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# HEALTH EFFECTS OF SYNFUELS TECHNOLOGY - A REVIEW

by

L. P. Sanathanan, C. A. Reilly,
S. A. Marshall, and K. E. Wilzbach

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Division of Environmental Impact Studies

April 1981

Prepared for the U. S. Department of Energy
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Washington, D. C. 20545

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*Biomedical and Environmental Research Program

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# ABSTRACT

This document contains annotated synopses of available information pertinent to health impacts of synthetic fuel technologies under development, and identifies needs for further information. The report focuses on carcinogenesis, which appears to be a special problem with coal conversion technologies. This review is intended to serve as a reference for the NEPA Affairs Division of DOE in its evaluation of the overall synthetic fuel program and specific projects in the program. Updated versions of this document are expected to be prepared annually or semiannually as new information becomes available.

# 1. INTRODUCTION

The inability of U.S. oil and natural gas resources to satisfy present or projected requirements of the country, and the increasing need to reduce our dependence on imported oil recently have provided impetus to the development of a synthetic fuels industry. The President's Energy Message of July 15, 1979, included major plans to stimulate the production of synthetic fuels at the rate of approximately two million barrels per day (MMBPD) by 1990. The current target for the synfuels program is to produce gaseous and liquid fuels from coal and shale at the rate of approximately 1.3 MMBPD (crude oil equivalent) by 1995.[1] Plans are underway for demonstration and commercial coal gasification and demonstration coal liquefaction plants. There will be substantial economic incentives to convert coal to liquid and gaseous fuels, and to chemical feedstocks. In terms of providing a petroleum substitute, oil shale technology probably is even closer to commercialization. There are two oil shale projects, Rio Blanco and Cathedral Bluffs, actively proceeding towards commercial-scale operations on federal lease tracts in Colorado, and at least nine others at the stage of field testing. Large-scale utilization of coal and shale, however, will be accompanied by substantial health hazards unless adequate controls are implemented.

Coal-derived products generally are more toxic than the petroleum-based products they will be replacing, because of the extreme aromaticity of the coal molecule and its high content of nitrogen, sulfur, and oxygen. Products and effluents generated from liquefaction contain carcinogenic polycyclic and heteroatomic organics. Coal-conversion products are, in many cases, chemically similar to coal tar, one of the oldest known industrial feedstocks and a confirmed source of carcinogens. A large pilot liquefaction facility at Institute, West Virginia, operating between 1952 and 1969, was associated with increased incidence of skin cancer and pre-tumorous conditions in plant workers.[2] There is some concern over worker exposure to potentially carcinogenic compounds during shale retorting as well, but to a lesser degree than during coal conversion. Oil shale technology faces the serious problem of potential water quality impacts from the enormous volume of mining and spent shale (due to runoff and leaching) involved in the conversion of shale to oil. It is thus natural that there will be much regulatory attention focused on synfuel technologies.

While it is possible to mitigate the potential health hazards with suitable control technology, this will be reflected in the increased cost of energy. The key to successful implementation of the synfuels program will be the design of processes that are at the same time environmentally acceptable and cost-effective. Risk-benefit analysis plays an important role in this regard, as an aid to decisions concerning various mitigative measures and control technologies. It involves identifying important sources of health risks and efficiently allocating the expenditure for risk reduction among various categories of risk. There also is the question of establishing a level to which overall health risks should be reduced. Satisfactory risk management is thus predicated on our ability to assess health risks from various components of the synfuel cycle and from the whole cycle.

A rigorous assessment of the health risks associated with synfuels is not possible at present because of limited operating experience and consequent lack of data. The purpose of this review is to compile and summarize available information on health impacts of synfuel processes relevant to a risk-benefit assessment, and to identify needs for further information.

Some of the health impacts of coal conversion are similar to those of other coal-utilizing industries and are given only a cursory treatment in this review. Health impacts that are unique to coal conversion are addressed in a systematic way and key issues are identified in Section 2. The report focuses on carcinogenic issues, since the threat of cancer is the single largest health concern as perceived by the public. Key issues facing oil shale technologies are different from those of coal conversion and these differences are pointed out in Section 2. Sections 3 and 4 contain annotated synopses of available information pertinent to health impacts of coal conversion and shale oil extraction. In particular, Section 3 includes an overview of the different coal liquefaction, coal gasification, and oil shale processes under development, design aspects that relate to health effects, characteristics and sources of emissions, and a discussion of control measures. Section 4 includes a review of relevant bioassay tests and epidemiological data and a comparison of coal conversion products with products of petroleum refineries and coke ovens. Section 5 represents an attempt to do an integrated health risk assessment on a national scale, based on the information that precedes it. Section 5 is necessarily speculative in nature and involves rough approximations and qualitative statements on relative risks. Nevertheless, it permits identification of important gaps in existing information and provides a framework for future work in risk assessment. Section 6 delineates areas requiring further investigation. Section 7 is a selected bibliography including references cited in the review, but not restricted to these. Each article listed in the bibliography is followed by a summary and comments.

## REFERENCES

1. U.S. Department of Energy, Synthetic Fuels and the Environment: An Environmental and Regulatory Impacts Analysis, DOE/EV-0087 (1980).

2. R.J. Sexton, The hazards to health in the hydrogenation of coal-IV. The control program and the clinical effects. Arch. Environ. Health 1:208-231 (1960).

# 2. KEY ISSUES IN HEALTH RISK ASSESSMENT FOR SYNFUEL TECHNOLOGIES

Risk assessment involves analyzing chains of events characterized by Activity → Source → Exposure → Dose → Response relationships. Activities pertaining to coal conversion are discussed first under appropriate segments of the fuel cycle. Key issues unique to coal conversion are identified within each segment, with a focus on carcinogenesis. Key issues facing oil shale technologies are different from those of coal conversion and these differences are pointed out in the remainder of this section.

## COAL CONVERSION

### Coal Mining and Transportation

Health effects from this segment are similar to those of coal combustion, and are omitted from further consideration until Section 5, where a projection of health impacts is made on the basis of existing information.

### Conversion Plant (Production)

Coal conversion produces unique emissions, products, and by-products that contain a variety of potentially carcinogenic compounds such as polycyclic aromatic hydrocarbons (PAHs). Releases of carcinogenic chemicals could occur both within the conversion facility (fugitive emissions, by-products, spills and accidents), resulting in worker exposure, and in the environment (plant emissions, stack releases, process waters, etc.). Air emissions also contain conventional pollutants such as sulfur dioxide and nitrogen oxides that are not addressed here, since they are already regulated and their potential health impacts are reasonably well defined.

Key problems include identification of the dominant sources of pollution and determination of the chemical composition and toxic properties of effluents, products, and by-products. Information on emissions can be obtained by extrapolating data from pilot and demonstration plants, supplemented by data from fossil-fuel power plants, petroleum refineries, and coking operations. There are major uncertainties arising from the limited amount of data for different process parameters (type of coal, reactor design, different pressure and temperature ranges, etc.) and for different operating modes (start-up, steady-state, and upset). Characterization of the potential carcinogenicity of most emissions is limited to rapid screening for mutagenicity by *in vitro* assays, supplemented by *in vivo* rodent tests for carcinogenicity of those found to be most strongly mutagenic. These incomplete characterizations introduce large uncertainties into subsequent determination of adverse human health effects.

## Transportation of Coal Conversion Products

Problems in this segment are similar to those for petroleum products except for toxic properties of products. There are extensive data for the transport of petroleum products and these should be used in conjunction with the toxicity information for coal-derived products.

## Combustion of Coal Fuels (End Use)

Coal-derived fuels will be used primarily for transportation (diesel and gasoline engines), for utility and commercial boilers, and for home heating. There are limited data on combustion in a test boiler, and no data on automobile emissions. When the data on combustion of coal-derived fuels become available, exposure assessments can be made by analogy with the combustion of petroleum products and coal. A key issue in the end-use and also, to some extent, the transportation and handling of coal liquids is whether product upgrading (by means of hydrotreating) is necessary to decrease potential health risks.

## OIL SHALE

Health hazards from shale mining are similar in some respects to those of coal mining, but the higher dust level resulting from the larger volume of shale involved, and the silica content of the shale dust lead to greater risks for shale miners relative to coal miners. Also, the location of shale deposits near aquifers that are crucial sources of water in the West pose water quality problems that are more severe than those arising from coal mining.

At the shale retorting stage (which corresponds to coal conversion) there is some concern over worker exposure to potentially carcinogenic compounds, but to a lesser extent than during coal conversion. A major hazard associated with the conversion of shale to oil may occur after conversion. The enormous volume of spent shale and the possibility of leaching pose a potential threat to water quality.

Issues relating to the transportation and end-use segments of the fuel cycle are similar for coal conversion and oil shale technologies.

# 3. INFORMATION ON SYNFUEL TECHNOLOGIES RELEVANT TO RISK ASSESSMENT

There are a number of synthetic fuel technologies undergoing research and development. In this discussion, those processes that should become commercially available by the mid-1980s for synthetic fuel production are analyzed. This section is divided into two parts, with the first part devoted to coal conversion processes and the second to oil shale technologies. Each part begins with an overview of the relevant technologies.

## COAL CONVERSION

### High-, Medium- and Low-Btu Gasification

Gasification processes use coal to produce gaseous fuel that can be directly burned, used as chemical process feedstock, or used as an intermediate product that can be converted into a fuel through an indirect liquefaction process. Depending on operating parameters, gasification processes can produce either low-Btu gas (less than 200 Btu per scf) or medium-Btu gas (200 to 500 Btu per scf). The medium-Btu gas can then be upgraded to methane in a reaction to produce high-Btu gas (900 to 1000 Btu per scf).

Several types of gasifiers are in use that produce low- and medium- Btu gas. Typically, these react coal with steam and oxygen to yield a gaseous product. The Koppers-Totzek gasifier uses all coals, the Winkler gasifier uses non-caking coals, and the Lurgi gasifier can use either lignites or non-caking coals. Processes that are under development or at preliminary demonstration-scale plant design include slagging Lurgi, COGAS, U-gas, and Texaco. The Texaco gasification process is considered to be in the most advanced stage of development. This process can use all types of U.S. coal and has no liquid by-products.

Several plants have been designed to produce synthetic natural gas from coal by combining the components of various commercial systems. These include the Lurgi gasifier to produce medium-Btu (synthesis) gas; gas cleanup systems; and the methanation unit for conversion of petroleum synthesis gas to methane. The methanation unit for coal synthesis gas has not yet been tested commercially. A commercial-scale plant designed to use this technology with North Dakota lignite is under active consideration for construction and large-scale testing.

## Indirect Liquefaction

In this process coal is converted to a liquid product by first gasifying the coal to produce a mixture of carbon monoxide and hydrogen. This mixture of CO and $H_2$ is referred to as synthesis gas. It is an intermediate product and is allowed to react with the help of a catalyst to form liquid products.

The Fischer-Tropsch process converts synthesis gas to liquid products and has been operating in South Africa (SASOL) using a Lurgi gasifier. Synthesis gas also may be used to produce methanol, which may ultimately be processed into gasoline by means of a catalyst. This has been done by the Mobil Oil Company, the process name being Mobil M.

## Direct Liquefaction

In the direct liquefaction processes, a coal slurry is reacted directly with hydrogen, thus eliminating the intermediate gasification step used in the indirect liquefaction process. After hydrogenation, the solids and liquids are separated. The residual solids are then burned in a gasifier to generate hydrogen and steam. The quality of the liquid produced depends on the extent of hydrogenation and can be either of a boiler fuel grade or of a synthetic crude grade. Four major direct liquefaction processes are under development: two Solvent-Refined Coal processes (SRC-I and SRC-II), and the H-Coal and Donor Solvent processes.

## Concerns in Coal Conversion Processes

The conversion technologies considered to be favorable from the point of view of cost-effectiveness and impact upon the environment are high-Btu gasification processes and liquefaction processes. Of the high-Btu gasification processes, the favorable candidate is Lurgi. Of the liquefaction processes, the candidates considered favorable are H-Coal, SRC-I, SRC-II, and Fischer-Tropsch. To assist in evaluating the environmental risks and carcinogenic emission characteristics associated with each of these processes, relevant information is provided in Table 3.1.

For comparisons of the various coal conversion processes, characteristics of the conversion reactors must be considered. Operational characteristics of the various coal conversion processes are given in Table 3.2. It is clear from the considerations based upon chemical kinetics that at a given pressure, the likelihood of survival of a high-molecular-weight organic carcinogen drops with increasing temperature. For this reason, Lurgi and Air-Blown Lurgi processes are expected to emit small to negligible amounts of high-molecular-weight organic carcinogens. On the other hand, the Fischer-Tropsch process, because of its low operating temperature, will produce relatively large amounts of these compounds. As operating pressures are increased, the production of these high-molecular-weight carcinogens will increase at a given temperature. Such predictions are based upon well-founded principles of chemical reaction kinetics.

The various carcinogenic compounds of concern in coal gasification and liquefaction are listed in Table 3.3. In addition to organic carcinogens, carcinogenic trace elements and radionuclides could be expected to be present in virtually each coal conversion process. For each of the various processes there is a well-defined set of principal reactants, products, and by-products, including wastes. These are listed in Table 3.4.

Table 3.1. Possible Sources of Carcinogenic Compounds Listed for the Various Coal Conversion Processes[a,b]

| Process | Raw Materials | Intermediate-Stage Carcinogens | Post-Conversion Stage Carcinogens |
|---|---|---|---|
| High-Btu gasification | | | |
| Lurgi | Crushed, non-caking coal; water; nickel (catalyst) | Particulates, scrubbing fluids, by-product oil | Sulfur particulates, some organics |
| Indirect liquefaction | | | |
| Fischer-Tropsch | Lurgi gasification, Fe/Co catalytic reactor | Hydrocarbons | Numerous organics |
| Direct liquefaction | | | |
| H-Coal | Pulverized coal, $H_2$ | Hydrocarbons, scrubbing fluids, light and heavy organics | Numerous organics, fuel oil |
| SRC-I | Pulverized coal, $H_2$ | Hydrocarbons, light and heavy organics | Hydrocarbons, light organics, fuel oil, solid fuel |
| SRC-II | Pulverized coal, $H_2$ | Hydrocarbons, light and heavy organics | Numerous organics, fuel oil |

[a] See Refs. 1 and 2.

[b] Common to all processes as well as to intermediate stage and fast conversion stage are effluents of such hazardous material that contain radionuclides and compounds of arsenic and selenium.

Table 3.2. Reaction Conditions for Various Coal Conversion Processes[a]

| Process | Reactor Press. (psi) | Reactor Temp. (°F) |
|---|---|---|
| Lurgi | 350-450 | 1140-1400 |
| Fischer-Tropsch | 330-360 | 450-620 |
| H-Coal | 2250-2700 | 850 |
| SRC-I | 1000 | 815 |
| SRC-II | 1000 | 850 |

[a] See Ref. 3.

Table 3.3. Potential Health Hazards in Coal Liquefaction and Gasification Process Streams[a]

| Chemical Classification | Compound | Phase | Remarks |
|---|---|---|---|
| Amines | Diethylamines | Gas | Potenital source of nitrosamines from reaction with nitrogen oxides |
| | Methylethylamines | Gas | |
| Heterocyclics | Pyridines | Gas/liquid | |
| | Pyrroles | Gas/liquid | |
| Hydrocarbons | Benzene | Gas/liquid | |
| Phenols | Cresols | Gas/liquid | May be promoters |
| | Alkyl cresols | Gas/liquid | |
| Polynuclear | Anthracene | Gas | |
| Aromatics | BaP[b] | Aerosols | |
| | Chrysene | Particulate | |
| | Benzo[a]anthracene | | |
| | Benzo[a]anthrone | | |
| | Dibenzo[a,l]pyrene | | |
| | Dibenzo[a,n]pyrene | | |
| | Dibenzo[a,i]pyrene | | |
| | Indeno[k,2,3-c,d]pyrene | | |
| | Benzoacridine | | |
| Trace elements[c] | Nickel | Gas | As $Ni(CO)_4$ |
| | Beryllium | Gas | |
| | Cadmium[b] | Gas | |
| | Arsenic[b] | Liquid | |
| Organo-metallics[c] | Nickel carbonyl | Gas | |
| Fine particulates[c] | Sulfur particulates | Gas | May be a carcinogen promotor |
| | Coke | Gas | |
| | Coal dust | Gas | |

[a] See Ref. 1, Vol. II, pages 10-52.

[b] Potential mutagens or teratogens, based on Teratogen/Mutagen Sulfide, Register of Toxic Effects of Chemical Substances, National Institute for Occupational Safety and Health.

[c] Radionuclides also may occur as trace elements, organo-metallic compounds, and in the fine particulate effluents.

Table 3.4. Products, By-Products, and Wastes for Coal Conversion Processes[a]

| Process | Products | By-products and Wastes |
|---|---|---|
| Lurgi | Off-gas (450 Btu/scf) | Sulfur, ash |
| Fischer-Tropsch | Petroleum, LPG, oil, wax, gas, alcohol | Ash, $H_2S$, $CO_2$ |
| Hydrocarbonization | High-Btu gas, fuel oil | Sulfur, ash, monoammonium phosphate |
| H-coal | Synthetic crude gas | Ash, ammonia, $H_2S$ |
| SRC-I | SRC, gas, light oil | Sulfur, minerals, vent gas |
| SRC-II | Pipeline gas, LPG, naphtha, fuel oil | Sulfur, slag |

[a] See Ref. 1, Vol. I, Sec. 3; and Ref. 4, Sec 1.9.

The existence of organic carcinogens in a process emission stream will depend on the reactor type and the control equipment used. Fine particulates will be present when one of the process products is a solid. However, fine particulates due to coal preparation and transportation are expected to be almost the same for all processes.

All coal conversion schemes yield, to varying degrees, matter wastes and thermal waste. The two principal vehicles that carry thermal waste are discharge into the atmosphere and discharge into a body of either stationary or flowing water. The manner in which this unuseable heat is discharged is critically dependent upon the site characteristics of the coal conversion plant. Depending upon the plant's site topography, meteorology, and hydrology, an optimum choice can be made for that discharge scheme which best satisfies federal, state, or regional statutes. Whatever these statutory requirements are, their commonality is a prescribed allowable impact-related change in ambient temperature over a given region of space referenced from the source. Thus, depending upon the magnitude of the caloric discharge per unit of time, the dispersion must be such as to accommodate these requirements. The control technology for thermal waste dispersion is highly developed. Among its various constituents are appropriately dispersed water temperature recording sensors and devices as well as computer modeling programs for predicting thermal dispersion, given a set of initial conditions. These programs are based upon classical equations of state.

The remaining wastes are either gaseous, liquid, or solid. These waste streams, their components, and their technologies for control are given in Tables 3.5 through 3.9. As shown in these tables, the high-Btu gasification and indirect liquefaction schemes generate more wastes than do the low-Btu and medium-Btu gasification schemes. An inspection of these tables will demonstrate that whereas the wastes of major concern often are the same for various processes, their quantities and concentrations are process-dependent.

## OIL SHALE

A glossary of oil shale terms is presented at the end of this section of text.

Oil shale is a sedimentary deposit that contains layers of bound organic matter called kerogen. When the shale is heated (retorted) at temperatures in the range of 1000°F, it yields combustible gases, shale oil, and a solid residue called spent, retorted, or processed shale. Crude shale oil can be obtained by retorting either above-ground or in-situ (in place). In surface retorting, the shale is mined and then directly or indirectly heated in retorting vessels. In a true in-situ (TIS) process, a deposit first is fractured by explosives and then retorted underground. TIS is at present a primitive technology, although R&D and field tests are being conducted. Modified in-situ (MIS) is a more advanced in-situ method in which a portion of the deposit is removed by room and pillar mining and the rest is shattered (rubbled) and ignited by explosives and retorted underground. The mined portion can be either retorted on the surface or discarded as waste. The crude shale oil can be burned as a boiler fuel, or it can be converted into a synthetic crude oil (syncrude) by adding hydrogen. The syncrude also can be burned as boiler fuel, or it can be converted to petrochemicals or refined like most conventional crudes. It is better as a source of jet fuel, diesel fuel, and the other heavier distillates than as a source of gasoline.[8-10]

Table 3.5. Uncontrolled Gaseous Waste Streams and Pollutants of Major Concern from Coal Gasification/Indirect Liquefaction Production Systems[a]

| | | Potential Pollution Source | | | |
|---|---|---|---|---|---|
| Operation/Waste Stream | Pollutants of Major Concern | High Btu | Indirect Liquefaction | Low Btu | Medium Btu |
| Coal preparation | | | | | |
| Coal dust from coal storage and handling | Particulate matter similar in composition to coal feedstock | X | X | X | X |
| Coal dryer off-gas | CO, light hydrocarbons, particulate matter | X | X | X | X |
| Coal gasification | | | | | |
| Coal feeder vent gas | Gaseous species including CO, $H_2S$, $NH_3$, HCN, and light hydrocarbons; trace elements; organics | X | X | X | X |
| Startup vent gas | Raw product gas constituents including CO, $H_2S$, $NH_3$, HCN, and light hydrocarbons; trace elements; organics | X | X | X | X |
| Pokehole gas | Raw product gas constituents including CO, $H_2S$, $NH_3$, HCN, and light hydrocarbons; trace elements; organics | | | X | X |
| Ash lockhopper vent gas | Gaseous species including $H_2S$, $NH_3$, HCN, and light hydrocarbons; trace elements; organics | X | X | X | X |
| Gas purification | | | | | |
| Acid gas | Gaseous species including $H_2S$, COS, $CS_2$, CO, $CO_2$, light hydrocarbons, and mercaptans | X | X | X | X |
| Stripping and/or flashed gas | Gaseous species including $H_2S$, $NH_3$, CO, $CO_2$, HCN, COS, and light hydrocarbons | X | X | | |
| Product upgrading/synthesis | | | | | |
| Shift conversion catalyst regeneration/decommissioning off-gas | Oxidized sulfur compounds, volatile trace elements | X | X | | |
| Spent sulfur guard decommissioning off-gas | Oxidized sulfur compounds | X | | | |
| Methanation catalyst decommissioning off-gas | Possibly trace amounts of $Ni(CO)_4$, particulate matter | X | | | |
| Liquid product synthesis catalyst regeneration off-gas | CO, particulate matter | | X | | |
| Fugitive emissions | | | | | |
| Gas from product and by-product storage | Volatile hydrocarbons | X | X | X | X |
| Gas from valves and flanges | Volatile hydrocarbons | X | X | X | X |

[a] See Refs. 1 and 2.

Table 3.6. Uncontrolled Liquid Waste Streams and Pollutants of Major Concern from Coal Gasification/ Liquefaction Production Systems[a]

| | | Potential Pollution Source | | | |
|---|---|---|---|---|---|
| Operation/Waste Stream | Pollutants of Major Concern | High Btu | Indirect Liquefaction | Low Btu | Medium Btu |
| Coal preparation | | | | | |
| Coal pile runoff | Inorganics leached from coal feedstock, suspended solids | X | X | X | X |
| Coal gasification | | | | | |
| Ash sluice water | Trace elements | | | X | |
| Gas purification | | | | | |
| Process condensate from gas quenching and cooling | $NH_3$, $H_2S$, trace elements, tar and oil, organic acids, phenols | X | X | X | X |
| Acid gas treatment still bottoms/spent solvent from Rectisol process | $NH_3$, phenols, cyanides and thiocynates, methanol | X | X | X | X |
| Product upgrading/synthesis | | | | | |
| Liquid product synthesis wastewater | Organic acids, ketones, hydrocarbons | | X | | |

[a] See Refs. 1, 2, and 5.

Table 3.7. Uncontrolled Solid Waste Streams and Pollutants of Major Concern from Coal Gasification/ Liquefaction Production Systems[a]

| | | Potential Pollution Source | | | |
|---|---|---|---|---|---|
| Operation/Waste Stream | Pollutants of Major Concern | High Btu | Indirect Liquefaction | Low Btu | Medium Btu |
| Coal preparation | | | | | |
| Coal refuse | Trace elements, particulate matter | X | X | X | X |
| Coal gasification | | | | | |
| Gasifier ash | Trace elements, organics | X | X | X | X |
| Gas purification | | | | | |
| Dust from particulate removal in hot cyclones | Trace elements, organics | | | X | |
| Product upgrading/synthesis | | | | | |
| Spent shift conversion catalyst | Trace elements, especially Co and Mo | X | X | | |
| Spent sulfur guard | Zn | X | | | |
| Spent methanation catalyst | Ni | X | | | |
| Spent liquid product synthesis catalyst | Trace elements | | X | | |

[a] See Refs. 1, 2, and 6.

## Table 3.8. Air Pollution Control Processes Applicable to Coal Gasification/Indirect Liquefaction Production Systems[a]

| Discharge Stream/ Pollutants Requiring Control | Control Method |
|---|---|
| Sulfur recovery | Claus, Stretford, Giammarco-Vetrocoke |
| Hydrocarbon removal/$H_2S$ concentration | ADIP |
| Tail gas treatment for additional $H_2S$ sulfur recovery | SCOT, Beavon, IFP-1, IFP-2, Sulfreen, Cleanair |
| $SO_2$ control and/or recovery | Wellman-Lord, Chiyoda Thoroughbred 101, Shell copper oxide, lime/limestone slurry scrubbing, double alkali, magnesium oxide scrubbing |
| CO, hydrocarbon control | Thermal oxidation, catalytic oxidation, flares, activated carbon adsorption, vapor recovery, floating roof storage |
| Particulate control | Fabric filter, electrostatic precipitation, venturi scrubbing, cyclones, dust suppression with water sprays |
| Resource recovery | Compression and recycling |
| $NO_x$ control | Combustion modification, dry and wet processes |

[a] See Ref. 3.

## Table 3.9. Wastewater Treatment Proceses Potentially Applicable to Coal Gasification/Indirect Liquefaction Production Systems[a]

| Process Operation | Control Method |
|---|---|
| Oil and suspended solids removal | Gravity separation, flotation, coagulation-flocculation, filtration |
| Dissolved gases removal | Conventional steam stripping, Chevron WWT, Phosam-W, Lurgi-Chemi Linz AG ammonia recovery processes |
| Dissolved/particulate organics removal | Phenosolvan process, biological oxidation. chemical oxidation, activated carbon adsorption, adsorptive resins, thermal oxidation |
| Separated tar/oil and sludge treatment | Emulsion breaking, gravity thickening, centrifugation, vacuum filtration; drying beds |
| Dissolved inorganics removal | Ion exchange, reverse osmosis, electrodialysis, freezing, electrochemical treatment, multieffect evaporation |
| Ultimate disposal | Evaporation ponds, deep well injection |

[a] See Refs. 1-3 and 5-7.

## Surface Oil Shale Retorting

Two methods for surface retorting are of industrial interest: the direct- and the indirect-heated methods. In the direct-heated process, heat is supplied by creation of a combustion zone within the retort. In the indirect-heated processes, gases are circulated to an external reactor for combustion. Heat is transferred back to the retort by the hot circulating combustion gases or heated solids (e.g., ceramic balls) through the retort and the external combustion. The products and residuals from these two methods differ somewhat in their chemical and physical properties. Five oil shale retorting processes have been tested on a pilot-plant scale. All the processes have operated in the indirect heating mode with one process capable of operating in either mode.

Surface processes require mining of oil shale by either underground or open-pit surface methods. The mined oil shale must be crushed and sized before retorting, and following retorting, large volumes of retorted or "spent" oil shale must be disposed of and the area reclaimed.

## Modified In-Situ Oil Shale

The modified in-situ (MIS) process involves mining or removing by some other means (e.g., leaching out of solid minerals) of up to 30 percent of the shale from the retort zone so that void volume is created and permeability is increased. The remaining oil shale in the retort is then explosively fractured and retorted in place. In the case of leached shale, the shale is not fractured; hot gas is injected as the retorting medium. Retorting can then be accomplished by moving the retorted oil either horizontally (for thin shale deposits) or vertically (for thick shale deposits). The mined shale fraction could be processed above-ground in a surface retort.

Three MIS processes currently are of interest: (1) vertical processing, (2) horizontal processing preceded by mining or removing some of the shale, and (3) creation of voids by solution mining of soluble salts. In each of these processes, the raw shale oil is then physically separated from water produced in the retorting process and from particulate material carried over from the retort. Following product recovery, crude shale oil (from any process) requires further treatment to remove nitrogen, oxygen, and sulfur compounds and to reduce viscosity and pour points to allow pipeline or tanker transport. Removal of the nitrogen compounds requires a special refinery process.

## Location and Characteristics of Oil Shale Deposits

In assessing the health and environmental impacts of extracting oil from shale, it is important to know where oil shale deposits occur. Within the U.S., there are numerous areas where oil shale may be found, but with the present status of the global petroleum market and the best available technology for extracting an oil product from shale, the only area considered to be commercially viable is that known as the Green River Formation. This area is located in Northwestern Colorado, Southwestern Wyoming, and the East-Central area of Utah.

Table 3.10 indicates the nature and areal extent of shale deposits in the Green River Formation. The total area of oil shale deposits in this formation is estimated to be 15,000 square miles; of this, an area of about 5,000 square miles is high-grade oil shale yielding 25 gallons or more of oil per ton of ore. The Green River Formation is estimated to contain the equivalent of 8 trillion barrels (bbl) of crude shale oil, of which 400 billion barrels (bbl) are thought to be recoverable economically by present technology. The human population in this area is of the order of 120,000, which translates into an average population density of 3 persons per square mile. Given the anticipated expansion in population, the known distribution of shale oil reserves, and the production target of 200,000 bbl per day (bbl/d) for 1990, it becomes possible, in principle at least, to assess impact to health and the environment using characteristics of the various conversion processes most likely to be used in the oil shale industry. Tables 3.11, 3.12 and 3.13 provide the characteristics of oil shale and retorting processes.

Table 3.10. A Summary of Oil Shale Deposits in Wyoming, Utah, and Colorado[a]

| State | Area Name | Area[b] (100 mi$^2$) | Area of High-Grade Oil Shale (100 mi$^2$) |
|---|---|---|---|
| Wyoming | Green River Basin | | |
| | area - a | 0.5 | - |
| | area - b | 2 | - |
| | area - c | 55 | 21 |
| | Great Divide Basin | 4 | - |
| Utah | Unita Basin | 67 | 15 |
| Colorado | Piceance Basin | 16 | 14 |
| | Battlement Mesa | 1 | |
| | Grand Mesa | 2 | |

[a] See Refs. 11-15.

[b] The total approximate area of oil shale in the Green River Formation in 15,000 mi$^2$. Of this, 5,000 mi$^2$ is the approximate area of the high-grade oil shale (1 mi$^2$ contains 640 acres). An area is defined to be high-grade if the oil shale is ten or more feet thick and if it yields at least 25 gallons of oil per ton of shale.

Table 3.11. Sample Composition of an Oil Shale Section Averaging 25 Gallons of Oil per Ton[a]

| Component | Content (wt %) |
|---|---|
| Organic matter | |
| Carbon[b] | 11.11 |
| Hydrogen[b] | 1.42 |
| Nitrogen | 0.33 |
| Sulfur | 0.14 |
| Oxygen | 0.80 |
| Total | 13.8 |
| Mineral matter | |
| Carbonate (principally dolomite) | 41.38 |
| Feldspars | 18.10 |
| Quartz | 11.21 |
| Clays (principally illite) | 11.21 |
| Analcite | 3.45 |
| Pyrite | 0.86 |
| Total | 86.2 |

[a] See Ref. 16.

[b] The ratio of carbon to hydrogen is 7.82.

Table 3.12. A Typical Analysis of Products Obtained from the Pyrolysis of Oil Shale as Determined from a Modified Fischer Assay[a]

| | Typical Values[a,b] | | |
|---|---|---|---|
| Component | L | M | H |
| Oil (gal/ton) | 10.5 | 26.7 | 36.3 |
| Oil | 4.0 | 10.4 | 13.8 |
| Water | 0.5 | 1.4 | 1.5 |
| Spent shale | 94.4 | 85.7 | 82.1 |
| Gas | 1.1 | 2.0 | 2.2 |
| Loss | - | 0.5 | 0.4 |

[a] See Ref. 16.

[b] Weight percent except as indicated.

[c] (L) indicates very-low-grade shale, (M) medium-grade shale, and (H) high-grade shale.

Table 3.13. Characteristics of the Various Oil Shale Retorting Methods[a]

| Methods | | Input | Product | By-Products |
|---|---|---|---|---|
| USBM Gas Combustion | Direct heat<br>900°F<br>1 atm | Crushed OS, air, gas, water | Oil | Off-gas, retorted shale with organic content |
| Hydrotorting | Direct heat<br>1000°F<br>120/140 atm | Crushed OS, hydrogen catalyst | Oil (high aromatic content) | Retorted shale free of organic matter |
| Union Oil Company | Direct heat<br>2000°F<br>1 atm | Crushed OS, air | Oil (light hydrocarbon) | Shale ash, flue gas |
| Tosco II | Indirect heat<br>1000°F<br>1.5 atm | Crushed OS, alumina balls | Naphtha, gas oil, residual oil | Spent shale, flue gas |
| Petrosia | Indirect heat<br>1.5 atm | Crushed OS, hot recycled gas | Light and heavy oils | Flue gas, retorted shale slurry |
| Lurgi/Ruhr | Indirect heat<br>1000/2000°F<br>1 atm | Crushed OS, heat carrier solids | Oil for cement production and steam generation | Flue gas, shale ash |
| USBM | In-situ<br>Several atm | Air recycled gas | Oil | Flue gas |
| Occidental | In-situ<br>Several atm | Air recycled gas | Oil | Flue gas |

[a] See Refs. 11-13.

As in any chemical process, temperature and pressure play a vital role in determining the outcome of the retorting process. High-pressure retorting reduces oil yield significantly and in turn produces a larger volume of light hydrocarbon gases. The crude shale oil produced at high pressures has higher aromaticity and a lower pour point than the low-pressure shale oil. Sulfur and nitrogen content of oils do not change significantly with pressure. Esso Research and Engineering Company claims that retorting oil shale under pressure with an inert gas such as nitrogen improves the oil product quality comparable to that obtained with hydrogen. One conclusion relevant to health effects to be drawn from these observations is that high-pressure retorting of oil shales seems a more likely process for yielding potentially carcinogenic aromatic compounds.[11]

The effect of temperature on the pyrolysis of oil shale also has been studied.[12] It has been found that an increase in temperature of pyrolysis produces an increase in the density of the oil product and also causes a decrease in the hydrogen-to-carbon ratio. In addition, an increase in temperature causes more gas product to evolve from the process, and decreases the fraction of methane and other light hydrocarbons in favor of the production of $H_2$ and $CO_2$. The conclusion to be drawn that is relevant to health effects is that increasing the retorting temperature produces a decrease in the fraction of carcinogenic organic gases, but at the same time reduces the fuel quality of the product oil and gas.

## Major Concerns Relating to Oil Shale Mining, Shale Oil Production and Usage

An assessment of information produced to date has identified specific environmental problems and constraints that have clear implications for future environmental acceptability of commercial shale development.[17] They are summarized in Table 3.14 and are discussed here under the categories of air quality, water quality and supply, spent shale disposal/reclamation, and occupational health and safety. These concerns are associated with oil shale mining and retorting, by-product and waste streams and the shale oil product itself. Table 3.15 is a summary of the projected resource needs and residuals for surface and in-situ oil shale processes as compared with coal-based synthetic fuel processes at a 50,000-bbl/day plant size.

### Air Quality

Air quality concerns relate to the production of both criteria pollutants (e.g., carbon monoxide, nitrogen oxides, sulfur oxides, hydrocarbons, particulate matter, and photochemical oxidants) and noncriteria pollutants (e.g., trace metals (mercury, arsenic, and boron), hydrogen sulfide, and ammonia) from surface and in-situ retorting; and particulate matter and noncriteria pollutants associated with dusts from mining and crushing of raw shale and resuspension of disposed spent shale. Table 3.16 is a summary of the technology of present-day air pollution control techniques.

Surface retorting facilities have been studied and information is available on the character of gaseous and particulate emissions from some processes. This information has not been interpreted to determine the effect of many process variables, short- and long-term effects on air quality, or consequences to ecology and human health. Information on in-situ and modified in-situ processes stems largely from Occidental and Geokinetics field tests and pilot retorts operated by Laramie Energy Technology Center and Lawrence Livermore Laboratory. Fugitive gaseous emissions have not been studied in detail, and additional research and development is needed.

Control of particulates resulting from oil shale production is a serious problem. For large surfaces at the mine, "wetting" or vegetation of the stock piles can be used to control fugitive emissions whereas for more limited areas (e.g., conveyors, crushers), baghouse filters, scrubbers, and cyclones are used to control particulate emissions. Fugitive emissions due to traffic, wind, etc., are a potential problem and may require the use of chemical additives and best control management practices.

Sulfur in raw oil shale amounts to about 0.7 percent by weight; approximately one-third is associated with the organic fraction and two-thirds is found as iron pyrites or similar compounds. During retorting, about 40 percent of the organic sulfur in shale appears as $H_2S$ in the produced gases, and the other 60 percent as heavier sulfur compounds in the raw shale oil, spent shale, or water residuals. The Stretford process is used to capture the hydrogen sulfide before it is emitted to the ambient atmosphere (efficiencies are about 95 to 99 percent). If shale oil or low-Btu gas from the retort (or another fuel) is used for steam generation or any other combustion process, sulfur oxides will be formed and flue-gas desulfurization scrubbers or an equivalent process must be used for tail-gas cleanup.

## Table 3.14. Critical Environmental Factors and Constraints of Surface Versus In-Situ Oil Shale Retorting[a]

| Surface Oil Shale Retorting[b] | In-Situ Oil Shale Retorting[c] |
|---|---|
| Critical Environmental Factors | Critical Environmental Factors |
| Mining and disposal of shale (reclamation; worker health and safety in mining operation).<br>Air quality (PSD limits, particulates, and $SO_2$) fugitive emissions.<br>Water quality (retorting waste water). | Water quality (potential aquifer disruption and contamination; surface water contamination).<br>Mining operations (workers' health and safety).<br>Control of raw oil shale at surface. |
| Constraining Factors | Constraining Factors |
| No constraining environmental factor if adequate controls are developed, i.e., for the control of dust, leachate, and eroded lands.<br>Allowable PSD increments are critical factors in siting.<br>WQC assessment indicates water supply from Upper Colorado River adequate to support oil porduction of about 1.3 million barrels per day without diversion from agriculture, industry, or other projected uses. | Possibility of long-term hydrological disturbances or introduction of hazardous materials into aquifers would preclude large-scale development in areas where aquifers are present if controls not adequate.<br>Underground work envirionment could present high risk for exposure to uncontrolled toxic and carcinogenic materials. Worker environment is largely uncharacterized. |
| Environmental Assessment Information | Environmental Assessment Information |
| Available information from previously operated pilot retort (Paraho). No sizeable retort or mining operation active.<br>Data from prior retorting under analysis and assessment (EPA, DOI, DOE, and industry).<br>Options for increasing level of environmental R&D activity:<br>(1) with tax credit, execute joint test programs on new industry retort and mining operations.<br>(2) Accelerate Phase II of DOE surface retort PON to construct and operate multiple retort designs. Conduct joint research program with industry contractors.<br>(3) Develop regional meteorological model for oil shale region.<br>Complete environmental assessment by 1984-1985. | By 1983-1984, planned modified in-situ project should deliver adequate controls for protection of workers, waste disposal, treatment of liquid wastes and contaminated waters, fugitive emissions, and retort abandonment strategy. |

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[a] See Refs. 11-13, 16, and 18.

[b] Production of syncrude from oil shale via mining, surface retorting and upgrading.

[c] Syncrude from processing of oil shale by underground retoring and surface upgrading.

Table 3.15. Process Requirements and Pollutants Associated with Synfuel Conversion Technologies, Based on Preliminary Design Studies (normalized to 50,000 barrels per day oil equivalent)[a]

| Process | Input (tpd) | Conversion Thermal Efficiency (%) | Water[b] Requirements (acre-ft/yr) | Air Emissions with Controls (tpd) | | | | | $CO_2$ (tdp) | Solid Waste (tpd) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | $SO_x$ | $NO_x$ | CO | HC | TSP | | | |
| Oil Shale (surface) | 125,000 (25 gal/ton shale) | 65-70 | 6,000-10,000 | 1-5 | 10-30 | 1-5 | 1-5 | 3-10 | 18,000 | Spent shale<br>Shale dust and coke | 108,000<br>4,000 |
| Oil Shale (modified in-situ) | 140,000 (25 gal/ton shale) | 58-63 | 2,000-4,000 | 1-3 | 5-20 | 1-2 | 1-2 | 1-2 | 20,000 | Raw shale[c] | 45,000 |
| Fischer-Tropsch (indirect liquefaction) | 31,000 (subbituminous 8,500 Btu/lb) 0.45% sulfur | 56-60 | 11,000-12,000 | 9-14 | 5-8 | NA | NA | 1-1.5 | 21,000 | Coal prep. refuse<br>Ash<br>Sulfur | Negligible, thick seam<br>1,800-2,000<br>65-70 |
| Exxon Donor Solvent (direct liquefaction) | 20,000 (bituminous 12.663 Btu/lb) 4% sulfur | 60-64 | 7,500-8,500 | 16-18 | 5-6 | 1-1.5 | 0.01-1 | 0.3-0.4 | 14,000 | Coal prep. refuse<br>Ash<br>Sulfur | 8,000-9,000<br>2,500-3,000<br>500-600 |
| Solvent-Refined Coal (SRC) (direct liquefaction) | 21,000 (bituminous 12.518 Btu/lb 3.5% sulfur | 58-62 | 5,500-6,500 | 5-10 | 9-10 | 1.5-2.5 | 1-2 | 2-3 | 14,000 | Coal prep. refuse<br>Ash and slag<br>Sulfur | 8,000-9,000<br>5,000-7,000<br>450-500 |
| Mobil Technology (coal-to-methanol-to-gasoline) | 31,000 (subbituminous 8,500 Btu/lb) 0.45% sulfur | 56-58 | 11,000-12,000 | 9-14 | 5-8 | NA | NA | 0.5-1.5 | 21,000 | Coal prep. refuse<br>Ash<br>Sulfur | Negligible, thick seam<br>1,800-2,100<br>65-70 |
| Lurgi Dry Ash (high-Btu coal gasification 250 MMSCF/day) | 38,000 (lignite 6,783 Btu/lb) 0.6% sulfur | 58-60 | 8,000-10,000 | 35-40 | 16-17 | NA | NA | 2-3 | 29,000 | Coal prep. refuse<br>Ash (coker)<br>Sulfur | Negligible, thick seam<br>2,500-3,000<br>500-600 |
| Coal-fired powerplant[d] (1330 MWe) | 12,750 (bituminous 12,000 Btu/lb) 2% sulfur | 36 (direct firing) | 15,000-20,000 | 76 | 35 | -<br>(negligible) | - | 5 | 31,000 | Coal prep. refuse<br>Ash<br>Sludge (100% solids) | 3,000-4,000<br>1,500<br>1,600 |

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[a] See Ref. 17.

[b] The actual water requirements for a specific site can be substantially reduced through maximum use of dry cooling and water contained in raw coal feed.

[c] Can be surface-retorted.

[d] Assumes state-of-the-art lime/limestone nonregenerable $SO_x$ scrubbing, electrostatic precipitators, combustion modification $NO_x$ control, and wet cooling towers as a basis for the estimates. Current NSPS for utility boilers also was assumed.

Note: No attempt has been made to show emissions from the end-use applications of synfuels, e.g., fuel for boilers, motor fuels.

Table 3.16. Technological Readiness of Air Pollution Control Techniques[a]

| Pollutant and Control System | Readiness Rating | Comments |
|---|---|---|
| Dust | | |
| Water sprays | High | Effective and in general use with wetting agents added as needed. Low cost. Increased water needs. |
| Road paving | High | Reduces vehicle maintenance. |
| Cyclone separators | High | Low cost. Effective only for large particles. |
| Scrubbers | High | Low capital cost and maintenance requirements. High energy and water requirements needed for high removal efficiency. |
| Baghouse filters | Medium | High efficiency. Moderate energy and maintenence requirements. Low cost. Not suitable for high-temperature gas streams. Requires more area than other systems. Waste disposal experience lacking. |
| Electrostatic precipitators | Low to medium | Efficiency sensitive to dust loading, temperature, and particle resistivity. Good removal efficiency. Low operating costs and maintenance. Good for large gas volumes. High capital cost. |
| $H_2S$ | | |
| Stretford process | Medium | Extensive application in refining industry. Good for large volumes of dilute gases. Being tested for modified in-situ gases. |
| Selexol, purisol, rectisol, istosoliam, fluor solvent, and other physical systems | Medium | Being tested for coal gasification streams. No experience with oil shale emissions. |
| Claus process | Medium | Extensive experience in several industries. Needs concentrated feed streams. High maintenance needs and downtime. |
| Tail gas cleaning | | |
| SCOT process | High | Long experience with Claus plants. |
| Beavon process | High | Long experience with Claus plants. |
| IFP process | Medium | Used with Claus plants that produce elemental sulfur. May be applicable directly to retort gases. |
| $SO_2$ | | |
| Wellman-Lord process | Medium | Thirty installations worldwide. High capital cost. High energy requirements. |
| Double alkali process | Medium | Used successfully in Japan since 1973. Waste disposal could be costly. |
| Nahcolite ore process | Low | Limited but successful testing to date. |
| $NO_x$ | | |
| Combustion control | High | Can easily be designed into new plants. Low capital and operating cost. |
| Diesel exhaust control | Medium | Recirculation of exhaust gases can lead to maintenance problems. |
| HC and CO | | |
| Combustion control | High | Use of excess air easily accomplished. |
| Evaporation control | High | Use of floating roof tanks is very effective but increases capital costs. |
| Control of fugitive emissions | Low | Control is difficult because of the large number of dispersed sources. |

[a] See Ref. 19.

The kerogen fraction of the raw shale can contain up to 2 percent nitrogen. The extent of nitrogen oxides formation from use of retort off-gases or shale oil to heat the retort will be related to flame temperature, residence time, and the air/fuel mixture. The Ammonex process, a commercially available stripping process, used in conjunction with the Stretford process, can be used to reduce the nitrogen oxides to oxygen and nitrogen. Nitrogen in the shale oil can be removed by hydrotreating during upgrading operations.[13]

Combustion efficiency during oil shale retorting is not expected to be a significant problem. Hydrocarbon and carbon monoxide emissions therefore will be small. The low-Btu gas formed during retorting will be either flared or used for onsite steam production with traditional flue-gas cleanup controls.

## Water Quality and Supply

Water resource impacts encompass effluent control and water supply issues. In the semi-arid Piceance and Unita geological basins in Colorado and Utah, where most of the high quality oil shale resource is found, water pumped from mines or drawn for process use is expected to be recycled or consumed. Effluent problems are focused on potential contamination of aquifers and surface waters by leaching from spent shale piles, evaporative and lagoon concentrates, or from burned-out in-situ retorts rather than direct emissions. Some potential contaminants to aquifers and surface waters are acids, water-soluble organic carcinogens, radionuclides, and metallo-organic compounds. Problems with in-situ processes concerning backflood water and fugitive gas emissions may result in contamination of groundwater aquifers. Groundwater supplies and surface water supplies fed by groundwater aquifers might be affected for very long periods of time (e.g., 50 years), thereby creating difficulties in securing adequate water supplies for retort operations.

Stabilization and management of spent shale and other wastes from surface retorting processes will require additional research and development before the leaching concerns are resolved. For surface operations, long-term information is lacking on stabilization of shale piles, leachate rates, and retort and other wastewaters as they may affect surface water and groundwater. There is a lack of knowledge regarding the changes in form and toxicity of inorganic and organic residuals that may occur by microbial or chemical action.

There is some evidence from preliminary tests that wastewater produced from oil shale retorting contains chemicals that are potential genetic hazards. Further testing must be conducted to determine the actual degree of hazard associated with this waste stream and possible cleanup processes, but the preliminary data indicate that the wastewater likely would be defined as hazardous under the proposed RCRA regulations.

Effects of in-situ processes on groundwater and relationships between groundwater and surface water impacts are poorly understood. The variables that affect the quantity and quality of retort water also are poorly understood. Means have not been developed for preventing contamination of groundwater aquifers by backflood water for in-situ operations.

Wastewater from surface retorting operations (up to 100 gallons per ton of input shale and more from some in-situ operations) and process water from product upgrading operations will have to be controlled. Water treatment systems for surface retorting can be used for cleanup, and the wastewater can then be used for moisturizing spent shale. Under current planning, oil shale developers envision zero discharge of their wastewaters.

### Spent Shale Disposal/Reclamation

Major uncertainties exist with surface retorting concerning disposal of the large volumes of spent shale generated by surface retorting. Disposal of spent shale and storage of raw shale could create land disturbances of large magnitude, potential accumulation of such toxic substances as nickel, cadmium, and radionuclides in vegetation, and contamination of groundwaters and surface waters from acid runoff.

Retorted shale contains varying amounts of organic and inorganic residuals, depending on the retorting process. It presents a major solid waste management and disposal problem for the surface and modified in-situ operations in terms of both amount and content. Retorted shale will have a density, after compaction, of about 75 to 100 pounds per cubic foot ($lb/ft^3$). This means that for every 50,000 barrels of surface retorted shale oil produced, there will be enough spent shale to occupy a volume of almost 2 million cubic feet, or about a 2-foot depth over a square mile every month of operation. Above-ground retorted shale from modified in-situ operations would have considerably less solid waste to be disposed of. Large areas are required for the storage of raw shale and the disposal of retorted shale. The resulting potential loss of habitat for plant and animal communities and natural erosion of the disposal piles by wind and water may not be fully mitigated by vegetating or physically stabilizing the disposal piles. Problems and uncertainties related to the vegetation of retorted shale include water requirements, accumulation of toxic trace substances such as arsenic, selenium and total dissolved solids in the vegetation, and long-term stability.

Environmental control systems to mitigate these impacts should, in most cases, be available; however, potential problems with stability of waste piles will require several years to emerge and uncertainties will remain for 10 to 20 years. Spent shale can be either returned to the mine or stockpiled aboveground, in which case it will be compacted and vegetated or otherwise stabilized to prevent erosion by wind or water. Dust is controlled by the application of water or chemical wetting agents. Surface disposal options include filling valleys and recontouring surfaces. The major consideration is to ensure that the large quantities of spent shale can be economically disposed of with minimum environmental damage.

### Occupational Health and Safety

The occupational work force will be exposed to an environment largely uncharacterized in terms of industrial hygiene and safety analyses.[16] The workers will be exposed to possible toxic materials such as silica dust and diesel fumes. There are no proven protective health measures for in-situ operations, primarily because the problems have not yet been adequately defined. Quantitative risk estimates for chronic low-level exposures (by inhalation or skin contamination) to the complex spectrum of toxic inorganic and organic constituents of the dusts, vapors, and gases are poorly defined with respect to health effects. While little literature is available on worker health and safety, foreign literature indicates that there may be several worker health impacts related to the operation of shale oil processes. Individual dose monitors for the uncharacterized organic residuals are not available; guidelines for a hygiene program have not been performed, and controls for inhalation protection from other industries will have to be adapted.

Toxicological studies will be required to determine biological effects due to pollution exposures (e.g., pulmonary, skin, and genetic studies as well as behavioral, metabolic, and neurotoxicological research and development). In addition, safety practices will need to be applied to protect against the hazards of room and pillar mines and the explosiveness and fire hazards of shale dust, and to ensure the integrity of in-situ retorts. Additional biological and chemical research will be required to screen and evaluate the crude shale oil and its refined products.

Health and safety problems are not quantified, and as a result controls and procedures are not defined. It is projected that controls from other industries could be adapted. The situation at this stage of research and development presents some risk because there is potential for uncontrolled emissions of both toxic and carcinogenic materials. Existing information is not adequate to allow judgments to be made relative to the disposal of spent and raw shale and health and ecological effects of the effluent and emission streams on a long-term basis.

## Uncertainties in Pollution Control

The proposed mining operations are among the largest ever conceived and as such will require extraordinary efforts to control air pollution. For example, underground mining on tracts U-a and U-b would have mine ventilation rates as high as 12 million cubic feet per minute ($ft^3/min$). Cleaning this volume of gas could be both difficult and expensive. The large ventilation volume is required by mining health and safety regulations and cannot be reduced.

Open pit mines could be much larger than underground mines. Problems with fugitive dust would be increased by the larger quantities of solids that must be handled on the surface. Much relevant experience has been gained through the extraction and processing of other minerals such as coal, copper, uranium, and bauxite. The simpler control techniques (such as water sprays) have been thoroughly demonstrated. However, the potential size of oil shale mines may create problems for the more complex, collection-type control systems that have worked well in smaller mines. The cost of air pollution control for deeply buried oil shale deposits is not known. The amount of overburden that must be removed, and for which pollution control would be needed, may be prohibitively large.

In general, the control technologies appear to be fairly well developed, and should be adaptable to the first generation of oil shale plants. Full evaluation will not be possible until the methods have been tested in commercial-scale operations for sustained periods.

## Costs of Air Pollution Control

The costs of controlling pollutants from an oil shale plant would be particularly sensitive to the lifetime of a project, the plant design, the scale of operation, and the extent of emission removal required by environmental standards.

The relation of the cost of pollutant control to the degree of removal usually is not linear; i.e., the costs generally are considerably higher to increase a pollutant's removal from 98 to 99 percent than from 90 to 95 percent. Consequently, most control costs will be strongly influenced by the degree of removal required by environmental standards. Higher removals will be more costly for individual plants but would allow the region to accommodate a larger industry within the framework of the air quality regulations.

Another example of the effect of facility design on control costs is whether the processes of upgrading and refining are included. If so, other subprocesses such as retorting could take advantage of the efficient control systems that are an integral part of any modern refinery. If refining were not done onsite, control systems still would have to be provided for the other operations. The same degree of removal efficiency could be achieved but with higher costs.

The Denver Research Institute (DRI) recently estimated the costs of environmental control in three projects, based on technologies with highest projected removal efficiencies. Two regulatory scenarios were considered. Under the "less strict" scenario for particulate control in the Colony plant, for example, it was assumed that particulate reductions from point sources would average 98.5 percent, and that for nonpoint sources of fugitive dust reductions of 92.2 percent would be required. The average particulate reduction for the plant was assumed to be 98.3 percent. Under the more strict scenario, overall particulate reductions of 99.5 percent were assumed for point and nonpoint sources. With some differences, similar control scenarios were assumed for other regulated pollutants, and for the other two oil shale projects. The control costs for individual contaminants varied widely from project to project. In each project, however, the largest capital and operating costs were for $SO_2$ and particulate removal. Capital costs for $SO_2$ control equipment, for example, were more than $25 million for the tract C-a and C-b projects, which strongly rely on modified in-situ retorting and which will have to clean large quantities of dilute retort gas. A much lower capital investment (about $10 million) is needed for the Colony project because the TOSCO II retorts produce a much smaller volume of retort gas.

According to DRI's analysis, the overall costs of air pollution control range from $0.91 (C-b project) to $1.16 (Colony project) per barrel of oil produced. These costs would have been considered very high in the early 1970s when oil was selling for about $4/bbl. They are less significant under present conditions with oil prices exceeding $30/bbl.

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# GLOSSARY OF OIL SHALE TERMS

| | |
|---|---|
| Oil Shale | A sedimentary, layered rock that contains organic matter of moderate to low solubility in petroleum-based solvents, but which can be converted to a soluble liquid by heating. Although similar in its history of formation to petroleum, tar sands, and coal, oil shale differs from these raw materials in being composed of rather long-chain molecules that tend to be insoluble in conventional solvents. |
| Kerogen | The organic component of oil shale. |
| Shale Oil | The liquid oil product derived from the pyrolysis of oil shale. |
| Pyrolysis | A generic term given to the thermally activated destructive decomposition of kerogen. |
| Retort | A furnace or kiln within which pyrolysis takes place. |
| Spent Shale | The solid residue resulting from the pyrolysis of oil shale. This material, which is sodium-rich, could prove useful as a feed for building blocks and in glass making. It also could be used in the automobile catalytic converter industry. |
| Bitumen | A benzene-soluble organic product resulting from the pyrolysis of kerogen. This material is very useful in the immobilization of some radioactive wastes as well as some hazardous chemical agents. |
| Fischer assay | A practical and relatively simple procedure for determining the quantity of recoverable liquid oil as well as other organic products from oil shales. |
| Modified Fischer assay | In this assay, a 100-gram sample of oil shale is crushed and heated at 500°C (932°F) in a sealed aluminum retort. As the kerogen is pyrolyzed, the evolved gaseous products are collected and measured. |
| Empirical formula for Green River kerogen | Corresponds to the following percentage composition:<br>C 80.5<br>H 10.3<br>N 2.4<br>S 1.0<br>O 5.8 |

## 4. INFORMATION ON CARCINOGENIC RISKS OF SYNFUEL PRODUCTS

The conversion of coal to either gaseous or liquid fuels can be accomplished through a variety of technological procedures, all of which pose varying degrees of potential health risks to man. Likewise, the extraction of oil from shale presents certain potential health risks. There have been numerous attempts to define these health risks.[1-3] Some of the risks are known and thus can be quantitated and relatively accurate risk estimates made, while others are ill-defined or as yet unrecognized.

One basis for estimates of carcinogenic risks to humans can come from epidemiological data. Unfortunately, there currently is little available information directly related to coal conversion technologies, and what is available is related only to occupational exposure. Thus, risks to the general population are extremely difficult to estimate quantitatively. Most indirectly related epidemiological data come from the chemical and steel industries and are usually derived from a single toxicant (coal conversion effluents by their nature are extremely complex; there are upwards of 1000 different chemical species). Evidence for potential hazard from conversion comes from the higher cancer incidences in workers involved with coke ovens and coal tar, processes similar in many respects to conversion technologies.[4] Most available information is historical in nature and may or may not be applicable to worker exposures under current plant operation conditions (OSHA didn't come into existence until 1970). Harris et al. provide a good synopsis of currently available information.[5]

There is one well-documented incident of increased cancer risk for workers in a synfuel plant. The Union Carbide Corporation operated a coal liquefaction (hydrogenation) pilot plant at Institute, West Virginia, from 1952 to 1962. Of the 359 workers employed during that period 10 individuals developed skin cancer, an increase of 20 times the incidence in the general U.S. population.[6] The health status of these ten workers was followed and there was no apparent increase in other cancers and no subsequent development of systemic cancer.[7] Sixty percent of the skin cancers occurred in maintenance workers,[8] individuals with the greatest potential contact with the hydrocarbon by-products. Again, the relationship of these observations to current processes is questionable. The technologies themselves are different and hygiene, sanitation controls, and worker habits could be much different in current plants.

Two additional facilities, the Lurgi gasification facility at Sasol, South Africa (full-scale commercial operation since 1952) and the gasifier at Kosovo, Yugoslavia, provide the greatest potential for getting data on human experience. At present, only limited information is available, but both facilities have maintained worker health records and these are being made available to occupational health study groups.

Significant human exposures to shale-derived oils occurred in the Scottish spinning and weaving industry during the early 1900s. The spindles, so-called "mules," were lubricated with shale oil, and an increased incidence of scrotal cancers was observed in the worker population. The lack of personal hygiene was felt to play a major role in the subsequent development of this form of cancer and thus, as with coal conversion processes, this historical demonstration of the carcinogenicity of shale oil cannot be directly applied to plants that will operate under current U.S. standards.

There is some recent industrial experience with the extraction of oil from shale but little of this experience comes from U.S. operations. A reasonably large-scale industry has been in operation in Estonia for several decades. What information is available is consistent with data from coal conversion facilities, i.e., an increased incidence of skin cancer occurs in the occupationally exposed population.

As operational experience from coal conversion and shale extraction facilities grows in the U.S., more epidemiological information will be forthcoming. In the interim, health assessments must rely on estimates of exposure based first on chemical characterization of process streams and effluents and second on indirect data on the biological activity of these materials derived from an array of in vitro and in vivo biological test systems (Fig. 4.1).

Chemical and biological evaluation of synfuel products as well as shale-derived oils indicates that there is a potential health risk because the presence of bacterial and mammalian mutagens has been detected, and because the principal mutagenic components identified have been independently demonstrated (either directly or as members of a class) to be mutagenic and carcinogenic in laboratory studies, and in some cases carcinogenic in man. Performed either simultaneously or iteratively with the chemical analysis, a tiered bioassay program is used to determine the degree of biological activity with different products, process materials, and effluents from different plants (PDU, pilot, or demonstration) or under different modes of operation. Table 4.1 is a listing of a selected sample of the types of assay systems available for application in a bioassay program, and illustrates some of the advantages and limitations of these systems. In practice, materials are first tested for cytotoxicity (cell killing or damage) and genotoxicity (e.g., Ames Salmonella assay, yeast mutation assays, etc.) in rapid screening tests. When materials are found to show activity in these simple screening procedures, additional study is done in mammalian cells (e.g., CHO hamster embryo cell HGPRT mutation assay, drosophila mutations, human leukocyte mutation, etc.). If the materials again show strong activity, whole animal tests under acute, subacute, and chronic exposure conditions can be done. In the case of a suspected carcinogen in vitro transformation studies can be carried out (C3H10T1/2 cells) as well as in vivo exposure to the lung through inhalation studies and skin by skin painting.

With these procedures, a number of carcinogenic hydrocarbons have been identified in coal conversion products. These include the classic carcinogen benzo(a)pyrene, dibenz(a,h)anthracene, chrysene, and 7-methylbenz(a)acridine, as well as aromatic amines, i.e., naphthylamine and benzidine. Also present are benzene a putative human leukemogen and trace elements such as chromium

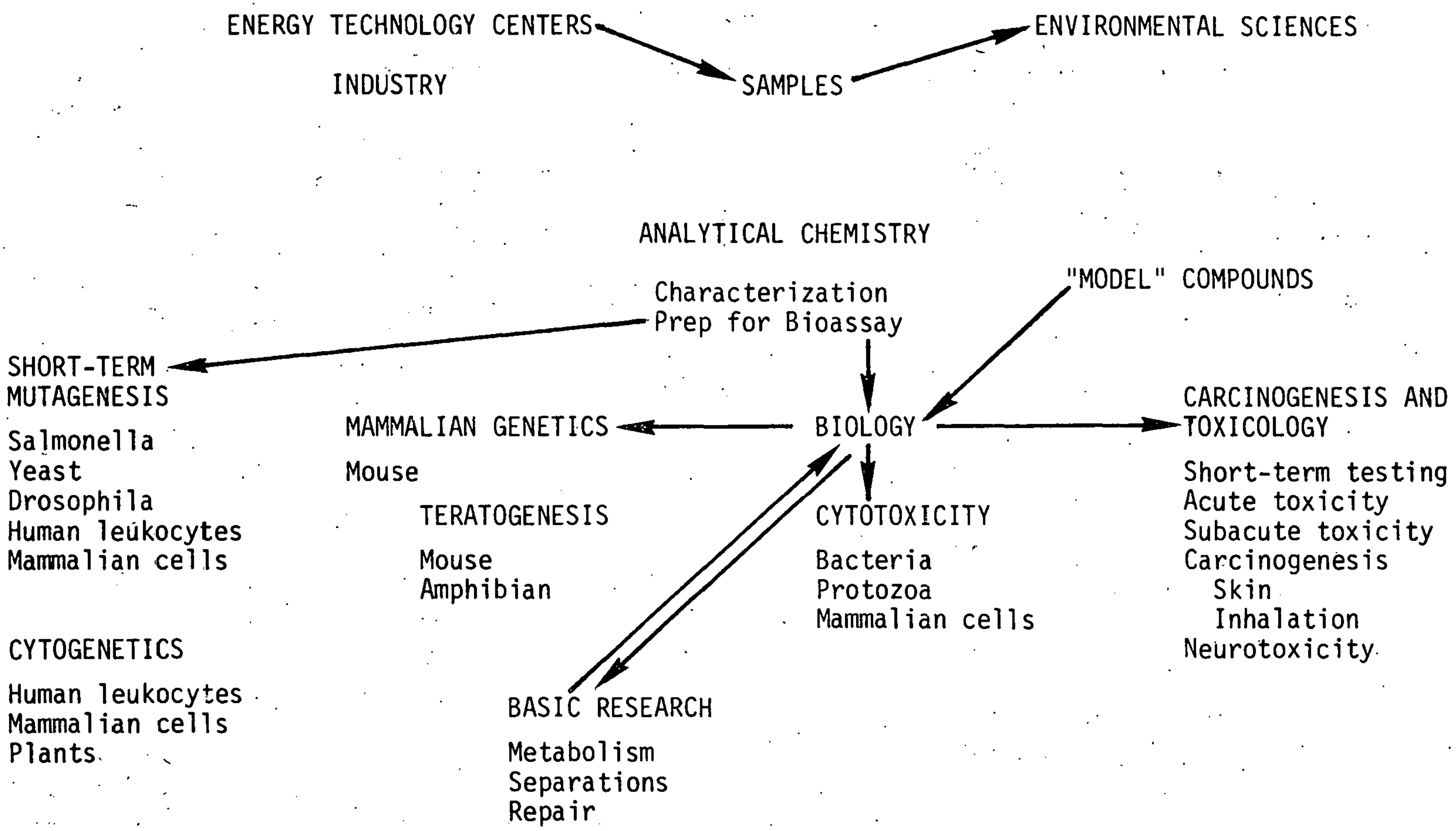

Fig. 4.1. Strategy for Chemical and Toxicological Characterization of Synfuels Products and By-Products

## Table 4.1. Selected Sample of *In Vitro* and *In Vivo* Test Systems Useful for Toxicological Evaluations

| Test System | Assay | Advantages | Limitations |
|---|---|---|---|
| Bacteria | | | |
| *Salmonella* | Reverse mutation (Ames Test) | 85-90% correlation with known carcinogens | Not sensitive to metals, hormones, polyhalogenated compounds. Usefulness with complex materials not well established. |
| *E. coli* pol A | DNA - alteration | Up to 75% correlation with known carcinogens | Nondiffusable chemicals. Not easily studied. |
| Yeast | | | |
| *Saccharomyces cerevisiae* | Forward or reverse mutation | Detection of a potentially larger array of mutagens | Little practical experience currently available. |
| Mammalian Cell Culture | | | |
| Chinese hamster cells | Forward mutation | Mammalian cell (potentially easier extrapolation to humans); 95% correlation with carcinogens | Longer procedure than other mutation assays. |
| Mouse myeloma cell | Sister chromatid exchange | Suspension cultures | Limited experience. |
| C3H10T1/2 cells | Transformation | *In vitro* indication of carcinogenicity | Relatively long procedure not totally equatable to carcinogenesis. |
| Human leukocytes/ fibroblasts | Forward mutation | Human cell | Limited experience, especially with complex mixtures. |
| Animals | | | |
| Mice | Skin carcinogenesis | True test for carcinogenicity | Labor-intensive, prolonged exposures required. |

and arsenic capable of being carcinogenic. Of course, this list is not exhaustive, but only representative of what is present. In a typical SRC-II product oil there are thousands of hydrocarbon species each with the potential for chemical interaction (synergism and antagonism); thus, it is easy to see the expansive data base required for a quantitative risk assessment. That data base does not now exist for any of the synfuel technologies. However, under a host of programs (DOE, EPA, and private industry) directed toward each emerging technology, the necessary information is beginning to be compiled.

Animal tests of carcinogenicity are underway and preliminary information is available. Materials already shown to be carcinogenic when applied repetitively to mouse skin include raw shale oils,[9] synthoil,[10] and SRC-II heavy distillate.[11] Hydrotreating (hydrogenation of the conversion product) has been demonstrated to decrease the mutagenicity of SRC-II materials determined to be carcinogenic.[12] While it might be predicted then that these materials would be less carcinogenic, that has not yet been demonstrated.

Some compounds when identified have an already available historical data base. For example, such evidence is available for certain aromatic amines that as a chemical class have been strongly implicated as major contributors to the mutagenic (and possibly carcinogenic) activity of synfuels through occupational exposure in the dye industry and in industrial processes involving aromatic amines as antioxidants. Exposure to aromatic amines in these industries caused increased incidence of bladder cancer. However, it may not be possible to predict the site of action and toxicity of the aromatic amines when they are present in the complex mixtures of chemicals associated with the synfuel technology. Nevertheless, the presence of significant amounts of aromatic amines, which are demonstrated human carcinogens, is of concern. Occupational and other exposure should be minimized.

Exposure to polycyclic aromatic hydrocarbons (PAHs) should be minimized as a general rule. In the coking industry, workers are putatively at an increased risk for lung cancer. The degree of the excess risk may be related to the exposure of PAH, most commonly represented by benzo(a)pyrene, a well-known carcinogen in laboratory animals and a ubiquitous environmental chemical generally associated with combustion sources. Smoking is a compounding variable. The synfuel products, process materials, and effluents contain neutral PAHs that are well-known carcinogens for laboratory animals, causing squamous cell carcinomas when applied to the skin. Their carcinogenic activity also is of concern. In measurements of mutagenic activity associated with most processes, the aromatic amines have been shown to contribute most to the activity. Data still are being accumulated in laboratory animals as to the contribution of aromatic amines as carcinogens.

Most mutagens and carcinogens of concern for their potential effects on health/environment are indirect carcinogens. The organism exposed to the chemicals metabolizes them via a series of enzymatic reactions. This series of metabolic detoxification reactions generally serves to allow excretion of the chemicals. However, some metabolic products are highly reactive allowing covalent binding to critical cellular components such as protein and nucleic acid, including DNA. This binding can lead to disruption of various cellular functions, including genetic damage that can be recognized as mutations, and presumably to cancer. The enzymes responsible for these reactions are present in all vertebrates examined, including man. The complexity of the series of reactions, including its dependence on genetics, physiological state, and exposure conditions does not allow metabolic activation to be addressed by any general protocol, although for certain model chemicals the reactions have been studied.

In summary, some carcinogens are present in all steps of coal conversion processes and in the retorting and refining of shale-derived oils. While some of these agents have been identified and the potential for exposure semi-quantitated, most of the chemical and biological evaluations currently are incomplete. Further work in areas such as fugitive emissions, atmospheric transformation and transportation, chemical interactions within complex mixtures, and metabolic activation must be done before quantitative estimates of the carcinogenic risk to man of a synfuel industry can truly be accomplished.

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# 5. HEALTH IMPACTS OF A NATIONAL SYNFUELS PROGRAM

For purposes of risk assessment it is convenient to divide the fuel cycle into the following segments:

- Coal/shale mining and transportation
- Coal conversion/shale retorting
- Transportation of products
- Combustion of coal fuels/shale oil

Except for the first segment, the limited nature of the data presently available makes it impossible to carry out a rigorous assessment of impacts. However, with the available data on products and effluents and their toxicities, some assumptions regarding production and end use, and analogies drawn from the petroleum industry, rough assessments are made and areas of concern are identified here. In addition, some insight is provided into these impacts by comparing them with those of direct coal utilization.

The current national synfuel goal is production of synfuels at the rate of 1.3 MMBPD (roughly 0.3 MMBPD of shale oil, 0.5 MMBPD of coal liquid, and 0.5 MMBPD of gas, in crude oil equivalent terms) by 1995. In terms of providing a petroleum substitute, oil shale technology probably is the closest to commercialization. The technology for surface retorting is more advanced than <u>in situ</u> retorting at present, and is expected to be the primary means of shale oil production in the near future. It is anticipated that the goal of 0.5 MMBPD of coal liquids will be met predominantly by indirect liquefaction (specifically, the Fischer-Tropsch process embodied in the SASOL plants in South Africa). Direct liquefaction (SRC or EDS) is likely to contribute approximately 25% of the coal liquid production. The Lurgi fixed-bed process is the leading high-Btu coal gasification technology and has been commercially demonstrated outside the U.S. The Lurgi gasifier also is expected to yield most of the medium-Btu power and synthesis gas requirements. Low-Btu gas is not expected to be produced in large quantities and generally will be captively employed as fuel gas or used on-site for combined-cycle power generation. For the analysis of health impacts, an output of 0.5 MMBPD of shale oil was assumed to be produced by surface retorting and 0.5 MMBPD of oil or its equivalent each from coal liquefaction and high-Btu gasification. Low-Btu gasification was not included in the analysis because of its relatively small contribution, and medium-Btu gasification enters only indirectly into the analysis as an intermediate stage in indirect liquefaction and high-Btu gasification. Data on inputs and environmental residuals (assuming control technologies considered likely within the next 10 years) for Oil Shale Surface Retorting, SRC-II, and Lurgi-prepared substitute or synthetic natural gas (SNG) are given in Table 5.1. Data of this type are not available for the Fischer-Tropsch process (except that its energy efficiency is known to be 57%). Therefore, the SRC-II data are used for estimating the health impacts of liquid fuels. This probably yields a conservative estimate since the Fischer-Tropsch process is likely to be environmentally cleaner, although it is less energy-efficient.

## Table 5.1. Input-Output Information for Oil Shale Surface Retorting, the Lurgi and SRC-II Processes (normalized to an output of 1 Mbpd oil equivalent)[a]

| | Paraho Indirect Shale Retort | SRC-II | SNG (Lurgi) |
|---|---|---|---|
| Input | | | |
| Shale/coal | 1,520,000 tpd[b] | 530,000 tpd | 510,000 tpd |
| Water | 150 Mgpd[b] | 170 Mgpd | 240 Mgpd |
| Output (products and by-products) | | | |
| High-Btu gas | | - | 5,400 Mcfpd[b]<br>1 Mgpd |
| Naphtha | | | |
| Liquid light fuel oil | - | 416,500 bpd[b] | |
| Heavy fuel oil | - | 456,800 bpd | |
| Substitute natural gas | - | 3,550 Mcfpd | |
| Synthetic crude | 760,000 bpd | | |
| Liquefied petroleum gas | 30,000 bpd | 300,150 bpd | |
| Coke | 6,500 tpd | | |
| Ammonia | 2,900 tpd | 2,550 tpd | 2,420 tpd |
| Sulfur | 1,350 tpd | 11,500 tpd | 2,500 tpd |
| Tar | - | 3,700 bpd | $88 \times 10^{10}$ Btupd |
| Residuals | | | |
| Air emission (tpd) | | | |
| CO | 60 | 20 | 25 |
| HC | 60 | 10 | 10 |
| $NO_x$ | 400 | 400 | 450 |
| Particulates | 140 | 30 | 30 |
| $SO_x$ | 60 | 150 | 300 |
| Total | 720 | 610 | 815 |
| Water streams | | 450 tpd | 170 tpd |
| Solid waste | 108,000 tpd | 32,000 tpd | 33,000 tpd |

[a] This table is based on information in Tables 6.18 of Ref. 1, Tables 1-35, 1-45 and 1-48 of Ref. 2, and Table 2.1 of Ref. 3.

[b] tpd = tons per day
Mgpd = million gallons per day
Mcfpd = million cubic feet per day
bpd = barrels per day

## Coal/Shale Mining and Transportation

It follows from Table 5.1 that in order to meet the stated goals for shale oil, coal liquefaction, and coal gasification, it would be necessary to mine approximately 0.7 million tons of shale, and an additional 0.5 million tons of coal per day.

The additional coal mining involved represents roughly 25 percent of the present level (775 million tons of coal were mined in 1976)[4]. The primary health impacts from coal mining are occupational hazards to coal miners. Based on figures provided by Morris et al.[5], estimates of these health hazards from additional coal mining would be 0-40 disease-related deaths, 250-500 nonfatal diseases, 20-60 accident-related deaths, and 2700-3000 accident-related injuries per year. If an equivalent amount of coal were used directly for electric power, these numbers would increase by roughly 10-40 accident-related deaths and 350-450 accident-related injuries per year from transportation of coal. In the case of coal conversion processes, the coal normally would be processed at the mine mouth and hence there would be no hazard from coal transportation per se. However, this would be more than offset by the hazards from transportation of coal products that occur at the third stage, which are discussed separately.

Occupational safety risks associated with shale mining are similar to those of hard-rock mining where fatalities are five times more frequent than in the manufacturing industry. The frequency of disabling injuries from underground mining (excluding coal mining) is two and a half times higher than from manufacturing.[6] Coal mining is even more hazardous, with an accident rate at least five times that observed during the mining of over 2 million tons of shale so far. Allowing for the fact that this record for shale was achieved in experimental mines that employed for the most part, experienced miners, it seems fair to rate coal mining as three times as dangerous as shale mining. The safety risks associated with shale mining, then, would be no higher than those associated with coal mining required to generate an equivalent amount of Btu by coal conversion in spite of the much higher levels of mining required for shale oil (which is almost three times that required for coal conversion). The accident rate associated with the mining stage, however, would be twice as much for oil shale technology as it would be for direct coal utilization because of the six to one ratio in the amount of mining necessary for generating the same amount of Btu's by the two processes. The total incremental impact on safety risks from shale and coal mining thus can be considered to be roughly 45 percent of the present impact from coal mining. In addition to safety risks, there are health hazards stemming from inhalation of fibrogenic dust, high noise levels, and contact with irritant gases, which are common to shale and coal mining. The relevant figures for coal mining presented earlier in the context of coal conversion probably are applicable to shale mining with a three-fold adjustment to account for the higher level of mining and the consequently higher magnitude of dust produced in shale mining. (Dust emissions from mining are included under "particulates" in Table 5.1). Also, the silica content of the shale dust is likely to be more toxic, and is known to cause silicosis, a disabling fibrotic disease of the lungs. In addition to the problem of fugitive dust, there are hazards unique to shale mining resulting from the inhalation of nitrogen oxide fumes emitted by diesel exhausts, and possible exposure to carcinogens (e.g. PAHs and trace elements that might be produced during mining). The magnitude of the PAH hazard has not been determined, but is likely to be much smaller than the PAH hazard present at the retorting stage.

Apart from the primary health impacts, which are occupational, there are major potential public health impacts from water quality degradation that could result from coal and shale mining. It has been estimated that up to 11,000 miles of streams and 70 reservoirs, primarily in the eastern coal mining regions, have been adversely affected by sedimentation from surface mines, erosion of spoil piles, and acid mine drainage containing high concentrations of iron and manganese.[7] Disruption of aquifers during mining also is a major concern, especially in the West where water is scarce and where most of the shale deposits are located.

## Coal Conversion/Shale Retorting

Because there are substantial differences in the impacts of coal conversion and shale retorting, these are discussed separately and comparisons are made wherever they are appropriate.

Since liquid and gaseous products, unlike electricity, can be transported economically over long distances, synthetic fuel plants, unlike coal-fired electric boilers, can be located in remote areas near the sources of coal. Besides shifting some of the sources of pollution from electricity generation and end use to the conversion sites, the coal conversion route can achieve actual reduction of emission in some cases (primarily sulfur oxide emissions because of sulfur removal during conversion). The net result will be a reduction in the population exposure to the pollutants produced, and a substantially decreased share of the emission burdens of densely populated areas, making it easier to meet the requirements of the Clean Air Act Amendments. Another advantage to use of coal fuels is that they can be stockpiled and used as replacement fuels to overcome the reliability problems associated with the use of flue-gas desulfurization (FGD) in coal combustion.

The emissions data for coal liquefaction (SRC-II) and high-Btu gasification plants are provided in Table 5.1. Wastewater streams consist primarily of dissolved solids and will be treated to meet standards. In some cases there may not even be any water pollutants since all water may be recycled (especially in regions where water is scarce), with no effluent leaving the facility. It thus is sufficient to consider air pollutants and solid waste. Air emissions are produced mostly from fuel combustion and from the sulfur recovery plant. The figures for particulate and sulfur dioxide emissions reflect the use of fabric filters and electrostatic precipitators with a 99 percent clean-up efficiency for particulate removal, and the use of Claus recovery plants with 95% efficiency for sulfur removal. The levels of these and other common air pollutants are low for coal conversion compared to coal combustion and are well within acceptable limits from the standpoint of public health. (For a fair comparison with coal combustion, figures on the combustion of coal-derived fuels must be included; combustion is discussed later in this section. The composite picture for coal conversion still compares favorably with that for coal combustion as far as common air pollutants are concerned). However, coal liquefaction is known to produce emissions containing polycyclic aromatic hydrocarbons, which are potentially carcinogenic. Again, the use of controlled combustion devices and the location of conversion plants in remote areas ensures adequate protection to the public.

From the standpoint of occupational health, there are important health hazards both in the form of fugitive emissions and accidental exposure to products and by-products. The high phenol content of aqueous condensates produced from coal gasifiers presents a hazard in the form of acute toxicity. Carcinogenic compounds such as benzene, toluene, xylene, and their associated hydrocarbons are present in fugitive emissions and by-products of gasifiers. Particulates and aerosols present in emissions from plant operation are likely to have PAH concentrations that could pose an occupational health hazard. The synthetic gases themselves, unlike coal liquids, are relatively safe products because of acid gas removal and other cleanup systems associated with gas preparation. For indirect liquefaction, gasifier effluents or byproducts are essentially comparable to those from gasification facilities. There is very little toxicity information on the other products and by-products from indirect liquefaction. Products, by-products and fugitive emissions from direct liquefaction are decidedly more hazardous (and in particular more carcinogenic) than their gasification counterparts. For direct liquefaction, based on evidence from related industries such as coke ovens and older gasworks, the major hazards are lung, skin, and scrotal cancer, and bronchitis. The causative agents are likely to be polycyclic organics, aromatic amines, and heterocyclic sulfur compounds. These carcinogens become more concentrated in residual oils with successive distillation.

The risks to plant personnel from inhalation of fugitive and accidental hydrocarbon emissions and from dermal contact with liquid residues (from maintenance operations or accidental spills) are considerably greater in coal conversion facilities compared to others such as petroleum refineries, and therefore warrant a more stringent industrial hygiene and worker monitoring program. Hazards have been identified and means exist for controlling them, so that the incremental occupational health impacts associated with the conversion stage are likely to be negligible. However, a more rigorous assessment of hazards associated with various worker protection measures (based on probabilistic risk modeling and epidemiological data) is necessary to evaluate the adequacy of these measures.

Evaluation of hazards during the conversion stage must include the question of solid waste disposal. Unlike direct coal combustion, all coal conversion technologies produce solid wastes predominantly at conversion sites, which are likely to be in remote areas, where opportunities for waste disposal are available. These solid wastes, however, may be more hazardous and may require more careful handling than is necessary for FGD scrubber sludges and fly ash.

Controlled emission rates for oil shale surface retorting are provided in Table 5.1. Data for air emissions are based on the assumption that dusty air streams from crushers and ore storage areas would be processed in baghouses, as would the flue gas from the retort preheater. Flue gases from the retort and the spent shale moisturizer would be treated in a hot precipitator. A Stretford unit would be used for removal of sulfur compounds. Nitrogen oxides and CO emissions would be reduced by combustion controls on all burners, and HC emissions would be reduced with floating-roof storage tanks and a thermal oxidizer flare system. As in the case of coal conversion, the levels of common air pollutants are low for shale retorting compared to coal combustion. The HC and sulfur oxide emissions of crude shale oil combustion are high compared to those of coal combustion. However, crude shale oil will be upgraded before its end use, and refined shale oil compares favorably with coal combustion, as can be inferred from Table 5.2. The incremental nationwide impact on air quality from all the synfuel processes thus will be small, especially in comparison to direct combustion sources (this is substantiated by Table 5.3, which provides a nationwide projection of particulates, $SO_2$, and nitrogen oxides in 1995 from several sources). However, this does not insure the acceptability of regional impacts. The PSD-II classification of the oil shale locations and their proximity to PSD-I areas could constrain the size of the oil shale industry to 1 MMBPD.[9]

Oil shale retort workers will be subjected to health hazards from accidental exposure to products and by-products similar in nature to those in coal conversion. However, the risks are likely to be less in the case of shale oil, since it probably is less toxic than are coal products, as indicated by biochemical tests and the lower nitrogen content of shale oil. The risks to oil shale workers would still be higher than risks to workers in petroleum refineries.

A major hazard associated with the conversion of shale to oil may be after conversion. Oil shale retorting results in an enormous volume of spent shale, about 20 to 40 percent greater than that of the original shale. Over 30 years, a 50,000-bpd plant would result in enough spent shale to cover 3.5 square miles to a depth of 200 feet. Leaching of spent shale from above-ground disposal areas or from backfilled mines poses a major potential threat to water quality. PAHs, salts, and metals may dissolve in surface streams and groundwater and infiltrate public drinking water supplies. The PAH content of leachates is 100 to 1000 times higher than is found in normal ground or surface water. Adequate controls, including revegetation and catchment basins, must be designed to minimize surface water and groundwater impacts.

### Transportation and Handling

Raw shale oil and coal-derived crude oils are complex chemical mixtures. In general, they differ from crude petroleum oil in having a comparatively high concentration of nitrogen-containing (basic) and phenolic compounds in addition to having neutral compounds and polycyclic aromatic hydrocarbons commonly found in crude petroleum oils. However, synthetic gasoline and diesel/fuel oil fractions produced by indirect liquefaction and from shale would be roughly comparable to their petroleum counterparts because they are largely composed of straight-chain molecules and because of blending with polymerics to increase octane/cetane numbers. Because of acid gas removal, synthetic gases also are relatively safe products. Thus, the transportation and handling of synthetic gas, upgraded shale oil, and coal liquids from indirect liquefaction are not likely to pose any additional hazards. Crude shale oil is more toxic than petroleum crude and less toxic than crude oils derived from direct liquefaction. Crude shale oil will be upgraded to yield middle distillates to be used primarily as diesel oil and jet fuel. The upgrading most likely will be done in refineries in the Gulf Coast or Midwest. This would entail some transportation of crude shale oil, but the hazards are expected to be minimal because of the limited quantities involved, in spite of the somewhat higher toxicity of crude shale oil compared to petroleum crude. Transportation and handling of coal liquids derived from direct liquefaction also would be more hazardous in comparison to petroleum products, but again, the incremental hazard would be minimal since the 0.5 MMBPD coal liquid target set for 1995 is likely to involve only 25 percent of direct liquefaction fuels with perhaps less than 50 percent in the form of heavy distillates.

Table 5.2. Emissions from Combustion of High-Btu Gas, SRC-II Fuel and Coal (normalized to 1 MMBPD oil equivalent)[a]

| Process | Air Pollutants (tpd) CO | HC | $NO_x$ | Particulates | $SO_x$ | Total |
|---|---|---|---|---|---|---|
| Upgraded shale oil | 60 | 120 | 300 | 20 | 750 | 1250 |
| High-Btu gas | 30 | 15 | 136 | 37 | 2 | 220 |
| SRC-II | 190 | 40 | 1200 | 90[b] | 750 | 2340 |
| Coal (utility boiler FGD) | 110 | 40 | 1800 | 90[b] | 1700 | 3800 |
| Natural gas | 33 | 14 | 120 | 32 | 1 | 200 |
| Oil | 190 | 40 | 540 | 90[b] | 450 | 1400 |

[a] This table is based on information in Tables 1-46 and 1-49 of Ref. 2 and Table 3 of Ref. 8.

[b] Revised NSPS regulations call for no more than 90 tons per day (tpd) in utility boilers.

Table 5.3. Estimated Emission Source Contributions in 1995 for Particulates, Sulfur Dioxide, and Nitrogen Oxides[a] (million tons)

| | Particulates | Sulfur Oxides | Nitrogen Oxides |
|---|---|---|---|
| Coal-fired power plants | 1.23 | 15.07 | 8.31 |
| Industrial combustion | 0.54 | 5.87 | 4.65 |
| Coal conversion plants | 0.02 | 0.20 | 0.09 |
| Oil shale plants | 0.02 | 0.01 | 0.11 |
| Other emission sources | 10.22 | 6.98 | 11.52 |
| Total | 12.03 | 28.13 | 24.68 |
| Percent synfuels/ total emissions | 0.3% | 0.8% | 0.8% |

[a] From Table 5-10 of Ref. 8.

## Combustion of Coals and Shale Fuels (End Use)

For the same reasons stated in the preceding paragraph, the combustion of synthetic gases (see data in Table 5.2) and the combustion of liquids from indirect liquefaction are not likely to be any more hazardous compared to their petroleum counterparts. Considering that crude shale oil will be upgraded before its end use, there will not be any significant hazards associated with the combustion of shale oil, as is evident in Table 5.2. At present, there are no data on automobile emissions from the use of coal or shale-derived gasoline or diesel fuel. This is a serious data gap considering that transportation represents a major end use, and one to which there will be maximum population exposure over the widest area. Based on the present petroleum consumption pattern (source: Department of the Interior News Release) it is likely that roughly 50 percent of synthetic liquids will be used as transportation fuel (diesel, jet, and gasoline engines) and the other 50 percent for utility and commercial boilers (residual or distillate grade) and home heating (distillate grade). SRC-II fuel is likely to be used for utility/commercial boilers and home heating and, as shown in Tables 5.1 and 5.2, it is associated with higher pollutant levels than synthetic gas, but lower levels than coal combustion. A major combustion test of SRC-II fuel was carried out by Consolidated Edison Company of New York with 4500 bbl of SRC-II fuel in a test boiler. Nitrogen oxide emissions were 70 percent greater than those obtained for the No. 6 fuel oil presently used in such boilers. Particulate emissions were nominally lower for SRC-II fuel oil than for No. 6 fuel and were below the EPA-proposed standard of 0.03 lb/MMBtu. Total hydrocarbon emissions were less than 3 parts per million by volume (ppmv) and carbon monoxide levels were maintained below 50 ppmv. Thus the SRC-II fuel did not indicate any greater tendency toward incomplete combustion than the No. 6 petroleum-based fuel. Polcyclic organic matter (POM) emission levels with both fuel oils were less than $6 \times 10^{-6}$ lb/MMBtu and were substantially lower than those obtained with coal-fired boilers. The SRC-II fuel used in the test, however, had a light-to-heavy distillate ratio of 6 to 1, which may not be typical. The transportation, handling, and combustion of the SRC-II fuel need further investigation, especially for fuel oils having a greater proportion of heavy distillate. However, because of the limited direct liquefaction target set for 1995, there is no cause for alarm. Hydrotreating of the SCR-II products has been shown to reduce mutagenicity substantially. In particular, mutagenicity can be reduced by an order of magnitude by increasing the hydrogen content of the product by 1.5 percent[10] at an estimated cost of approximately $5/bbl. The need for hydrotreating needs to be evaluated more thoroughly from a risk-benefit point of view.

It is noted that the production of 1.3 MMBPD of synthetic fuels which are meant to be petroleum and natural gas substitutes constitutes only 9 percent of the present level of petroleum and natural gas consumption (based on the 1974 figure of 56 quads given in Ref. 11). Compared to an increase of 45 percent in coal consumption (including an equivalent of 15 percent from shale) relative to present levels and an associated increase in mining and other hazards, the increase in transportation, handling, and combustion hazards due to a 9 percent substitution for petroleum and natural gas probably is insignificant.

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9. An Assessment of Oil Shale Technologies, Stock No. 052-003-00759-2, Washington, D.C. (June 1980).
10. D. Sutterfield et al., Proceedings of the Second DOE Environmental Control Symposium, Reston, Va., March 1980.
11. U.S. Department of the Interior, Energy Perspectives (February 1975).

# 6. SUGGESTIONS FOR FUTURE RESEARCH AND ANALYSIS

On the basis of major health impacts and information gaps that have been identified in the preceding sections, the following priorities for further work are suggested.

## OCCUPATIONAL HEALTH IMPACTS

The most significant and immediate health impact of coal conversion and oil shale technologies is that resulting from occupational exposure. This problem merits the most attention since a number of shale and coal conversion facilities are in pilot operation at the present time and are likely to proceed to full-scale commercial operation in the near future. In the case of oil shale technologies, the major health impact is in the mining stage, and although the problem is a significant one, there is sufficient information about it and the means to control it. For coal conversion, the major health impact occurs at the conversion stage. There is a definite lack of knowledge concerning the nature and magnitude of the occupational health hazards present during the conversion of coal. Thus there is a high priority for further work in terms of risk assessment and procedures for controlling occupational hazards in this area.

The assessment of occupational risks must be based on epidemiological data, primarily from the Kosovo gasification complex in Yugoslavia; a comparison of this data with similar data, including those on coke oven workers; and results of monitoring tests for the detection of carcinogens in the human body. An analysis of data from the Kosovo plant already has been initiated by the U.S. EPA and DOE. Data from the Sasol Lurgi gasification facility in South Africa also need to be analyzed. It also is important to initiate prospective epidemiologic studies at all future U.S. liquefaction, gasification, and shale retorting sites.

Procedures to mitigate occupational risks also must be developed. These should include screening tests (there already are some tests) for the purpose of determining which individuals are at high risk to polycyclic aromatic hydrocarbons.

## PUBLIC HEALTH IMPACTS

Public health impacts from large-scale utilization of coal and shale probably are less immediate and somewhat secondary to occupational health impacts. Nevertheless, they are significant and need further study. Information gaps and priorities for further work in this area are discussed under the following broad categories.

## Health Effects Data for Processes and Effluents

Future research related to health effects of coal conversion and oil shale products should concentrate on those materials for which the least information is available, and for which exposure is expected to be the greatest. Table 6.1 gives a set of priorities in this research area.

Table 6.1. Suggested Priorities for Characterization of the Chemical Composition of Coal Conversion and Shale Retort Discharges

| Discharge Source | Priority |
|---|---|
| Leaching of contaminants from disposal areas (especially from backfilled shale retorts) | High |
| Aqueous discharge of organics | High |
| Emissions from combustion of liquefaction products | Medium |
| Airborne release of contaminants | Low |
| Aqueous discharge of trace elements | Low |
| Aqueous discharge of inorganics | Low |

The processes that merit more data acquisition are Fischer Tropsch (indirect liquefaction), Mobil M (indirect liquefaction), and Exxon Donor Solvent (direct liquefaction). For the processes designated as likely candidates in Section 3, it is most important to generate health effects data for combustion products that have the maximum exposure. Fugitive emissions from these processes also need to be studied.

## Research Methodology

Mutagenicity/carcinogenicity short-term assays are relatively well developed and have been successfully used in synfuels testing. Figure 4.1 gives an integrated bioassay/chemical characterization paradigm that currently is followed at the various national laboratories where much of the basic research is being performed.

In addition to studying materials produced at demonstration facilities, it is necessary to do parametric process studies (to study the effects of temperature, pressure, etc. and of various operating modes) using bench-scale gasification facilities.

The assessment of public health impacts will also be aided by the implementation of epidemiologic studies at all future U.S. liquefaction, gasification, and shale retorting sites, and the analysis of existing epidemiological data from the Kosovo gasification complex in Yugoslavia and the Sasol Lurgi gasification facility in South Africa.

## Risk Assessment

Risk assessment models using estimated exposure and toxicity data, integrated with production assessment and product utilization data, should be developed. Figure 6.1 gives an overall structure for risk assessment. For the exposure/dose components of health risk assessment the following types of analysis are needed.

1. The determination of doses required from synthetic fuel products/byproducts and effluents to produce hazardous effects.
2. Correlation between chemical composition of products, etc. and their potential toxic effects.
3. An evaluation of the relative hazards presented by these products in comparison to products from analogous industries (e.g. direct coal combustion and petroleum-based fuels).
4. Extrapolation of *in vitro*, short-term bioassay data to human health effects.
5. Integration of evidence from bioassay tests and epidemiologic studies.
6. Analysis of chemical interactions within complex mixtures and metabolic activation.
7. Analysis of atmospheric transformation and transportation.

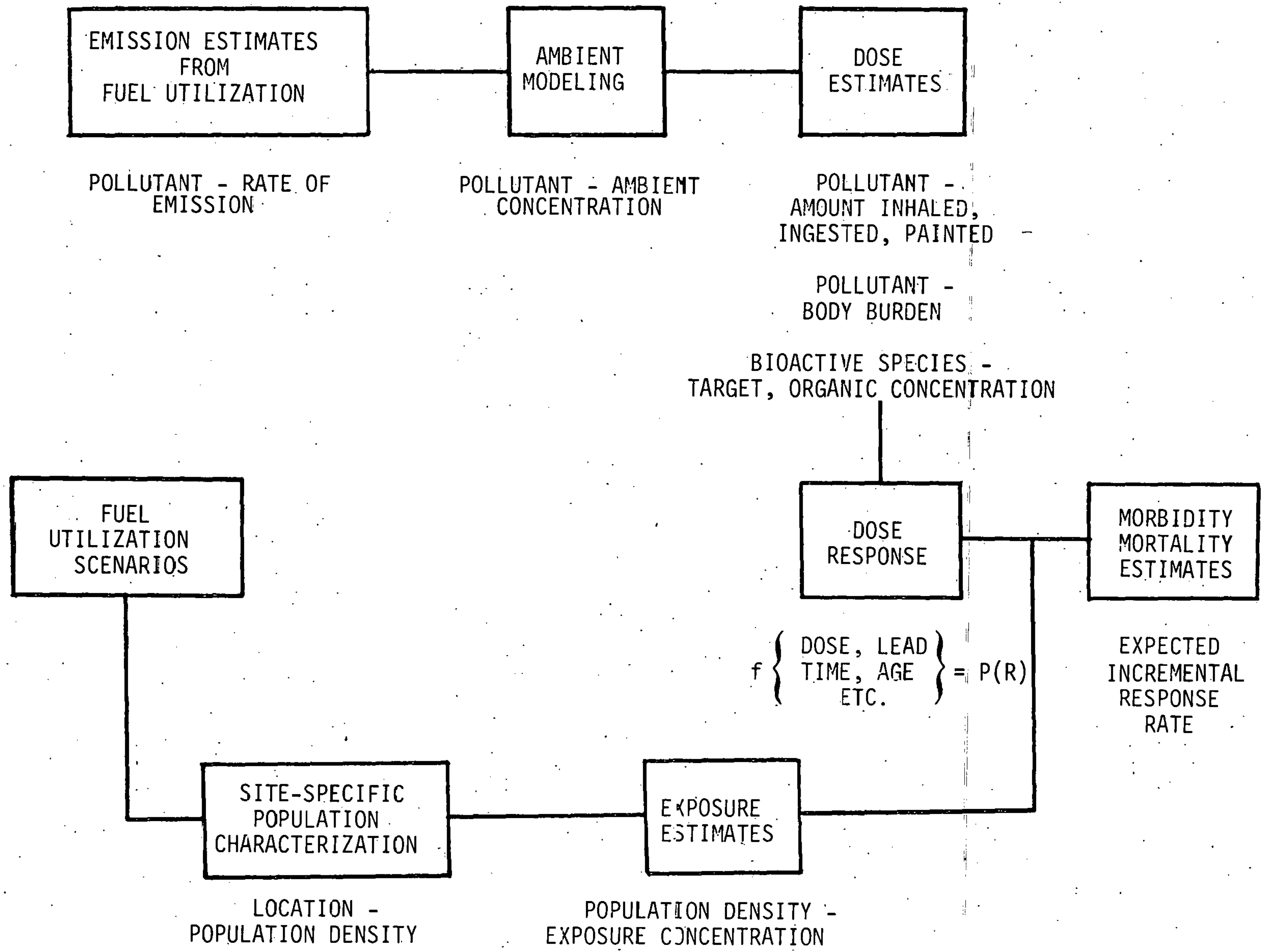

Figure 6.1. Elements of Risk Assessment Associated with Fuel Utilization

# 7. SELECTED BIBLIOGRAPHY

The bibliography is divided into three sections: those references of use to readers interested in the areas of both coal conversion and oil shale technologies; those of use primarily in the area of coal conversion technology; and those of use primarily in the area of oil shale technology.

## COAL CONVERSION/OIL SHALE

G.L. Baughman, Synthetic Fuels Data Handbook (1978).

The Synthetic Fuels Data Handbook discusses technical details of shale sectoring and coal-conversion technology with regard to engineering data, energy efficiencies and fuel production, and operating modes. Detailed process diagrams and product properties are given for each process, and a detailed description of effluents and process conditions producing effluents and wastes is provided. Each shale technology is described as are the synthoil, methanol, H-coal, SRC, and Exxon Amos Solvent processes, with product information and emissions data. There is an extensive bibliography on process technology for each coal-conversion system.

R.M. Byrnes (Ed.), Refining Synthetic Liquids from Coal and Shale, Energy Engineering Board, National Academy of Sciences, National Academy Press, Washington, D.C. (1980). 195 pp.

This document contains a discussion of all aspects of synthetic fuels production and utilization, including a resume and historical review of health and environmental effects. The topics discussed are future product requirements, coal liquefaction processes, oil shale extraction processes and products, refining of coal and shale liquids, hydrogen production, environmental and health effects, and research and development. Each section includes a comprehensive bibliography. The health effects section compares the relative toxicities of each synfuel product, including oil shale, to the toxicity of petroleum products. This section is concerned with future product requirements, and includes discussions of the types and amounts of liquid fuels projects, and the nature of future fuels and the transportation engines to be used for combustion.

K.E. Cowser (Ed.), Coal Liquids Evaluation and Paraho-Sohio Shale Oil Quarterly Progress Reports for the Periods Ending March 31, 1980, September 30, 1979, and December 31, 1979. Oak Ridge National Laboratory Documents TM-7275, TM-7344, and TM-7271.

The results of collaborative studies on the physical chemistry, organic analysis, biotesting and environmental testing of shale-derived and coal-derived liquids are discussed in these documents. The identification of chemical substituants of the complex environmental mixtures responsible for this bioactivity was a primary objective of these studies. Biological studies included microbial mutagenesis, comparative mutagenesis using higher organisms, teratogenesis assays, cellular cytotoxicity, and terrestrial and aquatic studies. Chemical studies included organic extraction, chemical class fractionation, and analytical studies on the qualitative and quantitative composition of the chemical class fractions generated using various organic fractionation schemes. A discussion of the organization of the national laboratory program for research on synthetic fuels is included.

Energy Research and Development Administration, Alternative Fuels Demonstration Program, Vol. 2. (1977).

In this second volume of a two-volume set, consideration is directed to the NEPA requirement of alternatives to the proposed action of obtaining synthetic fuels from coal and shale oil. A number of alternatives are presented that the authors consider to be meaningful. These alternatives are presented along with reports on their technologies, available resources, location sites, and design specifications. Consideration also is given to the conditions of the energy market and how various processes may be combined to yield an alternative that is economically supportable.

J. Golden, R.P. Ouellette, S. Saari, and P.N. Cheremisinoff, Environmental Impact Data Book, Ann Arbor Science Publishers, Inc. Ann Arbor, Mich. 860 pp.

This book is a model reference for information relative to designing risk assessment strategies. It provides data and model risk assessment methodologies for a number of environmentally related human health problems, such as those involving air quality, water resources, toxic chemicals, energy-related problems, and socioeconomic influences. Data systems applicable to exposure, biological effects, environmental effects, epidemiology, product assessment and marketing projections are discussed, and EPA numerical water and air quality criteria are described. Energy production scenarios as related to pollution problems are included. Risk assessment model-building is described, and a large amount of criteria data are provided. This book is a very valuable source of production, consumption, and demographic data for nearly any type of environmental assessment, and each chapter is adequately documented.

Oak Ridge National Laboratory, Symposium on Potential Health and Environmental Effects of Synthetic Fossil Fuel Technologies, CONF-78090, Oak Ridge National Laboratory, Oak Ridge, Tenn., September 25-28, 1978.

This symposium procedings from Oak Ridge National Laboratory is a comprehensive summary of health effects information related to synthetic fossil fuel technology. Included in this volume are a summary of processes and control technology, including solid waste management, hot gas desulfurization processes, and emissions control. Detailed chemical characterization utilizing chemical-classification techniques and physical and analytical methods is provided by contributing authors. Compositions of petroleum and synthetic crude oils are compared, and a description of trace elements in pollutant and products from coal conversion technology is given. Biological effects, including mutagenicity, carcinogenicity, inhalation toxicology and pharmacokinetics, are described. Explanations of the integrated chemical/biological testing approaches and "phased" bioassay programs are provided. Environmental transport and ecological effects are discussed, as well as epidemiological studies and occupational health control technology.

U.S. Department of Energy, Relative Health Effects of Gasoline and Heating Fuel, Derived from Petroleum or Synthetic Crudes - Task 3, prepared by Enviro Control, Inc. (May 13, 1980).

This recent unpublished document summarizes process technologies for the production of crude synthetic oils and fuels derived from them. Direct and indirect liquefaction and shale oils are considered, as well as transportation and other fuels derived from them. Chemical composition of these products is discussed at length, and all data are compared to crude petroleum or refined petroleum products. The health effects of these products are reviewed. Most of the information is derived from the ORNL or Battelle Laboratory work, but a number of references are given to petroleum-based products toxicity studies. In vito and in vivo studies are discussed, and there is a short section on combustion products. The final section is devoted to a discussion of the research needs for synfuels, health effects, and chemical characterization.

U.S. Department of Energy, Synthetic Fuels and the Environment: An Environmental and Regulatory Impacts Analysis, DOE/EV-0087 (June 1980).

This document provides a concise overview of all synfuel technologies and a good discussion of their environmental impacts. It also contains information on regulations and costs of meeting regulatory requirements. The coverage of health effects is broad, but lacking in specific information.

## COAL CONVERSION

L.L. Anderson and D.A. Tillman, Synthetic Fuels From Coal--Overview and Assessment (1979).

This book contains a technical description of coal-conversion systems, including a historical review of coal-conversion development and a technical description of low-, medium-, and high-Btu gas production from coal, heavy liquids, light liquids, and chemicals. For each process, the process technology, fuel use characteristics, thermodynamics of coal conversion, product utilization, and production assessment data are described in detail. A chapter is devoted to emission characteristics, economic issues and environmental impacts of coal-conversion technology. The current petroleum and fossil-fuel consumption and demand profile is discussed.

Battelle-Pacific Northwest Laboratories, Biomedical Studies on Solvent Refined Coal (SRC-II) Liquefaction Materials: A Status Report, PNL-3189 (October 1979).

This report and the associated appendix, along with the 1978 Oak Ridge study, is one of the most informative multimedia chemical analytical/ bioassay studies performed on synfuels production. The document is concerned only with solvent-refined coal liquid products (SRC-II), produced by the Pittsburgh and Midway Company's pilot plant in Ft. Lewis, Washington. SRC-II heavy and light distillates, process and wash solvents, and lights oil were obtained from the reaction of Kentucky coal. The chemical characterization/biotesting data are compared to crude shale oil data collected from Anvil Point's Colorado Paraho shale (24 gal/ton Fischer assay). The process materials were subjected to chemical-class fractionation and the fractions submitted to bioassay using a comprehensive in vito battery, supplemented with some in vito tests (skin painting, teratogenicity, acute oral toxicity). The SRC-II heavy distillates were more toxic/ mutagenic/carcinogenic than the lower-boiling fractions, shale oil was less active, and crude petroleum inactive. The most toxic materials were found to be 3-4 heterocydic primary amines, present in the basic fraction of the SRC-II heavy distillates and, to a lesser extent, in the oil basic fraction. One of the most important findings in this study was the increased tumor incidence found in mice after skin painting.

L.E. Bostick, M.R. Smith, D.O. Moore, and D.K. Webber, Coal Conversion Control Technology, Vol. II. Gaseous Emissions, Solid Wastes, EPA-600/7-79-228b, U.S. Environmental Protection Agency (1979).

In this report, information is presented on coal conversion process streams. Presently available and evolving technologies are evaluated with respect to present and proposed international, federal, regional, and state environmental standards. The conclusion reached in the report is that it is possible to develop technologies capable of reducing each stream component of each process to an environmentally acceptable level, but that to do so would be a costly and difficult endeavor.

H.M. Braunstein, E.D. Copenhauer, and H.A. Pfuderer, Environmental Health, and Control Aspects of Coal Conversion: An Information Overview, Vols. 1 and 2. ORNL/EIS-94, Oak Ridge National Laboratory, Oak Ridge, Tenn. (1977).

This two-volume edition from Oak Ridge is the predecessor to the Health Effects Symposium volume published in 1978. These are exhaustive, detailed descriptions of coal and coal conversion technologies, with information on demography, ecology, health effects, process descriptions, and chemical and physical characterization. Information is categorized under gasification, liquefaction, and insitu gasification of coal; process effluents and control technologies; and analysis of emissions. Environmental health effects information includes microbial and plant interactions of effluents and products (hydrocarbon), trace elements, PAH, and nitrogen oxides. Effects on the ecosphere and food chain for aquatic and terrestial biota are discussed in depth. Metabolism, pharmacokinetics, carcinogenicity, mutagenicity, etc. These volumes are perhaps the most valuable of all in-depth reviews of coal conversion technology.

Characterization of Coal Liquids Derived from the H-Coal Process, BERC/RI76/10 (November 1976). 35 pp.

This booklet is a very concise description of the H-coal process, including a history of process development and hydrocarbon coal-conversion research. This report is concerned with two overhead products, fuel oil and syncrudes, both produced from Illinois #6 coal. Each mode produced a vacuum bottoms product. Conditions of operation are 72,000 psi and 850°F reactor temperature. Physical property testing of the products was performed using ERDA technology, and the chemical composition of both products was determined in detail. Distillates from each process were prepared and the chemical composition compared. The effect of operating conditions on product composition is discussed.

J.H. Gray, H-Coal Pilot Plant Environmental Controls, Ashland Synthetic Fuels, Inc. Presented at the Second Department of Energy Control Symposium, Reston, Va. (1980).

A description is given of the H-Coal process as well as the H-Coal pilot plant located at Catlettsburg, Kentucky, which currently is awaiting commissioning. An overview of the plant is provided, including a list of its cooperators, followed by a geographical description and an enumeration of the various operational functions of the plant and a discussion of environmental impact controls. These controls are directed to the abatement of water pollution, air pollution (both gaseous and particulate pollutants), and solid waste pollution.

W.H. Griest, D.L. Coffin, and M.R. Guerin, Fossil Fuels Research Matrix Program; K.E. Cowser, H-Coal Pilot Plant Project Quarterly Progress Report for the Period Ending December 31, 1979; K.E. Cowser, Coal Liquids Evaluation and Paraho-SOHIO Shale Oil Status Report for the Period Ending September 30, 1979; K.E. Cowser, University of Minnesota-Duluth Coal Gasification Project Quarterly Progress Report for the Period Ending March 31, 1980; K.E. Cowser, Pike County Coal Gasification Project Quarterly Progress Report for the Period Ending March 31, 1980. Oak Ridge National Laboratory, Oak Ridge, Tenn.

These Oak Ridge National Laboratory (ORNL) reports contain up-to-date summaries of synfuels research activities at that laboratory. The Fossil Fuels Research Matrix Program is especially important because it contains the repository code for synfuels samples stored at the ORNL. Also included is the overall plan for the synfuels research program, the individual projects completed, underway, and proposed, and the names of the senior investigators. The integrated chemical analytical/bioassay approach is outlined. Other reports in the series deal with the Pike County Gasification Project, University of Minnesota-Duluth Coal Gasifier, Paraho Shale Oil, and the H-Coal Pilot Plant Project at Trenton, New Jersey, and Catlettsburg, Kentucky. A summary of chemical characterization, health effects, and environmental effects research is provided, as well as a bibliography of articles published by ORNL on synfuels subjects during the reporting period.

B.S. Hass and H.E. Kubitschek, Development and Application of Screening Tests for Hygas Process Stream Samples, U.S. Department of Energy, Argonne National Laboratory Internal Report (1979).

This is a summary report covering a two-year initial study of genetic toxicology of coal gasification processes. The study was directed at developing methods to be used to examine mutagenicity and toxicity of crude and fractionated HYGAS process stream samples. The principal tool used was the Ames Salmonella assay. Although the Ames assay conventionally provides qualitative information, an effort was made to establish quantitative limits of risk. The report describes in detail the various problems encountered in studying a multicomponent stream specimen such as that encountered in the study.

I. Howard-Smith and G.J. Werner, Coal Conversion Technology, Noyes Data Corporation, Park Ridge, N.J. (1976).

This monograph is a highly specialized source of information on processes and techniques of coal conversion. More than one hundred processes are discussed in some detail, providing such information as product(s) yielded, in some cases detailed engineering and economic information, and process developer(s) and sponsor(s). The monograph also contains a useful glossary of technological terms and a list of acronyms.

P.D. Junkin, L.M. Tipton, and W.C. Yu, Implications of Environmental Compliance on D.O.E. Gasification ECT Act. Presented at the Second Department of Energy Control Symposium, Reston, Va. (1980).

The subject of this paper is effective planning and implementation of the U.S. Department of Energy's coal gasification projects to control environmental impacts. The paper considers in some detail the problems of making decisions regarding plant siting and design while considering environmental regulations presently in existence as well as those thought likely to appear in the future.

Memphis Light, Gas, and Water Division, Industrial Fuel Gas Demonstration Plant Program (1979).

The status of the U-gas demonstration plant at Memphis, Tennessee, is described, covering such topics as design, site selection and evaluation, environmental effects (management, schedule, water quality, hydrology, ecology, socioeconomic factors, and noise), permits, equipment, license agreements, costs, etc. Recent pilot plant results also are described and tables of data included.

A.H. Pelofsky (Ed.), Coal Conversion Technology, Problems and Solutions, American Chemical Society, Washington, D.C. (1979).

This is the proceedings of a symposium on coal conversion technology. It consists of fourteen contributed papers on the problems related to processes of coal conversion and the resolution of these problems. In addition, a round-table discussion at the end of the book provides additional insight into such matters as the use of western and eastern coal, product pricing, the long-range global impact of $CO_2$ generation from coal processing plants, and political problems that may arise from coal processing.

D.K. Schmalzer and C.R. Moxley, Environmental Control Systems for the SRC-II Demonstration Plant, The Pittsburgh and Midway Mining Company. Presented at the Second Department of Energy Control Symposium, Reston, Va. (1980).

A demonstration-scale SRC-II coal liquefaction plant has been contracted by the Department of Energy to the Pittsburgh and Midway Mining Company (subsidiary of the Gulf Oil Corporation) for design, construction, and operation. The focus of this paper is planning for controls to protect employees' health. To this end a process description is given, followed by a list of controls on air emissions, liquid emissions, and solid waste disposal. This is followed by a plan for worker's safety and health.

J.C. Tao and A.F. Yen, Environmental Control Systems of SRC-1 Demonstration Plant, Air Products/Wheelabrator-Frye joint venture. Presented at the Second Department of Energy Control Symposium, Reston, Va. (1980).

This paper is a description of the environmental controls at the SRC-I demonstrations plant at Newman, Kentucky, which produces solvent-refined coal, liquid fuels, and anode coke. These controls deal with the problem of producing an environmentally clean product whose feed is a dirty, high-sulfur-bearing coal and with the problems associated with operating an environmentally clean process throughout the entire operating cycle of the plant.

U.S. Department of Energy, Liquefaction, Demonstration Plants, Gasification, Coal--Quarterly Reports (April-June 1977).

These DOE quarterly reports describe the current status of DOE projects and list significant publications in coal conversion processes. Separate issues are concerned with a single process--coal liquefaction, coal gasification, or demonstration and plants. Each quarterly issue updates the project information. Program schedules and projections for production are included, as well as location, size, and financial considerations. Process descriptions are given in flow-chart and narrative forms. Upgrading information is provided. Each issue has a useful glossary of snyfuels definitions and terms.

U.S. Department of Health, Education and Welfare, Occupational Exposures in Coal Gasification Plants (September 1978), 198 pp.

This NIOSH criteria document contains a process description of each coal conversion process and describes the criteria accumulated to generate a recommendation for coal gasification occupational standards. The document discusses potential exposures to workers expected from coal and engineering controls. Standards-setting options are discussed with respect to the type of coal reacted and the operating modes of the facility. Future research needs for standards-setting are discussed, and an annotated bibliography is provided.

U.S. Department of Health, Education and Welfare, Potential Health Hazards Involved with Coal Gasification (November 1978).

This NIOSH technical report summarizes the historical development of coal conversion technology with respect to potential health hazards. The unit operation of coal conversion, from coal preparation and storage to end-use of gasification products, is discussed; coal liquefaction is not. A complete exposition of emissions and pollution products from each stage of the gasification process is provided in detail, including a discussion of the nitrogen heterocycles present in toxic gasifier tars and oils. Possible adverse health effects of various pollutants identified in coal conversion effluents are discussed.

U.S. Environmental Protection Agency, Recommended Health and Safety Guidelines for Coal Gasification Pilot Plants, EPA-600/7-78-007 (January 1978). 173 pp.

This EPA publication discusses coal gasification process technology in some detail, with regard to potential occupational health perspectives. Monitoring of the work environment, employee health protection programs, safety, and the relationship between identified pollutants and human health effects are discussed. Monitoring is an area of emphasis in this publication. Methods for sampling and characterizing airborne toxicants are discussed, and the role of vapor-phase materials is appreciated. The design of safe work plans for coal-conversion facilities is discussed, and a detailed discussion of "safe" levels for industrial pollutants is provided.

U.S. Environmental Protection Agency, Applicability of Petroleum Refinery Control Technologies to Coal Conversion, EPA-600/7-78-190, Interagency Energy/Environment R&D Program Report (October 1978).

This EPA document, prepared by TRW, is most valuable as a reference for comparison of petroleum refinery process effluents to coal-conversion process effluents. The chemical characterization of refinery and coal conversion effluent streams and by-products is complete, and there is an excellent summary of toxic material common to both processes, and different for both processes. An exposition of the toxic substances identified in the various effluent streams is provided, and is accompanied by detailed tables describing the toxic effects of each substance. Materials include: carcinogenic PAH compounds, major heavy metals, and organometallics. Approaches to waste management and control technology are discussed in detail, and a bibliography is included.

U.S. Environmental Protection Agency, Engineering Evaluation of Control Technology for the H-Coal and Exxon Donor Solvent Processes, EPA-600/7-79-168 (July 1979). 112 pp.

This EPA issue document deals with process descriptions and a design for control technology for pilot and planned commercial direct liquefaction H-Coal and Exxon Donor Solvent coal-conversion plants. The H-Coal plant is a 600 ton-per-day pilot plant being constructed in Cattletsburg, Kentucky, by Hydrocarbon Research, Inc. The Exxon donor solvent plant is a 250 tons-per-day pilot plant being constructed in Baytown, Texas. This report describes the process technology and emissions data for the two plants, and for proposed commercial plants. The process and emissions information is very detailed and comprehensive. Emissions information includes solid, liquid, and air emission waste streams, with physical and chemical analysis. Control technology is proposed for each process.

U.S. Environmental Protection Agency, Pollutants from Synthetic Fuels Production: Sampling Analysis Methods for Coal Gasification, EPA-600/7-79-201, Interagency Energy/Environment R&D Program Report (August 1979).

This EPA document describes the relationship of reaction conditions to chemical composition of effluents from a bench-scale gasification facility reacting semibatch (1.5 kg/batch). This experimental system is versatile, being able to react small batches of coal in short periods of time. The gasifier is constructed so that the operation mode (gas stream, temperature, pressure) can be varied, the inputs and outputs monitored, energy transfer efficiencies calculated, and pollutants quantified through an associated chemical-class fractionation/chemical analysis scheme. Collection and sampling techniques are described for particulates, organic condensibles and vapors. Volatile organics are collected from the gas stream by polymeric solvents and analyzed by capillary GL/mass spectrometry. Nine U.S. coals have been gasified in 57 runs, and the data collected, analyzed, and interpreted.

U.S. Environmental Protection Agency, SASOL: South Africa's Oil from Coal Story--Background for Environmental Assessment, EPA-600/8-80-002 (1980). 35 pp.

This EPA document is a concise reference for Sasol II process technology, providing a historical background to the Sasol coal-conversion facility at Sasolburg, South Africa. The Lurgi/Fischer-Tropsch indirect liquefaction complex produces chemical feedstock and transportation fuel from low-grade coal in the Transvaal. Sasol II will consume 14 million tons per year of coal, refine 2.9 million tons of crude oil per year, and cost $2.8 billion dollars. Sasol III, a new facility equal to Sasol II, and Sasol II together will produce 112,000 barrels of oil per day, about 50 percent of South Africa's needs. A chemical analysis of Sasol II products and a product spectrum are provided, as well as a discussion of by-products, effluents, and intermediates.

C.Y. Wen and E.S. Lee (Eds.), Coal Conversion Technology, Addison-Wesley Co., Reading, Mass. (1979). Presented at the Second Department of Energy Control Symposium, Reston, Va. (1980).

This is an extensive and up-to-date source book on coal properties and coal processing. The book is composed of four articles, each of which contains its own bibliography, and the book itself has an author's index and subject index. In addition, the appendix contains twelve tables of coal properties and coal processing information that would be of great use in engineering as well as statistical studies.

R.J. Young, W.J. McKay, and J.M. Evans, Coal Gasification and Occupational Health (1978).

This is a review article that treats occupational hazards from coal-conversion technology. It presents an overview of gasification technology, including the identification of potentially hazardous pollutants present in emissions, product, and waste streams. An attempt has been made to quantify a risk or hazard assessment to human health by permitting parameters related to toxicity in the occupational microenvironment. A final section summarizes current research efforts being carried out by OSHA. A well-documented bibliography is presented. This review is especially interesting in that target organ toxicity from coal-conversion technology is discussed.

## OIL SHALE

American Chemical Society, Symposium on Alternate Feedstocks for Petrochemicals, Synthetic Fuels, Symposium Publications (1980). 800 pp.

This document contains abstracts and research reports on the current status of synfuels technology, including oil shale developments. Symposia sessions presented are listed in the index, and topics include oil shale, tar sands, synthetic fuels (federal options), fluidynamics of coal conversion, and a session on information needs of the petroleum industry. Health effects, testing, environmental impacts and chemistry of oil shale products and industry are included, as well as a discussion of regulatory problems and current status of various federal agency research and development programs concerning oil shale and other synthetic fuels.

R. Brown (Ed.), Health and Environmental Effects of Oil Shale Technology, Federal Interagency Committee on the Health and Environmental Effects of Energy Technologies, The Mitre Corp., Metrek Division, McLean, Va. (1979). 260 pp.

This report on oil shale technology represents an interagency response to the President's directive to identify health and environmental problems associated with the development of a large oil shale industry for the production of liquid fuels. The requisite research information needs associated with these problems are outlined. The report contains a review of specific health and environmental issues and problems associated with the industry and a consideration of the research strategies required to approach them. No actual research data are presented, only a projection of research needs. Specific research needs are identified, such as the problem of complex organic environmental materials, conduct of human epidemiological studies, development of short-term bioassay screening paradigms specifically for the products of this industry, etc. In addition to health effects, aquatic ecology, water quality, terrestrial effects planning, and ambient sampling and monitoring need to be discussed. No bibliography is provided, but a detailed list of participants is included.

Council for Environmental Quality, Energy Alternatives, a Comparative Analysis, Science and Public Policy Program, University of Oklahoma, Norman Ok., U.S. Govt. Printing Office Document 041-011-0025-4 (1975). 600 pp.

This document is a comprehensive discussion of all aspects of alternative energy resources, means of exploitation, development of energy technologies from these resources, transportation, mining, preparation processing, emissions, environmental considerations, etc. Chapter 2 is a very comprehensive description of the oil shale resource, exploration, mining, transportation, processing, reclamation, etc., technologies to 1975, but contains little information concerning health risk and biological/ human health effects. Environmental impacts of the industry are discussed for each category of technology, but not in depth. This document, although dated, provides a useful single-source comparison of oil shale to other synthetic fuel technologies.

U.S. Department of Energy, Health and Environmental Effects of Synthetic Fuels, Appendix 2, Federal Interagency Committee on the Health and Environmental Effects of Energy Technologies, Executive Scientist, Mitre Corp., McLean, Va. (1979). 400 pp.

This compendium is a compilation of project information representing an inventory of federal energy-related environment and safety research maintained by the U.S. Department of Energy. It contains a list of specific research and development activities related to synthetic fuels. This list is computer-categorized--basic research, applied research, technology transfer, field study, health effects (divided by type of health effect studies), pollutants considered, etc. The specific projects concerned with shale oil technology are designated by computerized subheadings. The project information is given in abstract form, with the name and address of the principal investigator. Projects to 1978 are listed.

U.S. Environmental Protection Agency, Environmental Issues Associated with Synfuel Utilization (Draft Report), prepared by TRW Energy Systems, Planning Division, McLean, Va. (1980). 150 pp.

This as yet unreleased draft report is a technology and market assessment report for all synfuels, with an emphasis on oil shale industrial development. This report is a discussion of utilization projections into the second decade of the twenty-first century, including industry build-up scenarios, plant location, production projections, and distribution projections. One half of the report is concerned with an environmental analysis of synfuels utilization, in which the emphasis is to make exposure prediction based upon the utilization scenarios. The report contains five appendices which document distribution patterns, physical and chemical characterization of products, health-effects testing results, and a valuable section on combustion and end-use properties of synfuels, including shale oil. The body of the report as well as each appendix is well referenced.

U.S. Office of Technology Assessment, An Assessment of Oil Shale Technologies, Washington, D.C., U.S. Government Printing Office, Serial No. 052-003-00759-2 (June 1980).

This document provides the best overview of shale oil extraction processes and associated environmental and socioeconomic problems. The overview is supported by data including those on air and water pollutants. Various constraints and policy options for oil shale development also are discussed in this document.

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