

Figure 1-5: Relative CO₂ emissions from combustion of various fuel sources.

Source: U.S., DOE, Asst. Sec. for Environment, Off. of Technology Impacts 1980, p. 5-32.

factors (e.g., coal combustion and deforestation) and mitigating measures (e.g., substitution of nuclear power and energy conservation) .

2.0 ARE THERE SIGNIFICANT ENVIRONMENTAL DIFFERENCES AMONG THE COAL LIQUEFACTION PROCESSES?

This section summarizes the variations in environmental impact that are related primarily to differences among coal liquefaction processes. Figures 2-1 and 2-2 are simplified diagrams showing effluent streams which must be dealt with in direct and indirect

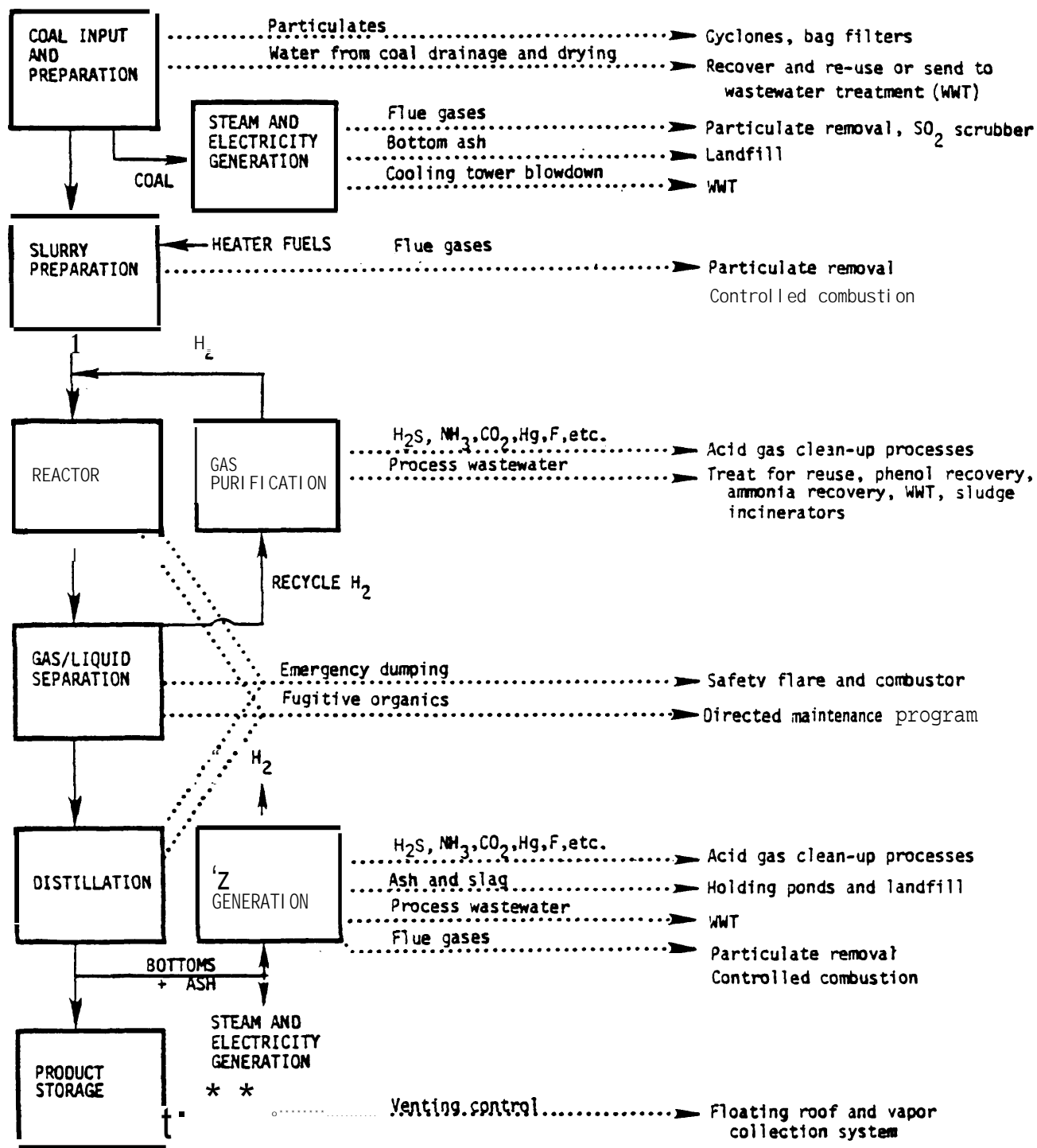


Figure 2-1: Simplified Direct Liquefaction Process-waste Stream Sources and Control

PROCESSES

EFFLUENTS.....➤

CONTROL

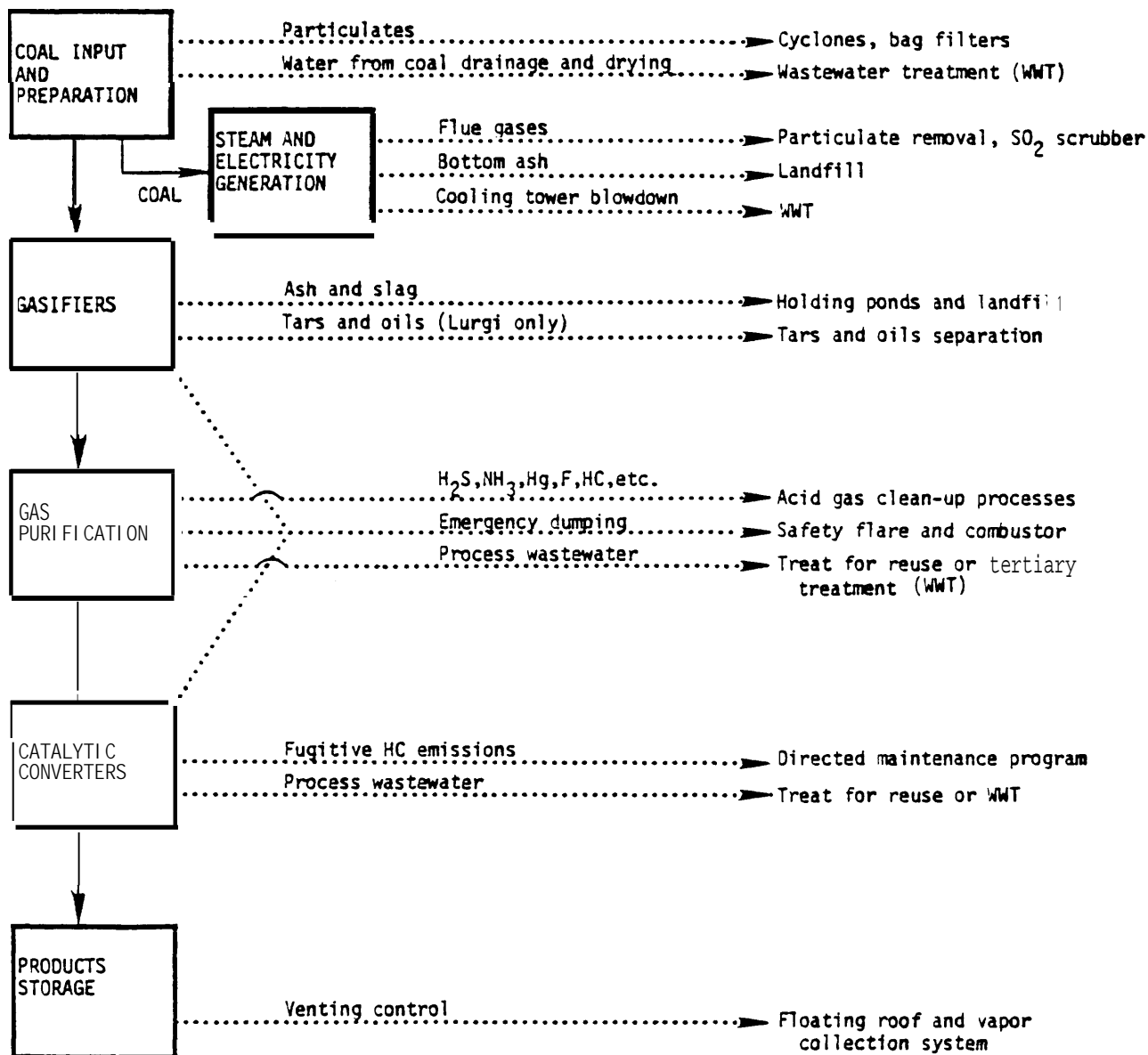


Figure 2-2 : Simplified Indirect Liquefaction Process-waste Stream Sources and Control

processes, respectively. While there are significant control process stream differences between the direct and indirect plants, both routes to liquid fuels must deal with the sulfur, nitrogen, and mineral matter in the coal feed. Potentially toxic hydrocarbons and deleterious oxygenated chemicals generated during processing which enter the gas or liquid effluent streams must also be controlled.

As indicated in the following subsection, important differences can be identified between the two major types of liquefaction technologies, direct and indirect. However, several factors complicate the comparison of technologies based on existing data, as described below:

(1) The environmental controls being planned for synthetic fuel plants are primarily based on utilizing technologies from the petroleum, utility, and similar industries, but (a) at present the designs are not final, and (b) there are important differences from this past experience. For example, the wastewater effluents from pilot plants have generally not been sent through a complete environmental control system such as those anticipated for commercial units. The waste streams of some plants have only been subjected to laboratory and bench-scale clean-up tests. Based on past experience, developers expect that extrapolation from bench-scale tests to commercial operations will not produce significant deviations.

However, several important differences can be found in coal liquefaction compared to previous refinery and petrochemical experience.

" Larger levels of trace elements emissions are involved; the fate and controls for emissions have not been determined, especially for direct processes;

- The problem of handling liquid streams containing large amounts of solids (mainly coal ash) presents mechanical design and operational difficulties because of pipe and valve erosion and the potential for flow blockage. This is primarily the case for direct processes (e.g., major problems of this type were encountered in the H-coal pilot plant);

- Large quantities of reduced sulfur compounds are produced which require handling; and

- The existence of large complex aromatic compounds in coal liquefaction process streams and end-products (especially for direct processes), some of which are known carcinogens, presents relatively unique problems. The coal tar industry has experience with such compounds, but under very different circumstances .

(2) Direct comparison of emission levels and control costs between different liquefaction processes is difficult because the bases and premises of the plant designs differ from one developer to another. As an example, the sulfur concentration in the coal feed is important. If a sulfur recovery system is designed to collect 99.8 percent of the sulfur, the effluent will have total sulfur emissions directly proportional to the sulfur in the coal; i.e., 5 percent sulfur coal will release 5 times more sulfur than a one percent feed. Costs may differ because of plans based on different choices of process steps (e.g., selection based on reputed higher reliability levels but at lower control levels). All these types of decisions are bound up in commercial plant designs so that the only valid comparisons between processes would be from designs which used the same bases for the different processes. Without that commonality, cross-comparisons can be highly misleading.

(3) Finally, although synfuel plants will be regulated under a large number of state and federal environmental laws, emission control standards are not yet developed. Plants are currently being designed with environmental controls that developers believe are adequate to obtain the necessary permits. At the same time, EPA and DOE are drafting Pollution Control Guidance Documents (PCGD's) which will provide recommended "guidelines" for the liquefaction technology prior to commercialization. These PCGD's are not legally binding for industry but are advisory for permitting and environmental impact statement review officials.

Given these three areas of uncertainty, analyses of environmental differences among processes must be made with caution. For example, although the literature may report different air emission levels for two different processes, these differences may not necessarily reflect basic differences in the processes. Rather, they might result from different assumptions about the controls applied or the coal characteristics, and from different methods of analysis. The following sections address whether or not differences exist among process types in the following categories:

- Air and water pollution levels under "routine" operating conditions;
- Potential accidents or "upset" conditions;
- Health risks; and
- Conversion efficiency and end-products.

2.1 EMISSIONS DURING "ROUTINE" OPERATING CONDITIONS

Air Emissions

Figure 1-3 given earlier shows the range, across five liquefaction processes (both direct and indirect) of emission levels of selected pollutants under normal operating conditions. The ranges in the data can be attributed to four factors:

- The different processes considered;
- Different sources for the data;
- Different assumptions about controls applied; and
- Calculations based on differing coal types (i.e., heat, ash, and sulfur content).

Despite these uncertainties, there do not appear to be major differences between the levels of "criteria" air pollutants emitted by the various processes under normal operating conditions. This conclusion reflects the fact that for all processes, the majority of gaseous emissions are produced in the auxiliary parts of the liquefaction system (i.e., coal handling, furnaces, boilers, acid gas treatment systems, etc.). These emission sources can all be handled by similar control techniques regardless of the process. The more important variables are coal type and the fuel used for auxiliary energy production (e.g., electric power production). In sum, it is not currently possible to distinguish among the technologies for these variables.

Water Effluents

For similar reasons there is also uncertainty about differences in wastewater pollution levels; in fact, the data on liquid

effluent levels is subject to even greater uncertainty than for air emissions. In its preliminary analysis of wastewater treatment for indirect processes, EPA concluded that water pollution control has been "neglected" in synthetic fuel analyses, producing large data gaps and an immediate need for demonstration of the technical and economic viability of effluent controls (Inside EPA, 1980).

Despite the uncertainties, important differences exist between direct and Lurgi indirect processes on the one hand and the remaining indirect processes on the other. These differences are due primarily to the fact that wastewater treatment for direct processes and the Lurgi indirect processes, unlike the others, require phenol separation and the handling of large quantities of complex organic compounds which are produced from the initial coal reactions. For these processes, estimated capital costs for wastewater treatment systems represents about **3 to 5** percent of total plant investment. In contrast, indirect processes based on Koppers-Totzek or Texaco gasification have expected capital costs for wastewater treatment of about two percent, or less, of total plant investment (U.S., EPA, Research Triangle Park 1981).

2.2 UPSET/ACCIDENT RISKS

In many cases of environmental analysis of synfuel plants, the pollution rates and subsequent impact analyses are based on levels that occur during "routine" or "normal" operating conditions. However, of equal environmental concern are the impacts caused by accidents or "upset" conditions.

When process upsets or emergencies occur, such as the blockage of a flow line, they will require the immediate venting of gases to relieve internal pressures and to prevent accidents. This venting will be done through a controlled combustor/flare system typically used in chemical and petrochemical plants. When this happens, normal pollution control systems are by-passed leading to higher emission rates of particulate, SO₂, unburned hydrocarbons, and other pollutants. To illustrate, Table 2-1 shows estimated SO₂ emission rates for the SRC II demonstration plant under upset conditions. A single occurrence of Case B would emit as much SO₂ in 2 hours as normally occurs during 4 to 10 days of operational Depending on how often they occur, such upsets could account for significant proportions of total emissions. And, the environmental impacts of such peak loadings could be greater than those occurring under normal conditions, although this question is seldom addressed in environmental studies. In the case of the SRC II demonstration plant, the flare stack will be about **235** feet high and in some events will emit a flame 100 feet wide and over 600 feet long.² Although the vent/flare system is designed to perform under these circumstances, if plants are located close to urban areas some psychological and aesthetic concerns may be raised.

Accidents and upsets affecting the wastewater treatment system can also occur; for example, surges of toxic compounds could kill

¹In some cases if incomplete combustion in the vent/flare system occurs, H₂S and hydrocarbons may also be released.

²The **flare** stack is **only** used when the rate of venting cannot be handled by the controlled combustor.

TABLE 2-1: ESTIMATED SO₂ EMISSIONS FROM THE FLARE IN THE SRC II DEMONSTRATION PLANT DURING UPSET CONDITIONS

Case	Event Description	Duration (hours)	SO ₂ Emissions (tons)
A	One coal dissolver blown down from normal operating pressure to near atmospheric pressure in 45 minutes.	3/4	1
B	Two gasifiers vented at full load upstream of purification.	2	12.9
c	One load dissolver at full rate without purification.	4	5.6
D	Two gasifiers at full rate and pressure. Blocked in and blown down in 5 minutes, bypassing purification.	1/12	.03

Source: Adapted from U.S., DOE 1980, p. C-57.

the organisms in biological treatment systems. Unless adequate capacity exists in wastewater holding ponds, such events could lead to the direct discharge of toxic effluents into surface streams.

Since no commercial size liquefaction plants have operated in the United States, there are no data to measure the frequency of upsets.¹ However, based on comparisons between direct, indirect, and petroleum refining processes, inferences can be drawn on relative frequencies. The greater complexity of the direct processes vis-a-vis the indirect routes suggests that the former would

¹Demonstration and pioneer commercial plants which involve scale-up risk, since their design is based on pilot plant information, can be expected to have more frequent upsets than future commercial plants whose design involves little or no scale-up risk.

encounter more frequent upsets. Similarly, direct process units, although similar to many refinery steps, would have greater frequency of upsets because of the high level of solids present in many of the streams.¹ Those solids may cause plugging and erosion which would not be encountered in refinery processing. There is a large economic incentive to minimize such upsets because reduced plant on-stream-time dramatically lowers the return on investment. Commercial plant constructors and operators would make use of all information to maintain high on-stream-times.

2.3 ENVIRONMENTAL HEALTH RISKS

Direct liquefaction processes, and to a lesser extent indirect processes based on Lurgi gasification, create significantly greater environmental health risks than other coal liquefaction processes. This stems from the complex organic compounds which are contained in the intermediate streams and high boiling point end-products of some of the liquefaction processes. In contrast, with indirect processes using entrained or fluidized bed gasifiers (such as Texaco, Koppers-Totzek, or Winkler) all the complex organic molecules are destroyed and converted to gas consisting primarily of hydrogen, carbon monoxide, carbon dioxides, water, and methane. Purified hydrogen/carbon monoxide mixtures are then catalytically converted to methanol, gasoline, or Fischer-Tropsch liquids, which

¹Some indication of the frequency of accidents in refineries can be obtained from reported fire losses. According to data reported by the American Petroleum Institute covering the 1975-79 time period, there were between 1.15 to 1.42 fires (with losses exceeding \$1,000) per refinery per year (API, 1977-80).

have health risks similar to currently used liquid fuels: toxicity upon ingestion or inhalation, and some risk of cancer upon repeated contact, ingestion, or inhalation.¹

On the other hand, indirect processes using Lurgi gasifiers produce a wider range of organic compounds including some heavy oil and tars that contain polynuclear aromatic hydrocarbons and amines that have been associated with carcinogenic and mutagenic activity. The compounds are present in product streams from the gasifier and enter into wastewater streams during gas purification. Direct processes produce much greater amounts of these polynuclear aromatic hydrocarbons and amines. These compounds are contained almost entirely in the heavy products end (above 650°F), including intermediate streams, waste streams, and end-products. Occupational and public health risks from exposure are created because these compounds can enter the environment in several ways:

- . Fugitive hydrocarbon emissions (i.e., leaks from valves, flanges, etc.);
- " Releases during plant accidents;
- Releases in wastewater;
- Direct contact with direct process end-products; and
- Combustion products from using direct process liquids.

Even if developers of synfuels are aware of these problems, and taking particular care to protect workers, the degree of risks are

¹**Cancer** risk from compounds in gasoline and Fischer-Tropsch liquids as compared to direct process liquids are substantially lower (see Background Report and further discussion in this section). However, the range of the common compounds in gasoline, such as benzene, are implicated in elevated cancer rates (see Kingsbury et al. 1979).

highly uncertain at the present time. The principal issues are:

- What fractions pose the greatest health risks?
- What are the types and degrees of risk?
- What are the possible mitigating measures? and
- What differences occur among technologies?

In order to answer these questions, systematic laboratory testing of process streams, plant emissions and effluents, and end-products is needed. The outcome of a program of initial biological screening tests could be available during the next several years. However, long term clinical or epidemiological data is always likely to be inadequate to substantiate human health risk (see Section 4).

One of the greatest environmental health concerns is the release of these highly toxic substances through "fugitive hydrocarbon emissions" (i.e., emissions from leaks in valves, flanges, pump seals, process drains, etc.).¹ This is a particular concern for direct processes because of the polynuclear aromatic hydrocarbons and amines in many of the process streams. Studies of existing oil refineries have shown high levels of nonmethane hydrocarbon (NMHC)²

¹The concentration and fate of toxic and carcinogenic materials in these fugitive emissions is uncertain. According to several studies, only liquids boiling above **650°F** showed carcinogenic activity (see Background Report). Just what fraction of such a stream leaking from a valve would vaporize into the air or drip onto the ground is uncertain. The possibility is that both air and surface water pollution could result.

²**Nonmethane** hydrocarbons is a very broad spectrum since it includes every hydrocarbon from ethene and ethylene on up to asphalts (i.e. , it is everything other than methane itself) . Therefore levels of NMHC has no direct relationship to concentrations of carcinogenic hydrocarbons. For example, leaks from propane storage would yield high NMHC values in the complete absence of **car-**
cenogenic or mutagenic compounds.

fugitive emissions implying that a potential for human exposure to these hydrocarbons exists. However, coal synfuel developers believe that such emissions can be substantially reduced through a "directed maintenance program." For example, for the SRC II demonstration plant it is estimated that 679 tpy of fugitive NMHC's will be emitted in an "unmitigated" case, but only 97 tpy with a "directed maintenance program." All developers contacted (represented by the six coal conversion technologies identified) are committed to such a program. However, what constitutes a directed maintenance program has not been rigorously specified, but generally it would require systematic monitoring for leaks and repairing those that exceed certain levels. To what extent such a program would reduce fugitive emissions and their associated risks is still unclear except that theoretically it would represent an improvement over conventional refinery practices.

2.4 PRODUCT AND CONVERSION EFFICIENCY DIFFERENCES

Differences in the products and in the conversion efficiency of various liquefaction processes can result in very different environmental impacts. For example, if two processes produce the same product but one has a higher conversion efficiency, then it will, on a per-unit-of-energy basis, cause fewer impacts associated with mining and liquefaction. Direct comparisons generally are not possible, however, because of uncertainties in the data (i.e., on energy conversion efficiency) and because of the wide range of products produced. Some processes produce all transportation fuel,

such as the Mobil Methanol-to-Gasoline (MMG) process, whereas other processes produce more fuel oil suitable for stationary boilers. In addition, the MMG and methanol processes do not require any further refining step, whereas such refining is generally required with the direct processes to produce transportation fuels.

Figure 2-3 summarizes the product distribution from the six kinds of coal liquefaction processes. The proportion of each type of product can be varied somewhat; the proportions shown are those currently planned for demonstration and commercial plants (Rogers and Hill 1979). As shown in Figure 2-3, the indirect processes produce a much higher proportion of transportation fuels than the direct processes, which produce primarily heavy fuel oils. The direct processes can be adjusted to produce a higher fraction of transportation fuels; for example, the EDS process could be modified to shift the proportion of fuel oil from about 52 to 33 percent, with an attendant increase in naphtha and lighter fuels (Epperly, Plumlee and Wade 1980), but with a decrease in total throughput and thermal efficiency (see Figure 2-4).

In order to compare processes, Figure 2-5 gives three different bases¹ for comparing the "efficiency" of the six processes being

¹No single measure of energy efficiency is adequate; these three measures were chosen to illuminate the range of important considerations. However, even these three measures are inadequate in that they do not explicitly take into account (a) the differences in engine efficiency that different fuels might yield; for example, differences in miles per million Btu's between gasoline and methanol; and (b) energy requirements for additional refining (if any -- see Section 2.5). In addition, efficiency calculations do not reflect the differences in fuel quality that two different processes might produce (e.g., middle distillates from Fischer-Tropsch are more suitable for producing diesel and jet fuels than similar fractions from direct processes).

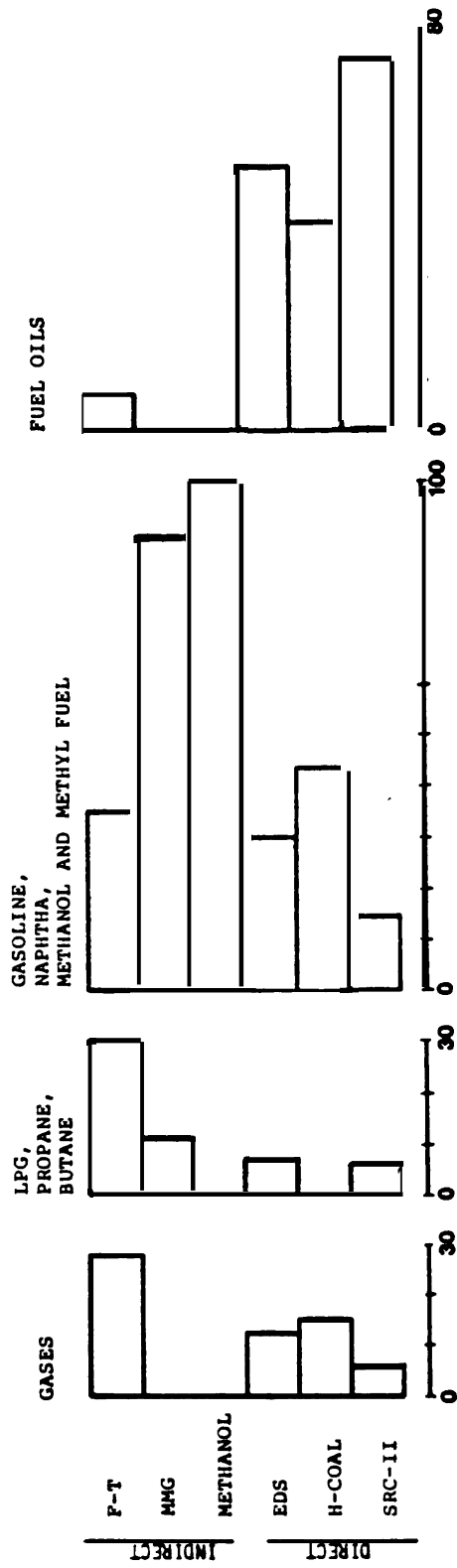


Figure 2-3: Comparison of product outputs.
 (product shares in percent on
 a Btu basis)

Source: Perceived from Rogers and Mill 1979

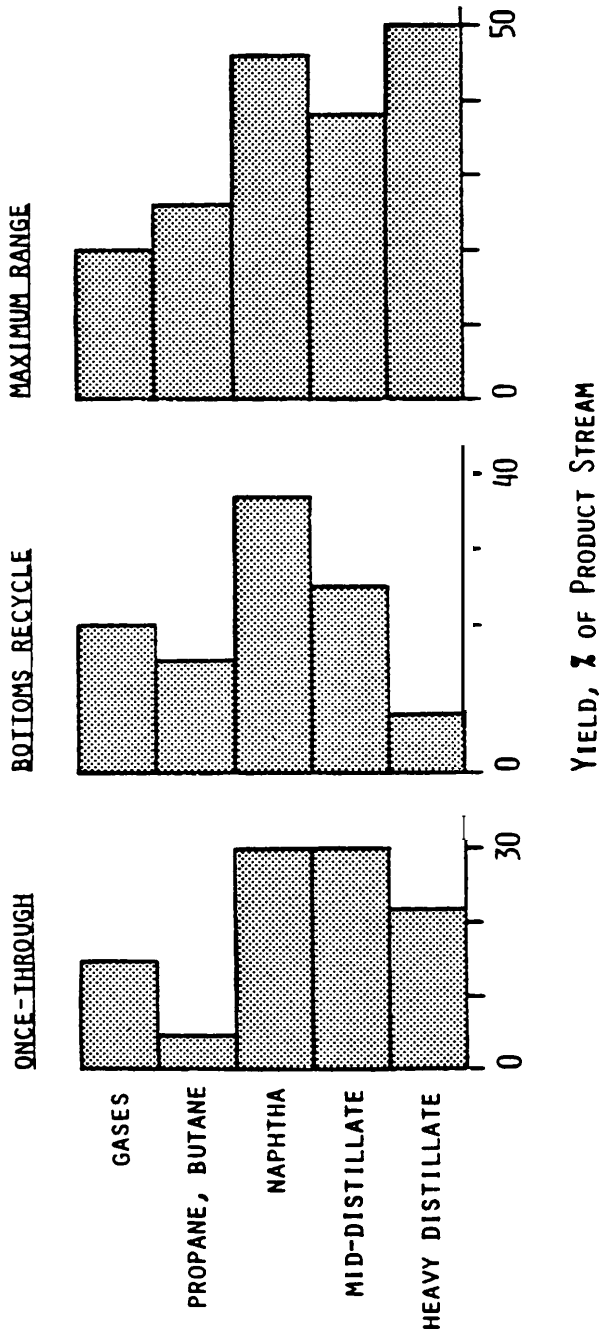
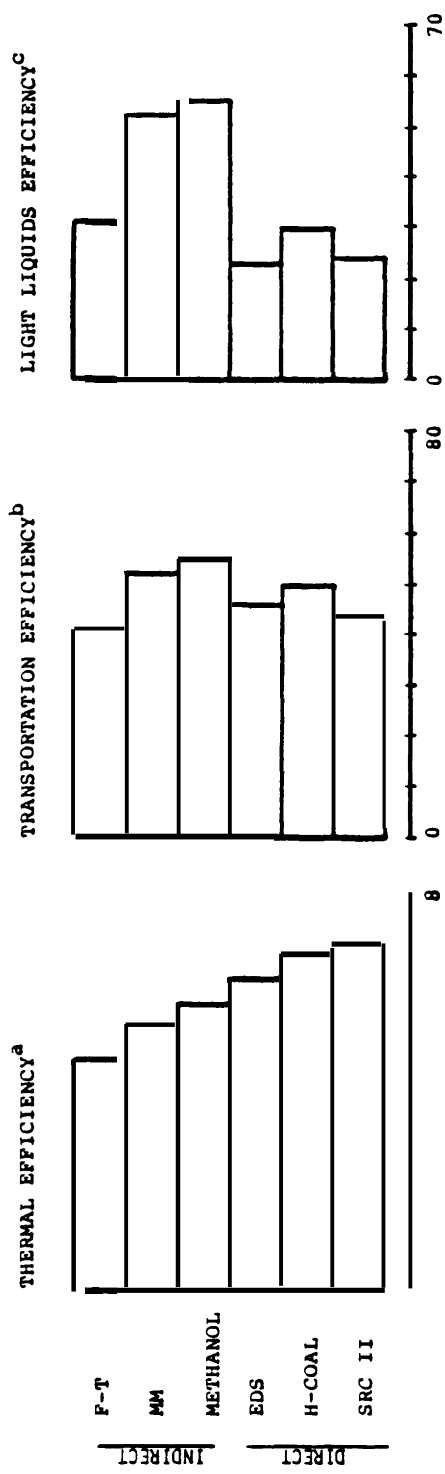


Figure 2-4: Range of Product Outputs from the Exxon Donor Solvent Process

Source: Adapted from Epperly, Plumlee and Wade 1980.



^aTotal hydrocarbon energy/total plant input with steam and electricity produced onsite.

^bAs in ^a, with total HC input corrected to indicate costs for upgrading to transportation fuel (gasoline grade) from the heavier fuel fractions.

^cAs in ^a, but include only hydrocarbons for transportation: propane, butane, LPG, me , naphtha, and No.2 Oil.

Figure 2-5: Comparison of Conversion Efficiencies

considered. The first bar graph shows overall percent thermal energy efficiency (i.e., total Btu's output divided by Btu's of energy input) . This comparison shows that the direct processes are substantially more efficient, ranging from the 69 percent SRC II process to the 46 percent Fischer-Tropsch indirect process.

Accordingly, it would require 50 percent more coal, with all its attendant environmental and human health and safety impacts, **to use** Fischer-Tropsch process instead of the SRC II process for an equivalent Btu value of output.

At the other extreme, the "light liquids efficiency" is an index that only measures the thermal efficiency for producing fuels that can be directly used for transportation purposes with little or no upgrading. This includes the propane, butane, LPG, naphtha, and No. 2 fuel oil fractions. In this case methanol and methanol-t o -gasoline have the highest efficiency, and the EDS and SRC II processes compare unfavorably. On this basis these latter processes would require two to four times the plant capacity to produce an equivalent amount of fuel that could be easily used by the transportation sector.

A third means for directly comparing these various processes is "transportation efficiency" represented by the middle bar graph of Figure 2-5. This "transportation efficiency" index is based on the Btu output of liquids, weighted against a value scale based on the economic cost of transforming that liquid to a high grade transportation fuel. For example, unleaded premium gasoline is weighted 1.0, the more efficient fuels of butane and propane are weighted

1.08 and 1.07 respectively (see Background Report, and Rogers and Hill 1979). Fuel oil is penalized, with a weighting of 0.56. Although the weights are based on economic costs and prices, they provide an approximation of transportation energy value of the product mixes at the liquefaction stage. When compared to thermal efficiency, the transportation efficiencies are lower across the board, reflecting the relative energy cost of upgrading coal liquids to transportation fuels. Methanol and methanol-to-gasoline processes have the highest "transportation efficiency, " (54.6 percent and 52.2 percent, respectively), while Fischer-Tropsch and SRC II have the lowest (41.5 and 44.2 percent, respectively).¹

2.5 UPGRADING AND REFINING

Comparison among the coal liquefaction processes should take into account the demand for the various products, and the feasibility and efficiency of refining and upgrading to meet market needs. From an environmental perspective, important factors include:

- . How efficient will be the refining process to produce transportation fuels;
- Will grass roots refining capacity be needed; and
- What types of refinery impacts may occur.

The two classes of coal liquefaction processes have different refining needs. The MMG process produces a product directly usable

¹This comparison does not consider the superior quality of diesel fuel from the **Fischer-Tropsch** process compared to similar fractions from direct processes. Thus, **Fischer-Tropsch** may not be distinguishable from other processes in about the 45 percent transportation efficiency range.

as transportation fuel. The Methanol process can be considered to manufacture a blending stock for transportation fuels used in conventional engines, a feedstock for the MMG process, or pure ethanol to be used directly in appropriately modified engines. For these technologies, the conversion efficiencies described in the previous section represent the efficiencies for final products. For the Fischer-Tropsch process, a low octane gasoline (unsuitable for motor fuel unless upgraded) is a major product along with other transportation fuels such as diesel fuel. As indicated previously, some fuel oils are produced by the Fischer-Tropsch process which would require cracking and reforming to make transportation fuels.

The direct coal liquefaction processes produce light, middle, and heavy distillate fractions, with proportions varying depending on the specific process type and the amount of "recycle" or the residence time liquids spend in reactor vessels. The light distillate or naphtha fractions of direct processes make good gasoline blending stock after reforming. The EDS and H-coal processes can produce up to two-thirds naphtha and one-third fuel oil to maximize liquids with transportation value. The SRC II process, as indicated earlier, produces a greater amount of heavy products, although its product slate is also variable. In all cases, however, significant refining of the range of liquids is required to produce high proportions of transportation fuels. Because of the extensive refining requirements, including large hydrogen requirements, refining to transportation fuels is an energy intensive process. Table 2-2 indicates the efficiency of refining SRC-II liquids to

TABLE 2-2: EFFICIENCY OF REFINING SRC-II LIQUIDSa

Refinery Characteristics	Total Input Btu Requirement ^b (10 ⁶ Btu/day)	Product Output ^c (10 ⁶ Btu day)		
		Gasoline	Jet Fuel	Efficiency
High severity hydrotreating	356,483	75,260	204,060	78.4
Intermediate severity hydrotreating	347,697	89,967	88,243	80.0
High severity hydrotreating and fluid catalytic cracking	352,423	265,000	--	75.2
Intermediate severity hydrotreating and single stage hydrocracking	335,524	265,000	--	79.0

^aRefinery characteristics and data from Frumkin and Sullivan 1980.

^bIncludes a composite of SRC II syncrude, boiler fuel and electricity. SRC syncrude = 5.76 x 10⁶ Btu/bbl; boiler fuel = 6.2 x 10⁶ Btu/bbl; electricity = 10.5 x 10⁶ Btu/MW. See Background Report.

^cGasoline = 5.3 x 10⁶ Btu/bbl; jet fuel = 5.7 x 10⁶ Btu/bbl.

gasoline and jet fuel. The low efficiency range, from about 75 to 80 percent, reflects the extensive cracking and hydrogenation requirements to upgrade these liquids.

The energy efficiency of refining improves as additional fuel oil remains in the product output (Frumkin and Sullivan 1980). Based on discussions with staff of direct process developers, they expect to utilize naphtha fractions as a gasoline blending stock and use heavier fractions to back out petroleum as a boiler fuel (Gulf Mineral Resources Co. 1980; Exxon Research and Development Corp. 1980; and Hydrocarbon Research Corp. 1980). In addition, environmental impact statement documentation for SRC II and SRC I facilities indicates that middle and heavy fractions will be used for boiler fuels (U.S., DOE 1981a, 1981b).

For these reasons, over the short term, environmental disturbances from additional refinery requirements for both direct and indirect coal liquids appear to be minimal. However, over the longer term if demand for transportation fuels cannot be met by petroleum liquids, refining direct process liquids to transportation fuels may be more favorable (Chevron Research 1981). Under these circumstances the most efficient refining operations for direct liquids would be from new grass roots refineries (Frumkin and Sullivan 1980) and refining coal liquids may be a significant environmental issue. Many of the issues are closely related to those for the liquefaction process itself, such as concerns about air and water quality, siting, and health considerations. The liquefaction processes can be ranked generally on the basis of