Chapter 10

Environment, Health, and Safety Effects and Impacts

Contents

TABLES

FIGURES

Chapter 10

Environment, Health, and Safety Effects and Impacts

INTRODUCTION

There are major differences in the risks to public health and the environment associated with the alternative approaches to reducing the dependence of the U.S. transportation sector on foreign oil. Depending on the level of development, the production and use of synthetic fuels imply massive increases in mining (and agriculture and forestry for biomass), construction and operation of large conversion plants producing substantial quantities of waste products (some of which are toxic), and fuel products that may be different from the fuels now in commerce and that may thus represent different risks in handling and use.

Electrification of autos would require large increases in electric power production, which in turn imply major increases in powerplant fuel use and emissions. Also, the use of electric cars would decrease the use of conventional vehicles and thus yield reductions in vehicular emissions as well as changes in vehicle materials and operating characteristics.

Increased automotive fuel efficiency would involve changes in vehicle size, materials, operating characteristics, and emissions. All the strategies would reduce the use of petroleum that would otherwise have been imported, and adverse effects associated with the strategies should be partially offset by the resulting environmental benefit of reductions of oil spills and other hazards.

This section identifies potential effects on the environment and human health of these three alternative (or complementary) approaches to reducing or eliminating oil imports. Because of significant uncertainties in the precise characteristics of the technologies to be deployed, their potential emissions and the control levels possible, and future environmental regulations and other important predictive factors, the approach of this evaluation is relatively informal and qualitative. We attempt to put the alternatives into reasonable perspective by identifying both a range of potential effects and, given the availability of controls and incentives to use them, the most likely environmental problems of deployment. The major emphasis in the discussion of synthetic fuels is on coal-based technologies. OTA has recently published reports on biomass energy[1] and oil shale,[2] both of which contain environmental assessments.

---

[1] *Energy* From Biological Processes, OTA-E-124 (Washington, D. C.: U.S. Congress, Office of Technology Assessment, July 1980).

[2] An Assessment of Oil Shale Technologies, OTA-M- 118 (Washington, D. C.: U.S. Congress, Office of Technology Assessment, June 1980).

AUTO FUEL CONSERVATION

Some measures taken to improve the fuel economy of light-duty vehicles might have significant effects on automobile safety and the environment. Major potential effects include changes in vehicle crashworthiness due to downsizing and weight reduction, environmental effects from changes in materials and consequent changes in mining and processing, and possible air-quality effects from the use of substitutes for the spark-ignition engine,

Motor Vehicle Safety

The shift to smaller, lighter, more fuel-efficient cars has led to heightened concern about a possible increase in traffic injuries and fatalities. Part of this concern stems from evidence that occupants of smaller cars have been injured and killed at rates considerably higher than the rates associated with larger cars. The National Highway Traffic Safety Administration (N HTSA) has recently estimated that a continuing shift to smaller vehicles could result in an additional 10,000 traffic deaths per year (with total annual road fatalities of 70,000) by 1990 unless compensating measures are taken.

In light of these concerns, OTA examined available evidence on the relationship between vehicle size and occupant safety in today's auto fleet, and reviewed some attempts—including the NHTSA estimate—to extrapolate this evidence to a future, downsized fleet.

Occupant Safety and Vehicle Size in Today% Fleet

Much of the current concern about the safety of small cars is based on statistical analysis of national data from the Fatal Accident Reporting System (FARS), which contains information on fatal motor vehicle accidents occurring in the United States. For example, an analysis of FARS data on automobile occupant deaths conducted by the Insurance Institute for Highway Safety (IIHS) (fig. 22) shows that deaths per registered vehicle increase substantially as vehicle size (measured by length of wheelbase) decreases.[4] Furthermore, this trend occurs for both single- and multiple-vehicle crashes. The trend is so strong that the annual occupant deaths per registered small subcompact are more than twice as high as the rate for full-size cars–3.5 per 10,000 cars compared with 1.6 per 10,000.

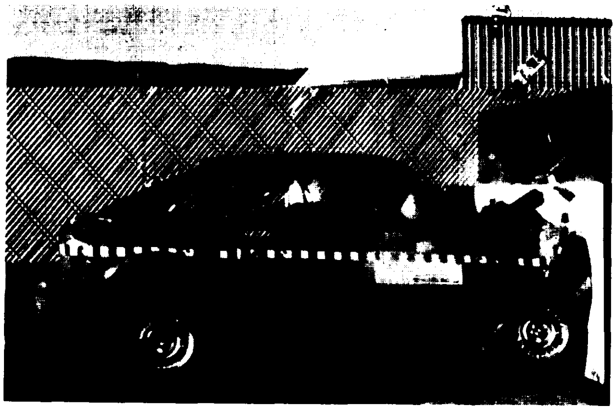
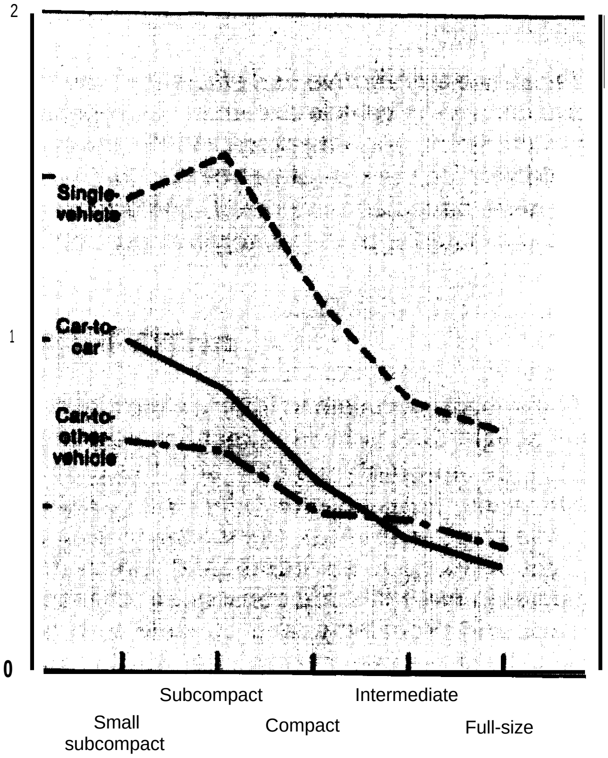


Photo credit: National Highway Traffic Safety Administration

Crash tests sponsored by the National Highway Traffic Safety Administration are an important source of information for understanding the mechanics of crashes and evaluating auto safety features

The relationships illustrated in figure 22 tempt one to conclude that small cars are much less safe than large cars in virtually all situations. For a variety of reasons, however, the information in the figure must be interpreted with care. First, the recent crash tests sponsored by NHTSA[5] (new cars were crashed head-on into a fixed barrier at 35 miles per hour) seemed to indicate that the differ-

Figure 22.—Passenger-Car Occupant Death per 10,000 Registered Cars by Car Size and Crash Type: Cars 1 to 5 Years Old in Calendar Year 1980-



SOURCE: Insurance Institute for Highway Safety.

---

[3] National Highway Traffic Safety Administration, *Traffic Safety Trends and Forecasts*, DOT-HS-805-998, October 1981.

[4] Insurance Institute for Highway Safety, *Status Report*, vol. 17, No. 1, Jan. 5, 1982.

[5] The crash tests are described in several references. A useful, clear reference is "Which Cars Do Best in Crashes?" in the April 1981 issue of Consumer Reports. Also see M. Brownlee, et al., "Implications of the New Car Assessment Program for Small Car Safety, " in proceedings of the Eighth International Technical Conference on Experimental Safety Vehicles, Wolfsburg, Germany, Oct. 21-24, 1980, NHTSA report.

ences in expected occupant injuries between vehicles in the same size class–i.e., differences caused by factors other than size—can be greater than any differences between the size classes. importantly, the results imply that relatively minor changes in engineering and design, such as inexpensive improvements in the steering column and changes in the seatbelt mechanisms, can produce improvements in vehicle crashworthiness that may overwhelm some of the differences caused by size alone. The results of the tests can be applied only to occupants wearing seatbelts (11 percent of total occupants), however, and only to new cars in collisions with fixed objects.

Another reason to be cautious is that the IIHS analysis may be overlooking the effect of variables other than car size. For example, the age of drivers and occupants is a critical determinant of fatality rates. Younger drivers tend to get into more serious accidents,[7] and younger occupants are less likely than older ones to be killed or seriously injured in otherwise identical crashes.[8] Because the average age of drivers and occupants is not uniform across car size classes—it is believed that smaller cars tend to have younger drivers and occupants—the observed differences in fatality rates may be functions not only of the physical characteristics of the cars but also of differences in the people in those cars.

Other variables that should be considered in interpreting injury and fatality statistics include safety belt usage (drivers of subcompact cars have been reported to use seatbelts at a significantly higher rate than drivers of intermediate and large cars[9]), the average number of occupants per car, and differences in maneuverability and braking capacity (i. e., crash avoidance capability) between big and small cars. *

Several analyses have tried to account for the effect of some of these variables.[10] However, these analyses use different data bases (e.g., State data such as that available from North Carolina, and other national data bases such as the National Accident Sampling System and the National Crash Severity Study), different measures of vehicle size (wheelbase, the Environmental Protection Agency (EPA) interior volume, weight, etc.), different formulations of safety (e.g., deaths per 100,000 registered vehicles, deaths per vehicle-mile driven, deaths per crash), and in addition their data reflect different time frames. Few analyses correct for the same variables. Consequently, it is extremely difficult to compare these analyses and draw general conclusions.

Also, credible data on total accident rates for all classes of cars, and more detailed data on accident severity, are not widely available. This type of data would allow researchers to distinguish between the effects of differences in crashworthiness and differences in accident avoidance capability in causing the variations in fatalities measured in the FARS data base. For example, studies of accident rates in North Carolina indicate that subcompacts are involved in many more accidents than large cars.[11] Consequently, the relationship between fatalities per registered vehicle and car size, and that between fatalities per crash and car size could be significantly different for this data set, with the latter relationship indicating less dependence between safety and vehicle size than appears to be the case in the former. Unfortunately, such data are available only in a few jurisdictions and cannot be used to draw nationwide conclusions.

Finally, the existing data base reflects only current experience with small cars. In particular, the data reflect no experience with the class of extremely small sub-subcompacts that currently are sold in Japan and Europe but not in the United States. it is conceivable that widespread introduction of such cars into the U.S. fleet, triggered by

---

[6] R. H. Stephenson and M. M. Finkelstein, "U.S. Government Status Report," in proceedings of the Eighth International Technical Conference on Experimental Safety Vehicles, op. cit.

[7] H. M. Bunch, "Smaller Cars and Safety: The Effect of Downsizing on Crash Fatalities in 1995, " HSRI Research Review (University of Michigan), vol. 9, No. 3, November-December 1978.

[8] Ibid.

[9] Stephenson and Finkelstein, op. cit.

*The effect of improved crash avoidance capability and other safety factors may be perverse. To the extent that drivers may take more chances in reaction to their perception of increased safety, they can negate the effectiveness of safety improvements. The tendency of drivers of large cars to use seatbelts at a lower rate than drivers of small cars may be an indicator of such a reaction.

[10] A variety of these are described in J. R. Stewart and J. C. Stutts, "A Categorical Analysis of the Relationship Between Vehicle Weight and Driver Injury in Automobile Accidents, " NHTSA report DOT-HS-4-O0897, May 1978.

[11] J. R. Stewart and C. L. Carroll, "Annual Mileage Comparisons and Accident and Injury Rates by Make, Model, " University of North Carolina Highway Safety Research Center.

their lower sales prices or by renewed oil price increases, could have severe safety consequences. NHTSA engineers are concerned that occupants of sub-subcompacts might be endangered not only by the increased deceleration forces that are the inevitable danger to the smaller vehicle in multicar crashes, but also by problems of managing crash forces and maintaining passenger-compartment integrity that are encountered in designing and building cars this small.[12]

Despite these problems, some conclusions about the relationship between vehicle size and safety can be drawn. For example, the strong positive relationship between vehicle size and safety in a//accidents combined and in car-to-car collisions has been confirmed in virtually all analyses.[13] However, the size/safety relationship does not appear to be as "robust" for single-car collisions, which accounted for about half of all passenger-car occupant fatalities in 1980. Although several studies conclude that there is a strong positive relationship between car size and safety in this class of accidents,[14] I Q and the IIHS analyses show a very strong relationship,[15] some studies have concluded that this positive relationship disappears among some size classes when the data are corrected for driver age and other variables.[16] However, even these studies show that subcompacts fare worse than all other size classes in single-vehicle accidents. "

Forecasting Future Trends in Auto Safety

Attempts to forecast the effects on traffic safety of a smaller, more fuel-efficient fleet—a result of further downsizing within each size class as well as a continued market shift to smaller size classes—are confronted with severe analytical difficulties. First, if the forecast is to account for the effects of important vehicle and driver-related variables, the forecasters must predict how these variables will change in the future—e.g., for each size class, forecasters must predict future values of average driver age, vehicle miles driven, occupancy rates, seatbelt usage, etc. And they must either estimate future size dimensions in each car class and the number of vehicles in each class in the fleet, or else postulate these values. Second, forecasters must construct a credible model that describes the relationship between traffic safety (e.g., injury and fatality rates) and key vehicle and driver-related variables in such a way that the model will remain valid over the time period of the forecast.

The models used by NHTSA[18] and others[19] to project future safety trends generally use simple statistical representations of the relative risk of accidents or injuries and fatalities. The traffic fatality projections examined by OTA all relied on accident data that included older design automobiles even though few such vehicles are likely to remain in the fleet when the date of the projection arrives.

In particular, NHTSA's widely disseminated estimate of 10,000 additional annual traffic deaths by 1990[20] assumed that exposure to fatality risk is a function only of vehicle weight and the number of registered vehicles in each weight class. No account is taken of the effect of recent vehicle design changes, age and behavior of drivers, differences in crash avoidance capabilities, differences in annual vehicle-miles driven and vehicle occupancy rate between various automobile size classes, and other variables. Similar shortcomings exist in the other projections. The resulting projections of future changes in traffic injuries and fatalities should be considered as only rough, first-order estimates.

---

[12] J. Kanianthra, Integrated Vehicle Research Division, NHTSA, personal communication, March 1982.

[13] Stewart and Stutts, op. cit.

[14] For example, several studies cited in Stewart and Stutts, op. cit.; also, J. H. Engel, Chief, Math Analysis Division, NHTSA, "An Investigation of Possible Incompatibility Between Highway and Vehicle Safety Standards Using Accident Data," staff report, April 1981; also, J. O'Day, University of Michigan Highway Safety Research Institute, personal communication, March 1982.

[15] IIHS, op. cit.

[16] Stewart and Stutts, Op. cit.

[17] I bid.

[18] NHTSA, op. cit. The model briefly described in this report appears to be similar to the forecasting model used in J. N. Kanianthra and W. A. Boehly, "Safety Consequences of the Current Trends in the U.S. Vehicle Population, " in proceedings of the Eighth International Technical Conference on Experimental Safety Vehicles, op.cit.

[19] W. Dreyer, et al., "Handling, Braking, and Crash Compatibility Aspects of Small Front-Wheel Drive Vehicles, " Society of Automotive Engineers Technical Paper Series 810792, June 1981. Also, Bunch, op. cit. Also, J. Hedlund, "Small Cars and Fatalities—Comments on Volkswagen's SAE Paper, " internal NHTSA memorandum, Feb. 4, 1982.

[20] NHTSA, op. cit.

Because of the weaknesses in available quantitative projections of future fatality rates, OTA examined current injury/fatality data and other sources for further evidence of whether or r-tot downsizing and a mix shift to smaller size classes would have a significant effect on safety. In particular, the following observations are important to answering this question:

1. A safety differential between occupants of small and large cars in multiple-car collisions does not necessarily imply that reducing the size of all cars will result in more deaths in this class of accidents. Although available data clearly imply that reducing a vehicle's size will tend to increase the vulnerability of that vehicle's occupants in a car-to-car collision, the size reduction also will make the vehicle less dangerous to the vehicle it collides with. Under some formulations of accident exposure and fatality risk, these two factors may cancel each other out. For example, Volkswagen has calculated the effect of increasing the proportion of subcompacts in today's fleet. Using FARS data and forecasting assumptions that are well within the plausible range, Volkswagen concluded that an increase in subcompacts would actually lead to a decrease in traffic fatalities in car-to-car collisions.[21] Other models using different formulations and data bases might come to different conclusions. For example, models using traffic safety data from North Carolina probably would arrive at a different result. In this historical data set, subcompacts colliding with subcompacts have been found to have a considerably greater probability of causing a fatality than collisions between two full-size cars.[22] Presumably, models using this data set would be likely to forecast that a trend toward more subcompacts would lead to an increase in car-to-car crash fatalities.
2. If small cars are less safe than large cars in single-car accidents, then a decrease in the average size of cars in the fleet with no compensatory improvements in crashworthiness clearly should imply an increase in injuries and fatalities in this class of accidents. As just discussed, some studies suggest that a consistent relationship between size and safety does not exist for compact, midsize, and full-size cars in single-car accidents.[23] On the other hand, subcompacts do fare worse than the other classes in these studies.[24] Consequently, if these studies are correct, a general downsizing of the fleet might have only a small effect on fatalities in single-car accidents, while a drastic shift to very small cars could cause a large increase in such fatalities.

The results of these studies may not be widely applicable. Other studies observe a definite size/safety relationship across all size classes.[25] And some factors tend to favor this alternative conclusion. For example, the higher seatbelt usage in smaller cars should tend to make small cars appear safer in the raw injury data, and thus tend to hide or weaken a positive size/safety relationship. Taking differences in seatbelt usage into account might expose or strengthen such a relationship.[26] Also, analysis of FARS data that includes only vehicles up to 5 years old produces a stronger size/safety relationship than analysis of the whole fleet.[27] Most studies use the whole fleet, but the more limited data set might prove to be better for a projection of the future because it reflects only newer-design automobiles. Finally, as discussed in chapter 5, the larger crush space and passenger compartment volume available to the larger cars should give them, at least theoretically, a strong advantage in the great majority of accidents. On the other hand, an opposing factor favoring those studies showing less dependence between vehicle size and crashworthiness is the limited evidence of increasing accident rates with decreasing car sizes.[28] This offers a reason other than

---

[21] Dreyer, et al., Op. cit.

[22] K. Digges, "Panel Member Statement," Panel on ESV/RSV Program, in proceedings of the Eighth International Technical Conference on Experimental Safety Vehicles, op. cit.

[23] Stewart and Stutts, op. cit.

[24] Ibid.

[25] Supra 14,

[26] Stephenson arid Finkelstein, op. cit.

[27] Based on a comparison of II HS's analysis, op. cit., and Engel's analysis, op. cit.

[28] Stewart and Carroll, op. `cit.

(or in addition to) differences in crashworthiness for the differences in fatalities among the various auto size classes.

3. Although most arguments about downsizing and traffic safety have focused on vehicle occupants, the inclusion of pedestrian fatalities will affect the overall argument. About 8,000 pedestrians were killed by motor vehicles in 1980,[29] and analysis of FARS data indicates that pedestrian fatalities per 100,000 registered cars increase as car size increases[30]—i.e., reducing the average size of cars in the fleet might decrease pedestrian fatalities because of the reduced "aggressiveness" of smaller cars towards pedestrians. If policy concern is for total fatalities, this effect should lessen any overall adverse safety effect of downsizing the fleet.
4. Much of the available data implies that traffic fatalities will rise if the number of collisions between vehicles of greatly different weights increases. This points to three dangers from a downsized fleet. First, for a limited period of time, the number of collisions of this sort might increase because of the large number of older, full-size cars left in the fleet. This problem should disappear within a decade or two when the great majority of these older cars will have been scrapped. Second, a more permanent increase in fatalities could occur if large numbers of very small sub-subcompacts–cars not currently sold in the U.S. market—were added to the passenger vehicles fleet. The potential for successful large-scale sales of such vehicles will depend on their prices—they may be significantly less expensive than current subcompacts—as well as future oil prices and public perceptions of gasoline availability. Third, car-truck collisions, which today represent a significant fraction of occupant fatalities (car-to-other-vehicle accidents account for about 25 percent of total occupant fatalities[31]), may cause more fatalities unless the truck fleet is downsized as well. Subcompacts fare particularly poorly in car-truck collisions, and a large increase in the number of vehicles in this size class could create substantial problems.

The available statistical and physical evidence on auto safety suggest that a marked decrease in the average vehicle size in the automobile fleet may have as a plausible outcome an increase in vehicle-occupant fatalities of a few thousand per year or more. This outcome seems especially likely during the period when many older, heavier vehicles are still on the road. Also, such an outcome seems more likely if the reduction in average size comes mainly from a large increase in the number of very small cars in the fleet, rather than from a more general downsizing across the various size categories in the fleet.

The evidence is sufficiently ambiguous, however, to leave open the possibility that only a minor effect might occur. And, as discussed in the next section, improvements in the safety design of new small vehicles (possibly excluding very small sub-subcompacts) probably could compensate for some or all of the adverse safety effect associated with smaller size alone. Some automobile analysts feel that significant safety improvements are virtually inevitable, even without additional Government pressures. For example, representatives of Japanese automobile companies have stated[32] that the present poor record of Japanese cars in comparison with American small cars is unacceptable and will not be allowed to continue. Major improvements in Japanese auto safety would seem likely to force a response from the American companies. Also, General Motors has begun to advertise the safety differentials between its cars and Japanese models, an indication that American manufacturers may have decided that safety can sell. On the other hand, because of its severe financial difficulties, the industry may be reluctant to pursue safety improvements that involve considerable capital expenditures.

Safer Design

Increases in traffic injuries and fatalities need not occur as the vehicle fleet is made smaller in

---

[29] NHTSA, *Fatal* Accident Reporting System *1980.*

[30] Based on an analysis of data presented in Engel, OP. cit.

[31] NHTSA, op. cit.

[32] Reported in the April 1981 Consumer *Reports,* OP. cit.

[33] Ibid., and IIHS, op. cit.

size. Numerous design opportunities exist to improve vehicle safety, and some relatively simple measures could go a long way towards compensating for adverse effects of downsizing and shifts to smaller size classes.

Increased use of occupant restraint systems would substantially reduce injuries and fatalities. NHTSA analysis indicates that the use of air bags and automatic belts could reduce the risk of moderate and serious injuries and fatalities by about 30 to 50 percent.[34]

Simple design changes in vehicles may substantially improve occupant protection. As noted in evaluations of NHTSA crash tests, design changes that are essentially cost-free (changing the location of restraint system attachment) or extremely low cost (steering column improvements to facilitate collapse, seatbelt retractor modifications to prevent excessive forward movement)[35] appear to be capable of radically decreasing the crash forces on passenger-car occupants.

A variety of further design modifications to improve vehicle safety are available. As demonstrated in the NHTSA tests,[36] there are substantial safety differences among existing cars of equal weight. One important feature of the safer cars, for example, is above-average length of exterior structure to provide crush space. Also, the Research Safety Vehicle Program sponsored by the Department of Transportation shows that small vehicles with safety features such as air bags, special energy-absorbing structural members, anti laceration windshields, improved bumpers, doors designed to stay shut in accidents, and other features can provide crash protection considerably superior to that provided by much larger cars.

Two forms of new automotive technology introduced for reasons of fuel economy could also have important effects on vehicle safety. First, the incorporation of new lightweight, high-strength materials may offer the automobile designer new possibilities for increasing the crashworthiness of the vehicle. Because some of the plastics and composite materials currently have problems resisting certain kinds of transient stresses, however, their use conceivably could degrade vehicle safety unless safety remains a primary consideration in the design process. Second, the use of electronic microprocessors and sensors, which is expected to become universal by 1985 to 1990 to control engine operation and related drivetrain functions, could eventually lead to safety devices designed to avoid collisions or to augment driver performance in hazardous situations.

Modifications to roadways can also play a significant role in improving the safety of smaller vehicles. For example, concrete barriers and roadway posts and lamps designed to protect larger vehicles have proven to be hazards to subcompacts[37] in single-vehicle crashes, and redesign and replacement of this equipment could lower future injury and fatality rates.

Mining and Processing New Materials

Aside from the beneficial effects of downsizing on the environmental impacts of mining—by reducing the volume of material required–vehicle designers will use new materials to reduce weight or to increase vehicle safety. Table 71 shows four candidates for increased structural use in automobiles and the amount of weight saved for every 100 lb of steel being replaced.

It appears unlikely that widespread use of these materials would lead to severe adverse impacts. Magnesium, for example, is obtained mostly from seawater, and the process probably has fewer pollution problems than an equivalent amount of iron and steel processing, Most new aluminum

Table 71 .—Material Substitutions for Vehicle Weight Reductions

Structural material	Weight saved/100 lb steel replaced
Magnesium	75
Fiberglass-reinforced composites. . .	35-50
Aluminum	50-60
High-strength low-alloy steel	15-30

SOURCE: M. C. Flemming and G. B. Kenney, "Materials Substitution and Development for the Light-Weight, Energy-Efficient Automobile," OTA contractor report, February 1980

MR. J. Hitchcock and C. E. Nash, "Protection of Children and Adults in Crashes of Cars With Automatic Restraints, " in Eighth International Technical Conference on Experimental Safety Vehicles, op. cit.

[35] Brownlee, et al., Op. cit.

[36] Ibid.

[37] IIHS, op. cit.

probably would be obtained by importing bauxite ore or even processed aluminum, rather than expanding domestic production. if kaolin-type clays are used for domestic production, waste disposal problems could be significant; however, the cost of producing aluminum from this source currently is too high to make it economically worthwhile.

Use of high-strength low-alloy steel will likely lead to slightly lowered iron and steel production because of the higher strength of this material, with a positive environmental benefit. Finally, the use of plastics and reinforced composites would substitute petrochemical-type processing for iron and steel manufacture, with an uncertain environmental tradeoff.

Air Quality

Regulation of automobile emissions under the Clean Air Act of 1970 (Public Law 91-614) and subsequent amendments has sharply reduced the amount of pollutants from automobile exhaust in the atmosphere. Assuming that present standards and proposed reductions in permissible levels of hydrocarbons (HC), carbon monoxide (CO), and nitrogen oxides (NO_x are met, the aggregate of automobile emissions by 1985 will be roughly half of what they were in 1975 despite an increase of 25 percent in the number of cars on the road and a corresponding rise in total miles of vehicle travel. * By 2000, if the 1985 standards have been maintained and complied with, the aggregate of automobile emissions of HC, CO, and NO_x will be 33, 32, and 63 percent of today's levels, respectively. Particulate emissions would be about one-half of today's levels—and possibly much lower, depending on the progress in control of particulate emissions from diesels.

The reductions expected by 1985 will have been brought about by a combination of two basic forms of emission control technology—methods of limiting the formation of pollutants through control of fuel-air mixture, spark timing, and other conditions of combustion in the engine, and systems to remove pollutants from the exhaust before it is discharged into the atmosphere. The effectiveness of both techniques has been greatly enhanced by the advent of electronic engine controls in recent years.

By 1985, when electronic engine controls will be virtually universal in passenger cars, the mandated levels of 3.4 grams per mile (gpm) CO, 0.41 gpm HC, and 1.0 gpm NO_x can probably be met by spark-ignition engines with little or no penalty in fuel economy beyond that associated with the lower engine compression ratios dictated by (low-octane) lead-free gasoline. * And although this fuel penalty may be charged to the control of CO, HC, and NO_x emissions because lead-free gasoline is required to protect catalytic converters, the reduction in lead additives to gasoline may also be justified on the basis of its beneficial effect in reducing lead emissions and, consequently, the level of lead in human tissue. Assuming that reducing lead in gasoline is desirable even without the catalytic converter requirement, the much-argued tradeoff between fuel economy and emissions that seemed so compelling in the 1970's is unlikely to remain a major issue with the spark-ignition engine by the last half of the 1980's.

A shift to still smaller vehicles and the introduction of new engines (and substantial increases in the use of current diesel technology) may affect the tradeoff between air quality and control costs. Because lower vehicle weights and lesser performance requirements will allow substantially smaller engines, the grams per mile emission standards should be easier to meet for most engine types. And, although manufacturers can be expected to respond to this opportunity by cutting back on emission controls, there will be an enhanced potential for eventually lowering emissions still further. On the other hand, some of the engines—e.g., the gas turbines and diesels—may pose some control problems, with NO_x and particulate especially.

---

*These projections, based on an earlier study by OTA[38] have been adjusted to account for more recent data on automobile use and the lower projected growth rates used in this study.

[38] *Changes in the Future Use* and Characteristics of the Automobile *Transportation* System, OTA-T-83 (Washington, D. C.: U.S. Congress, Office of Technology Assessment, February 1979).

*Although high-octane lead-free gasoline can be, and is, manufactured, the fuel savings it might allow from higher compression engines may be counterbalanced by additional energy required for refining. The exact energy required to produce higher octane lead-free gasoline will be very specific to the refinery, feedstock, and refinery volumes.

Table 72 briefly describes some of the emissions characteristic of current and new engines for light-duty vehicles. The potential emission problem with diesels appears to be the major short-term problem facing auto manufacturers today in meeting vehicle emission standards. There appears to be substantial doubt that diesels can comply with both NO_x and particulates standards without some technological breakthrough, because NO_x control, already a problem in diesels, conflicts with particulate control. This problem is especially significant because diesel particulate are small enough to be inhaled into the lungs and contain quantities of potentially harmful organic compounds.

The effect on human health of a substantial increase in diesel particulate emissions is uncertain, because clear epidemiologic evidence of adverse effects does not exist and because there is doubt about the extent to which the harmful organics in the emissions will become biologically available—i.e., free to act on human tissue *—after inhalation.[39] However, a sharp increase in the number of diesel automobiles to perhaps 25 percent of the market share, which appears possible by the mid-1990's, probably should be considered to represent a significant risk of adverse health effects unless improved particulate controls are incorporated or unless further research provides firmer evidence that diesel particulate produce no special hazard to human health.

Table 72.—Emissions Characteristics of Alternative Engines

Current spark ignition. —Meets currently defined 1983 standards.
Current (indirect injection) diesel.—Can meet CO and HC standards, but NO_x remains a problem. NO_x control conflicts with HC and particulate control. Future particulate standards could be a severe problem.
Direct-injection diesel. —Meets strictest standards proposed for HC and CO. NO_x limit 1 to 2 g/mile depending on vehicle and engine size. Possible future problems with particulates, odor, and perhaps other currently unregulated emissions.
Direct-injection stratified-charge.— Needs conventional spark-ignition engine emission control technology to meet strict HC/CO/NO_x standards. Better NO_x control than diesel. In some versions particulate likely to be problem.
Gas turbine-free shaft.—Attainment of 0.4 g/mile NO_x limit a continuing problem, appears solvable, maybe with variable geometry. Other emissions (HC, CO) no problem,
Single shaft. —Same basic characteristics as comparable free shaft. Better fuel economy may help lower NO_x emissions.
Single shaft (advanced). –NO_x emissions aggravated because of higher operating temperatures.
Stirling engine (first generation).—Early designs have had some NO_x problems, but should meet tightest proposed standards on gasoline, durability probably no problem, emissions when run on other fuels not known.

SOURCE: Adapted from: J. B. Heywood, "Alternative Automotive Engines and Fuels: A Status Review and Discussion of R&D Issues," contractor report to OTA, November 1979.

ELECTRIC VEHICLES

The substitution of electric vehicles (EVs) for a high percentage of U.S. automobiles and light trucks may have a number of environmental effects. The reduction in vehicle-miles traveled by conventional gasoline- and diesel-powered vehicles will reduce automotive air pollution, whereas the additional requirements for electricity will increase emissions and other impacts of power generation. Changes in materials use may have environmental consequences in both the extractive and vehicle manufacturing industries. The use of large numbers of batteries containing toxic chemicals may affect driver and public health and safety. The different noise characteristics of electric and internal combustion engines imply a reduction in urban noise levels, while differences in size and performance may adversely affect driving safety. Finally, there may be a variety of lesser effects, for example, safety hazards caused by installation and use of large numbers of charging outlets.

Power Generation

As discussed in chapter s, utilities should have adequate reserve capacity to accommodate high

---

*Initially, the organics adhere to particulate matter in the exhaust. In order for them to be harmful, they must first be freed from this matter. In tissue tests outside the human body ("in vitro" tests), they were not freed, i.e., they did not become biologically active. This may be a poor indicator of their activity inside the body, however.

[39] Health Effects Panel of the Diesel Impacts Study Committee (H. E. Griffin, et al.), National Research Council, *Health Effects of* Exposure to *Diesel* Exhaust, National Academy of Sciences, Washington, D. C., 1980.

levels of vehicle electrification without adding new powerplants. For example, if the utilities could use load control and reduced offpeak prices to confine battery recharging to offpeak hours, half of all light-duty vehicular traffic could be electrified today without adding new capacity. Given the probable constraints on EVs, however, a 20-percent share probably is a more reasonable target for analysis. *

The effects on emissions of a 20-percent electrification of vehicular travel are mixed but generally positive. If present schedules for automotive pollution control are met and utilities successfully restrict most recharging to offpeak hours, this level of electrification would, by the year 2010, lead to the following changes in emissions** compared with a future based on a conventional fossil fuel-powered transportation system:

- less than a l-percent increase in sulfur dioxides (SO_2),
- about a 2-percent decrease in NO_x,
- about a 2-percent decrease in HC,
- about a 6-percent decrease in CO, and
- little change in particulates.[40]

The positive effects on air quality may in reality be more important than these emission figures imply. The addition of emissions due to electricity production occurs outside of urban areas, and the pollution is widely dispersed, while the vehicle emissions that are eliminated occur at ground level and are quite likely to take place in dense urban areas. Thus, the reduction in vehicular emissions should have a considerably greater effect on human exposure to pollution than the small increase in generation-related emissions. Also, any relaxation of auto emissions standards will increase the emissions reductions and air quality benefits associated with "replacement" of the (more polluting) conventional autos. On the other hand, future improvements in automobile emission controls–certainly plausible given progress during the past decade–might decrease the air quality benefits of electrification. *

Other effects of increased electricity demand must also be considered. Most importantly, a 20-percent electrification of cars will lead to substantial increases in utility fuel use, especially for coal. Although the extent of increased coal use will depend on the distribution of EVs, if the vehicles were distributed uniformly according to population, coal would supply about two-thirds of the additional power necessary in 2010,41 requiring the mining of about 38 million additional tons per year. ** If the EVs replaced gasoline-powered cars getting 55 mpg, the gasoline savings obtained by the coal-fired electricity—about 36 billion gal/yr–could also have been obtained by turning the same amount of coal into synthetic gasoline.***

Resource Requirements

EVs will use many of the same materials, in similar quantities, as conventionally powered vehicles, but there will be some differences which may create environmental effects. EVs, for exam pie, will require more structural material than their conventional counterparts because of the substantial weight of the batteries (at least with existing technology). More importantly, the batteries themselves will require some materials in quantities that may strain present supply. Table 73 shows the increase in U.S. demand for battery materials for 20-percent electrification of light-duty vehicular travel by 2000.

The effect on the environment of increases in materials demand is difficult to project because the increased demand can be accommodated in a number of ways. In several cases, although U.S.

---

*As noted elsewhere, however, this is still an extremely optimistic market share even for the long term, unless battery costs are sharply reduced and longevity increased, or gasoline availability decreases.

**Assuming existing emission regulations for powerplants.

[40] W. M. Carriere, et al., The Future *Potential of Electric* and Hybrid *Vehicles,* contractor report by General Research Corp. to OTA, forthcoming.

"It is equally reasonable to speculate about future improvements in powerplant emission controls. For example, more stringent controls on new plants as well as efforts to decrease SO_2 emissions from existing plants in order to control acid rain damages could increase the benefits of electrification.

[41] Ibid.

**Assumptions: 12,000 Btu/lb coal; vehicle energy required = 0.4 kWh/mile at the outlet; total 2010 vehicle miles = 1.55 trillion miles, 20 percent electric; electrical distribution efficiency = 90 percent; generation efficiency = 34 percent.

***Assuming a synfuels conversion efficiency of coal into gasoline of 50 percent.

Table 73.—increase in U.S. Use of Key Materials for 20 Percent Electrification of Light-Duty Travel (year 2000)

Battery type	Material	Percent increase [a]
Lead-acid	Lead	31.2
Nickel-iron	Cobalt	18.2
	Lithium	14.3
	Nickel	21.3
Nickel-zinc	Cobalt	31.8
	Nickel	34.3
Zinc-chloride	Graphite	50.0
Lithium metal sulfide	Lithium	103.6

[a] Assuming 100 percent of the batteries are of the category shown ... the percent increases thus are *not* additive for the same materials.

SOURCE: W. M. Carrier, et al., *The Future* Potential of Electric and Hybrid Vehicles, contractor report to OTA by General Research Corp., forthcoming.

and world identified reserves currently are insufficient, increased demand probably will be met by identifying and exploiting new reserves. The environmental effects would then be those of expanding mining and processing in the United States or abroad. In other cases, mining of seabed mineral nodules or exploitation of lower quality or alternative ores (e.g., kaolin-type clays instead of bauxite to produce aluminum) could occur. Supplies of some materials may be made available for cars by substituting other materials for nonautomotive demands.

In general, the potential for finding additional resources and the long-range potential for recycling indicate that major strains on resources—and, consequently, environmental impacts of unusual concern—appear to be unlikely with levels of electrification around 20 or 30 percent. Local areas subject to substantially increased mining activity could, however, experience significant impacts.

Noise

EVs are generally expected to be quieter than combustion-engine vehicles, and electrification should lower urban noise. The effect may not, however, be large. Although automobiles account for more than 90 percent of all urban traffic, they contribute only a little more than half of total urban traffic noise and a lesser percentage of total urban noise. A recent calculation of the effect on noise levels of 100-percent conversion of the automobile fleet to electric vehicles predicts a reduction in total traffic noise of only 13 to 17 percent.[42]

Safety

EVs will affect automotive safety because of their lower performance capabilities and different structural and material configuration. Lower acceleration and cruising speed, for example, could pose a safety problem because it could increase the average velocity differential among highway vehicles and make merging more difficult. Many EVs will be quite small and, as discussed in the section on auto fuel conservation, this may degrade safety. On the other hand, compensating changes in driver behavior or redesign of roads in response to EVs could yield a net positive effect.

Similarly, the net effect of materials differences is uncertain. The strong positive effect of removing a gas tank containing highly flammable gasoline or diesel fuel will be somewhat offset by the addition of the battery packs, which contain acids, chlorine, and other potentially hazardous chemicals. Collisions involving EVs may result in the generation of toxic or explosive gases or the spillage of toxic liquids (e.g., release of nickel carbonyl from nickel-based batteries). Finally, the necessity to charge many of the vehicles in locations that are exposed to the weather creates a strong concern about consumer safety from electrical shock.

Occupational and Public Health Concerns

In addition to the potential danger to drivers (and bystanders) from release of battery chemicals after collisions, there are some concerns about the effects of routine manufacture, use, and disposal of the batteries. Manufacture of nickel-based batteries, for example, may pose problems for women workers because several nickel compounds that may be encountered in the manufacturing process are teratogens (producers of birth defects). Also, because many potential battery materials (lead, nickel, zinc, antimony) are per-

---

[42] W.M. Carriere, General Research Corp., personal communication, June 19, 1981.

sistent, cumulative environmental poisons, the prevention of significant discharges during manufacture as well as proper disposal (preferably by recycling) must be assured. Finally, routine venting of gases during normal vehicle operations may cause air-quality problems in congested areas.

These risks do not appear to pose difficult technological problems (most have been rated as "low risk" in the Department of Energy's (DOE) Environmental Readiness Document for EVs[43]) and existing regulations such as the Resource Conservation and Recovery Act provide an opportunity for strict controls, but institutional problems such as resistance to further Government controls on industry obviously could increase the level of risk. Recycling could pose a particular problem unless regulations or scale incentives restrict small-scale operations, which are often difficult to monitor and regulate.

---

[43] U.S. Department of Energy, *Environmental Readiness Document,* Electric and Hybrid Vehicles, Commercialization Phase III P/arming DOE/ERD-0004, September 1978.

SYNTHETIC FUELS FROM COAL

Development of a synthetic fuels industry will inevitably create the possibility of substantial effects on human health and the environment from a variety of causes. A 2 million barrels per day (MMB/D) coal-based synthetic liquid fuels industry will consume roughly 400 million tons of coal each year, * an amount equal to roughly half of the coal mined in the United States in 1980. The several dozen liquefaction plants required to produce this amount of fuel will operate like large chemical factories and refineries, handling multiple process and waste streams containing highly toxic materials and requiring major inputs of water and other valuable materials and labor. Transportation and distribution of the manufactured fuels not only require major new infrastructure but are complicated by possible new dangers in handling and using the fuels. Table 74 lists some of the major environmental concerns associated with coal-based synfuels. Note that the severity of these concerns is sharp/y dependent on the level of environmental control and management exerted by Government and industry.

The health and environmental effects of the synfuels fuel cycle can be better understood by dividing the impacts into two kinds. Some of the impacts are essentially identical in kind (though not in extent) to those associated with more conventional combustion-related fuel cycles such as coal-fired electric power generation. These "conventional" impacts include the mining impacts, most of the conversion plant construction impacts, the effects associated with population increases, the water consumption, and any impacts associated with the emissions of environmental residuals such as SO_2 and NO_x that are normally associated with conventional combustion of fossil fuels.

Another set of impacts more closely resembles some of the impacts of chemical plants and oil refineries. These include the effects of fugitive HC emissions and the large number of waste and process streams containing quantities of trace metals, dangerous aromatic HCs, and other toxic compounds. These are referred to as "nonconventional" impacts in this section.

This distinction between "conventional" and "nonconventional" impacts is continued throughout this discussion. In particular, for the conventional impacts, synfuels plants are explicitly compared with coal-fired powerplants. A further understanding of the scale of coal-fired powerplants should allow this comparison to better

---

*This corresponds to an average process efficiency of about 55 percent and coal heat content of about 20 x 10^6 Btu/ton. The actual tonnage depends on the energy content of the coals, the conversion processes used and the product mixes chosen. Process efficiencies will vary over a range of 45 to 65 percent (higher if large quantities of synthetic natural gas are acceptable in the product stream), and coal heat contents may vary from 12 million to 28 million Btu/ton.

Table 74.—Major Environmental Issues for Coal Synfuels

Land use and water quality	Air quality	Ecosystems	Safety and health	Other
Mining				
Short- and long-term land use changes, erosion, and uncertainty of reclamation in arid West Aquifer disturbance and pollution Nonpoint source water pollution (acid mine drainage—East; sedimentation—West) Subsidence	Fugitive dust (especially in the West)	Disruption of wildlife habitat and changed productivity of the land Siltation of streams Habitat fragmentation from primary and secondary population growth	Mining accidents Occupational diseases in underground mining (e.g., black lung)	Increased water use for reclamation Coal transportation impacts on road traffic and noise
Liquefaction and refining				
Potential surface and ground water pollution from holding ponds Wastewater discharges (East) Disposal of large amounts of solid wastes Local land use changes Construction on flood plains	Emission of "criteria pollutants" (i.e., NO_x, SO_2, particulate, etc. Fugitive emission of carcinogenic substances Possible release of trace elements Releases during "upset" conditions Possible localized odor problems	Air pollution damage to plants Contributions to acid rain Wildlife habitat fragmentation from population increases Contribution to the "greenhouse" effect	Occupational safety and health risks from accidents and toxic chemicals Carcinogens in direct process intermediates and fuel products	Water availability issues (especially in the West)
Product transport and end-use				
Product spills from trains, pipelines, and storage	Changed automotive exhaust emissions (increase in some pollutants, decrease in others) Increased evaporative emissions from methanol fuels Toxic product vaporization	Acute and chronic damages from spills	Exposure to spills Uncertain effects of trace elements and HCs	Potential change in fuel economy Methanol corrosion and reduction of existing engine longevity

SOURCE: M. A. Chartock, et al., Environmental Issues of Synthetic Transportation Fuels From Coal, OTA contractor report, forthcoming

serve the reader. A 1,000-MWe plant, for example, serves all the electrical needs (including requirements for industry) of about 400,000 people. A plant of this size would be large but not excessively so for a new facility, because many currently planned coal-fired plants are larger than 600 MWe, and the nationwide average capacity of planned units is 433 MWe.[44] Existing plants are, on the whole, much smaller than these new plants, with an average capacity of only 57 MWe.[45] Some existing plants, however, are very large: Arizona Public Service Co.'s Four Corners plant in New Mexico, for example, has a capacity of 2,212 MWe.[46]

This comparison is intended to place the environmental and health impacts of a synfuels plant side by side with the impacts of a technology that may be more familiar to readers. We stress, however, that this comparison is not relevant to a comparison of coal liquids and coal-based electricity as competing alternatives.

---

[44] R. W. Gilmer, et al., "Rethinking the Scale of Coal-Fired Electric Generation: Technological and Institutional Considerations," in Office of Technology Assessment, *The Direct Use of Coal, Volume II,* Part A, 1979.

[45] Ibid.

[46] Federal Energy Regulatory commission, *Steam-Electric Plant Air and Water Quality Control Data, Summary Report,* October 1979.

Such a comparison can be made only by carefully considering the end uses for the competing energy forms, which we have not done. For use in automobile travel, however, a synthetic fuel may prove to be as efficient in its utilization of coal energy as a powerplant producing electricity for EVs (see "Electric Vehicles, Power Generation" in this chapter), In this case, to the extent that a synfuels production facility produces fewer (or more) impacts than a powerplant processing the same amount of coal, the impact of the energy-production stage of the "synfuels to motor fuel" fuel cycle may be considered to be environmentally superior (or inferior) to the same stage of the "electric auto" fuel cycle.

It is also stressed that the "nonconventional" effects associated with the toxic waste streams produced by synfuels plants are essentially impossible to quantify at this time, because of significant uncertainties associated with the type and quantity of toxic chemicals produced, the rate at which these chemicals might escape, the effectiveness of control systems, the fate of any escaping chemicals in the environment, and finally, the health and ecological impacts of various exposures to the chemicals.

Because of these uncertainties, there may be a temptation to judge synfuels production mainly on the basis of its "conventional," and more quantifiable, impacts. In OTA's opinion, this is a mistake, because the toxic wastes pose difficult environmental questions and also because the magnitudes of several of the more conventional impacts are themselves quite uncertain.

Mining

A large coal-based synfuels industry will consume a significant portion of U.S. coal output. Although actual coal-production growth during the remainder of this century is uncertain, several sources agree that total production on the order of 2 billion tons per year is possible by 2000.[47] At this level a 2 MMB/D coal synfuels capacity would require roughly 20 percent of total U.S. production in 2000.

The impacts of a mine dedicated to synfuels production should be essentially the same as those from other large mines dedicated to power production and other uses, and thus these impacts fit into the "conventional" category. Although the coal requirement for a unit plant with a 50,000 barrel per day (bbl/d) output capacity—at least 5 million tons per year*—is high by today's standards, mines are already tending towards this size range where it is feasible (e.g., eight mines in the Powder River Basin produced more than 5 million tons of coal each in 198048). On the other hand, it is not clear that the geographic distribution (and thus the distribution of impacts) of synfuels coal production and production for other uses will be similar. Because it is difficult to predict where a future synfuels industry will be located, the nature of any differences between mining for synfuels and mining for other uses is uncertain.

As discussed in another OTA report,[49] although many of coal mining's adverse impacts have been mitigated under State and Federal laws, important environmental and health concerns remain. The major concerns are likely to be /and reclamation failure, acid mine drainage, subsidence of the land above underground mines, aquifer disruption, and occupational disease and injury. Mining for synfuels conversion will experience all of these impacts, although not at all sites.

The following discussion of mining impacts relies primarily on the OTA report:

Reclamation.– The use of new mining methods that integrate reclamation into the mining process and enforcement of the Surface Mine Control and Reclamation Act (SMCRA) should reduce the importance of reclamation as a critical national issue. However, concern remains that a combination of development pressures and inadequate knowledge may lead to damage in particularly

---

[47] *The Direct Use of Coal:* Prospects and Problems of Production and Combustion, OTA-E-86 (Washington, D. C.: U.S. Congress, Office of Technology Assessment, April 1979). Also available from Ballinger Publishers in a March 1981 edition.

*The potential range is about 5 million to 18 million tons per year. The 5-million-ton extreme represents a 65-percent efficient process (not truly a lique faction process because half of its output is syngas; the upper limit of efficiency for processes producing primarily liquids is about 60 percent) using very-high-value (28 million Btu/ton) Appalachian coal. The 18-million-ton extreme represents a 45-percent efficient process using low-energy (12 million Btu/ton) lignite.

[48] *An Assessment* of the Development Potential and Production Prospects of *Federal Coal* Leases, OTA-M-150 (Washington, D. C.: U.S. Congress, Office of Technology Assessment, December 1981).

@The *Direct Use* of *Coal,* op. cit.

D g g m w m m g

vulnerable areas—arid lands and alluvial valley floors in the West, prime farmland in the Midwest, and hardwood forests, steep slope areas, and flood-prone basins in Appalachia. Although most of these areas are afforded special protection under SMCRA, the extent of any damage will depend on the adequacy of the regulations and the stringency of their enforcement. Recent attempts in the Congress to change SMCRA and administration actions to reduce the Office of Surface Mining's field staff and to transfer enforcement responsibilities to State agencies have raised concerns about the future effectiveness of this legislation.

Acid Mine Drainage.Acid mine drainage, if not controlled, is a particularly severe byproduct of mining in those regions—Appalachia and parts of the interior mining region (indiana, Illinois, Western Kentucky) —where the coal seams are rich in pyrite. The acid, and heavy metals leached into the drainage water by the acid, are directly toxic to aquatic life and can render water unfit for domestic and industrial use. Zinc, nickel, and other metals found in the drainage can become concentrated in the food chain and cause chronic damage to higher animals. An additional impact in severe cases is the smothering of stream bottom-dwelling organisms by precipitated iron salts.

Acid drainage is likely to be a significant problem only with underground mines, and only after these mines cease operating. Assuming strong enforcement of SMCRA, acid drainage from active surface and underground mines should be collected and neutralized with few problems. only a very small percentage of inactive surface mines may suffer from acid seepage. Underground mines, however, are extremely difficult to seal off from air and water, the causal agents of acid drainage. Some mining situations do not allow adequate permanent control once active mining and water treatment cease. A significant percentage of the mines that are active at present or that will be opened in this century will present acid drainage problems on closure.

In a balancing of costs and benefits, it may not be appropriate to assign to synfuels development the full acid damage associated with synfuels mines, even though these mines will have acid drainage problems. This is because drainage problems may taper off as shallower reserves are exhausted and new mines begin to exploit coal seams that are deeper than the water table. Many of these later mines will be flooded, reducing the oxidation that creates the acid drainage. It is possible that many or most acid drainage-prone mines dedicated to a synfuels plant would have been exploited with or without synfuels development.

Subsidence.–Another impact of underground mining that will not be fully controlled is subsidence of the land above the mine workings. Subsidence can severely damage roads, water and gas lines, and buildings; change natural drainage patterns and river flows; and disrupt aquifers. Unfortunately, there are no credible estimates of potential subsidence damage from future underground mining. However, a 2 MMB/D industry could undermine about a hundred square miles of land area (about one-tenth the area of Rhode Island) each year, * most of which would be a potential victim of eventual subsidence.

Subsidence, like acid drainage, is a long-term problem. However, SMCRA does not hold developers responsible for sufficient time periods to ensure elimination of the problem, nor does it specifically hold the developer responsible to the surface owner for subsidence damage. The major "control" for subsidence is to leave a large part of the coal resources—up to 50 percent or more—in place to act as a roof support. There is obviously a conflict between subsidence prevention and removal of the maximum amount of coal. Moreover, the supports can erode and the roof collapse over a long period of time. The resulting intermittent subsidence can destroy the value of the land for development. An alternative mining technique called longwall mining deals with some of these problems by actually promoting subsidence, but in a swifter and more uniform fashion. Longwall mining is widely practiced in Europe but is in limited use in the United States. It is not suitable for all situations.

Aquifer Disruption.–Although all types of mining have the potential to severely affect ground water quantity and quality by physical disruption of aquifers and by leaching or seepage into them, this problem is imperfectly understood. The shift of production to the West, where ground water is a particularly critical resource, will focus increased attention on this impact. As with other sensitive areas, SMCRA affords special protection to ground water resources, but the adequacy of this protection is uncertain because of difficulties in monitoring damages and enforcing regulations and by gaps in the knowledge of aquifer/mining interactions,

Occupational Hazards.–Occupational hazards associated with mining are a very visible concern of synfuels production, because coal workers are likely to continue to suffer from occupational disease, injury, and death at a rate well above other occupations (see table 75), and the total magnitude of these impacts will grow along with the growth in coal production.

The mineworker health issue that has received the most attention is black lung disease, the non-

Table 75.—Fatality and Injury Occurrence for Selected Industries, 1979

	Fatalities		Nonfatal injuries	
	Number	Rate[a]	Number	Rate[a]
Underground bituminous.	105	0.09	14,131	12.30
Surface bituminous .	15	0.02	2,333	3.47
All bituminous coal[c] (and lignite)	137	0.064	16,464	10,20
Other surface mining[b] (metal, nonmetal, stone, etc.).	97	0.07	8,121	5.82
Petroleum refining[c]. .	20	0.0011	8,799	5.30
Chemical and allied products[c].	55	0.0025	78,700	7.20
All industries	4,950	0.0086	5,956,000	9.20

[a] Rate per 200,000 worker-hours (100 worker-years).

[b] For all companies.

[c] For companies with 11 or more workers; fatality data Include deaths due to job-related accident and Illness.

SOURCE: Bureau of Labor Statistics, personal communication, 1981; and Staff, Mine Safety end Health Administration, personal communication, 1981.

---

*Assuming half of the coal is produced by eastern and central underground mining, 18,000 acres undermined per 10^{15} Btu of coal.

clinical name for a variety of respiratory illnesses affecting underground miners of which coal workers' pneumoconiosis (CWP) is the most prominent. Ten percent or more of working coal miners today show X-ray evidence of CWP, and perhaps twice that number show other black lung illnesses—including bronchitis, emphysema, and other impairments.[50]

To prevent CWP from disabling miners in the future, Congress mandated a 2-mg/m^3 standard for respirable dust (the small particles that cause pneumoconiosis). However, critics now question the inherent safeness of this standard and the soundness of the research on which it is based. Furthermore, other coal mine dust constituents—the large dust particles (that affect the upper respiratory tract) and trace elements–as well as fumes from diesel equipment also represent continued potential hazards to miners.

Mine safety–as distinct from mine health–has shown a mixed record of improvement since the 1969 Federal Coal Mine Health and Safety Act establishing the Mining Enforcement and Safety Administration was passed. The frequency of mining fatalities has decreased for both surface and underground mines, but no consistent improvement has been seen in the frequency of disabling injuries, Coal worker fatalities numbered 139 in 1977, and disabling injuries approached 15,000.[51] Each disabling injury resulted in an average of 2 months or more of lost time. The number of disabling injuries has been increasing as more workers are drawn to mining and accident frequency remains constant.

As shown in table 75, surface mining is several times safer than underground mining. But some underground mines show safety records equal to or better than some surface mines. Generally, western surface mines are safer than eastern surface mines. As western surface-mine production assumes increasing prominence, accident frequency industrywide is likely to decline when expressed as accidents per ton of output. But this statistical trend may conceal a lack of improvement in safety in deep mines.

Liquefaction

Coal liquefaction plants transform a solid fuel, high in polluting compounds and mineral matter, into liquid fuels containing low levels of sulfur, nitrogen, trace elements, and other pollutants. In these processes, large volumes of gaseous, liquid, and solid process streams must be continuously and reliably handled and separated into end-products and waste streams. Simultaneously, large quantities of fuel must be burned to provide necessary heat and steam to the process, and large amounts of water are consumed for cooling and, in direct liquefaction processes, as raw material for hydrogen production. These processes, coupled with the general physical presence of the plants and their use of a large construction (up to 7,000 men at the peak for a single 50,000 bbl/d plant) and operating force (up to 1,000 workers per plant), lead to a variety of potential pathways for environmental damage.

As noted previously, the following discussion divides impacts into "conventional" and "nonconventional" according to the extent to which the effects resemble those of conventional combustion systems. The discussion does not consider the various waste streams in detail because of their complexity. Appendix 10-A lists the gaseous, liquid, and solid waste streams, the residuals of concern, and the proposed control systems for generic indirect and direct liquefaction systems. DOE's Energy Technologies and the Environment handbook,[52] from which appendix 1O-A is derived, describes these streams in more detail.

Conventional Impacts

An examination of the expected "conventional" impacts reveals that, with a few exceptions, they are significant mainly because the individual plants are very large and national synfuels development conceivably could grow very rapidly—

---

[50] National Institute for Occupational Safety and Health, *National Study* of *Coal* Workers' *Pneumoconiosis,* unpublished reports on second round of examinations, 1975. Cited in *The* Direct Use of *Coal,* op. cit.

[51] Mine Safety and Health Administration, "1 njury Experience at All coal Mines in the United States, by General Work Location, 1977, " 1978. Cited in The Direct Use of *Coal,* op. cit.

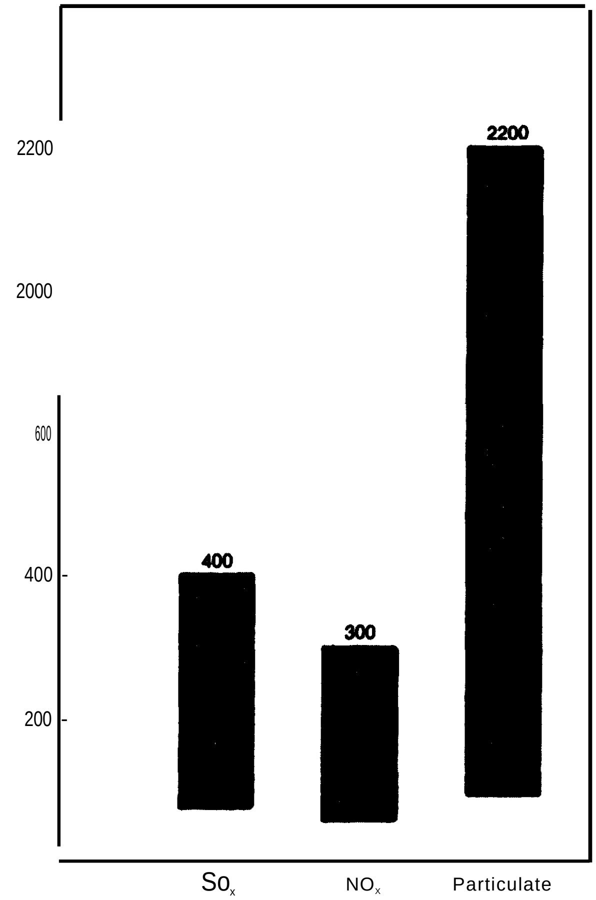
[52] U.S. Department of Energy, Energy Technologies and *the* Environment, *Environmental* Information *Handbook,* DOE/EV/74010-1, December 1980.

not because the impacts per unit of production are particularly large.

Air Quality.– Emissions of criteria air pollutants* from synfuels generally are expected to be lower than similar emissions from a new coal-fired powerplant processing the same amount of coal.[53] A 50,000 bbl/d synfuels plant processes about as much coal as a 3,000 MWe powerplant,** but (as shown in fig. 23) emits SO_2 and NO_x in quantities similar to those of a plant of only a few hundred megawatts or less. For particulate, synfuels plant emissions may range as high as those from a 2,200-MWe plant, but emissions for most synfuels plants should be much lower.

In any case, particulate standards for new plants are quite stringent, so even a 2,200-MWe plant (or a "worst case" synfuels plant) will not have high particulate emissions. CO emissions from synfuels plants are expected to be extremely low, and are likely to be overwhelmed by a variety of other sources such as urban concentrations of automobiles. HC emissions, on the other hand, conceivably could create a problem if fugitive emissions—from valves, gaskets, and sources other than smokestacks—are not carefully controlled. Although the level of fugitive HC emissions is highly uncertain, emissions from a 50,000 bbl/d SRC II plant could be as high as 14 tons/day–equivalent to the emissions from several large coal-fired plants–if the plant's valves and other equipment leaked at the same rate as equipment in existing refineries.[54]

Figure 23.-Size Ranges of New Coal-Fired Powerplants With Hourly Emissions Equal to 50,000 bbl/day Synfuels Plants



SOURCE: M. A. **Chartock,** et al., "Environment Issues of Synthetic **Tranportation** Fuels From Coal," contractor report to OTA, table **revised** by OTA.

The broad emission ranges shown in figure 23 reflect very substantial differences in emission projections from developers of the various processes. OTA's examination of the basis for these projections leads us to believe that the differences are due less to any inherent differences among the technologies and more to differences in developer control decisions, assumptions about the effectiveness of controls, and coal characteristics. The current absence of definitive environmental standards for synfuels plants will tend to aggravate these differences in emission projections, because developers have no emissions targets or approved control devices to aim at. EPA has been working on a series of Pollution Control Guidance Documents (PCGDs) for the several synfuels technologies in order to alleviate this problem. The proposed PCGDs will describe the control systems available for each waste stream and the level

---

*"Criteria air pollutants" are pollutants that are explicitly regulated by National Ambient Air Quality Standards under the Clean Air Act. Currently, there are seven criteria pollutants: SO_2, CO, NO_x, photochemical oxidants measured as ozone (O_3), nonmethane HC, and lead.

[53] M. A. Chartock, et al., *Environment/ /sSues of Synthetic Transportation Fuels From Coal,* Background Report, University of Oklahoma Science and Public Policy Program, report to OTA, forthcoming.

**The actual range is about 2,500 to 3,600 MW for synfuels process efficiencies of 45 to 65 percent, powerplant efficiency of 35 percent, synfuels load factor of 0.9, powerplant load factor of 0.7.

[54] Oak Estimate of Fugitive *Hydrocarbon Emissions for SRC II Demonstration P/ant*, for U.S. Department of Energy, September 1980. Based on "unmitigated" fugitive emissions.

of control judged to be attainable. However, the PCGDs became embroiled in internal and interagency arguments and apparently may not be completed and published in the foreseeable future.

The air quality effects of synfuels plants on their surrounding terrain vary because of differences in local conditions—terrain and meteorology—as well as the considerable range of possible emission rates. Some tentative generalizations can, however, be drawn from the variety of site-specific analyses available in the literature. One important conclusion from these analyses is that individual plants generally should be able to meet prevention of significant deterioration (PSD) Class II limits* for particulate and SO_2 with planned emission controls, although in some cases (e.g., the SRC II commercial-scale facility once planned for West Virginia) a major portion of the limit could be used up.[55] In addition, NO_x and CO emissions are unlikely to be a problem for individual plants in most areas, while regulated HC emissions should remain within ambient air quality guidelines if fugitive HC emissions are minimized.[56]

Restrictions will exist, however, near PSD Class I areas in the Rocky Mountain States and nonattainment areas in the eastern and interior coal regions. Several of the major coal-producing areas of Kentucky and Tennessee are currently in nonattainment status, and siting of synfuels plants in those areas is virtually impossible without changes in current regulations or future air quality improvement.[57] Finally, failure to control fugitive HC emissions conceivably could lead to violations of the Federal shot-t-term ambient standards near the plant because, as noted above, the potential emission rate is quite high and because the emissions are released near ground level and will have a disproportionately large effect on local air quality .58

Some potential restrictions on siting maybe obscured in current analyses by the failure to consider the short-term air quality effects of upsets in the conversion processes. For example, under extreme upset conditions, the proposed (but now canceled) Morgantown SRC II plant would have emitted as much $S0_2$ in 2 hours as it would have emitted during 4 to 10 days of normal operation.[59] Unfortunately, most environmental analyses of synfuels development have tacitly assumed that control devices always work properly and plant operating conditions always are normal. These assumptions may be inappropriate, especially for the first generation of plants and particularly for the first few years of operating experience.

On a wider geographic scale, most analyses show that the emissions impact of a synfuels industry will be moderate compared with total emissions from all sources. For example, DOE has estimated 1995 emissions from all major sources for particulate, SO_2, and NO_x. Its calculations show that a 1.3 MM B/D synfuels industry (combining gasification, liquefaction, and oil shale) would represent less than 1 percent of national emissions for all three pollutants.[60] A more intensive development—a 1 MM B/D liquefaction industry concentrated in Wyoming, Montana, and North Dakota—would represent a 7.7 percent (particulate), 9.8 percent (SO_2), 32 percent (No_x), and 1,7 percent (HC) increase over 1975 emissions in a region where existing development—and thus the existing level of emissions—is quite low.[61] These additional emissions are not insignificant, and there has been speculation that high levels of development could cause some acid rain problems in the West, especially from

---

*PSD regulations limit the increases in pollution concentrations allowed in areas whose air quality exceeds national ambient standards. Class I areas, generally national parks and other areas where pristine air quality is valued very highly, are allowed only minimal increases. Class III areas are areas designated for industrial development and allowed substantial increases. Most parts of the country presently are designated Class II areas and allowed moderate increases in concentrations. PSD limits are under intense scrutiny by Congress and appear to be primary candidates for change under the Clean Air Act reauthorization.

[55] Chartock, et al., op. cit.

[56] Ibid.

[57] Ibid.

[58] I. L. White, et al., Energy From the West, Impact Analysis *Report Volume I*, /introduction *and* Summary, U.S. Environmental Protection Agency report EPA-600/7-79-082a, March 1979.

[59] U.S. Department of Energy, *Draft* Appendix C *of Final Environmental* Impact Statement: *SRC-II* Demonstration Plant, Plant Design and Characterization of Effluents, 1980.

[60] U.S. Department of Energy, Synthetic Fuels and the *Environment,* An *Environmental and* Regulatory Impacts Analysis, DOE/EV-0087, June 1980.

[61] Chartock, et al., op. Cit.

NO_x. * Nevertheless, if control systems work as planned and facility siting is done intelligently, coal-based synfuels plants do not appear to represent a severe threat to air quality.

Water Use. -Water consumption has also been singled out as a significant impact of a large-scale synfuels industry, especially in the arid West. Synfuels plants are, however, less intensive consumers of water than powerplants consuming similar amounts of coal. A 3,000-MWe plant—which processes about as much coal annually as a 50,000 bbl/d facility–will consume about 25,000 acre-feet of water per year (AFY), whereas the synfuels facility is unlikely to consume more than 10,000 AFY and may consume considerably less than this if designed with water conservation in mind. According to current industry estimates, a standard 50,000 bbl/d facility will consume about as much water as a 640 to 1,300-MWe plant. Using stricter water conservation designs, the facility may consume as much water as a 400- to 700-MWe plant.[62] Achieving an annual synfuels production of 2 MMB/D might require 0.3 million AFY, or only about 0.2 percent of the projected national freshwater consumptive use of 151 million AFY in 2000.[63]

Environmental impacts associated with synfuels water requirements are caused by the water consumption itself and by the wells, pipelines, dams, and other facilities required to divert, store, and transport the necessary water.

The impacts associated with consumption depend on whether that consumption displaces other offstream uses for the water (e.g., the developer may buy a farmer's water rights) or is additive to existing uses. In the former case, the impact is caused by eliminating the offstream use; in displacing farming, for example, the impact may be a reduction in soil salinization that was being caused by irrigation as well as a reduction in water contamination caused by runoff of fertilizers and pesticides. Any calculation of impacts is complicated, however, by the probability that large reductions in economic activities (such as farming) in one area will result in compensating increases elsewhere as the market reacts to decreases in production.

if the water consumption is additive to existing uses, it will reduce downstream flows. In surface streams or tributary ground waters connected to these streams, the consumption may have adverse effects on the ability of the stream to dilute wastes and to support recreation, fishing, and other instream uses downstream of the withdrawal. Also, consumption of ground water, if excessive, may lead to land subsidence and saltwater intrusion into aquifers.

The impacts associated with wells, dams, and other infrastructure may also be significant. improperly drilled wells, for example, can lead to contamination of drinking water aquifers. Dams and other storage facilities will increase evaporative and other losses (e.g., Lake Powell is underlaid with porous rock and "loses" large amounts of water to deep aquifers). In many cases, the lands submerged by reservoirs have been valuable recreational or scenic areas. In addition, in some circumstances dams can have substantial impacts, including drastic changes in the nature of the stream, destruction of fish species, etc. On the other hand, the ability of dams to regulate downstream flow may help avoid both flooding and extreme low-flow conditions and thus improve instream uses such as recreation and fishing.

Although consumptive water use by synfuels will be small on a national basis, local and even regional effects may be significant. Prediction of these effects is made difficult, however, by a number of factors, including substantial uncertainties in water availability assessments, levels of disaggregation in many assessments that are insufficient to allow a prediction of local and subregional effects, and the variety of alternative supply options available to developers. Water availability

---

*Current understanding of the transformation of NO_x emissions into nitrates and into acid rain is not sufficient to allow a firm judgment to be made about the likelihood of encountering an acid rain problem under these conditions.

[62] H. Gold, et al., *Water Requirements for Steam-Electric Power Generation and Synthetic Fuel Plants in the Western United States*, U.S. Environmental Protection Agency report EPA-600/7-77-037, April 1977. Assumes powerplant load factor of 70 percent, synfuels load factor 90 percent. Synthoil is used as a baseline liquid fuels plant.

[63] U.S. Water Resources Council, *Second National Water Assessment, The Nation's Water Resources 1975-2000, Volume II*, December 1978.

considerations for the five major river basins where synfuels development is most likely to occur are discussed in chapter 11.

Work Force and Population Impacts.-The size of the synfuels work force will be large compared with power generation; for a 50,000 bbl/d plant, it is equivalent to the work force that would be needed for powerplants totaling 4,000 to 8,000 Mw (during peak construction) and to plants totaling at least 2,500 MW (during operation)[64] (see ch. 8 for detailed discussion). These high work force values are particularly important for western locations, because significant population increases caused by energy development place considerable stress on semiarid ecosystems through hunting and recreational pressures, inadequate municipal wastewater treatment systems, and limited land use planning.

Summary of Conventional Impact Parameters. –Table 76 provides a capsule comparison of the conventional environmental impacts of synfuels plants and coal-fired plants.

Nonconventional Impacts

The remaining, "nonconventional" impacts of synthetic fuel plants represent substantially different environmental and health risks than do coal-fired plants and other combustion facilities. The conversion of coal to liquid fuels differs from coal combustion in several environmentally important ways. Most importantly, the chemistries of the two processes are considerably different. Liquefaction is accomplished in a reducing (oxygen poor) environment, whereas combustion occurs in an oxidizing environment. Furthermore, the liquefaction reactions generally occur at lower temperatures and usually higher pressures than conventional combustion.

One major result of these chemical and physical differences is that the heavier HCs originally

Table 76.—Two Comparisons of the Environmental Impacts of Coal-Based Synfuels Production and Coal-Fired Electric Generation [e]

Type of impact	A. Coal-fired generating capacity that would produce the same impact as a 50,000 bbl/d coal-based synfuels plant, MWe	B. Side-by-side Comparison of environmental impact parameters		
		3,000 MWe generator	50,000 bbl/d synfuels	Units
Annual coal use	2,500-3,600 [b]	6.4-15.0	5.3-17.9	million tons/yr
Annual solid waste	(2,500-3,600)± [c]	0.9-2.0+	0.6-1 .8+	million tons/yr
Annual water use:				acre feet/yr
Current industry estimates	640-1,300	25,000	5,400-10,800	
Conservation case	400-700		3,400-5,900	
Annual emissions:				tons/yr
Particulate	120-2,800	2,700	100-2,500	
Sulfur oxides	90-500	27,000-108,000	1,600-9,900	
Nitrogen oxides	70-400	63,000	1,600-7,800	
Hourly emissions:				lb/hr
Particulate	90-2,200	880	30-800	
Sulfur oxides	70-40	8,800-35,200	500-3,200	
Nitrogen oxides	60-300	20,500	500-2,500	
Peak labor	4,100-8,000	2,550	3,500-6,800	persons
Operating labor	2,500	440	360	persons

[a] In example A, the powerplant uses the same coal as the synfuels plant, New Source Performance Standards (NSPS) apply, SO_x emissions assumed to be 0.6 $lb/10^9$ Btu. In B, NSPS also apply but SO_x emissions can range from 0.3 to 1.2 $lb/10^6$ Btu. In both cases, the synfuels plant Parameters rePresent a range of technologies, with a capacity factor of 90 percent and an efficiency range of 45 to 65 percent; the powerplant is a baseload plant, with a capacity factor of 70 percent, efficiency of 35 percent.

[b] In other words, the amount of coal—and thus the amount of mining—needed to fuel a 50,000 bbl/d synfuels plant is the same as that required for a 2,500 to 3,600 MWe powerplant.

[c] A synfuels plant will have about as much ash to dispose of as a coal-fired powerplant using the same amount of coal. It may have less scrubber sludge, but it may have to dispose of spent catalyst material that has no analog in the powerplant . . . thus the ±.

SOURCE: M. A. Chartock, et al., *Environmental Issues* of Synthetic Transportation *Fuels* From *Coal,* Background Report, University of Oklahoma Science and Public Policy Program, contractor report to OTA, July 1981,

---

[64] I. L. White, et al., *Energy From the* West, *Energy Resource Development* Systems *Report, Volume II: Coal,* U.S. EPA report EPA-600/7-79 -060b, March 1979. Used for powerplant work force only (for a 3,000-MWe plant, construction peak is 2,545, operating force is 436),

in the coal or formed during the reactions are not broken down as effectively in the liquefaction process as in combustion processes, and thus they appear in the process and waste streams. The direct processes (see ch. 6 for a brief description of the various coal liquefaction processes) and those indirect processes using the lower temperature Lurgi gasifier are the major producers of these HCs; indirect processes using high-temperature gasifiers (e.g., Koppers-Totzek, Shell, Texaco) are relatively free of them.

The liquefaction conditions also favor the formation of metal carbonyls and hydrogen cyanide, which are hazardous and difficult to remove. Trace elements are less likely to totally volatilize and may be more likely to combine with or dissolve in the ash. The solids formed under these conditions will have different mineralogical and chemical form than coal combustion ash, and the volubility of the trace elements, which generally is low in combustion ash, is likely to be different. Consequently, solid waste disposal is complicated by the possibility that the wastes may be more hazardous than those associated with conventional combustion.

Finally, the high pressure of the processes, their multiplicity of valves and other vulnerable components, and, for the direct processes, their need to handle liquid streams containing large amounts of abrasive solids all increase the risk of accidents and fugitive emissions.

The major concerns from the "nonconventional" waste streams are occupational hazards from leaks of toxic materials, accidents, and handling of process intermediates, and ground and surface water contamination (and subsequent health and ecological damage) from inadequate solid waste disposal, effluent discharges, and leaks and spills.

Occupational Hazards.–Coal synthetic fuel plants pose a range of occupational hazards from both normal operations and upset conditions. Aside from risks associated with most heavy industry, including exposure to noise, dusts, and heat, and falls from elevated areas, synfuels workers will be exposed to gaseous and liquid fugitive emissions of carcinogenic and other toxic materials. During upset conditions, contact with hot gas and liquid streams and exposure to fire and explosion is possible. Table 77 lists some of the potential exposures from coal gasification plants documented by the National Institute for Occupational Safety and Health. Table 78 lists the potential occupational health effects associated with the constituents of indirect liquefaction process streams. Similar exposure and health-effect potentials would exist for any coal liquefaction process.

Although the precise design and operation of the individual plant is a critical factor in determining occupational hazards, there are certain generic differences in direct and indirect technologies that appear to give indirect technologies some advantages in controlling health and safety risks.

The advantages of indirect technologies include the need to separate only gases and liquids (the solids are eliminated in the very first gasification step) in contrast with the gas/liquid/solid phase separation requirements of direct processes; fewer sites for fugitive emissions than the direct processes; lower processing requirements for the process liquids produced (direct process liquids require additional hydrogenation); the abrasive

Table 77.—Potential Occupational Exposures in Coal Gasification

Coal handling, feeding, and preparation.—Coal dust, noise, gaseous toxicants, asphyxia, and fire
Gasifier/reactor operation. —Coal dust, high-pressure hot gas, high-pressure oxygen, high-pressure steam and liquids, fire, and noise
Ash removal, —Heat stress, high-pressure steam, hot ash, and dust
Catalytic conversion. —High-pressure hot gases and liquids, fire, catalyst, and heat stress
Gas/liquids cooling. —High-pressure hot raw gas and liquid hot tar, hot tar oil, hot gas-liquor, fire, heat stress, and noise
Gas purification. —Sulfur-containing gases, methanol, naphtha, cryogenic temperature, high-pressure steam, and noise
Methanol formation.—Catalyst dust, fire, and noise
Sulfur removal — Hydrogen sulfide, molten sulfur, and sulfur oxides
Gas-liquor separation. —Tar oil, tar, gas-liquor with high concentrations of phenols, ammonia, hydrogen cyanide, hydrogen sulfide, carbon dioxide, trace elements, and noise
Phenol and ammonia recovery. -Phenols, ammonia, acid gases, ammonia recovery solvent, and fire
Byproduct storage. —Tar, oils, phenols, ammonia, methanol, phenol recovery solvent and fire

SOURCE: Adapted from U.S. Department of Health, Education and Welfare, "Criteria for a Recommended Standard . . . Occupational Exposures In Coal Gasification Plants" (Cincinnati: National Institute of Occupational Safety and Health, Center for Disease Control, 19S43).

Table 78.—Occupational Health Effects of Constituents of Indirect Liquefaction Process Streams

Constituents	Toxic effects	Stream or area
Inorganic		
Ammonia	Acute: respiratory edema, asphyxia, death Chronic: no evidence of harm from chronic subirritant levels	Gas liquor
Carbon disulfide	Acute: nausea, vomiting, convulsions Chronic: psychological disturbances, mania with hallucinations	Concentrated acid gas
Carbon monoxide	Acute: headache, dizziness, weakness, vomiting, collapse, death Chronic: low-level chronic effects not established	Coal-lockhopper vent gas Raw gas from gasifier
Carbonyl sulfide	Little data on human toxicity	Concentrated acid gas
Hydrogen sulfide	Acute: collapse, coma, and death may occur within a few seconds. Insidious, may not be detected by smell Chronic: possible cocarcinogen	Coal-lockhopper vent gas Raw gas from gasifier Concentrated acid gas Catalyst regeneration off-gas
Hydrogen cyanide	Acute: headache, vertigo, nausea, paralysis, coma, convulsions, death Chronic: fatigue, weakness	Concentrated acid gas Coal-lockhopper vent gas
Mineral dust and ash	Chronic: possible vehicle for polycyclic aromatic hydrocarbons and cocarcinogens	Ash or slag
Nickel carbonyl	Acute: highly toxic, irritation, lung edema Chronic: carcinogen to lungs and sinuses	Catalyst regeneration off-gas
Trace elements: arsenic, beryllium, cadmium, lead, manganese, mercury, selenium, vanadium	(Complex)	Bottom ash Fly ash Gasifier ash Solid waste disposal
Sulfur oxides	Acute: intense irritation of respiratory tract Chronic: possible cocarcinogen	Combustion flue gases
Organic		
Aliphatic hydrocarbons	Most not toxic. N-Dodecane potentates skin tumors	Evaporative emissions from product storage
Aromatic amines	Acute: cyanosis, methemoglobinemia, vertigo, headache, confusion Chronic: anemia, skin lesions (aniline) Benzidine and beta-naphthylamine are powerful carcinogens	Coal-lockhopper vent gas Gas liquor
Single-ring aromatics	Acute: irritation, vomiting, convulsions Chronic: bone-marrow depression, aplasia	Coal-lockhopper vent gas Gas liquor
Aromatic nitrogen heterocyclics	Acute: skin and lung irritants Chronic: possible cocarcinogens	Gas liquor Coal-lockhopper vent gas
Phenols	Chronic: possible carcinogens, skin and lungs	Gas liquor
Polycyclic aromatic hydrocarbons (PAH)	Chronic: skin carcinogens, possible respiratory carcinogens	Gas liquor Coal-lockhopper vent gas Raw gas

SOURCE: US. Department of Energy, Energy Technologies and the Environment. Environmental Information Handbook DOE/EV/74O1O-1, December 1980.

nature of the direct process stream (which contains entrained solids); and fewer dangerous aromatic compounds, including polynuclear aromatics and aromatic amines, than in direct process streams. Lurgi gasifiers, however, produce a wider range of organic compounds than the higher temperature gasifiers and as a result are more comparable in health risk to direct processes.

In sum, however, the indirect processes appear to have a lower potential for occupational health and safety problems than the direct processes. In actual practice other factors—such as differences in the selection of control equipment and in plant design, maintenance procedures, and worker training—conceivably could outweigh these differences. In fact, developers of liquefaction processes appear to be aware of the potential hazards and are taking preventive action such as providing special clothing and providing frequent medical checkups. Nevertheless, the occupational health risk associated with synthetic fuel plants must be considered a major concern.

Ground and Surface Water Contamination.– A portion of the solid waste produced by liquefaction plants is ash-bottoms, fly ash, and scrubber sludge from the coal-fired boilers—materials that are routinely handled in all coal-fired powerplants today. Much of the waste, however, is ash or slag from the gasifiers producing synthesis gas or hydrogen and chars or "bottoms" from the direct processes (although much of the latter material is expected to be recycled to the gasifies), As noted previously, this material is produced in a reducing atmosphere and thus contains organic compounds as well as trace elements whose solubility may be different from that produced in the boiler.

Other solid wastes that may create disposal problems more severe than those of powerplant waste include spent catalysts and sludges from water treatment. Total solid wastes from a 50,000 bbl/d plant range from 1,800 to 5,000 or more tons per day.[65] At these rates, a 2 MM B/D industry would have to dispose of between 26 million and 72 million tons of wastes per year. The major concern from these materials is that water percolating through landfill disposal areas may leach the toxic organic compounds and trace elements out of the wastes and into the ground water. Currently, the extent of this risk is uncertain, although tests of EDS[66] and SRC-II[67] liquefaction reactor wastes and gasifier ash from several gasifiersba yielded leachates that would not have been rated as "hazardous" under Resources Conservation and Recovery Act criteria. *

One major problem with permanent landfill disposal, however, is that damage to ground water may occur at any future time when the landfill liner may be breached–many of the toxic materials in the wastes are either not degradable or will degrade very slowly, and may last longer than the design life of the liner.

Liquid effluent streams from liquefaction plants also pose potential water pollution problems. Although there are a number of wastewater sources that are essentially conventional in character—cooling tower and boiler blowdown, coal storage pile runoff, etc.—the major effluent streams, from the scrubbing of the gases from the gasifiers and from the water separation streams in the direct processes, contain a variety of organics and trace metals that will pose difficult removal problems. The direct processes are expected to have the dirtiest effluent streams, the indirect systems based on Lurgi gasifiers will also pose some problems because of their high production of organics, and the systems based on high-temperature gasifiers should have only moderate treatment requirements.[69]

Although total recycle of water is theoretically possible, in practice this is unlikely and "zero discharge" will only be achieved by using evaporation ponds. Aside from the obvious danger of breakdown of the pond liner and subsequent ground water contamination (or overflows from flooding), evaporation ponds may pose environmental problems through the formation of toxic gases or evaporation of volatile liquids. The complex mixture of active compounds in such a pond creates a particular hazard of unforeseen reactions occurring.

---

[65] Chartock, et al., op. Cit.

[66] R. C. Green, "Environmental Controls for the Exxon Donor Solvent Liquefaction Process, " Second DOE Environmental Control Symposium, Reston, Va., Mar. 19, 1981.

[67] Supra 59.

[68] *Inside* EPA, Sept. 26, 1980. As reported, researchers from TRW and Radian Corps. have tested ash from Lurgi, Wellman-Galusha, and Texaco gasifiers.

*Wastes are rated as "hazardous" and will require more secure (and more expensive) disposal if concentrations of pollutants in the leachates are greater than 100 times the drinking water standard.

[69] H. Gold, et al., "Fuel Conversion and Its Environmental Effects," Chemical Engineering Progress, August 1979.

Although the use of ponds to achieve zero discharge is practical in the West because of the low rainfall and rapid evaporation rates, zero discharge may be impractical at eastern sites without artificial evaporation, which is expensive and energy-intensive. Consequently, it appears probable that continuous or intermittent effluent discharges will occur at eastern plants, with added risks from control system failures as one result.

Environmental Management

The likelihood of these very serious potential environmental and health risks turning into actual impacts depends on a variety of factors, and particularly on the effectiveness and reliability of the proposed environmental controls for the plants, the effectiveness of environmental regulations and scientists' ability to detect damages and ascertain their cause.

In general, synfuels promoters appear to be confident that the control systems proposed for their processes will work effectively and reliably. They tend to view synfuels processes as variations of current chemical and refinery operations, albeit variations that will require careful design and handling. Consequently, the environmental controls planned for synthetic fuels plants are largely based on present engineering practices in the petroleum refining, petrochemical, coal-tar processing, and power generation industries.

There are reasons to be concerned about control system effectiveness and reliability, however, especially for the first generation of commercial plants. First, few of the wastewater effluents from either direct or indirect processes have been sent through a complete environmental control system such as those designed for commercial units. Process waste streams from several U.S. pilot plants have been subjected only to laboratory and bench-scale cleanup tests or else have been combined with waste streams from neighboring refineries and treated, with a poorly understood level of success, in the refinery control systems.

Second, scaling up from small-scale operations is particularly difficult for the direct processes, because of the entrainment of solids in the liquid process streams. Engineering theory for the scale up of solids and mixed solids/liquids processes is not well advanced. For the most part, the problem of handling liquid streams containing large amounts of entrained solids under high-temperature and pressure conditions is outside of current industrial experience.

Third, currently available refinery and petrochemical controls are not designed to capture the full range of pollutants that will be present in synfuels process and waste streams. Several of the trace elements as well as the polycyclic aromatic hydrocarbons (PAHs) are included in this group, although techniques such as hydrocracking are expected to help eliminate PAHs when they appear in process streams. (As noted previously, problems with the trace organics generally are focused on the direct and on low-temperature indirect processes, because high-temperature gasifiers should effectively destroy most of these compounds.)

Fourth, in some cases, compounds that generally are readily controlled when separately encountered appear in synfuels process and waste streams in combinations that complicate control. For example, current processes for removing hydrogen sulfide, carbonyl sulfide, and combustibles tend to work against each other when these compounds appear in the same gas stream,[70] as they do in synfuels plants. Also, the high level of toxics that appear in the waste streams may create reliability problems for the biological control systems.

Fifth, as noted earlier, the high pressures, multiplicity of valves and gaskets, and (for the direct processes) the erosive process streams appear to create high risks of fugitive emissions. plans for control of these emissions generally depend on "directed maintenance" programs that stress frequent monitoring and inspection of vulnerable components. Although it appears reasonable to expect that a directed maintenance program can significantly reduce fugitive emissions, rigorous specifications for such a program have not been published,[71] and some doubts have been raised

---

[70] Congressional Research Service, *Synfuels* From *Coal* and *the* National *Synfuels* Production Program: *Technical,* Environmental and Economic Aspects, December 1980 (Committee Print 11-74 No. 97-3, January 1981, U.S. Congress).

[71] U.S. Department of Energy, *Final Environmental Impact Statement:* Solvent Refined Coal-n Demonstration Project, Fort Martin, Monongalia County, W, Va., 2 vols., 1981.

about the adequacy of proposed monitoring for pioneer plants.

The significance of these technological concerns is uncertain. As noted previously, industry representatives generally have dismissed the concerns as unimportant, at least with regard to the extent to which pollution control needs might be compromised. Government researchers at EPA and DOE[72] have expressed some important reservations, however. On the one hand, they are confident that each of the synfuels waste streams is amenable to control, usually with approaches that are not far different from existing approaches to control of refinery and chemical process wastes. On the other hand, they have reservations about whether or not the industry's control program, as it is currently constituted, will achieve the high levels of control possible. Potential problem areas (some of which are related) include wastewater treatment, 'J control system reliability, and pollution control during process upsets.

Virtually all of the Government researchers OTA contacted were concerned that the industry programs were not addressing currently unregulated pollutants but instead were focusing almost exclusively on meeting immediate regulatory requirements. Several expressed special concern about the failure of some developers to exploit all available opportunities to test integrated control systems; they expected these integrated systems to behave differently from the way the individual devices behave in tests.

The above concerns, if well founded, imply that environmental control problems could have serious impacts on the operational schedules of the first generation of commercial plants. These impacts could range from extentions in the normal plant shakedown periods to extensive delays for redesign and retrofit of pollution controls.[74] Because of the large capital costs of the plants, there will likely be severe pressure on regulators to minimize delays and allow full-scale production to proceed. The outcome of any future conflicts between regulatory requirements and plant schedules will depend strongly on the public pressures exerted on the industry and Federal and State Governments.

There are reasons to believe that a great deal of public interest will be focused on the synfuels industry and its potential effects. For one, when plant upsets do occur, the results can be visually spectacular–for example, purging an SRC-II reactor vessel and flaring its contents can produce a flame up to 100 ft wide and 600 ft long.[75] It also seems likely that odor problems will accompany these first plants, and in fact the sensitivity of human smell may render it impossible to ever completely eliminate this problem. Malodorous compounds such as hydrogen sulfide, phenols, organic nitrogen compounds, mercaptans, and other substances that are present in the process and waste streams can be perceived at very low concentrations, sometimes below 1 part per billion.[76]

In addition, the presence of highly carcinogenic materials in the process and waste streams appears likely to sensitize the public to any problems with these plants. This combination of potential hazards and perceptual problems, coupled with the industry strategy of locating at least some of these plants quite close to populated areas (e.g., SRC-II near Morgantown, W. Va., now canceled, and the Tri-State Synthetic Fuels Project near Henderson, Ky.), appears likely to guarantee lively public interest.

The nature of the industry's response to unexpected environmental problems as well as its general environmental performance also will depend on the degree of regulatory surveillance and control exerted by Federal and State environmental agencies. Although the degree of surveillance and control will in turn depend largely on the environmental philosophy of the Federal and State Governments at various stages in the lifetime of the industry-a factor that is unpredictable-it will also depend on the legal framework of environ-

---

[72] Personal Communications with headquarters and field personnel, EPA and DOE.

[73] The draft of EPA's Pollution Control Guidance Document on indirect liquefaction also expressed strong concerns about wastewater treatment. *Inside* EPA, Sept. 12, 1980, "Indirect Liquids Draft Sees Zero Wastewater Discharge, Laments Data Gap."

[74] Some of the architectural and engineering firms submitting synfuels plant designs have incorporated certain control system flexibilities as well as extra physical space in their control systems designs. These features presumably would reduce schedule problems. Frederick Witmer, Department of Energy, Washington, D. C., personal communication.

[75] Supra 59.

[76] Supra 58.

mental regulations, the scientific groundwork that is now being laid by the environmental agencies, and the nature of the scientific problems facing the regulatory system.

Existing Federal environmental legislation gives the Occupational Safety and Health Administration (OSHA) and EPA a powerful set of tools for dealing with the potential impacts of synfuels development. OSHA has the power to set occupational exposure standards and define safety procedures for all identified hazardous chemicals in the workplace environment. EPA has a wide variety of legal powers to deal with synfuels impacts, including:

- setting National Emission Standards for Hazardous Air Pollutants (N ES HAPS) under the Clean Air Act;
- setting New Source Performance Standards, also under the Clean Air Act;
- setting effluent standards for toxic pollutants (which, when ingested, cause "death, disease, cancer, genetic mutations, physiological malfunctions or physical deformations") under the Clean Water Act;
- setting water quality standards, also under the Clean Water Act;
- defining acceptable disposal methods for hazardous wastes under the Resource Conservation and Recovery Act;
- defining underground injection guidelines under the Safe Drinking Water Act; and
- a variety of other powers under the mentioned acts and several others.[77]

The regulatory machinery gives the Federal environmental agencies a strong potential means of controlling synfuels plants' hazardous emissions and effluents. In general, however, the machinery is immature. Because there are no operating commercial-scale synthetic fuels plants in the United States, EPA has not had the opportunity to collect the data necessary to set any technology-specific emission and effluent limitations for synfuels plants. Aside from this inevitable problem, the environmental agencies have not fully utilized some of their existing opportunities for environmental protection. For example, EPA has allowed its authority to define standards for hazardous air pollutants to go virtually unused. In addition, in some areas, such as setting effluent guidelines and New Source Performance Standards for air emissions, EPA has a substantial backlog of existing industries yet to be dealt with.

The environmental research programs conducted by various Federal agencies will lay the groundwork for EPA's and OSHA's regulation of the synfuels industry. The key programs are those of EPA and OSHA themselves and those of DOE. DOE's programs appear likely to be essentially eliminated if current plans to dismantle DOE are successful. EPA and OSHA research budgets have both been reduced. In particular, EPA has essentially eliminated research activities aimed at developing control systems for synfuels waste streams, on the basis that such development is the appropriate responsibility of industry. As mentioned before, Federal researchers familiar with the industry's current environmental research programs perceive that the industry has little interest in developing control measures for potential impacts that are not currently regulated, and they believe that industry is unlikely to expand its programs to compensate for EPA's reductions.[78]

With or without budget cuts, EPA and OSHA face substantial scientific problems in setting appropriate standards for hazardous materials from synfuels technologies. Probably the worst of these problems is that current air pollution and occupational exposure regulations focus on a relatively small number of compounds and treat each one individually or in well-defined groups, whereas synfuels plants may emit dozens or even hundreds of dangerous compounds with an extremely wide range of toxicity (i.e., the threshhold of harm may range from a few parts per billion to several parts per thousand or higher) and a variety of effects.

The problem is further complicated by the expected wide variations in the amounts and types

---

[77] See table 4.1, *Synthetic Fuels and* the Environment: An *Environmental* and Regulatory *Impacts Analysis,* Office of Technology Impacts, U.S. Department of Energy, DOE/EV-0087, June 1980. Also, see ch. 5, The *Impacts of* Synthetic *Fuels* Development, D. C. Masselli, and N. L. Dean, jr., National Wildlife Federation, September 1981.

[78] Supra 72,

of pollutants produced. The synfuels waste streams are dependent on the type of technology, the control systems used, the product mix chosen by the operator (which determines the operating conditions), and the coal characteristics. The implication is that uniform emission and worker exposure standards, such as a "pounds per hour" emission limit on total fugitive HC emissions or a "milligrams per cubic meter" limit on HC exposures, are unlikely to be practical because they would have to be extraordinarily stringent to provide adequate protection against all components of the emission streams. Consequently, EPA and OSHA may not be able to avoid the extremely difficult task of setting multiple separate standards for toxic substances.

The regulatory problem represented by the toxic discharges is compounded by difficulties in detecting damages and tracing their cause. Because low-level fugitive emissions from process streams and discharges or leaks from waste disposal operations probably are inevitable, regulatory requirements on the stringency of mitigation measures will depend on our knowledge of the effects of low-level chronic exposures to the chemical components of these effluents. Aside from the problems of monitoring for the actual presence of pollution, problems may arise both from the long lag times associated with some critical potential damages (e.g., 5 to 10 years for some skin cancers, longer for many soft-tissue cancers) and from the complex mixture of pollutants that would be present in any emission.

Transport and Use

As synthetic liquids are distributed and used throughout the economy, careful control of exposure to hazardous constituents becomes less and less feasible. This is especially true for liquid fuels because of the multitude of small users and the general lack of careful handling that is endemic to the petroleum distribution system. Consequently, the toxicity of synfuels final products may be critical to the environmental acceptability of the entire synfuel "fuel cycle."

The pathways of exposure to hazardous substances associated with synfuels distribution and use include accidental spills and fugitive emissions from pipelines, trucks, and other transport modes and storage tanks; skin contact and fume inhalation by motorists and distributors; and public worker exposure to waste products associated with combustion (including direct emissions and collected wastes from control systems).

Evaluation of the relative danger of these exposure pathways and comparisons of synfuels to their petroleum analogs are extremely difficult at this time. Most environmental and health effects data on synfuels apply to process intermediates–"syncrudes"- rather than finished fuels. Combustion tests have generally been limited to fuel oils in boilers rather than gasolines in automobiles. 'g The tests that have been conducted focus more on general combustion characteristics than on emissions, and those emission characterizations that have been done measure mainly particulate and SO_x and NO_x rather than the more dangerous organics.[80] Adding to the difficulty of determining the relative dangers of synfuels use is a series of surprising gaps in health effects data on analogous petroleum products. Apparently, many of these widely distributed products are assumed to be benign, and monitoring of their effects has been limited.[81]

Table 79 presents a summary of the known differences in chemical, combustion, and health effects characteristics of various synfuels products and their petroleum analogs. The major characteristics of coal-derived liquid fuels are:

- The major concern about synthetic fuels products is their potential to cause cancer, mutations, or birth defects in exposed persons or wildlife. (Petroleum-based products also are hazardous, but usually to a lesser extent than their synfuels counterparts.)[82] In general, the heavier (high boiling point) liquids—especially heavy fuel oils—are the most dangerous, whereas most of the lighter products are expected to be relatively free of these effects. This distribution of effects may be considered fortunate because the lighter

---

[79] M. Ghassemi and R. Iyer, Environmental Aspects *of Synfuel* Utilization, U.S. Environmental Protection Agency report EPA-600/7-81-025, March 1981.

[80] Ibid.

[81] Ibid.

[82] Ibid.

Table 79.—Reported Known Differences in Chemical, Combustion, and Health Effects Characteristics of Synfuels Products and Their Petroleum Analogs

Product	Chemical characteristics	Combustion characteristics	Health effects characteristics
Shale 011			
Crude	Higher aromatics, FBN, As, Hg, Mn	Higher emissions of NO_x particulate and (possibly) certain trace elements	More mutagenic, tumorigenic, cytotoxic
Gasoline	Higher aromatics	Slightly higher NO_x and smoke emissions	
Jet fuels	Higher aromatics	Slightly higher NO_x and smoke emissions	Eye/skin irritation, skin sensitization same as for petroleum fuel
DFM	Higher aromatics	Slightly higher NO_x and smoke emissions	Eye/skin irritation, skin sensitization same as for petroleum fuel
Residuals	Higher aromatics		—
Direct liquefaction			
Syncrude (H-Coal, SRC II, EDS)	Higher aromatics and nitrogen		
SRC II fuel oil	Higher aromatics and nitrogen	Higher NO_x emissions	Middle distillates: nonmutagenic; cytotoxicity similar to but toxicity greater than No. 2 diesel fuel; burns skin. Heavy distillate: considerable skin carcinogenicity, cytotoxicity, mutagenicity, and cell transformation
H-Coal fuel oil	Higher nitrogen content	Higher NO_x emissions	Severely hydrotreated: nonmutagenic, nontumorigenic; low cytotoxicity
EDS fuel oil		Higher NO_x emissions	—
SRC II naphtha	Higher nitrogen, aromatics	—	Nonmutagenic, extremely low tumorigenicity cytotoxicity and fetotoxicity
H-Coal naphtha	Higher nitrogen, aromatics		Non mutagenic
EDS naphtha	Higher nitrogen, aromatics		
SRC II gasoline	Higher aromatics		
H-Coal gasoline	Higher aromatics		
EDS gasoline	Higher aromatics		
Indirect liquefact/on			
FT gasoline	Lower aromatics; N and S nil		Noncarcinogenic
FT byproduct chemical	—	N/A	—
Mobil-M gasoline	(Gross characteristics similar to petroleum gasoline)		
Methanol	—	Higher aldehyde emissions	Affects optic nerve
Gasification			
SNG	Traces of metal carbonyls and higher CO		
Low/medium-Btu gas	(Composition varies with coal type and gasifier design/operation)	(Emissions of a wide range of trace and minor elements and heterocyclic organics)	Nonmutagenic, moderately cytotoxic
Gasifier tars, oils, phenols	(Composition varies with coal and gasifier types; highly aromatic materials)	—	

SOURCE: M. Ghasseml and R. Iyer, Environmental Aspects of Synfuel Utilization, EPA-600/7-81-025, March 1981.

products–such as gasoline–are more likely to be widely distributed.

- Products from direct liquefaction processes appear more likely to be cancer hazards than do indirect process products, because of the higher levels of dangerous organic compounds produced in the direct processes.
- Coal-derived methanol fuel appears to be similar to the methanol currently being used, although there are potentials for contamination that must be carefully examined. Methanol is rated as a "moderate hazard" ("may involve both irreversible and reversible changes not severe enough to cause death or permanent injury'')[83] under chronic –long-term, low-level–exposure, although the effects of multi-year exposures to very low levels (as might occur to the public with widespread use as a fuel) are not known. Methanol has been assigned a hazard rating for acute exposures similar to that for gasoline,[84] but no comparison can be made for chronic exposures because data for gasoline exposure is inadequate.[85] [86] In automobiles, methanol use increases emissions of formaldehyde sufficiently to cause concern, but lowers emissions of nitrogen oxides and polynuclear aromatics.[87] Depending on the potential health effects of low levels of formaldehyde, which are not now sufficiently understood, and the emission controls on automobiles, methanol use in automobiles conceivably may provide a significant net pollution benefit to areas suffering from auto-related air pollution problems.
- Many of the dangerous organics that are the source of carcinogenic/mutagenic/teratogenic properties in synfuels should be controllable by appropriate hydrotreating. Tradeoffs between environmental/health concerns and hydrotreating cost, energy consumption, and effects on other product characteristics currently are not known.

---

[83] N. I. Sax, *Dangerous* properties of Industrial Materials, Fourth Edition, Van Nostrand Reinhold Co., 1975.

[84] Ibid.

[85] Ibid,

[86] Ghassemi and Iyer, Op. Cit.

[87] *Energy From* Biological processes, op. cit.

OIL SHALE

Production and use of synthetic oil from shale raises many of the same concerns about limited water resources, toxic waste streams and massive population impacts as coal-derived liquid fuels, but there are sufficient differences to demand separate analysis and discussion, OTA has recently published an extensive evaluation of oil shale;[88] the discussion here primarily summarizes the key environmental findings of that study.

U.S. deposits of high-quality oil shale (greater than 25 gal of oil yield per ton) generally are concentrated in the Green River formation in northwestern Colorado (Piceance Basin) and northeastern Utah (Uinta Basin), The geographic concentration of these economically viable reserves to an arid, sparsely populated area with complex terrain and relatively pristine air quality, and the impossibility of transporting the shale (because of its extremely low energy density) lead to a potential concentration of impacts that is (at least in theory) easier to avoid with coal-derived synfuels. Thus, compliance with prevention of significant deterioration regulations for SO_2 and particulates may constrain total oil shale development to a million barrels per day or less unless current standards are changed or better control technologies are developed.

Also, the lack of existing socioeconomic infrastructure implies that environmental impacts associated with general development pressures could be significant without massive mitigation programs. Although coal development shares these concerns (especially in the West) and has water and labor requirements as well as air emissions that are not dissimilar on a per-plant basis, it is unlikely to be necessary to concentrate coal development to the same extent as with oil shale. Thus, coal development should have fewer se-

---

[88] *An* Assessment of Oil Shale Technologies, Op. cit.

vere physical limitations on its total level of development.

The geographic concentration of oil shale development should not automatically be interpreted as environmentally inferior to a more dispersed pattern of development, however. Although impacts will certainly be more severe in the developed areas as a result of this concentration, these impacts must be balanced against the smaller area affected, the resulting pressure on the developers to improve environmental controls to allow higher levels of development, and the possibility of being able to focus a major monitoring and enforcement effort on this development. Also, the major oil shale areas generally are not near large population centers, whereas several proposed coal conversion plants are within a few miles of such centers and may consequently pose higher risks to the public.

The volume of the material processed and discarded by an oil shale plant is a significant factor in comparing oil shale with coal-derived fuels. A 50,000 bbl/d oil shale plant using aboveground retorting (AGR) requires about 30 million tons per year of raw shale* versus about 6 million to 18 million tons of coal (the higher values apply only to low-quality lignites converted in a relatively inefficient process) for a similarly sized coal liquefaction plant. A modified in-situ (MIS) plant requires about the same tonnage of feedstock as does the coal plant, Consequently, although the underground mining of shale thus far has had a much better worker safety record than coal mining, underground mining of coal may be safer than shale mining for an AGR plant on a "fuel output" basis, especially when full-scale shale mining begins. Mining for an MIS plant, on the other hand, will be safer than that for the coal plant unless previous shale experience proves to be misleading.

The very large amount of spent shale represents a difficult disposal problem. An AGR plant must dispose of about 27 million tons/yr of spent shale, at least five times as much solid waste as that produced by a similarly sized coal synfuels plant (MIS plants may dispose of about 6 million tons/yr of spent shale, one to three times the disposal requirements of a coal plant). At this rate, a 1 MMB/D industry using AGRs will have to dispose of approximately 10 billion cubic feet of compacted shale each year.

This material cannot be fully returned to the mines because it has expanded during processing, and it is a difficult material to stabilize and secure from leaching dangerous compounds—cadmium, arsenic, and lead, as well as organics from some retorts (for example TOSCO II and Parajo Indirect)—into surface and ground waters. It also may cause a serious fugitive dust problem, especially with processes like TOSCO II that produce a very fine waste. Even with secure disposal, it will fill scenic canyons and represents an esthetic and ecosystem loss. Current research on small plots indicates that short-term (a few decades) stability of spent shale piles appears likely if sufficient topsoil is applied, but the long-term stability and the self-sustaining character of the vegetation is unknown. For these reasons, solid waste disposal may be oil shale's major environmental concern.

As with coal liquefaction processes, the "reducing environment" in the retorts produces both reduced sulfur compounds and dangerous organics that represent a potential occupational hazard for workers from fugitive emissions and fuel handling. Crude shale oil appears to be more mutagenic, carcinogenic, and teratogenic than natural crude.

On the other hand, the refined products are less likely to be significantly different in effect from their counterparts produced from natural crude, and shale syncrude is less carcinogenic or mutagenic than syncrudes from direct coal liquefaction. Although comparisons of relative risk must necessarily be tentative at this early stage of development, it appears that the risks from these toxic substances–excluding problems with spent shale—probably are somewhat comparable to those of the cleanest coal-based liquefaction processes (indirect liquefaction with high-temperature gasifies).

Other oil shale environmental effects of particular concern include:

- The mining of oil shale generates large amounts of silica dust that is implicated in various disabling lung diseases in miners.

---

*assuming 25 gal of oil per ton of shale.

- Aside from the reduced sulfur compounds and organics, the crude shale oil contains relatively high levels of arsenic, and somewhat higher levels of fuel bound nitrogen than most natural crude does. These pollutants as well as the organics can be reduced in the refining operation.
- In-situ production leaves large quantities of spent shale underground and thus creates a substantial potential for leaching out toxic materials into valuable aquifers. Control of such leaching has not been demonstrated.
- Although oil shale developers are proposing to use zero discharge of point-source water effluents, it may be desirable in the future to treat water and discharge it. The state of water pollution control in oil shale development is essentially the same as in coal-derived synfuels, however. Many of the controls proposed have not been tested with actual oil shale wastewaters, and none have been tested in complete wastewater control systems.
- MIS production—whereby a moderate amount of mining is done to provide space with which to blast the shale into rubble and then retort it underground—may present a special occupational hazard to workers from explosions, fire, and toxic gases as well as a potential danger to the public if toxic fumes escape from the mine to the surface.

To summarize, the environmental concerns of oil shale production appear to be quite similar to those of coal-based synfuels production, but with two important differences. First, the geographic concentration of oil shale production will tend to concentrate and intensify its environmental and socioeconomic impacts to a greater extent than is likely to be experienced by coal development. Second, the problems of disposing of the huge quantities of spent shale associated with the AGR system appear to be substantially greater than those of coal wastes.

BIOMASS FUELS

Production of liquid fuels from biomass will have substantially different impacts from those of coal liquefaction and oil shale production. These are described in detail in OTA's Energy From Biological Processes[89] and summarized briefly here.

The liquid fuel that appears to have the most potential for large-scale production is methanol produced from wood, perennial grasses and legumes, and crop residues. Ethanol from grains has been vigorously promoted in the United States, but appears likely to be limited by problems of food/fuel competition to moderate production levels (a few billion gallons per year).

Obtaining the Resource

Environmental concerns associated with alcohol fuel production focus on feedstock acquisition to a greater extent than with coal liquefaction. All of the credible alcohol fuel cycles require various degrees of ecological alteration, replacement, or disruption on vast land areas. Taking into account the expenditure of premium fuels needed to obtain and convert the biomass into usable fuels, replacing about 10 billion gal/yr of gasoline with biomass substitutes would require adding intensive cropping to a minimum of about 25 million acres with a combination of sugar/starch crops (for ethanol) and grasses (for methanol).

If this savings were attempted strictly by the use of ethanol made from corn, the land requirement probably would be at least 40 million acres. If methanol from wood were the major source, much of the gasoline displacement theoretically could be obtained by collecting the logging residues that are now left in the forest or burned. To replace 10 billion gal over and above the amount available from residues would involve increasing the scale and intensity of management (more acreage under intensive management,

---

[89] *Energy* From Biological processes, OP. cit.

shorter times between thinnings, more complete removal of biomass, more conversion of low-quality stands) on upwards of so million acres of commercial forest. It might involve an increased harvest of forestland with lower productive potential—so-called “marginal lands’’—and it will almost certainly mean that lands not now subject to logging will be logged. Despite these difficulties, however, wood is the most likely source of large-scale biomass production.

If handled with care, a “wood-for-methanol” strategy could have a number of benefits. These include upgrading of poorly managed forests, better forest fire and pest control through slash removal, and reduced pressure on the few remaining unprotected stands of scenic, old-growth timber because of the added yields of high-quality timber that are expected in the long run from increased management.

Nevertheless, there is substantial potential for damage to the forests if they are mismanaged. High rates of biomass removal coupled with short rotations could cause a depletion of nutrients and organic matter from the more vulnerable forest soils. The impacts of poor logging practices—erosion, degraded water quality, esthetic damage, and damage to valuable ecosystems—may be aggravated by the lessening of recovery time (because of the shorter rotations) and any lingering effects of soil depletion on the forests’ ability to rebound. The intensified management may further degrade ecological values if it incorporates widespread use of mechanical and chemical brush controls, very large area clearcuts and elimination of “undesirable” tree species, and if it neglects to spare large pockets of forest to maintain diversity.

Finally, the incentive to “mine” wood from marginal lands with nutrient deficiencies, thin soils, and poor climatic conditions risks the destruction of forests that, although “poor” from the standpoint of commercial productivity, are rich in esthetic, recreational, and ecological values. Because the economic and regulatory incentives for good management are powerful in some circumstances but weak in others, a strong increase in wood energy use is likely to yield a very mixed pattern of benefits and damages unless the existing incentives are strengthened.

The potential effects of obtaining other feedstocks for methanol or ethanol production may also be significant. Obtaining crop residues, for example, must be handled with extreme care to avoid removing those residues that are critical to soil erosion protection. Large-scale production of corn or other grains for ethanol is likely to occur on land that is, on the average, 20 percent more erosive than present cropland. Aside from creating substantial increases in erosion, corn production will require large amounts of agricultural chemicals, which along with sediment from erosion can pollute the water, and will displace present ecosystems.

Equivalent production levels of perennial grasses and legumes, on the other hand, could be relatively benign because of these crops’ resistance to erosion as well as their potential to be obtained by improving the productivity of present grasslands rather than displacing other ecosystems. Although large quantities of agricultural chemicals would be used, the potential for damage will be reduced by the low levels of runoff from grasslands.

Conversion

Production of alcohol fuels will pose a variety of air and water pollution problems. Methanol synthesis plants, for example, are small indirect liquefaction plants that may have problems similar to those of coal plants discussed previously. The gasification process will generate a variety of toxic compounds including hydrogen sulfide and cyanide, carbonyl sulfide, a multitude of oxygenated organic compounds (organic acids, aldehydes, ketones, etc.), phenols, and particulate matter. As with coal plants, raw gas leakage or improper handling of tars and oils would pose a significant hazard to plant personnel, and good plant housekeeping will be essential. Because of low levels of sulfur and other pollutants in biomass, however, these problems may be somewhat less severe than in an equivalent-size coal plant.

Ethanol distilleries use substantial amounts of fuel–and therefore can create air pollution problems. An efficient 50-million-gal/yr distillery will consume slightly more fuel than a 30-Mw powerplant. There are no Federal emissions standards for these plants, and the prevailing local standards may be weak in some cases, especially for small onfarm operations.

The plants also produce large amounts of sludge wastes, called stillage, that are high in biological and chemical oxygen demand and must be kept out of surface waters. Although the stillage from grains is a valuable animal feed product and will presumably be recovered without the need for any further incentives, the stillage from sugar crops is less valuable and will require strict regulation to avoid damage to aquatic ecosystems, EPA has had a history of pollution control problems with rum and other distilleries, and ethanol plants will be similar to these.

APPENDIX 10A.– DETAILED DESCRIPTIONS OF WASTE STREAMS, RESIDUALS OF CONCERN, AND PROPOSED CONTROL SYSTEMS FOR GENERIC INDIRECT AND DIRECT COAL LIQUEFACTION SYSTEMS

Table 10A-1 .-Gaseous Emissions and Controls (indirect liquefaction)

Gaseous stream	Source	Stream components of concern	Controls	Comments
Fugitive emissions				
Vent gases				
Coal-lockhopper vent gas	Coal gasification	Carbon monoxide, hydrogen sulfide, tars, oils, naphtha, cyanide, carbon disulfide	Compression and recycle of pressurization gas, incineration of waste gas	
Ash-lockhopper vent gas	Coal gasification	Particulate, trace elements	Scrubber	The need for and the effectiveness of incineration/particulate control have not been defined
Concentrated acid gas	Gas purification	Hydrogen sulfide, carbonyl sulfide, carbon disulfide, hydrogen cyanide, carbon monoxide, carbon dioxide, light hydrocarbons, mercaptans	Stretford or ADIP/Claus processes followed by a sulfur recovery tail gas process, e.g., Beavon, and incineration of the Beavon off-gas in a boiler	The acid gases will be concentrated by the gas purification process. The control choice is dependent on the sulfur content of the gases; a combination of Stretford and ADIP/Claus may have the lowest overall costs.
Off-gases from catalyst regeneration	Catalytic synthesis	Nickel and other metal carbonyls, carbon monoxide, sulfur compounds, organics	Incineration in a flare, incinerator, or controlled combustion	Other control technology requirements not established
Evaporative emissions from stored products	Product storage	Aromatic hydrocarbons, C_5-C_{12} aliphatic hydrocarbons, ammonia	Vapor recovery systems, use of floating roof storage tanks, conservation vents. Incinerate	Control technologies used in petroleum refinery and other industries should be applicable to Lurgi plants; standards promulgated for the petroleum refining industry would probably be extended to cover the synthetic fuel industry.
Auxillary plant emissions				
Flue gases	Power/steam generation	Sulfur and nitrogen oxides, particulate trace elements, coal fines	Electrostatic precipitators, fabric filters, flue-gas desulfurization systems, combustion modification	Controls applicable to utility and industrial boilers would generally be applicable. Established emissions regulations would cover boilers at Lurgi plants
Cooling-tower drift and evaporation	Power/steam generation, process cooling	Ammonia, sodium, calcium, sulfides/sulfates, chlorine, phenols, fluorine, trace elements, water treatment chemicals	Proper design and siting can mitigate impacts	Recycled process water is used for cooling-tower makeup. If cooling-tower drift becomes a problem then the recycled water will receive additional treatment or makeup water will come from another source.
Treated waste gases	Gaseous emission controls (e.g., sulfur recovery	Hydrogen sulfide, carbonyl sulfide, carbon disulfide, hydrogen cyanide, carbon monoxide, carbon dioxide, light hydrocarbons	Essentially the same as for the concentrated acid gas	—

SOURCE' U.S. Department of Energy, Energy Technologies and the Environment, *Environmental* Information Handbook, DOEIEVI74O1O-1, December 1980

Table 10A-2.—Liquid Waste Stream Sources, Components, and Controls (indirect liquefaction)

Liquid waste stream	Source	Stream components of concern	Controls	Comments
Ash quench water	Gasification	Dissolved and suspended solids, trace elements, sulfides, thiocyanate, ammonia, dissolved organics, phenols, cyanides	Gravity settling of solids: the overflow from the settling basin is recycled back to the ash quenching operation	See table 10A-3 Streams, for final disposition of ash solids. Capabilities of technology in terms of clarified ash slurry water not known
Gas liquor	Gas purification	Sulfides, thiocyanate, ammonia, cyanides, mono- and polycyclic organics, trace metals, mercaptans	Lurgi tar/oil separator	Capabilities of tar/oil separation, Phenosolvan, and ammonia recovery well established in terms of removal of major constituents. Capabilities for removal of minor constituents not established. Limited cost data available on processes.
			Phenosolvan process	Removes dissolved phenols from water
			Phosam W or Chemi-Linz	Removes dissolved ammonia, produces saleable anhydrous ammonia.
			Bio-oxidation and reverse osmosis	Removes dissolved organics and inorganic.
Boiler blowdown	Power/steam generation	Dissolved and suspended solids	Use as cooling-tower makeup or as ash quench water makeup	Impacts on the quench system and subsequent treatment of clarified water not established.
Spent reagents and sorbents	Gaseous emission controls, wastewater treatment	Sulfides, sulfates, trace elements, dissolved and suspended solids, ammonia, phenols, tar oils, hydrogen sulfide, carbon dioxide	Recovery of reagents from air pollution control processes, addition to ash quench slurry	Applicable controls (e.g., resource recovery disposal in lined pond, dissolved solids removal, etc. are waste- and site-specific; cost and performance data should be developed on a case-by-case basis.
Acid wastewater	Product separation and purification	Dissolved organics, thiocyanate, trace elements	Oxidation, use as cooling-tower or quench water makeup	—
Leachates	Gasifier ash, boiler ash, FGD sludge, biosludge, spent catalysts	Trace elements, organics	Landfill should have impervious clay liner and a leachate collection system. If buried in the mine, the mine should be dry and of impervious rock or clay.	—
Treated aqueous wastes	Wastewater treatment	Dissolved and suspended solids, trace elements	Forced or natural evaporation	The effectiveness and costs of various applicable controls (e.g., solar or forced evaporation, physical-chemical treatment for water reuse, etc.) not determined.

SOURCE: U.S. Department of Energy, Energy Technologies and the Environment, *Environmental* Information Handbook, DCN2EVI7401O-1, December 1980.

Table 10A-3.—Solid Waste Stream Sources, Components, and Controls (Indirect liquefaction)

Solid waste stream	Source	Stream components of major concern	Controls	Comments
Ash or slag	Gasification	Trace elements, sulfides, thiocyanate, ammonia, organics, phenols, cyanides, minerals	Combined with boiler ash and flue gas desulfurization sludge and disposed of in a lined landfill or pond, or buried in the mine	Ash is more than 90 percent of the solid wastes generated at a Lurgi plant. The choice and design of disposal system depend on the ash content of coal and plant/mine site characteristics.
Scrubber sludge	Power/steam generation	Calcium sulfate, calcium sulfite, trace metals, limestone, alkali metal carbonates/sulfates	Disposed of with the gasifier ash	—
Boiler ash	Power/steam generation	Trace elements, minerals	Disposed of with the gasifier ash	
Sludge	Waste treatment	Trace elements, polycyclic aromatic hydrocarbons	Combined with gasifier ash, boiler ash and flue gas desulfurization sludge and disposed of in a lined landfiii or buried in the mine. May also be incinerated	Because of lack of data on waste quantities and characteristics, optimum control(s) cannot be established.
Spent catalysts	Gas shift conversion, catalytic synthesis, sulfur recovery (gaseous emission centrol)	Metalic compounds, organics, sulfur compounds	Process for material recovery, or fixation/ encapsulation and disposal in landiil or mine	The technical and economic feasibility of resource recovery have not been established
Tarry and oily sludges	Product/byproduct separation	Mono- and polycyclic aromatic hydrocarbons, trace elements	injection into the gasifier, disposal in a secure landfiil, return to the mine for burial, incineration	Because of lack of data on waste quantities and characteristics, optimum control(s) cannot be established

SOURCE: U.S. Department of Energy, Energy Technologies and the ***Environment, Environmental*** Information Handbook, DOI3EVI74O1O1, December 19S0.

Table 10A-4.—Gaseous Streams, Components, and Controls (direct liquefaction)

Operation/auxiliary process	Air emissions discharged	Components of concern	Control methods
Coal storage and pretreatment	Coal dust	Respirable dust, particulate, trace elements	Spray storage piles with water or polymer. cyclones and baghouse filters for control of dust due to coal sizing.
	Particulate-laden flue gas from coal dryers	Respirable dust, particulate, trace metals, sulfur and nitrogen oxides	Cyclones and baghouse filters. Wet scrubbers such as venturi.
Liquefaction	Preheater flue gas	Particulate, sulfur and nitrogen oxides	If other than clean gas, scrub for sulfur, nitrogen, and particulate components.
	Pressure letdown releases	Hydrocarbons, hydrogen sulfide, hydrogen cyanide, ammonia, PAH, hydrogen, phenols, cresylics	Flaring[a]
Separation:			
Gas separation	Pressure letdown releases	Same as for liquefaction letdown releases	Flaring[a]
Solids/liquids separation	Preheater flue gas	Same as the liquefaction preheater	If other than clean gas, scrub for sulfur, nitrogen, and particulate components.
	Particulate-laden vapors from residue cooling (SRC-II)	Particulate, hydrocarbons, trace elements	Cyclone and baghouse filter. Wet scrubbers.
	Pressure letdown releases	Same as for liquefaction letdown releases	Flaring[a]
Purification and upgrading:			
Fractionation	Preheater flue gas	Same as for liquefaction preheater	If other than clean gas, scrub for sulfur, nitrogen, and particulate components.
	Particulate-laden vapors from product cooling (SRC-I)	Same as for SRCII residue cooling	Cyclone and baghouse filter. Wet scrubbers
	Pressure letdown releases	Same as for liquefaction letdown releases	Flaring[a]
Hydrotreating	Preheater flue gas	Same as for liquefaction preheater	If other than clean gas, scrub for sulfur, nitrogen and particulate components.
	Pressure letdown releases	Same as for liquefaction letdown releases	Flaring[a]
Water cooling	Drift and evaporation	Ammonia, sodium, calcium sulfides/sulfates, chlorine, phenols, fluorine, trace elements, water treatment chemicals	No controls available—good design of water management system can minimize losses.
Steam and power generation	Boiler flue gas	Sulfur and nitrogen oxides, particulate	Sulfur dioxide scrubbing, combustion modifications.
Hydrogen generation	Preheater flue gas	Same as for liquefaction preheater	If other than clean gas, scrub for sulfur, nitrogen, and particulate components.
Acid gas removal	Pressure letdown releases	Hydrogen sulfide, hydrogen cyanide, carbon oxides, light hydrocarbons	Flaring[a]
Sulfur recovery	Flue gas	Same as for liquefaction preheater	If other than clean gas, scrub for sulfur, nitrogen, and particulate components.
	Low-sulfur effluent gas[b]	Hydrogen sulfide, hydrogen cyanide, sulfur dioxide	Carbon absorption. Direct-flame incineration. Secondary sulfur recovery (Beavon).
Hydrogen/hydrocarbon recovery	Pressure letdown releases	Hydrogen, hydrocarbons	Direct-fired afterburner
Product/byproduct storage	SRC dust (SRC-I)	Respirable dust, particulate	Spray storage piles with water.
	Sulfur dust	Elemental sulfur	Store in enclosed area.
	Hydrocarbon vapors	Phenols, cresylics, hydrocarbons, PAH	Spills/leaks prevention.

[a] Collection, recovery of useful products and incineration may be more appropriate.
[b] A secondary sulfur recovery process may be necessary to meet specified air emission standards.

SOURCE: U.S. Department of Energy, Energy Technologies and the Environment, Environmental Information Handbook, DOE/EV/74010-1, December 1980.

Table 10A-5.—Liquid Stream Sources, Components, and Controls (direct liquefaction)

Operation/auxiliary process	Wake effluents discharged	Components of concern	Control methods
Coal pretreatment	Coal pile runoff	Particulate, trace metals	Route to sedimentation pond.
	Thickener underflow	Same as above	Route to sedimentation pond.
Water cooling	Cooling tower blowdown	Dissolved and suspended solids	Sidestream treatment (electrodialysis, ion exchange or reverse osmosis) permits discharge to receiving waters.
Hydrogen generation	Process wastewater	Sour and foul wastewater; spent amine scrubbing solution	Route to wastewater treatment facility.
Acid gas removal	Process wastewater	Dissolved hydrogen sulfides, hydrogen cyanide, phenols, cresylics	Route to wastewater treatment facility.
Ammonia recovery	Process wastewater	Dissolved ammonia	Route to wastewater treatment facility.
Phenol recovery	Process wastewater	Dissolved phenols, cresylics	Route to wastewater treatment facility.

SOURCE: U.S. Department of Energy, Energy Technologies and the Environment, Environmental Information Handbook, DOE/EV/74010-1, December 1980.

Table 10A.6.—Soiid Waste Sources, Components, and Controls (direct liquefaction)

Operation/auxiliary process	Solid waste discharged	Components of concern	Control methods
Coal pretreatment	Refuse	Mineral matter, trace elements	Landfill, minefill
Solids/liquids separation	Excess residue (SRC-II) or filter cake (SRC-I)	Mineral matter, trace elements, absorbed heavy hydrocarbons	Gasification to recover energy content followed by disposal (landfill or minefill
Hydrotreating	Spent catalyst	Metallic compounds, absorbed heavy organics, sulfur compounds	Return to manufacturer for regeneration
Steam and power generation	Ash	Trace elements, mineral matter	Landfill, minefill
Hydrogen generation	Ash or slag	Trace elements, sulfides, ammonia, organics, phenols, mineral matter	Landfill, minefill

SOURCE: U.S. Department of Energy, Energy Technologies and the *Environment,* Environmental Information Handbook, DOEIEVI74O1O-1, December 1980

Chapter 11

Water Availability for Synthetic Fuels Development

Contents

TABLES

FIGURES

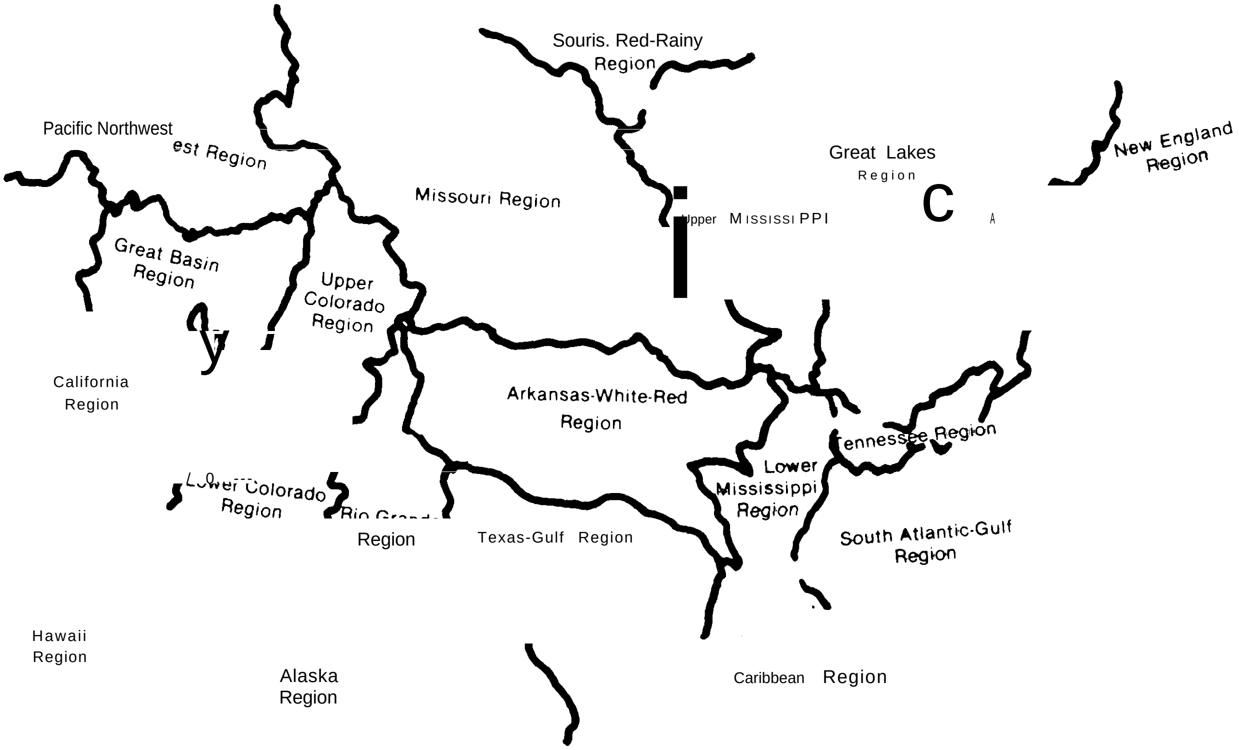
Chapter 11

Water Availability for Synthetic Fuels Development

INTRODUCTION

Operation of a synthetic fuels plant requires a steady supply of water throughout the year for both plant and site activities. Availability of water will be determined not only by hydrology and physical development potential, but also by institutional, legal, political, and economic factors which govern and/or constrain water allocations and use among all sectors. This chapter expands the environmental discussion of the role of water in synfuels development and examines the major issues that will determine both water availability for synfuels and the impacts of procuring water supplies for synfuels on other water users. There are five river basin areas where oil shale and coal resources are principally located: in the eastern basins of the Ohio, Tennessee and the Upper Mississippi, and in the western basins of the Upper Colorado and the Missouri (see fig. 24).

Figure 24.—Water Resources Regions



SOURCE: U.S. Water Resources Council, *The Nation's Water* Resources 197S2000, vol. 2, pt. 1, p. 3,

WATER REQUIREMENTS FOR SYNFUELS PLANTS

Estimates of the consumptive use requirements of generic synthetic fuels plants producing 50,000 barrels per day oil equivalent (B/DOE) of product are shown in table 80. In general, the actual amount of water consumed will vary according to the nature of the products produced, process methods, plant design, and site conditions. In coal conversion, the largest single component of total water consumption is typically for cooling, * with other major components being for hydrogen production, waste disposal, and revegetation. In producing synfuels from oil shale, retorting and upgrading require the most water; other major uses are for the handling and disposal of spent shale, and for revegetation.

Table 80.—Estimates of Net Consumptive Use Requirements of Generic Synfuels Plants (50,000 B/DOE)[a]

	Acre-feet/year	Barrels water/ barrel product
Gasification	4,500-8,000	1.9-3.4
Liquefaction.	5,500-12,000	2.3-5.1
Oil shale.	5,000-12,000	2.1-5.1

[a] Available estimates are based on theoretical calculations, conceptual designs, small-scale experimental facilities, etc. A range is shown for each generic process. In order to reflect differences among process technologies (e.g., Indirect liquefaction will generally consume more water than direct liquefaction; modified-in-situ will generally consume less water than aboveground oil shale processes), plant design options (e.g., alternative methods of water reuse, conservation, and cooling), and sites. Estimates also vary with the level of detail and state of development of the engineering designs. There are also at least two major elements of uncertainty surrounding these estimates. Firat, both the refinement and optimization of operational requirements are limited by the lack of commercial experience. Secondly, estimates commonly assume zero wastewater discharge, which is to be achieved via the treatment and reuse of plant wastewater for cooling water makeup and boiler feed; however, the treatment processes to be used generally have yet to be demonstrated on a commercial scale. Although the estimates shown in table 80 may thus not be representative of actual consumptive use requirements in specific cases, the magnitude of the other uncertainties concerning water availability in general, as discussed in this chapter, will likely overshadow the question of how much water will be required for expected synfuels development. The following references provide additional details:

1. Office of Technology Assessment, *An Assessment of Oil Shale Technologies*, June 1980, ch. 9.
2. Ronald F. Probstein and Harris Gold, *Water in Synthetic Fuel Production*, MIT Press, Cambridge, Mess., 1978.
3. R. M. Wham, et al., *Liquefaction Technology Assessment—Phase 1: Indirect Liquefaction of Coal to Methanol and Gasoline Using Available Technology*, Oak Ridge National Laboratory, Oak Ridge, Term., February 1981.
4. Exxon Research and Engineering Co., *EDS Coal Liquefaction Process Development*, phase V, vols. 1, II, and III, March 1881.
5. Harris Gold and David J. Goldstein, "Water Requirements for Synthetic Fuel Plants;" and Harris Gold, J. A. Nardella, and C. A. Vogel (ads.), "Fuel Conversion and Its Environmental Effects," *Chemical Engineering Progress*, August 1979, pp. 58-84.

SOURCE: Office of Technology Assessment.

Synfuels plants will also generally require water for other process-related activities such as environmental control (e.g., dust control) and for associated growth in population, commerce, and industry (e.g., for water supply and sewerage). Plant activities will not all require water of similar qualities. As examples, high-quality water is required for processing; intermediate-quality water is required for cooling; mining, materials preparation, and disposal activities are the least sensitive to water quality characteristics.

Procuring water supplies for synfuels plants will represent a small fraction of total plant investment and operations costs (typically less than 1 percent). * * Thus, assuming that the overall economic feasibility of the plant has been established, the more critical industrial considerations in selecting a water source will be the ease of acquiring water of appropriate quality and the certainty of the yield. Major water sources for synfuels would include the direct diversion of surface water, the purchase or transferring of existing water rights, the use of existing or the construction of new storage, the use of tributary and nontributary ground water,*** savings from improved efficiency, reuse, and conservation by all users, and interbasin diversions.

The feasibility and attractiveness of sources will vary among sites according to environmental, social, legal, political, and economic criteria, and

---

*The amount of water consumed in cooling will depend on many factors, including the degree to which evaporative or "wet" cooling, or dry cooling, are used. Air or "dry" cooling is an alternative to wet cooling but is less efficient and generally more expensive.

**Obtaining reliable and comparable cost data on the procurement of water to the synfuels industry is difficult because of variation in the conditions surrounding each sale (e.g. water rights vary according to their seniority, historic use, point of diversion, etc.). As examples, annual costs per acre-foot of consumption vary between $50 to $300; water rights have sold for as high as $2,000/acre-foot (in perpetuity). Assuming a cost of $2,000/acre-foot, water rights costs would still represent a maximum of only 0.8 percent of the cost of a $2 billion plant with an average annual consumption of 8,000 acre-feet. Note that what is bought is the right to use water, not the water per se.

Costs are, nevertheless, important industrial criteria for evaluating alternative sources of water supply. Costs will also be important for water resources planning efforts, as they will help to determine the nature and extent of impacts on other water users from synfuels development.

***The development of deep, nontributary ground water, which is hydrologically unconnected to the surface flow, can be considered as an "additional" source of water. Development of tributary ground water, which is hydrologically connected to streamflow, does not represent an increase in supply and may alter the surface flow regime, it is therefore difficult a priori to predict how and which water "packages" will be assembled. Evidence suggests that the industry is conservative in planning for a plant's water resource needs in order to ensure (both hydrologically and legally) that the plant obtains its minimum operating requirements. As examples, developers can secure several different sources of supplies; estimates of resource needs will include a margin of safety; and sources can be "guaranteed" by obtaining agreements not only with rights holders but also with upstream appropriators and/or potential downstream claimants. Synfuels technology modifications should also be forthcoming from the industry, if needed to reduce water needs.

IMPACTS OF SYNFUELS DEVELOPMENT ON WATER AVAILABILITY

In the aggregate, water consumption requirements for synfuels development are small. Achieving a synfuels production capability of 2 MMB/DOE would require on the order of 0.3 million acre-feet/year (AFY), which will be distributed among all of the Nation's major oil shale and coal regions. This compares with an estimated (1975) total national freshwater consumptive use of119 million AFY, of which about 83 percent is for agriculture.[1] Table 81 shows the general hydrologic characteristics of the principal river basins to be affected.

Although in the aggregate synfuels water requirements are small, each synfuels plant, nevertheless, is individually a relatively large water consumer. Depending on both the water supply sources chosen for a synfuels plant and the size and timing of water demands from other users, synfuels development could create conflicts among users for an increasingly scarce water supply or exacerbate conflicts in areas where water is already limited or fully allocated. Sectors that will be competing for water will vary among the regions and will include both offstream uses (e.g., agriculture, industry, municipalities) and instream uses (e.g., navigation, recreation, water quality control, fish and wildlife, hydropower). Because energy developers can afford to pay a relatively high price for water, nonenergy sectors are not likely to be able to compete economically against synfuels for water. However, it is speculative to identify which sectors may be the most vulnerable to synfuels development.

Public reactions to proposed water use change and nonmarket mechanisms can be used to allocate and protect water for use by certain sectors depending on the region and State. Examples of nonmarket mechanisms include the assertion of Federal reserved water rights, water quality legislation, and State water allocation laws. While such mechanisms may prevent developers from always obtaining all the water they need, the synfuels industry is expected to obtain the major portion of its water requirements.

---

[1] U.S. Water Resources Council, The Nation Water *Resources*—1975-2000, December 1978. The assessment projects a total national freshwater consumption of 151 million AFY in 2000, of which about 70 percent would be for agriculture.

Table 81 .—Regional Streamflow Characteristics 1975 [a] (millions acre-feet/year)

	Mean annual streamflow [b]	Consumption [c]		Low flow ratio [d]	Low flow month
		1975	2000		
Ohio	199	2.0	4.9	0.15	September
Tennessee	46	0.5	1.2	0.38	September
Upper Mississippi.	136	1.3	3.0	0.23	January
Upper Colorado.	11	2.7	3.6	0.12	July
Missouri	49	17.3	22.3	0.19	January

[a] U.S. Water Resources Council (WRC), The *Nation's Water Resources—1975-2000*.
[b] WRC, table IV-1. Note that all these outflows are inflows to a downstream river basin.
[c] WRC, table III-3.
[d] Ratio of the annual flow of a very dry year (that flow which will be exceeded with a 95-percent probability in any Year) to the mean annual flow. WRC, table IV-2.

SOURCE: US. Water Resources Council as tabulated by OTA.

Photo credit: Office of Technology Assessment

Competing uses will increase pressures on the Nation's water resources, especially in the arid West

The nature and extent of the impacts of synfuels development on water availability in general, and on competing water users, are controversial. The controversy arises in large part because of the many hydrologic, institutional, legal, and political constraints and uncertainties that will ultimately determine when, how, and if users will be able to obtain the water they need. Furthermore, analyzing these constraints and uncertainties is difficult because of many additional complex factors: the lack of dependable and consistent data, limitations of demand-forecasting methods, time and budget constraints, and the unpredictability of future administrative decisions and legal interpretations. In some cases, the uncertainties about water availability in general appear to be so large that they overshadow the question of how much water will be required for synfuels development.

OTA's study[2] found that there was considerable variation in the quality, detail, and scope of the water availability assessments that have been completed related to synfuels development. Few studies take into account all of the issues that will determine resource allocations and use; and studies rarely try to address the likely, cumulative water resource impacts of alternative decisions on reducing uncertainties and resolving conflict among competing water users. Decision makers need to be better informed about the assump-

---

[2] Wright Water Engineers, Inc., "Water Availability for Synthetic Fuels," prepared for the Office of Technology Assessment, June 1981.

tions and uncertainties upon which reports are predicated, so that estimates can be properly interpreted and tradeoffs can be evaluated.

Some of the major uncertainties about water availability for synfuels are discussed below. More informed decisions on water availability questions, however, can only partially be achieved by "improving" studies themselves; more informed decisions also depend on greatly improved water planning practices in general in the Nation. The present fragmentation of responsibilities for water policy, planning, and management effectively prevents an assessment of the cumulative impacts of water resource use on an ongoing and comprehensive basis. *

---

*The fragmentation of water-related responsibilities among agencies, States, and levels of governments arises in large part because river system boundaries rarely coincide with political boundaries. As a result, there can be major inconsistencies in water management practices across the country (e. g., inconsistent criteria for evaluation; the lack of integrated planning—including data management—for ground and surface waters, water quality and quantity, and instream and offstream uses).

WATER AVAILABILITY AT THE REGIONAL LEVEL

Eastern River Basins

In the principal eastern basins where energy resources are located (i.e. Ohio, Tennessee, and the Upper Mississippi), water should be adequate on the mainstems and larger tributaries, without new storage, to support planned synfuel development.[3] However, localized water scarcity problems could arise during abnormally dry periods or due to conflicts in use on smaller tributaries. The severity and extent of local problems cannot be fully ascertained from existing data and have not yet been examined comprehensively, * but, with appropriate water planning and management, these problems should be reduced if not eliminated.

There are, nevertheless, various uncertainties in the eastern basins that will influence water availability for synfuels development, and difficult local situations could arise.[4] For example, 7-day, 10-year minimum low flows are used to estimate water availability. * * These estimates are essentially based on recorded streamflow data which can be of varying quality. Furthermore, by using historical streamflow records directly, reports on water availability in the eastern basins characteristically underestimate the frequency of future critical low flows; i.e., as flow depletions increase in the future, the critical flow associated with the 7-day, 10-year frequency will actually occur more often in the future than the historical data would indicate.

The political, institutional, and legal factors that will determine water availability for synfuels in the eastern basins differ in type and complexity from those in the western basins. For example, the East and West have different regional hydrologic characteristics, with the East being relatively humid. There are also varying legal and administrative structures as shown in figures 25 and 26: riparian water law is generally applied in the East whereby riparian landowners are entitled to an equal, "reasonable" use of adjacent streamflow; the prior appropriation doctrine is generally applied in the West whereby water rights are based on "beneficial" use with priorities assigned according to "first in time, first in right. " Furthermore, in the East there is a general lack of treaties and compacts, and there are no major Federal (including Indian) reserved water rights questions.

Although water may thus appear to be more readily available for synfuels development in the East (e.g., through the transfer of ownership of riparian land), eastern water law can result in significant uncertainty concerning the dependability of the supply: because all users have equal

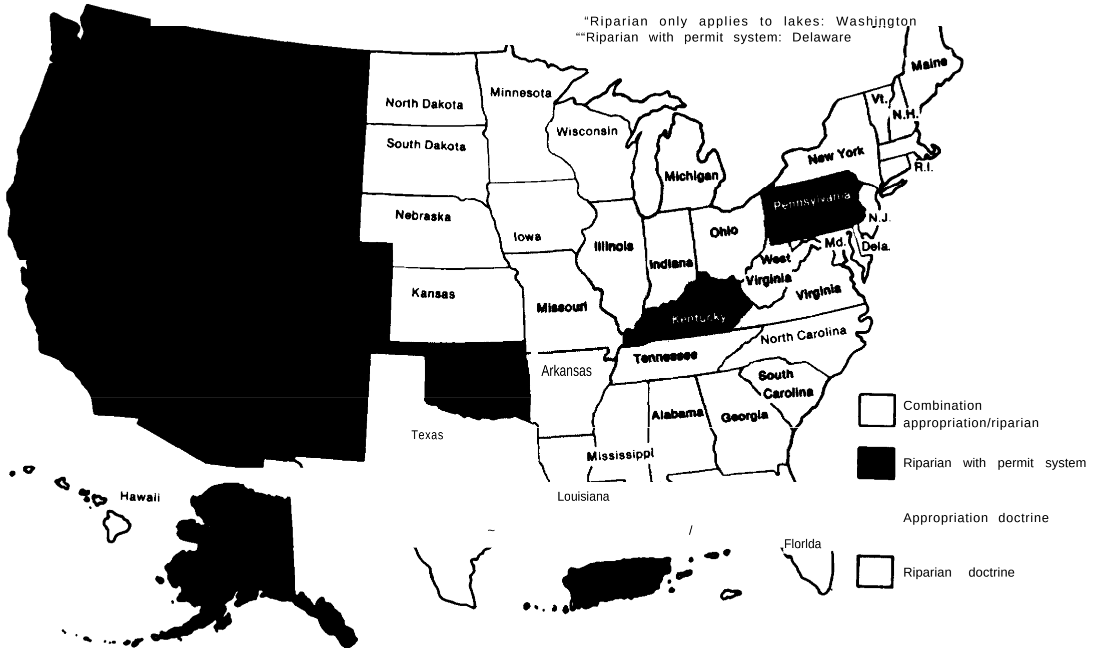
---

[3] 1 bid.

"For example, available reports related to ynfuels for the Tennessee River Basin generally deal with specific project sites; the sparsity of comprehensive information with respect to cumulative impacts and possible water use conflicts is presumably because of the large quantities of water available at the regional level. The Ohio River Basin Commission study focuses on water availability for plants located on the mainstem, even though there are facilities being proposed for tributaries.

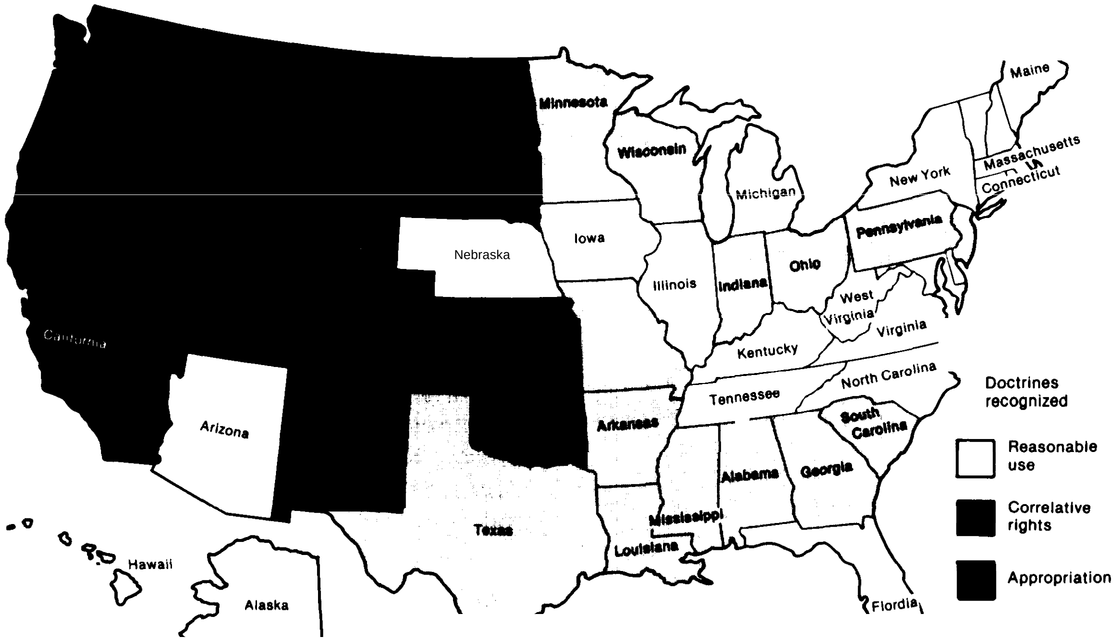
* *The use of the 7-day, 10-year minimum flow in the East is also the basis for water quality regulations and for estimating critical conditions for navigation in rivers with limited storage.

Figure 25.– The Nation's Surface Water Laws



SOURCE: U.S. Water Resources Council, (The *Nation's Water* Resources 7975-2000, vol. 2, **pt.** iv, P. 118).

Figure 26.— The Nation's Ground Water Laws



SOURCE: U.S. Water Resources Council, (The *Nation's* Water Resources 197%?000, vol. 2, pt. iv, p. 118).

rights under riparian law, the law does not protect given users against upstream diversions or against pumping by adjacent wells. * Uncertainty also arises because eastern water law has not been as well advanced through court tests as in the West. There are also questions in the East concerning the availability of water from Federal storage (i.e., in the Ohio River Basin) because of uncertainties regarding who has responsibility for marketing and reservoir operation.

The Western River Basins

Competition for water in the West already exists and is expected to intensify with or without synfuels development. There are potential sources of supply in both the Upper Colorado and the Missouri River basins that could support synfuels development. However, the issues determining whether and the extent to which these sources will be available for use differ between the two basins. These issues concern complex State water allocation laws, compacts and treaties, Federal including Indian reserved water rights claims, and the use of Federal storage. In addition, the use of "mean annual virgin flows" in both regions to characterize the hydrology results in the masking of important elements of hydrologic uncertainty.** However, and in contrast with the situation in the East, although the complex water setting in the West will probably make obtaining water difficult, the user will be more assured of a certain supply once a right is obtained.[s]

Missouri River Basin

The magnitude of the institutional, legal, political, and economic uncertainties in the Missouri River Basin, together with the need for major new water storage projects to average-out seasonal and yearly streamflow variations, preclude an unqualified conclusion as to the availability of surface water resources for synfuels development.b Ground water resources are not well understood in the basin, but are not likely to be a primary source of water for synfuels.

Major coal deposits for synfuels development in the Missouri River Basin lie within and adjacent to the Yellowstone River subbasin. The availability of water for synfuels from the Yellowstone subbasin, however, could be constrained by the provisions of interstate compacts, i.e., the Yellowstone River Compact. For example, at present all signatory States must approve any water exports from the basin (e.g., to the coal-rich Belle Fourche/Gillette area where water is scarce). Although export approval procedures are now being challenged in court and States have begun to modify approval procedures, such approvals are likely to take some time. Furthermore, additional storage would likely be required to develop fully the compact allocations.

Federal reserved water rights are often senior rights and have the potential of preempting current and future uses. These rights, however, have yet to be quantified and are a major source of uncertainty for water planning. The largest single component of Federal reserved rights are Indian water rights. There is a general lack of quantitative data concerning Indian water rights because of political controversy over which jurisdictions should be adjudicating the claims, varying interpretations of the purposes for which water rights reservations can be applied, and ongoing litigation.[7]

---

*For example, Federal storage has not yet been utilized in Illinois because delivery of the water from the reservoirs (e.g., to the synfuels plants) cannot be guaranteed along the river; riparian landowners along the way could intercept the released water. Energy companies are thus faced with having to build private pipelines.

**The accuracy of mean annual virgin flows is uncertain due to possible inaccuracies in the underlying data both on streamflows and on depletions. (Depletions are usually not measured directly for practical reasons.) Furthermore, virgin flow estimates are treated as both deterministic and stationary, rather than as time-varying, which prevents the variability of streamflows from being addressed accurately in areas lacking sufficient storage. Estimates of the mean annual virgin flow for the Colorado River at Lees Ferry vary from 12.5 million to 15.2 million acre-feet depending on the assumptions (in this case, the period of the historical record) used.

In general, the use of aggregated data, in the form of regional and basinwide averages, will mask the local and cumulative downstream effects of development on water availability. Such data do not provide information about either the seasonal variability of streamflows and demands or the relative positioning and hence interrelationships among users. These factors are important for identifying potential competition for water, especially in areas where water is scarce and subject to development pressures, as will often characterize locations for synfuels development.

‘Ibid.

[6] Ibid.

[7] The only "official" Government estimates of Indian reserved water rights project depletions (i.e. requirements) of 1.9 million acre-

(continued on next page)

Other major uncertainties that could effect the availability of water for synfuels concern State water allocation laws. For example, Montana has established instream flow reservations in the lower-Yellowstone River of 5.5 million AFY to protect future water quality and wildlife. Over 500,000 AFY have also been reserved in the basin for future municipal and irrigation use. Additional storage would be required to meet these reservations during years of low flow, but Montana State officials generally do not advocate the construction of new mainstem storage, even if instream flow shortages were to occur otherwise, as this would interfere with the free-flowing nature of the river.[8][9] No determination has yet been made as to how these instream flow reservations would be accommodated under the Yellowstone Compact.

The transferring of water rights from existing (e.g., agricultural) to new (e.g., synfuels) uses in Montana is subject to administrative restrictions under primarily the 1973 Water Use Act, and State environmental and facility siting acts.[10] Because of these restrictions, water rights are not freely transferable from existing users, and, in effect, there is presently no economic market for rights transfers.

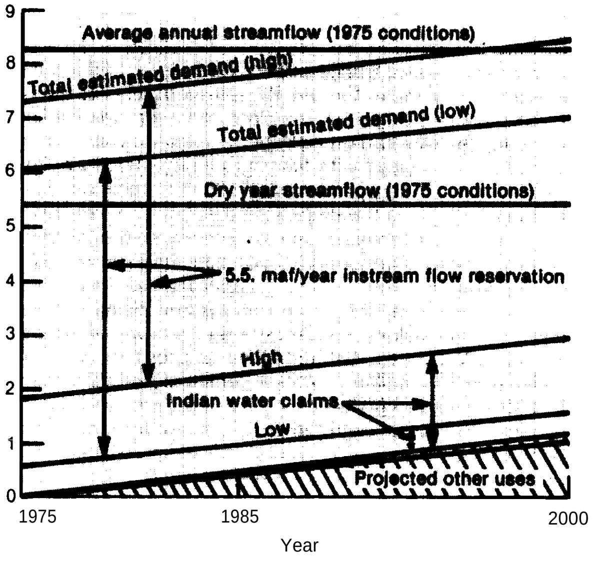
State water laws and statutory provisions in other Upper Basin States similarly could constrain water rights transfers to synfuels.11 As examples, water for irrigation takes precedence in these States over water for energy development, and the "public interest" is to be explicitly considered in approving water allocations. Alternatively, other laws could work to the disadvantage of nonenergy sectors, such as navigation in the Missouri region under the Federal Flood Control Act of 1944 (33 USC 701 -(b)).

Many of the water availability issues in the Missouri River Basin cannot be adequately evaluated because of a lack of supporting data and case law interpretations. Figure 27 illustrates the possible magnitude of uncertainty by superimposing the major projected consumptive uses (excluding synfuels) onto the availability of water in the Yellowstone River. As can be seen, assuming a low total estimated demand growth scenario, demands would not be met in a dry year without additional storage. Assuming a high-growth scenario, not only would demands not be met in a dry year without storage, but they would also exceed the average annual flow with additional storage.

Upper Colorado River Basin

Although water may not be available in certain tributaries and at specific sites, sources of water

Figure 27.–Streamflows and Projected Increased Incremental Water Depletions, Yellowstone River at Sidney, Mont.



SOURCE: "WaterAvailability for Synthetic Fuels," Wright Water Engineers, Inc., contractor report to OTA, June 5, 1981.

---

feet for the year 2020 in the Yellowstone. (U.S. Department of Interior, Water for Energy Management Team, Report *on* Water *for* Energy *in* the Northern Great Plains With Emphasis on the *Yellowstone* River Basin, January 1975.) A lower estimated value of 0.5 million acre-feet appeared in a 1960 background paper (for a larger framework study of the Missouri River Basin) by the Bureau of Reclamation. For a detailed discussion of Indian reserved water rights, the reader is referred to Constance M. Boris and John V. Krutilla, Water Rights and Energy Development in the *Yellowstone* River Basin, Resources for the Future, 1980.

[8] Wright Water Engineers, Inc., op. cit.

[9] Personal communications, Department of Natural Resources and Conservation, State of Montana.

[10] For a detailed discussion of State water allocation laws see Grant Gould, State Water Law in the West: *Implications* for Energy *Development,* Los Alamos Scientific Laboratory, Los Alamos, N. Mex., January 1979.

[11] Ibid.

generally exist in the Upper Colorado River Basin that could be made available to support OTA's low and high estimates of oil shale development through at least 1990. * However, the institutional, political, and legal uncertainties in the basin make it difficult to determine which sources would be used, the actual amount of water that would in fact be made available from any source to support synfuels development, and thus the water resource impacts of using any source for synfuels on other water users. Until major components of these uncertainties are analyzed quantitatively and start to become resolved, the extent to which synfuels production can be expanded beyond a level of several hundred thousand barrels/day (i. e., about 125,000 AFY) cannot be estimated with confidence.[12]

One potential source of water supply for synfuels is storage from Federal reservoirs. For example, approximately 100,000 AFY could be made available for synfuels from two Federal reservoirs on the western slope of Colorado (Ruedi and Green Mountain). However, the amount of water available is uncertain because of questions regarding firm yields, contract terms for water sales, which purposes are to be served by the reservoirs, competing demands, the marketing agent, and operating policy.

Under State water laws, water rights throughout the basin—in Colorado, Utah, and Wyoming—can generally be transferred (e. g., from agriculture) via the marketplace (i. e., sold) to synfuels developers who can afford to pay a relatively high price for water.[13] The degree to which developers rely on such transfers will determine the subsequent economic and social impacts on the users being displaced and, in turn, on the region. * The transfer process, however, is time-consuming and legally cumbersome, is constrained under State water law by the nature of the original right, and is subject to political and legal challenge.

Some provisions of the laws and compacts governing water availability to the States within the basin will not be tested and interpreted until water rights in the basin are fully developed. For example, procedures and priorities have not yet been developed for limiting diversions among the Upper Basin States when downstream commitments to the Lower Basin, under the Colorado River Basin Compact, cannot otherwise be met. There is also controversy about whether the Upper Basin States as a whole will be responsible for providing any of the 1.5 million AFY commitment to Mexico under the Mexican Water Treaty of 1944-45. Individual States within the basin, such as Colorado, have generally not yet developed procedures and priorities for internally administering their downstream delivery commitments for when the basin becomes fully developed; thus, the impacts of a State's allocation of available water to individual subbasins and users within that State, such as synfuels, cannot yet be determined. State water law also generally evolves through individual court cases, so that the cumulative effects of development are not known.

There are generally no institutional or financial mechanisms for obtaining water for synfuels, either through conservation or through increased efficiency in water use in other sectors, as in other parts of the country. In Colorado, for example, changes in agricultural practices to increase water efficiency are likely to be challenged legally, since downstream water rights appropriators are entitled to return flows resulting from existing albeit inefficient practices. It has been reported that basin exports for municipal uses could be reduced by as much as 200,000 to 300,000 AFY with improved water use efficiency.[14]

Other uncertainties that affect water availability for synfuels in the area include: Federal reserved water rights (e. g., for the Naval Oil Shale Reserve

---

*The low estimate for shale oil production in 1990 (see ch. 6) implies a range of annual water use of 20,000 to 48,000 acre-feet; the high estimate implies a range of 40,000 to 96,000 acre-feet. By 2000, annual water requirements would be, respectively, 50,000 to 120,000 acre-feet, and 90,000 to 216,000 acre-feet.

[12] Wright Water Engineers, Inc., op. cit.

[13] Gould, op. cit.

"irrigation requirements are determined by many factors, including climate, crop, irrigation methods, etc. Assuming that agriculture consumes 1.5 to 2.5 acre-feet/acre in the Rocky Mountain area, an average oil shale plant consuming 8,500 AFY would need to acquire water rights applicable to about 3,400 to 5,700 irrigated areas.

[14] Office of the Executive Director, Colorado Department of Natural Resources, The Availability of Water for Oil Shale and Coal Gasification Development in the Upper Colorado River Basin, Upper Colorado River Basin 13(a) Assessment, October 1979.

at Anvil Points, Colo.) have not yet been quantified; storage would have to be provided in the White River Basin (where the Uinta and Piceance Creek oil shale reserves are located) but prime reservoir sites are located in designated wilderness areas; there is as yet no compact between Colorado and Utah apportioning the flows of the White River; and in Colorado, in order to develop much of the deep ground water in the Piceance Basin, oil shale developers must prove that the ground water is nontributary, for which data are often lacking and difficult to obtain. The resolution of the uncertainties in the Upper Colorado could limit large-scale synfuels growth as illustrated in table 82, but "even at these highly aggregated levels for the entire Upper Colorado River Basin, the confidence limits or ranges that are placed on estimates of water availability are so broad that they tend to (overshadow) the amount of water needed for synfuels development."[15]

Table 82.—Preliminary Quantification of Uncertainties With Respect to Water Availability in the Upper Colorado River Basin

Annual amount available for consumption (millions of acre-feet)[a]		
	12.5 -15.2	Estimates of mean annual flow of the Colorado River at Lees Ferry
Subtract	7.5	Required delivery to the Lower Basin
	5.0 -7.7	
Subtract	0.75	Estimate of the Upper Basin's Mexican Treaty obligation
	4,25-6.95	
Subtract	.65	Estimated annual reservoir evaporation from Flaming Gorge, Lake Powell, and the Curecanti Unit Reservoirs
Total	3.60-6.30	
Annual projected consumptive demands (millions of acre-feet) In 2000[b]		
Total	4.10-4.78	(excluding synfuels)
Total	4.15-4.90	(including OTA low estimates for oil shale[c])
Total	4.19-5.00	(including OTA high estimates for oil shale[c])

[a] Does not make allowances for the quantification of Federal reserved water rights claims (the Naval Oil Shale Reserve at Anvil Points has claimed, for example, 200,000 AFY), the effect of potential environmental constraints (e.g., salinity control, protection of endangered species), or the availability of Federal storage.

[b] Estimates are for 2000 and exclude synfuels development (Colorado Department of Natural Resources, Section 13(a) Assessment of the Upper Colorado River Basin; 1975 estimate = 3.12 maf). Instream uses are not included.

[c] The low estimate for shale oil production in 1990 (see ch. 6) implies a range of annual water use of 20,000 to 48,000 acre-feet; the high estimate implies a range of 40,000 to 96,000 acre-feet. By 2000, annual water requirements would be, respectively, 50,000 to 120,000 acre-feet, and 90,000 to 216,000 acre-feet.

SOURCE: OTA based on Wright Water Engineers, Inc.

Wright Water Engineers, Inc., op. cit., p. IV-38.

Index

Index

U . S , GOVERNMENT PRINTING OFFICE : 1982 0 - 98-281 : QL 3