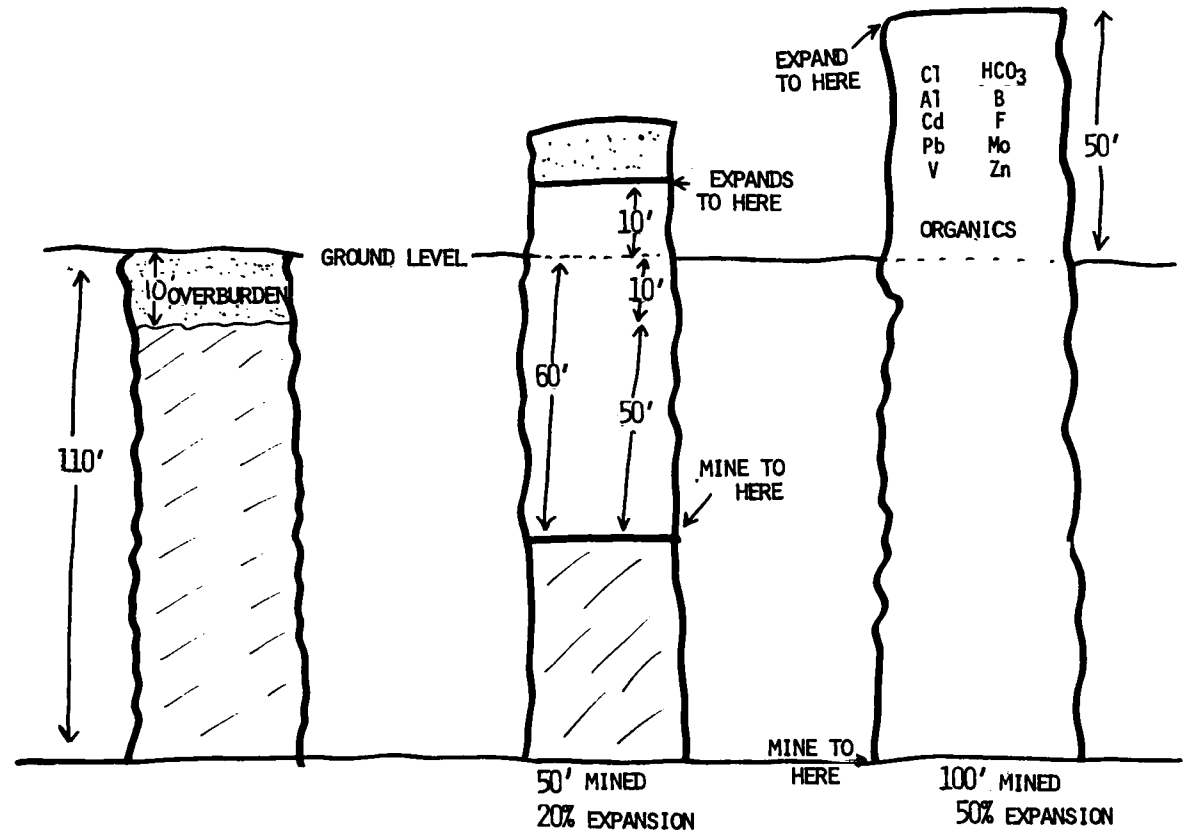


FIG. 6. SCHEMATIC SHOWING SPENT SHALE EXPANSION

Montana. In southeastern Indiana, a large labor force already exists. The shale region lies well within commuting range of Indianapolis, Cincinnati, and Louisville. Recently, two nuclear power plant projects (Marble Hill in Madison, Indiana and Zimmer in Cincinnati) have laid off construction workers. Indiana and Kentucky both contain many presently unemployed miners.

The land use and water availability conflicts from large scale oil shale development in Indiana will resemble those in Colorado and in the coal mining areas in Montana, Wyoming and South Dakota. However, because of the greater population and prevalence of farming, these conflicts may become more intense in Indiana than in the west.

7. ECONOMIC POTENTIAL FOR DEVELOPMENT OF EASTERN OIL SHALE

Before the discovery of oil in 1859, oil shale was a primary source of petroleum in the U.S. Today, however, uncertainty clouds economic feasibility of extracting oil from shale in the U.S. The USSR and China today produce shale oil commercially, as well as Brazil on a limited scale (6). Yet shale oil has not been an important source of energy in market economies. Indeed, engineers have viewed shale oil as "almost feasible" for at least the last thirty years (7). As recently as 1973, experts have pegged the projected price of oil from shale at as little as \$5.50 per barrel. Currently, estimates range from \$20 to \$30 per barrel. Advocates have regularly claimed over the years that a 20 percent rise in the world price of crude would make shale oil feasible. World oil prices have risen far more than 20 percent during the last decade, but shale oil has failed to become a major source of petroleum.

Comparisons of oil shale cost with current world prices for oil can mislead. The changes in the world market for oil since the early 1970s that provide opportunities for shale oil also contain new sources of economic risk. To understand the potential role of shale oil, one must first understand the basics of the world market for oil.

The Saudia Arabian and other OPEC reserves dominate the world supply of petroleum. Saudia Arabia alone has 24.6 percent of the world's proven reserves of oil (8). Saudia Arabia's internal needs require little oil, making them a major force in oil exports. While the prices the Saudis charge for their oil have risen dramatically since 1973, their production costs remain very low. Thus while the high OPEC prices seem to spur oil shale opportunities, these opportunities are illusory in that OPEC could undercut these with ease.

The feasibility of new energy technologies is based less on the current high prices for crude oil than on the uncertainty surrounding future price and availability. The cartel-like pricing behavior of OPEC coupled with political instability in the middle east have caused considerable confusion about future prices and supplies. The supply interruption following the Iranian revolution in 1979 dramatically showed the impact of a single country's internal events on the worldwide market for oil. The continuing concern about the potential impact of the war between Iran and Iraq on oil supplies offers another example.

Because of these concerns, shale oil could become attractive to develop despite its high cost because of the strategic role oil shale might play in the contingency plans of the U.S. government to insure a minimal domestic production capability for petroleum products. Oil from shale can be refined into liquid fuels such as gasoline or jet fuel (kerosene) for mobile use.

Thus, we will compare Indiana oil shale to other sources of liquid fuels in the U.S. and North America rather than with other sources of energy in the world.

The economic feasibility of Indiana shale oil depends on the cost of the shale oil itself and on the costs of possible alternatives. Few reliable estimates of shale oil costs exist, which is not surprising given the early stages of development of the industry. The costs for some alternate sources vary from well understood to substantial uncertainty. Should shale oil costs turn out relatively low when compared to those of the other alternatives turn out high, shale oil could prove feasible, and vice versa.

Estimating the cost of oil from Indiana shale in part depends on the technology chosen. One technology thought promising is based on the Petrosix Process developed over the last thirty years by Petrobras, the national oil company of Brazil. The Devonian shale found in Indiana resembles the shale found in Brazil and processed in the Petrobras pilot plant. Petrobras anticipates establishing commercial scale operations within the next few years. Allis Chalmers has developed another approach based on a roller grate retort. They have tested this process on Indiana shale in a small process development unit but not in a pilot plant stage. Cost estimates for either process will remain very difficult to develop before testing in pilot plant operations and even then the estimates will not likely be within less than plus or minus 30 percent of eventual full scale commercial costs.

The mining of the shale and transport to the process site are also important cost elements. The mining and transport costs will not substantially vary with the recovery technology but will vary with the details of the specific project. Unlike with western oil shale technologies which required underground mining, Indiana's oil shale lies just beneath the surface and can be extracted with conventional surface mining techniques.

Environmental costs associated with both processing and disposal of the spent shale will also affect oil shale development. Several sections above discuss the nature of these costs. They may well provide a source of diseconomies of scale. The waste disposal problems created by a very large scale facility are compounded by both the volume of the waste and its concentration in one location. A series of small scale facilities scattered throughout the shale region, while not reducing the volume of waste, could help spread it out and perhaps minimize the environmental impact of disposal. Such an approach might also reduce the costs of transporting shale to the process facilities but conversely could increase transportation costs of the processed oil.

In addition to the production and environmental costs of shale oil, we add the costs of the infrastructure needed to support the employment in the shale oil and supporting industries and external opportunity costs of using the land for shale oil development rather than alternative uses. Similarly, we should consider an opportunity cost associated with using water for shale oil rather than for competing uses. If such costs are borne by the public sector rather than the private and we must separately account for these costs.

Indiana oil shale is not the only domestic source of liquid fuel nor even necessarily the least costly. One possible alternative is western oil shale, primarily from Colorado, Utah, and Idaho. In the recent past, both large corporations and the U.S. Department of Energy have shown considerable interest in western shale. That interest has subsided somewhat recently in the face of concerns about water availability and environmental problems, not to mention changes in world oil prices. Such interest could easily revive, however,

should developers improve in situ production technology, which recovers the oil without removing the shale from the ground. In principle, in situ production promises to reduce the water requirements and the shale disposal problems of other technologies, but it has yet to prove feasible in application.

Increased oil production from U.S. fields either in Alaska or in the lower 48 states could provide another possible source of liquid fuels. The North Slope of Alaska has proven reserves of 9.6 billion barrels with the expectation that Alaskan reserves could eventually total as much as 15 billion barrels (9). Alaskan oil, however, has high transportation cost associated with bringing it to market. A drop in transportation costs could increase its role, to the detriment of the prospects for shale oil. Within the lower 48 states, major new finds, although possible, are not likely. A great deal of oil remains in existing fields, however, even after primary recovery techniques no longer produce. Recent years have seen excellent progress in secondary and tertiary recovery techniques applied to existing fields. Further technological improvements could substantially increase domestic recoverable reserves even without new finds.

Increased oil production could occur elsewhere in North America. Mexico has 8.5% of the world's proven reserves (almost twice those of the U.S.) and although much of their current production goes to their current needs, increased exports to the U.S. could be possible in the future (8). Canada also has the potential for increased oil production, particularly from the Athabasca oil sands in Alberta (6). U.S. has few sources of oil sands in California, Utah, and Kentucky. Improvements in recovery technology for oil sands might offer the prospects for imports from Canada or production from U.S. sources.

Theoretically, synthetic fuels from coal another possible source of liquid fuel. Since the establishment of the U.S. Synthetic Fuels Corporation in 1980 the government has focused on the production of synthetic fuels derived from coal. While assessments of the likely success of such programs vary both by source and over time, coal offers promise compared to shale in part because only one third the tonnage needs be mined per barrel of oil with coal as with oil shale (10). As with oil shale, the economic feasibility depends upon technological developments and solutions to the emerging environmental problems.

The uncertainties surrounding the costs of shale oil and the costs of the major domestic alternatives pose serious problems both for public policy and for energy companies. Oil shale differs from petroleum greatly in the sort of uncertainties developers must accept. The major risk in petroleum exploration is whether developers can find oil or not. But, oil shale abounds. The risk lies in technological invention. In any case, public and private officials faced with decisions expend funds to prepare for potential risk production must do so with uncertainties in every major area except exploration.

8. CONCLUSIONS (Figure 7)

Our paper describes the abundant oil shale resource available. It also describes an environment with considerable uncertainty in relation to environmental quality. We know there is air pollution. We know there are water quantity problems. We think there are water quality problems. The land use in that area is quite profitable as an agriculture resource. We have shown that there is considerable uncertainty about the potential technologies that exist. All of these, we believe, are susceptible to changes in economic and political

$$F_{Y=2100} = \int ? \times ?^? \times ?/ ? d?$$

FIG. 7. EQUATION TO SOLVE FOR F (= FUTURE)

conditions far removed from southern Indiana. We suggest that the Federal and State governments develop the appropriate research and monitoring systems to acquire and understand the background data and potential impacts. They could then develop mitigation systems, and allow review by the scientific and regulatory community. We note that the public agencies in the state of Indiana are not equipped to deal with the technological problems involved. We note that there is pressure to develop synthetic fuels from coal and to increase the production of Indiana coal. Sadly, we suspect that the opportunity to behave in a far-sighted fashion will slip from us and we will again proceed in a catch up, fix up mode. For those of us in the environmental science business, this constitutes a tragedy.

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