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VERIFICATION OF THE FOREIGN SYNFUELS INDUSTRIALIZATION EXPERIENCE
FINAL REPORT

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1.0 SUMMARY

Radian Corporation, the Institute of Gas Technology (IGT), and Resource Planning Associates (RPA) have conducted a survey of foreign commercial gasifiers for the U.S. Department of Energy (DOE), Office of Resource Applications, under DOE Contract No. DE-AC01-80-RA-5006. The purpose of this effort was to provide DOE with information on the type of data that is currently available from the foreign commercial gasifier experience. From this program effort, the potential availability and value of data from foreign facilities to the U.S. synfuels development effort may be assessed by DOE. The specific objectives of this program were to develop and verify a master list of commercial gasifiers operating in foreign countries and to conduct two case studies (site visits) of specific facilities.

The list of operating foreign gasifiers is presented in Appendix A of this report. The master list contains facilities which are currently operating or have been shut down for less than five years. For this study, it was assumed that facilities which have been shut down for a period greater than five years would not represent viable sources of information. This list represents the set of sources from which gasifier operation information is potentially available. Comments on this master list are as follows:

- The list (excluding facilities under construction) contains 61 foreign gasifier facilities: 8 based on Lurgi technology, 10 on Koppers-Totzek, 10 on Winkler, 12 on Wellman-Incandescent, 6 on Wellman-Galusha, 10 on Woodall-Duckman, 3 on Riley Morgan, and 2 on Stoic.
- The following foreign countries have coal gasification plants in operation: Bulgaria, Czechoslovakia, East Germany, Greece, India, Portugal, South Africa, Thailand, Turkey, the U.S.S.R., Yugoslavia, and Zambia.

- Presently, Brazil, China, India, Poland, and South Africa have gasifiers under construction or on firm order.

- South Africa is by far the country with the largest number of gasification facilities. India and East Germany follow South Africa in the number of operating facilities.

- The most active ongoing development of new technologies is found in West Germany, the United Kingdom, and the United States.

A key point in the selection of the case studies for this program was that the United States has obtained and is presently obtaining sufficient commercial experience with the smaller industrial-type gasifiers. However, no commercial experience exists with the larger synfuel-type gasifiers best represented by the latest Lurgi or Koppers-Totzek gasifiers (originally developed in West Germany and presently operated in South Africa and India). The case studies conducted for this program were for the Lurgi gasifiers at Sasol I and II and the Koppers-Totzek gasifiers in Modderfontein, South Africa.

General comments on the type of information made available during these site visits are as follows:

- Information on the general process design, including feedstock, and on the design philosophy (e.g., multiple trains) was made available and discussed.

- Earlier operational problems and current basic problems, such as coal fines content or troublesome components, were discussed with the facility operators.

- Detailed operational parameters such as start-up/shutdown procedures, actual steam or oxygen consumption, overall thermal efficiency, and detailed maintenance schedules were not available. In general, <u>all</u> detailed experience which was reflected in quantitative design parameters <u>was</u> considered proprietary information.

- Since both South African plants are operated by publicly held companies, general economic and financial information on horizontal and vertical integration, capital structure, capital costs, accounting standards, tax laws, etc., have been made available. However, the translation of such data to an application in this country is not straightforward.

Based on the information obtained during the Sasol and AECI case studies and the team's analysis of translatability and usefulness of that information to the U.S. synthetic fuels efforts, the following conclusions have been drawn:

- The choice between Lurgi and Koppers-Totzek gasifiers for any planned facility is mainly determined by the coal feedstock and, to a lesser degree, by the synthetic gas usage and plant size. Both processes can be applied usefully in this country.
- Coal-connected start-up and operating problems to be expected in U.S.-built gasification plants are comparable to those of a conventional coal-fired power plant, with the additional complication of multi-unit design typical for petroleum refineries.
- Because of the variability of gasifier performance with coal feedstock, no coal gasification plant based on a commercial technology should be erected in the United States without intensive, full-scale testing of the proposed feedstock in existing commercial plants. This front-end investment historically appears to have paid off.
- Additional case studies appear to be worthwhile only when the coal feedstock proposed for a planned facility is similar to that used at an existing facility. In this case, the operating experience of the existing commercial facility will be a valuable source of information to the designers and planners of the proposed facility.

- Capital costs for the first plants of a new technology are likely to be significantly underestimated. The cost estimates for the second and third plants of a given new technology, however, are likely to be much more accurate owing to the experience gained during construction and operation of the first plant.

- After the first government-assisted plant is built in the United States and proven feasible, traditional forms of debt and equity financing will become available for second and third generation plants. The Sasol I plant was not a profitable operation at first, but now has become a formidable cash generator. Sasol I's success and the prospects for Sasol II and III have enabled Sasol to raise substantial funds in the open equity markets.

2.0 INTRODUCTION

One of the principal barriers to rapid commercialization of low- and medium-Btu gasification in the United States is the lack of operating experience in the U.S. industrial environment. The Department of Energy has considered different methods for addressing this problem. One possibility is the development of a data base of worldwide gasifier operations information. However, a critical aspect in the development of such a data base is the availability and value of information from foreign gasifiers.

On 24 September 1980, the Department of Energy awarded Contract No. DE-AC01-80-RA-5006 to Radian Corporation (as prime contractor) and the Institute of Gas Technology and Resource Planning Associates (as subcontractors) for a program entitled "Verification of the Foreign Synfuels Industrialization Experience." The objective of this program was to determine the type of information that could be obtained from the considerable foreign experience with development and commercial operation of coal gasification facilities and how this information applies to U.S. operations.

To achieve this objective, the program involved documenting and verifying the extent of operating coal gasification facilities throughout the world and then conducting two case studies of specific facilities to determine the extent of cooperation and information (operational, economic, and environmental) that could conceivably be made available to the United States. Issues such as how this information would translate from the foreign experience to U.S. operations and how it would apply to domestic coal gasification industrialization efforts were also to be assessed. This document represents the final report for this project.

The program was performed as five basic steps, or tasks. These tasks were:

(1) Documentation and verification of a master list of coal conversion facilities in operation throughout the world.

(2) Development of a basis for comparison of these facilities with expected requirements in the United States.

(3) Categorization of worldwide facilities for selection of case studies.

(4) Selection and performance of two case studies.

(5) Analysis of how information available from foreign experience can enhance the U.S. coal conversion industrialization program.

The information gathered and the assessments made in this study are presented in the following order:

- Master List of Foreign Coal Gasification Facilities (Section 3.0)
- Basis for Comparison Between Foreign and U.S. Facilities (Section 4.0)
- Categorization of Foreign Facilities for Selection of Case Studies (Section 5.0)
- Case Studies (Section 6.0)
- Conclusions and Recommendations (Section 7.0)

3.0 MASTER LIST OF FOREIGN COAL GASIFICATION FACILITIES

The development and verification of a master list of operating foreign commercial gasifiers was the first task in this program. The term "commercial gasifiers" implies that these plants operate primarily for the purpose of providing low- or medium-Btu gas for commercial applications. This excludes pilot and product development units which operate as part of a process development program. The master list is presented in full in Appendix A. References that were used to prepare the master list appear in the Bibliography.

The information initially sought in compiling the list included:

- Facility location,
- Gasifier make and number of units,
- Vendor or engineers,
- Special design features,
- Installation date,
- Last date of operation,
- Coal type,
- Product gas (application), and
- Capacity per unit.

The approach used in developing the master list was to first utilize available lists from previous studies and gasifier vendors. An initial master list was developed which contained all major gasifiers which have been in operation between 1935 and the present. Early gasifier types, such as "blue water gas" generators, were not included due both to their large number and lack of relevance to current synfuel developments. This master list covered more than 200 foreign plants and included the following gasifier types: Wellman-Galusha, Riley-Morgan, Wilputte, Woodall-Duckham, Wellman-Incandescent, Foster-Wheeler-Stoic, Lurgi, Winkler, and Koppers-Totzek. This initial list was then verified via contacts with designers, vendors, international organizations, and selected foreign contacts. Appendix B presents a list of all contacts made by the project team.

From this cross-checking and verification effort, the extended list was refined to represent "verified information." The master list contains facilities which are currently operating or have been shut down for less than five years. For this study, it was assumed that facilities which have been shut down for a period greater than five years would not represent viable sources of information.

Comments on the compilation of the master list are as follows:

- All information presented in the master list has been cross-checked for verification. In assembling the master list, emphasis was placed on information from direct contacts. These sources were believed to have the most accurate and up-to-date information.
- The most valuable information came from developers of the pertinent gasification technologies. However, even these companies often had little knowledge about the present status of their plants--especially in the Eastern Block. In some cases, plants were still in operation, but were no longer using coal feedstock. Licensing companies had little up-to-date information. Sometimes, dates of order and dates of installation were confused.
- Only about 25 percent of all agencies contacted responded. The list has been updated throughout the project as additional information became available.

- Almost all responses did not cover the full range of information requested. This is understandable considering the amount of work involved to collect the requested data. In most cases, the response consisted of existing tables and other material used mostly for marketing purposes.

A synopsis of the information presented in the master list is as follows:

- The following foreign countries have coal gasification plants in operation: Bulgaria, Czechoslovakia, East Germany, Greece, India, Portugal, South Africa, Thailand, Turkey, U.S.S.R., Yugoslavia, and Zambia.
- West Germany and Great Britain have apparently mothballed their older Lurgi and Winkler-type plants; however, both countries are actively pursuing newer developments in gasification (e.g., U.K. development of the Slagging Lurgi at Westfield, West German Lurgi developments at Luenen).
- The list (excluding facilities under construction) contains 61 foreign gasifier facilities: 8 based on Lurgi technology, 10 on Koppers-Totzek, 10 on Winkler, 12 on Wellman-Incandescent, 6 on Wellman-Galusha, 10 on Woodall-Duckham, 3 on Riley Morgan, and 2 on Stoic.
- South Africa is by far the country with the largest number of gasification facilities. India and East Germany follow South Africa in the number of operating facilities.
- Gasifiers under construction are presented at the end of the master list. Presently Brazil, China, Poland, India, and South Africa have gasifiers under construction or on firm order.

4.0 BASIS OF COMPARISON BETWEEN FOREIGN AND U.S. FACILITIES

In order to select two case studies from the master list of foreign gasifiers, it was necessary to develop a basis for comparing the foreign experience with U.S. domestic environment. This task proved useful for two reasons:

- The comparison basis prevented the selection of gasification facilities that are operating in environments so different from the United States that the information obtained would not be translatable and of limited usefulness.
- For those gasification facilities that were selected, the comparative basis information alerted team members to the special circumstances that existed at the foreign facilities and allowed them to obtain the ancillary information that is required to translate the case study information to U.S. applications.

The information developed under this task is divided into two general categories: (1) a generic analysis of the design, construction, and operating factors that apply to plants built in foreign countries and the United States and (2) a country-by-country overview of economic and political factors that are involved in the decision to build large commercial industrial facilities. This analysis was performed for each country with gasification facilities which were candidates for a case study.

The information presented in this section is a summary of similarities and differences in design, construction, and operating practices between foreign and anticipated U.S. synthetic fuels plants. It was not possible to develop a direct comparison of foreign and domestic coal conversion practices because of the lack of operating coal gasification facilities in the United States. However, data from other process industries (notably the hydrocarbon and chemical process industries) can be used to establish how foreign facility information translates to U.S. operations. The information discussed below concerning construction codes, equipment sparing philosophy, plant capacities, length of work week, and plant logistics was chosen because of its particular relevance to the U.S. industrial environment.

An expanded discussion of the design, construction and operating factors, and country-by-country economic and political overviews can be found in Appendix C.

Construction Codes

There are numerous codes involved in the construction of a major engineering project such as a coal gasification plant. Prominent codes in the United States are the Uniform Building Code and the ASME (American Society of Mechanical Engineers) Pressure Vessel Code. Major foreign codes are those of DIN (Deutsches Institut für Normung e.V.) and ISO (International Organization for Standardization). In this analysis, international earthquake-resistant regulations were investigated in an attempt to obtain an indication of the variability of building codes throughout the world.[33,34,35] The 15 countries that were analyzed are listed in Table 4-1, along with the calculated design factor C (the numerical coefficient for base shear as described by the equation $F = CW$, where F is the total earthquake force at the base of the structure and W is the total vertical load considered for the seismic calculation assuming a zone of greatest earthquake potential). The mean for this sample of countries is 0.17, with a standard deviation of 0.05. These countries were grouped by their status as developing or developed countries, and the distributions of C coefficients compared. At the 90 percent confidence level, it cannot be concluded that there is a difference in the mean C values of the two types of countries. Thus, a case should be stated that the building codes

Table 4-1

BASE SHEAR COEFFICIENTS FOR SELECTED COUNTRIES

Country	Coefficient, C
Bulgaria	0.24
Canada	0.21
France	0.20
Federal Republic of Germany	0.10
Greece	0.16
India	0.16
New Zealand	0.23
Portugal	0.20
Rumania	0.15
Spain	0.21
Turkey	0.15
U.S.S.R	0.10
United States	0.11
Venezuela	0.15
Yugoslavia	0.12
Mean	0.17
Standard Deviation	0.05

in developing countries are not different than those of developed countries.

Equipment Sparing

Typical U.S. process plants spare important equipment such as pumps and compressors. The spare may be a complete back-up or some percentage of total capacity (e.g., 50 percent for a pair of pumps). Large pieces of equipment are generally not spared, although spare parts may be incorporated (e.g., a spare rotor may be specified for a centrifugal compressor).[36] Large international plant designs probably adhere to this same philosophy on sparing. The Westfield, Scotland gasifier of the British Gas Corporation required two percent of its total capital costs for spare equipment.[37] In developing countries where capital is usually scarce, such as India, less sparing of equipment would be expected. This lack of capital is evidenced in countries with high rates of interest, e.g., in Taiwan, where interest rates have reached 30 percent.[38] It appears that developed countries have a sparing philosophy similar to the United States and designs would translate 1:1. On the other hand, designs in developing countries may specify fewer numbers of spares compared to standard U.S. design practices because of the apparent lack of capital. This would indicate longer periods of downtime for gasifiers in developing countries relative to the United States.

Plant Capacities

In 1972, a published report stated that "typically, plants in less developed countries operate at five to ten percent of the scale of internationally competitive plants. The plants in less developed countries are of small design capacity and, in addition, they are underused."[39] Therefore, in this study, the capacities of projects for refineries, ammonia plants, ethylene plants, and methanol plants currently under construction or otherwise planned for developed and developing countries were analyzed.[40] Plants smaller than internationally competitive sizes usually produce a more expensive product, although they may be easier to operate.

- No difference could be found at the 90 percent confidence level for planned refinery capacities in either developed or developing countries, or the United States. The mean capacity for 20 refineries in developing countries is 17,000 m^3/day (107,000 bbl/day); for the 13 refinery projects in the United States, the mean capacity is 11,500 m^3/day (72,000 bbl/day).

- For ammonia plant capacities, a statistically significant difference at the 90 percent confidence level was found for the 12 plants in developed countries and the 63 plants in developing countries. The mean capacity for a plant in developed countries is 1,130 metric tons (1,250 tons) of ammonia per day compared to 875 metric tons (910 tons) per day in developing countries. The optimal size in India is reported to be 910 metric tons/day (1,000 tons/day).[14]

- For the 49 ethylene plants planned or under construction in the world, there were no significant differences in mean capacities for developed or developing countries, or the United States. World average plant capacity is about 281,000 metric tons (310,000 tons) per year.

- A significant difference was found in the mean capacities of methanol plants at the 90 percent confidence level. Average capacity for 24 plants in developing countries is about 580 metric tons (640 tons) per day of methanol; for 7 plants in developed countries, the mean is 1,540 metric tons (1,700 tons) per day.

From this analysis, one is inclined to say that average plant capacities are smaller in developing countries than in the United States. However, using 1980 data, no large differences in sizes as reported in Reference 39 were detected.

Length of Work Week

The average number of hours worked per week during 1977 in manufacturing for 23 developed and 28 developing countries was compared; a statistically significant difference was discovered at the 90 percent confidence level.[42] The mean for developed countries was 38.6 hours/week compared to 44.2 hours/week for developing countries. If shorter work weeks prevail for gasification plants in the United States and developed countries, a greater number of work shifts per week will be required for round-the-clock operation. Exactly 4.2 shifts are required for continuous operation and 40-hour work weeks. Four- and five-shift systems are common for power generation in developed countries. A report by the International Energy Agency suggests a four-shift system for a coal gasification system in a developed country.[43]

Plant Logistics

Coal gasification plants can be located next to the mine that serves them or remote from it. Minemouth siting of a plant reduces transportation costs of the coal. The Westfield, Scotland gasification plant is situated adjacent to a coal mine. Because the plant is located in a rural area, there has been some difficulty in obtaining the required number and quality of workers.[37] This is also expected to occur in western regions of the United States. The lack of manpower can be mitigated by importing workers; this practice translates into additional capital expenditures for housing and support services.

Depending on product application, plant size, and available transportation facilities, coal gasification plants proposed for the United States are often sited adjacent to a mine. A 1977 sampling of electric utilities projects showed that eight percent of the planned coal-fired plants were located at the minemouth.[44] Electric power plant practice is not directly applicable to potential gasification plants because power plants tend to be sited as near as possible to the load center they serve. This may not be as crucial for gasification plants.

5.0 CATEGORIZATION OF FOREIGN FACILITIES FOR SELECTION OF CASE STUDIES

The main objective of this program is to collect information on the foreign coal gasification experience for possible application in the United States. The most detailed information is expected from the two case studies to be selected in this task. As a general guideline, it can be assumed that case studies on processes unfamiliar to U.S. industry are of greater information value than those on processes utilized in this country. Therefore, in choosing facilities for the actual case studies, the master list of foreign gasifiers was assessed to determine the types of coal gasification processes which show the greatest potential for U.S. application.

5.1 Gasifier Groupings

All coal gasification processes can be characterized by the following factors:

(1) Application,

(2) Capacity,

(3) Development history, and

(4) Operational mode.

Applying these factors together, all currently operating gasification plants worldwide can be separated into two basic groups:

- Small, Industrial Gasifiers - These gasifiers are almost exclusively used for space or material heating in steel plants, brick or glass factories, and similar industries. The capacity of industrial gasifiers is limited to 91 metric tons/day (100 TPD) coal input. Historically, these gasifiers have not seen major development over the last 40 years; i.e., they did not grow from one model to the next model. In the normal operational mode, industrial gasifiers are air blown, low-Btu, fixed bed gasifiers, operating at atmospheric pressure. Both single- and two-stage fixed bed gasifiers are used for industrial applications.

- Medium to Large, Synfuel-Type Gasifiers - The application of these gasifiers normally is for ammonia, liquid hydrocarbon, or methanol synthesis. Some gasifiers produce town or fuel gas which can be be fed into a gas turbine for power generation. The capacity of the large synfuel units is currently limited to about 1,090 metric tons/day (1,200 TPD) coal input, with a 1,810 metric tons/day (2,000 TPD) capacity soon to be achieved. However, coal throughput is an evolutionary parameter; some of today's large synfuel-type gasifiers began with 136 metric tons/day (150 TPD) capacities or less for the early versions.

The development of the synfuel-type gasifiers historically occurred in distinctive steps, with capacity increasing at each step. The majority of the synfuel-type gasifiers operate as medium-Btu gas generators; i.e., oxygen blown. Some operate at atmospheric pressure, others at higher pressures. All ongoing development of the current commercial synfuel gasifiers shows the trend towards operation at elevated pressures. The commercial synfuel gasifiers are of fixed bed (single stage), fluidized bed, or entrained bed reactor design. The throughput per square foot of cross sectional area of all synfuel gasifiers is at least five times greater than that of industrial gasifiers.

The United States has extensive experience in single-stage industrial gasifiers and is starting to obtain experience with two-stage, fixed bed gasifiers by way of the Caterpillar plant in York, Pennsylvania (Wellman-Incandescent) and the Duluth, Minnesota (Foster-Wheeler-Stoic) plant. Considering that the gasification experience in the United States has centered on the small industrial gasifiers, the case studies were chosen from the group of larger synfuel-type gasifiers in operation abroad. This approach meant that the gasifiers of greatest interest were Lurgi, Koppers-Totzek, and Winkler.

5.2 State of Process Development

For the purposes of this study, the master list was consulted to choose the specific foreign facilities which would provide the most useful information for U.S. synfuel industry. The criteria for choosing facilities for possible case studies were threefold: (1) facilities must be of one of the three design types mentioned in Section 5.1, (2) facilities must show a significant development history in order to provide state-of-the-art design, and (3) facilities must have logged sufficient operating time so that useful information on plant start-up and operation would be available. The development histories for the three large synfuel-type gasifiers is discussed below.

Lurgi

The historical development of Lurgi gasification technology is as follows:

- First generation, 1936-1954: up to 135 metric tons (150 tons) per day unit capacity limited to lignites - Germany, Czechoslovakia, and Australia;
- Second generation, 1952-1965: up to 340 metric tons (375 tons) per day for all coal grades [1,360 metric tons (1,500 tons) per day for noncaking coals] using using an agitator for caking coals - West Germany, Pakistan, South Africa, England, and Korea;
- Third generation, 1969-present: up to 1,450 metric tons (1,600 tons) of coal per day - West Germany and South Africa.

Half of all currently operating Lurgi's are located in South Africa.

The fourth generation Lurgi gasifiers (Mark V) have a larger diameter and, therefore, a larger throughput (up to 1,810 metric tons (2,000 tons) per day). A Mark V prototype is presently in operation at Sasol I. Major new developments are aimed for increased throughput and for possible use of less reactive coals:

- Lurgi 100 [high pressure, 10,130 kPa (100 atm)], and
- BGC-Lurgi (Slagging Lurgi where the temperature is raised above the ash fusion point).

It appeared that the Lurgi process had the most development activity of the three major synfuels gasifiers. On the basis of the size, application, age, and operating experience, the most desirable Lurgi facilities to visit (in order of decreasing utility) were Sasol II/ Sasol I, Luenen (West Germany), and Westfield (United Kingdom).

Koppers-Totzek

The Koppers-Totzek historical development has been as follows (all the gasifiers were built by Krupp-Koppers):

- First generation, 1952-1956: up to 142,000 Nm^3/day (5 million SCFD)* - Spain, Japan, Belgium, Portugal, and Finland;
- Second generation, 1959-1970: up to 284,000 Nm^3/day (10 million SCFD)* - Greece, Turkey, East Germany, Zambia, and Thailand:
- Third generation, 1970-present: up to 568,000 Nm^3/day (20 million SCFD)* [or 390 metric tons (430 tons) per day] - South Africa;

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* - Two headed.

- Fourth generation: up to 1.13 million Nm^3/day (40 million SCFD)** [or 780 metric tons (860 tons) per day] - India.

The next development after the four-headed Koppers-Totzek in India is the Shell-Koppers gasifier, a pressurized entrained bed unit combining the Shell heavy oil gasification process with the Koppers-Totzek process.

In terms of newer generation facilities and established start-up and operating experience, the most desirable Koppers-Totzek plants to visit (in order of decreasing utility) were South Africa, India (four-headed), Greece, Turkey, East Germany, Thailand, and Zambia. The latest information indicates that the four-headed units in India are still in the start-up phase in spite of the fact that they were ordered more than 10 years ago.

Winkler

Unlike Lurgi and Koppers-Totzek, the Winkler gasifier did not evolve through identifiable development sequences. The first application of the Winkler was at a large commercial scale. Relatively little modification or development work has occurred since. Currently, Rhein-Braun in West Germany is working on a higher temperature pressurized version of the old Winkler gasifier. East Germany is apparently involved in new developments of the Winkler technology.

The advantages and disadvantages of these three gasifier types are summarized in Table 5-1. The analysis in Table

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** - Four headed.

5-1 agrees reasonably well with a study conducted by the Indian Government, which made Koppers-Totzek their first choice, Lurgi a close second (depending on feed and application), and Winkler a distant third. It should also be noted that the Winkler plants were the ones which were shut down first in countries like West Germany where ample experience had been gained on all three technologies.

5.3 Recommendations for Case Studies

From the standpoint of development activity and current utilization, Lurgi and Koppers-Totzek foreign gasifiers appeared to be the first choices for case studies. Current designs of these gasifiers should see application in the United States. Further, the development activities of these two technologies are sufficiently high for them to be a significant factor in gasification technology in the foreseeable future.

The following list of Lurgi and Koppers-Totzek gasifiers, in order of decreasing desirability, were recommended for case studies:

1. South Africa

   Sasolburg/Secunda (latest and largest Lurgi), Modderfontein (second to last generation Koppers-Totzek).

2. India

   Ramagundam or Talcher plants (latest and largest Koppers-Totzek).

3. Turkey/Greece

   Kutahya (second generation Koppers-Totzek, Winkler).

Table 5-1

ADVANTAGES AND DISADVANTAGES OF LURGI, KOPPERS-TOTZEK, AND WINKLER GASIFIERS

Lurgi Advantages

- Highest efficiency (with proper feedstock), especially for high-pressure application.
- Highest level of methane formation (an advantage for SNG production)
- Simple construction and operation (minimal corrosion).
- Minimal elutriation.
- High degree of operational safety (due to excess coal).

Lurgi Disadvantages

- Restricted to reactive coals.
- Sensitive to coal fines and strongly caking coals.
- Methane, phenol, and tar production (for small- to medium-sized plants).

Koppers-Totzek Advantages

- Minimal feed restrictions (can accept fines, caking coals, unreactive coals).
- No by-products.

Koppers-Totzek Disadvantages

- Lower efficiency due to atmospheric operation and high temperatures.
- High elutriation rate (50 to 80 percent of ash).
- Fine grinding (drying) required.

Table 5-1 (Continued)

ADVANTAGES AND DISADVANTAGES OF LURGI, KOPPERS-TOTZEK, AND WINKLER GASIFIERS

Winkler Advantages	Winkler Disadvantages
● Minimal feed preparation required, can accept fines.	● Small amounts of methane are formed and have to be removed for some applications, such as ammonia production.
	● Restricted to non-caking reactive coals with high ash fusion points (to avoid clinkering).
	● High elutriation rate (70 percent of ash).
	● Lower efficiency due to low carbon conversion (50 to 80 percent), causing ash disposal problems.
	● Lower efficiency due to atmospheric operation.

4. West Germany

   Luenen (Lurgi).

5. Great Britain

   Westfield (Slagging-Lurgi).

6. Yugoslavia

   Kosovo (Lurgi),
   Gorozde (Winkler).

After discussions with the DOE Project Officer, the Lurgi gasifiers in the Sasol complexes at Sasolburg and Secunda, South Africa, and the Koppers-Totzek gasifiers in the African Explosives and Chemistries Industries, Ltd. (AECI) No. 4 Ammonia Plant at Modderfontein, South Africa, were chosen for the two case studies in this program. Some consideration was also given to the four-headed Koppers-Totzek gasifiers at the Ramagundum plant in India. Plans to visit this facility were dropped due to the small amount of operating experience logged by this plant and a limitation of travel funds for the program.

6.0 CASE STUDIES

The overall objective of the Sasol and AECI case studies was to learn how much information plant operators are willing to share concerning their experience with the design, construction, start-up, and operation of commercial coal gasification facilities. The information sought included labor requirements, operating and maintenance experience, environmental requirements and controls, capital and operating expenditures, and overall operating experience and problems encountered. The on-site data obtained and more general information compiled are intended to supplement and qualify published data on the chosen processes.

As discussed in Section 5.0, the two most promising technologies are the Lurgi and the Koppers-Totzek coal gasifiers. The Lurgi gasifiers at Sasol I and II (South Africa) represent state-of-the-art technology for coal gasification. In addition, sufficient commercial hands-on experience has been obtained at Sasol I in its more than 25 years of operation. Similarly, the Koppers-Totzek gasifiers in AECI's No. 4 Ammonia Plant at Modderfontein, South Africa represent the latest development stage for this process for which at least five years of commercial operating experience has been accumulated; this time period is assumed to be sufficient to provide a realistic appraisal of system operation. Thus, Sasol I and II and the Modderfontein plant were chosen as case studies because they fulfill the qualifications cited in Section 5.0.

6.1 Case Study No. 1: Koppers-Totzek Gasifiers in AECI's No. 4 Ammonia Plant (Modderfontein, South Africa)

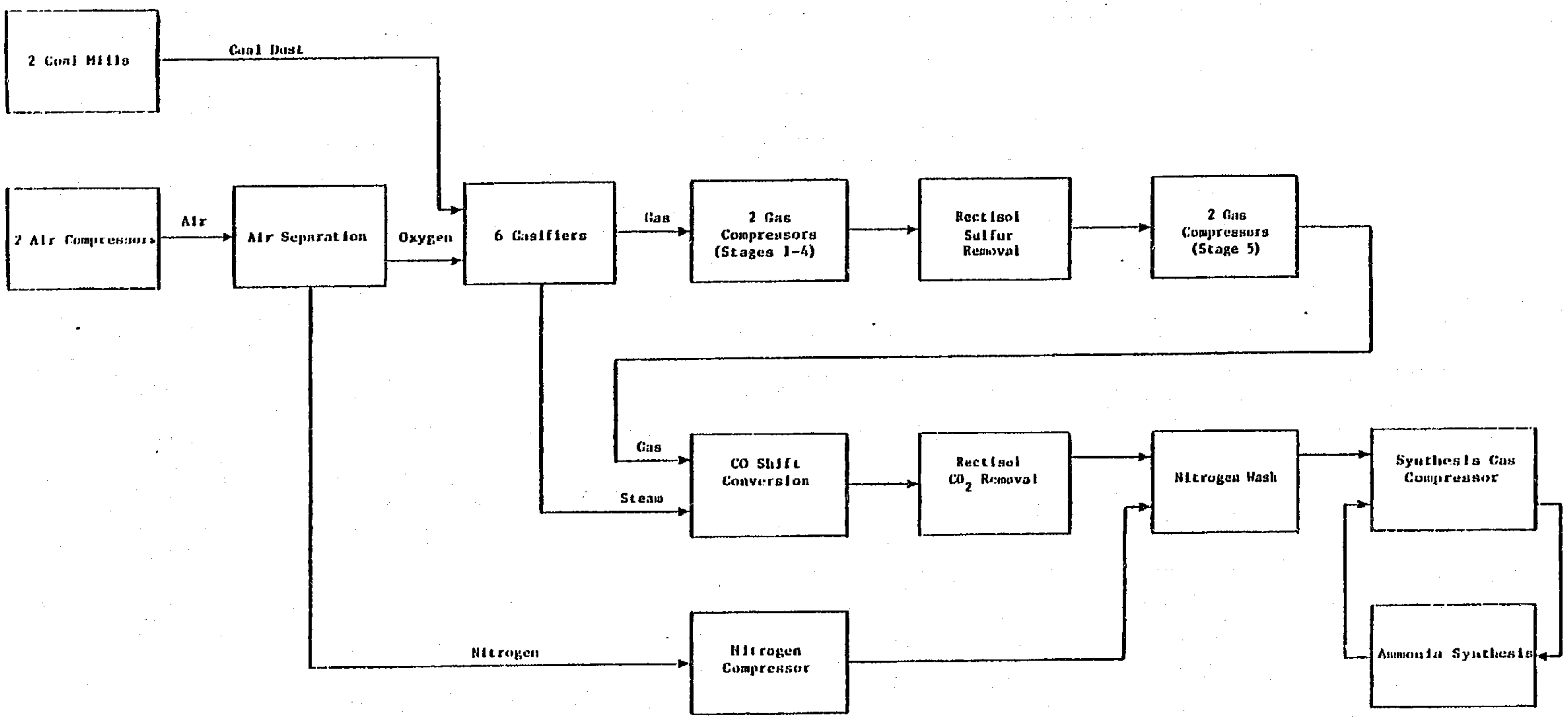
Most of the information reported for this case study was derived from personal interviews with engineering, plant operations, and management personnel associated with AECI's No. 4 Ammonia Plant. A complete list of contacts is presented in Appendix B. Supplementary information has also been taken from References 45 through 50.

Technology Description

After two and one-half years of construction, the 1,000 metric tons/day (1,100 TPD) ammonia from coal plant was commissioned at the end of 1974. The basic design philosophy called for double trains, as illustrated in the process scheme (Figure 6-1). Exceptions to this basic design philosophy are the air separation plant, the synthesis gas compressor, the Rectisol plant, CO shift conversion, liquid nitrogen wash, and the synthesis loop.

The coal mills are conventional ring and ball mills made by Babcock and Wilcox. The boilers are of spreader-stoker design [10,130 kPa (100 atm) steam production]. Most air and gas compressors are driven by steam turbines.

Cyclones and electrostatic precipitators are used for coal dust removal in the coal preparation plant, including the pulverized coal bunkers. Coal gasification is accomplished in six two-headed Koppers-Totzek gasifiers, each fed by four screw feeders. The product gas subsequently goes into a radiant boiler above the gasifier and then into two parallel tubular boilers. A wash tower removes part of the fly ash; the remainder is captured by electrostatic precipitators. Acid gas removal of the compressed product gas occurs in the Rectisol unit. The Rectisol unit operates in selective fashion; sulfur species (mainly H_2S) are removed prior to shift conversion, and CO_2 is removed after shift. Recovered H_2S is used as boiler fuel. The shift converter uses conventional iron oxide catalysts. Some CO_2



Source: Reference 63

Figure 6-1

SIMPLIFIED PROCESS SCHEME FOR AECI'S NO. 4 AMMONIA PLANT recovered from Rectisol is used for urea production, while the remainder is vented. The final traces of CO_2 in the product gas are removed by molecular sieve adsorbers, followed by a liquid nitrogen wash before the gas enters the synthesis loop.

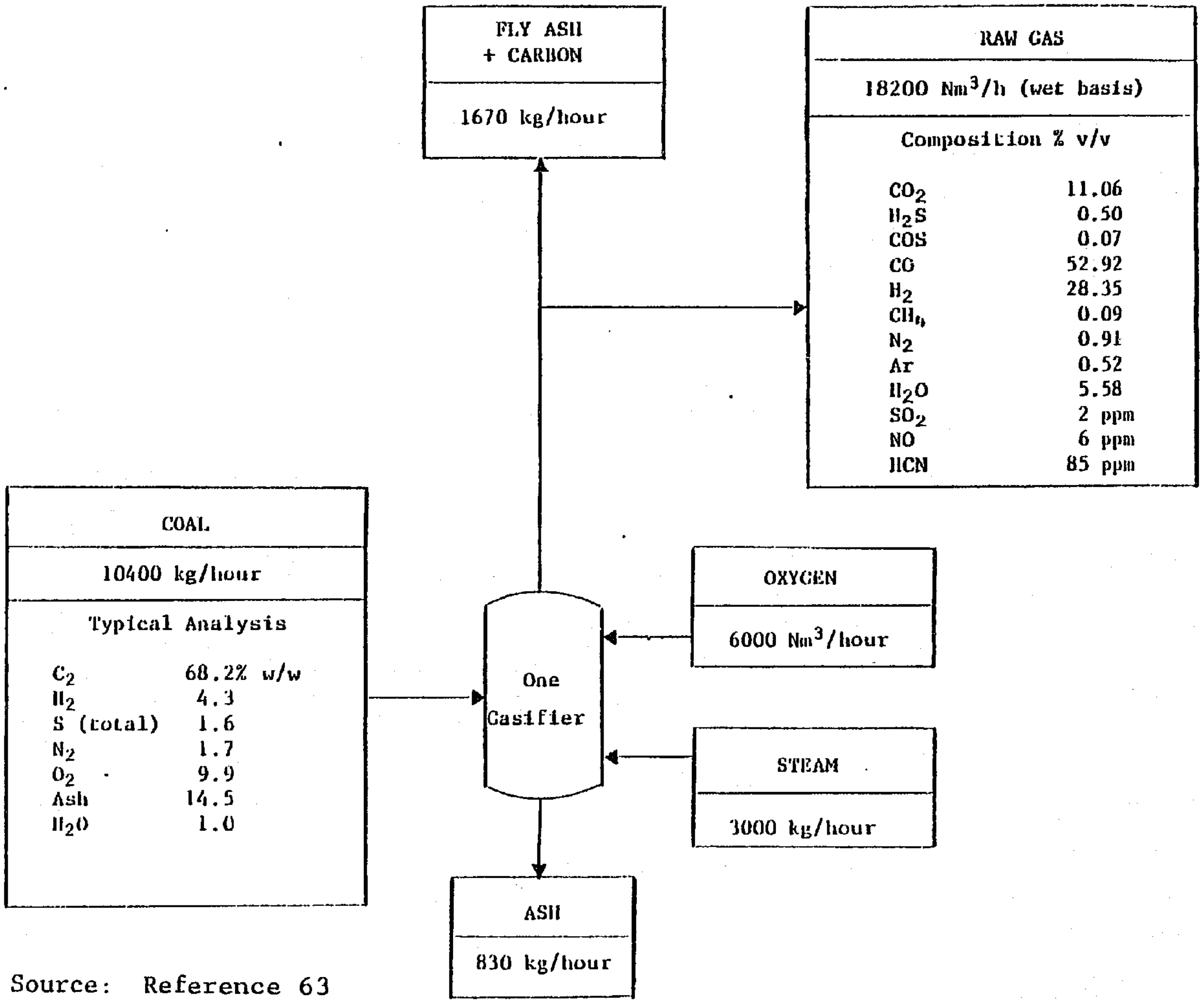
Design Mass Balance

Sub-bituminous coal is pulverized to 90 percent less than 90 μm and dried to one percent moisture by hot flue gas. Run-of-mine coal has 18 to 20 percent ash, 25 to 30 percent volatiles, and about 1 percent sulfur. The coal is shipped by rail over a distance of 128 kilometers (80 miles).

A nominal mass balance is shown in Figure 6-2. However, actual steam and oxygen consumption values differ for different coals. Details of these parameters are proprietary information.

Early Technical Problems

Actual South African coals were not tested in full-sized Koppers-Totzek gasifiers prior to design and construction of the Modderfontein plant. Thus, many design parameters were optimized for lignites, which previously were the most common feedstocks for Koppers-Totzek gasifiers. The reactivity of the South African coals, however, was lower than design assumptions. To compensate for this low reactivity, the gasification temperature had to be raised to about 1,600°C (2,900°F). The high operating temperature and the low coal ash fusion temperature acted to prevent the formation of a protective frozen slag layer on the reactor wall resulting in rapid erosion of the 4 cm thick refractory lining. Increasing the heat transfer through the lining by installing more steel pins proved a viable solution.



Source: Reference 63

Figure 6-2
DESIGN GASIFIER MASS BALANCE

The original feed coal to the gasifiers demonstrated low reactivity, thus preventing the design carbon conversion rate of 88 percent. A change of feedstock resulted in an increase of coal conversion efficiency to over 80 percent. Further increases could probably be achieved by finer pulverization.

Typically, Koppers-Totzek gasifiers show a 50/50 to 40/60 split between slag ash and fly ash. At Modderfontein, about 80 percent of all ash ends up as fly ash. Fortunately, all fly ash removal systems, such as water scrubbers and the connected water recovery systems, were able to cope with increased ash loads.

Early fouling problems of the Rectisol unit due to sulfur deposition were solved chemically. Fouling problems were also experienced in the nitrogen wash unit due to the presence of NO_x in the product gas.

The recycle water system associated with the catalytic shift converter showed early corrosion/erosion problems. These were corrected by reducing the flow rate and by introducing stainless steel piping.

Constant control of vital parameters like oxygen concentration in the product gas are designed to maintain safe operation. Oxygen must be kept out of the coal feeding/storage areas. When a certain number of the control parameters signal improper operation, the oxygen flow is shut off and the gasifier is purged with nitrogen. Malfunction of these controls (and possible operator error) had caused an explosion during earlier operations. There also were some initial difficulties with oxygen valves not closing completely.

Current Operating Experience

Design capacity of the gasifiers was reached immediately after initial start-up. At present, the plant's maximum gasification capacity is about 20 percent above design capacity. The original plant design called for all six gasifiers to be online simultaneously. At full load, under current operating conditions, however, five gasifiers can approximately achieve design capacity. The normal major overhaul interval for the gasifiers is two years, at which time the whole plant is shut down for a month. However, the gasifiers are shut down at regular intervals during operation for inspection of erosion damages on boiler erosion protection surfaces. The tubular convective waste heat boilers have proven to be the most problem-causing components because of long-term erosion of the tubes. In contrast to the convective boilers, the radiant boilers have caused few problems. The on-line factor for the gasifiers exceeds 85 percent.

Stable gasifier operation can be maintainted at 70 percent of design capacity and above. The turndown ratio, however, is not an important operating parameter as the gasifiers are mostly operated at or above design capacity. If reduced load is called for, one or more gasifiers are taken off line. The gasifiers are kept hot by two small start-up burners during short shutdown periods.

Cold start-ups take several hours. The detailed start-up and shutdown procedures were not revealed as they are considered proprietary information.

Environmental Considerations

TRW (U.S.A.) and Krupp-Koppers (W. Germany) performed a pollution source test program at the No. 4 Ammonia Plant in 1978. AECI engineers referred to this report as a source of environmental information. It can be concluded that the wastewater streams requirements for the plant are rather stringent, and the air pollution standards are more lax compared to U.S. standards. According to TRW, the wastewater streams have have less pollutants than the feed water going into the plant. Raw water to the plant consists of local river water and treated effluent from a local sewage plant.

No noticeable signs of air discharges were observed, with the exception of coal dust from the coal drying area (it was stated that the electrostatic precipitators were about to come down for a scheduled overhaul). AECI engineers did state, however, that all H_2S from the Rectisol unit is used as boiler fuel.

Operating Experience and Possible Improvements

The most troublesome components, according to AECI engineers, are the tubular waste heat boilers downstream of the gasifiers, as described above. Based on the hindsight that operating experience affords, a hypothetical redesign of the plant would include an additional spare gasifier, as well as a different design of the waste heat boilers as used on the latest Koppers-Totzek gasifiers.

Choice of Technologies

AECI made the decision to erect Koppers-Totzek gasifiers, as opposed to the Lurgi technology, based on two factors.

First, even though Sasol I had already corrected initial problems in their Lurgi units, no integrated coal-to-ammonia plant existed at that time based on the Lurgi technology; Krupp-Koppers, on the other hand, had ample experience with integrated ammonia plants. Second, because methane, oils, and tars are considered valuable by-products only for very large coal conversion plants, the absence of methane, oils, tars, and phenols in the Koppers-Totzek product gas made that technology the more viable option.

At the time the Modderfontein plant was built, Krupp-Koppers also offered the four-headed gasifiers which were previously ordered for a similar plant in India. The four-headed Koppers-Totzek gasifiers have about twice the design capacity and turndown capability as the two-headed design. However, in 1971-1972, no commercial experience had been accumulated with the four-headed gasifiers. Thus, the well-proven two-headed design was chosen by AECI.

Horizontal and Vertical Integration

AECI's ammonia-from-coal plant at Modderfontein differs from the Sasol factories in that the operation represents only a fraction of AECI's overall business interests. For Sasol, the oil-from-coal factories are the major source of revenues. Nevertheless, the Modderfontein operation demonstrates a significant degree of vertical integration and an even greater degree of horizontal integration than does Sasol's operations.

At the Modderfontein plant itself, the major product is ammonia to be used for nitrogen fertilizers. The company as a whole, however, is one of the major industrial concerns in South Africa and the largest in the chemicals sector. In addition to fertilizer chemicals like ammonia, ammonium nitrate, nitric acid, and sulfuric acid, the AECI group companies manufacture and sell a wide array of products, including crop protection products, veterinary and public hygiene products, animal feeds, chlor-alkali products, organic products, paints and coatings, explosives, blasting equipment, plastics, raw materials, vinyl products, auto plastics, PVC piping, and a great variety of industrial chemicals.

The vertical integration at AECI's Modderfontein operation is limited to marketing activities. The plant purchases both coal and catalysts from outside suppliers. The main product of the plant, ammonia, is used by AECI in the manufacture of fertilizer mixtures, as well as marketed directly by Triomf Fertilizer, Ltd., a subsidiary in which AECI holds a 49 percent interest.

Capital Structure

Another major difference between the Modderfontein plant and the Sasol factories lies in the method of financing capital costs. While Sasol relied primarily on Government grants, AECI financed the Modderfontein facility with internal funds generated by its operating companies. At the time the decision to build the plant was made (1972), AECI's long-term debt-to-equity ratio stood at 0.24 and cash flow (retained earnings plus depreciation) amounted to approximately $31 million. Of the outstanding common shares, 40 percent are held by Imperial Chemicals Industries, 40 percent by De Beers Industrial Corporation, and 20 percent by the general public.

All revenue and cost figures associated with AECI and the Modderfontein operations have been converted to U.S. dollars at a rate of $1.30 per South African Rand.

Capital Costs

No information was made available on capital costs for the No. 4 Ammonia Plant. AECI sources claimed this was confidential information. It was stated, however, that the construction of the plant was scheduled for 26 months; actual construction required 30 months. The plant became operational in the second half of 1974.

Operating Costs

As with capital costs, AECI claimed that operating cost information is confidential. Sources did state, however, that the two largest operating cost differences between the plant at Modderfontein and a similar plant operating in the United States are coal and electricity costs. Coal costs were estimated at approximatley $14/metric ton ($13/ton). Electricity is priced at 1 to 3 cents per kilowatt-hour.

Operating labor for the gasifier consists of four men--one man in the control room and three men outside in the plant. Four shift teams are utilized, and each man works a 42-hour week on the average. Gross wages for skilled (but nonprofessional) labor was estimated at approximately $18,000/year; wages for unskilled labor is near $8,000 to $9,000/year.

AECI engineers stated that if labor were cheaper, more manual labor would be utilized in the coal preparation section of the plant. Labor costs do not materially affect labor requirements in the gasification and gas processing sections of the plant because of the high degree of automatic control and instrumentation required to keep the plant operating safely and near optimum conditions.

Accounting Standards

AECI is a privately owned, profit-seeking company with 154.2 million shares listed on the Johannesburg Stock Exchange. The company conforms to generally accepted accounting standards which are quite similar to those established in the United States.

AECI values their inventories of raw and packing material stocks, product stocks, intermediates, and merchandise at standard cost using the last-in-first-out (LIFO) method.

Tax Laws

As a private company, AECI is subject to the South African standard rate of taxation, which was 42 percent of net income before taxation in 1980. AECI's effective tax rate was only 34 percent in 1980 due to tax credits for investment, dividends, and unnamed other allowances. In 1980, AECI claimed an investment tax credit of $6.1 million on fixed asset acquisitions of $124.3 million for an effective investment tax credit rate of 4.9 percent. In 1979, the effective credit was 7.5 percent. The investment tax credit applies to all companies in South Africa, not just to those utilizing coal as a feedstock.

Price Supports

Although the government did not participate in the financing of the No. 4 Ammonia Plant, plant operations do enjoy government price supports for ammonia. However, price supports apply to all ammonia producers regardless of their feedstock. Ammonia prices are set by the government using a pricing formula which allows specified returns on capital. The practice is not unlike that used to establish electricity prices from utilities in the United States.

Other Factors

AECI sources claim that the primary reason for switching to coal as a feedstock for ammonia plants in 1972 was the uncertainty concerning the future price and supply security of petroleum-derived naphtha. Also, railroad costs were expected to rise and increase the delivered cost of naphtha to the Modderfontein site, which is 650 kilometers (404 miles) from the port of import.

AECI engineers consider the Modderfontein plant poorly suited for large-scale feedstock testing, compared to the Koppers-Totzek gasifiers in Greece, due to the single/dual train arrangement of the plant.

6.2 Case Study No. 2: Lurgi Gasifiers at Sasol I, II, III Sasolburg and Secunda, South Africa

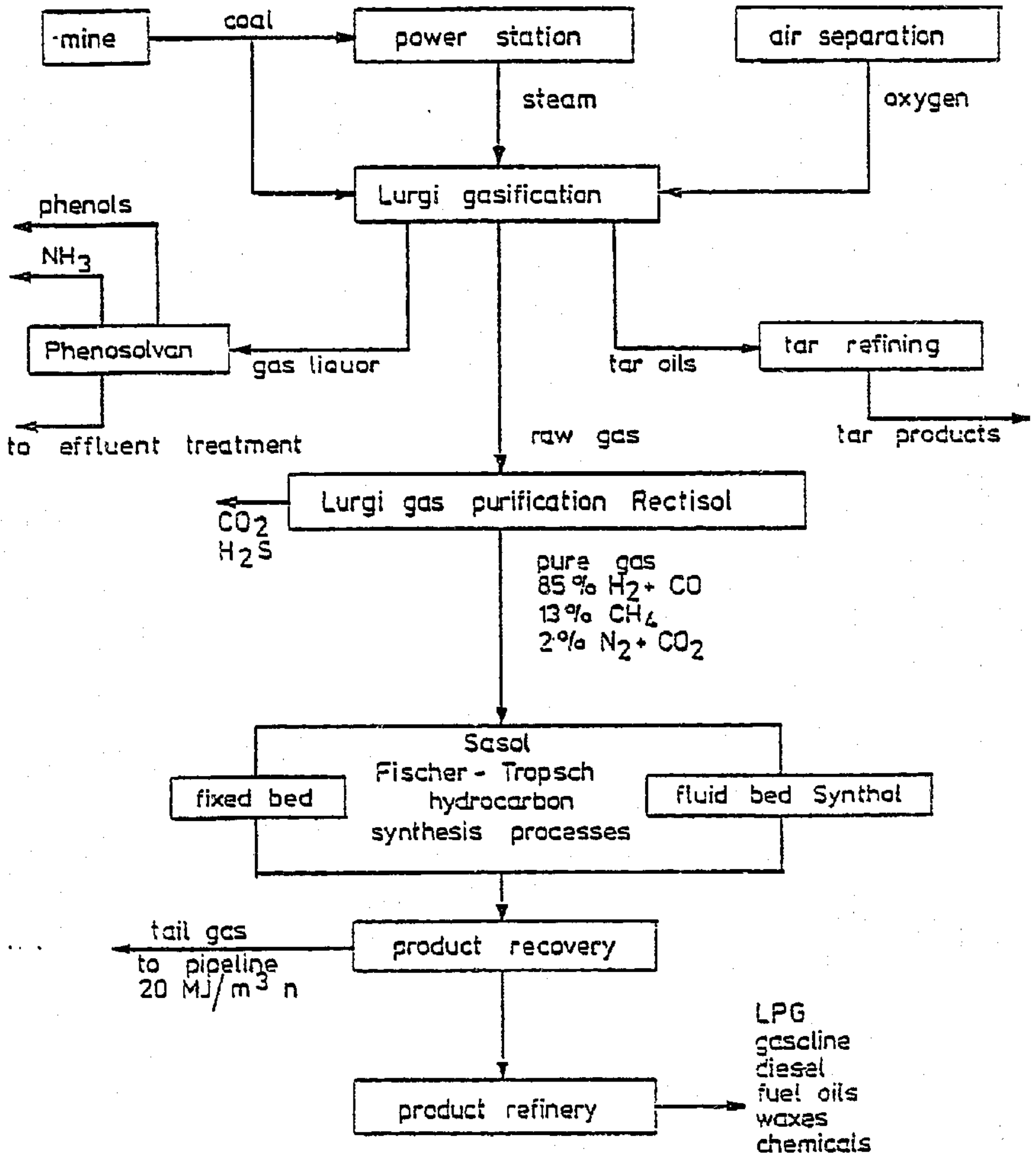
Most of the information reported for this case study was derived from personal interviews with engineering, research, plant operations, and management personnel associated with the Sasol I and Sasol II complexes and with the Lurgi gasifiers. A complete list of contacts is presented in Appendix B. Supplementary information has also been taken from References 51 through 61.

Technology Description

As early as 1936, Sasol demonstrated "commercial" synfuel activity in the form of an oil shale plant. When Sasol I was in the planning stage, the low price of natural crude made coal-into-oil conversion financially unattractive. Thus, emphasis was shifted from synthetic motor fuels to synthetic chemical feedstock and industry fuel gas (due to lack of any natural gas reserves). The Arab oil embargo in 1973-74 brought the attention back to synthetic motor fuels, resulting in the construction of Sasol II. The 1979 oil price hike in connection with the Iranian revolution was answered by the start of Sasol III.

For both Sasol I and Sasol II, about five years passed between the decision to build these plants and the completion of construction. Sasol II's construction was about 99 percent completed in April 1981. Its current production rate is approximately 80 percent of the design rate. Sasol III's construction was approaching 60 percent completion. Sasol III, which is really a carbon copy of Sasol II, will take about two-thirds the completion time of Sasol I and II due to the fact that very little new design was required and the construction crews (more than 30,000 people) already selected for the Sasol II site simply moved to the new site. Single production trains are often completed separately, so that partial production can be started before the whole plant is complete.

Sasol I, and especially Sasol II, show a basic multi-train design largely due to sheer size requirements. The simplified flow diagram for Sasol I and Sasol II is presented in Figures 6-3 and 6-4, respectively. Sasol I has a coal storage bunker capacity of 54,400 metric tons (60,000 tons). Run-of-mine coal is conventionally crushed and dry screened for Sasol I, while Sasol II uses wet screening due to the more friable feedstock. Fines from coal sizing are sent to the steam boilers (pulverized coal boilers) for power and steam generation. The larger sized 1.0 to 5.0 cm (0.4 to 2.0 inches) coal and some fines are fed into 17 gasifiers at Sasol I without any further preparation. The 10 original Mark III gasifiers initially had a



Source: Reference 55

Figure 6-3

SIMPLIFIED FLOW SHEET - SASOL I

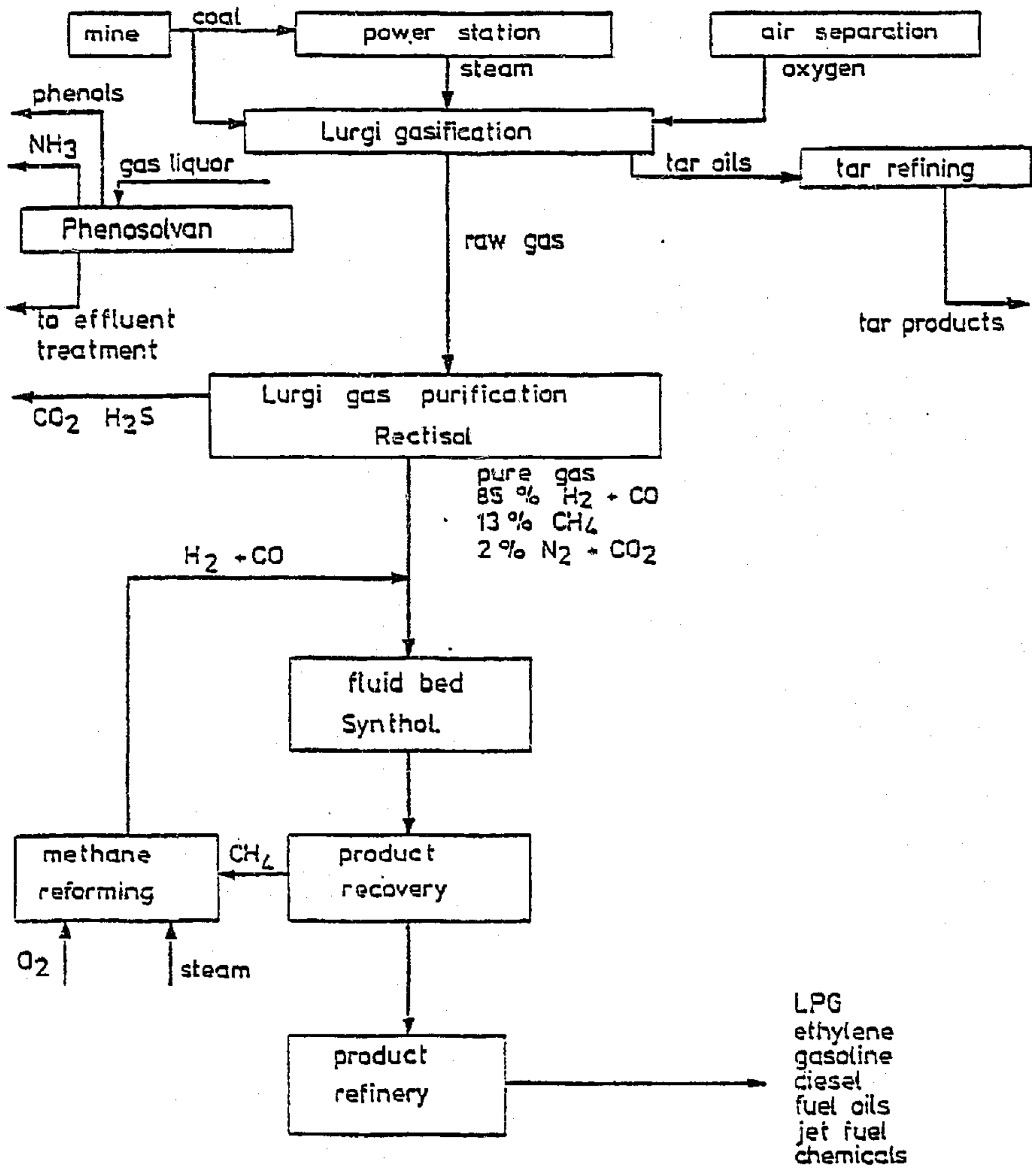


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Figure 6-4

SIMPLIFIED FLOW SHEET - SASOL II and III typical capacity of about 0.57 million Nm^3/day (20 MMSCFD) per unit. The later version of the Mark III gasifiers had a 0.85 million Nm^3/day (30 MMSCFD) capacity. Presently, the 13 Mark III gasifiers at Sasol produce between 0.85 and 1.13 million Nm^3/day (30 and 40 MMSCFD) per unit. In 1973, three Mark IV gasifiers were ordered. Though the Mark IV is only a few inches larger in diameter than the Mark III, the Mark IV has considerably higher throughput. Since mid-1980, a prototype Mark V gasifier [design capacity about 1,810 metric tons/day (2,000 TPD)] has been installed in the Sasol I gasifier house. Because of space limitations, the height for this Mark V is less than expected for optimal design. Sasol II has 36 Mark IV gasifiers with a capacity ranging between 1.13 and 1.5 million Nm^3/day (40 and 60 MMSCFD). At Sasol I, approximately 60 percent of the coal feed to the plant is used in the gasifiers; the remainder is combusted to generate steam and power for both internal use and for export. At Sasol II, no steam is exported, and some power is imported. The result is that 70 percent of coal feed goes to the gasifier and only 30 percent to steam boilers.

Raw product gas at Sasol I is cooled by waste heat boilers and by quench cooling. Sasol II replaces the water quench with air cooling. In both cases, the raw gas is scrubbed with cooled recycled gas liquor. The condensed gas liquor is separated in gas liquor separators into oils, tars, etc. The Phenolsolvan process and the phenol recovery are similar for Sasol I and Sasol II, while the ammonia recovery differs.

There are four Rectisol acid gas removal units in Sasol I, all of which are in constant operation. Currently, the Stretford units are not connected. The normal operation of

Stretford plants involves feed streams with much less CO_2 compared to the Sasol streams. Detailed information is not available due to ongoing negotiations between the Stretford licensors and Sasol Ltd. All H_2S in Sasol I and II is flared. Oil and tars from the gas liquor separators are further refined in the tar distillation units.

Sasol I emphasizes the synthesis of chemical feedstocks in addition to motor fuels production. Highest product flexibility is reached by using Arge (fixed bed) as well as Synthol (entrained bed) reactors for the Fischer-Tropsch synthesis process. The fixed bed process produces primarily longer, straight paraffinic hydrocarbon chains while the entrained bed forms lighter hydrocarbons often of olefinic character. Sasol II only uses Synthol reactors. Sasol II also differs from Sasol I in the reactor tail gas cleanup. The tail gases are either fed into a reformer or are sold as industrial fuel gas. The sale of fuel gas to the industrial complex in Sasol I has shifted from being considered a by-product to being almost the main product.

Operational Experience at Sasol I

A number of operating parameters, such as overall thermal efficiency, steam and oxygen consumption, and throughput have been reported in the literature. However, as discussed for the Koppers-Totzek gasifiers at Modderfontein, the reported values are only approximate numbers, which strongly depend on the actual operating conditions, including the feedstock. Data regarding actual thermal efficiency, steam/oxygen ratios, and gasifier temperatures are not available. Similarly, detailed startup and shutdown procedures are proprietary. Initially, cold startup of the Mark III units took three to four days; this time has since been reduced to 12 hours.

As discussed above, the average throughput has gradually been increased, as increased availability of the equipment has led to more experience. Currently, the availability rate exceeds 80 percent. The design capacity was achieved within a year from initial start-up. The present average capacity of the gasifiers exceeds the design capacity by over 20 percent.

The Lurgi Mark III and IV gasifiers are considered very reliable. The most serious corrosion/erosion wear occurs on the grates. The gasifiers are annually shut down for maintenance.

Operational Experience at Sasol II

The Sasol II plant is still in its start-up phase. Thus, many operating parameters, such as down time, are not yet firmly established. Other items, like overall thermal efficiency and oxygen/steam ratios, are either proprietary information or vary with conditions; e.g., with feedstock. Detailed start-up and shutdown information is strictly proprietary.

Most problems currently encountered at Sasol II are of a mechanical nature and are not connected with the special requirements and conditions of gasification or synthesis reactions.

The most fundamental opreating problem at Sasol II is related to the excessive fines content of the feed coal. Apparently, the Lurgi Mark IV gasifiers can operate with substantially more fines than specified by Lurgi design. However, carbon conversion, pressure drop, and throughput can be negatively affected by the higher fines content. There are indications that efforts for optimization of all parameters are ongoing. Since Sasol II buys electric power from nearby power plants, not as high a percentage of the fines is fed into the steam boilers as in Sasol I, which sells steam.

Sasol II coal is of higher quality (i.e., less ash) than Sasol I coal. Because of this difference in coal quality operational adjustments had to be made to properly control the gasification process in the Lurgi Mark IV gasifiers at Sasol II. Detailed information on these adjustments is not available.

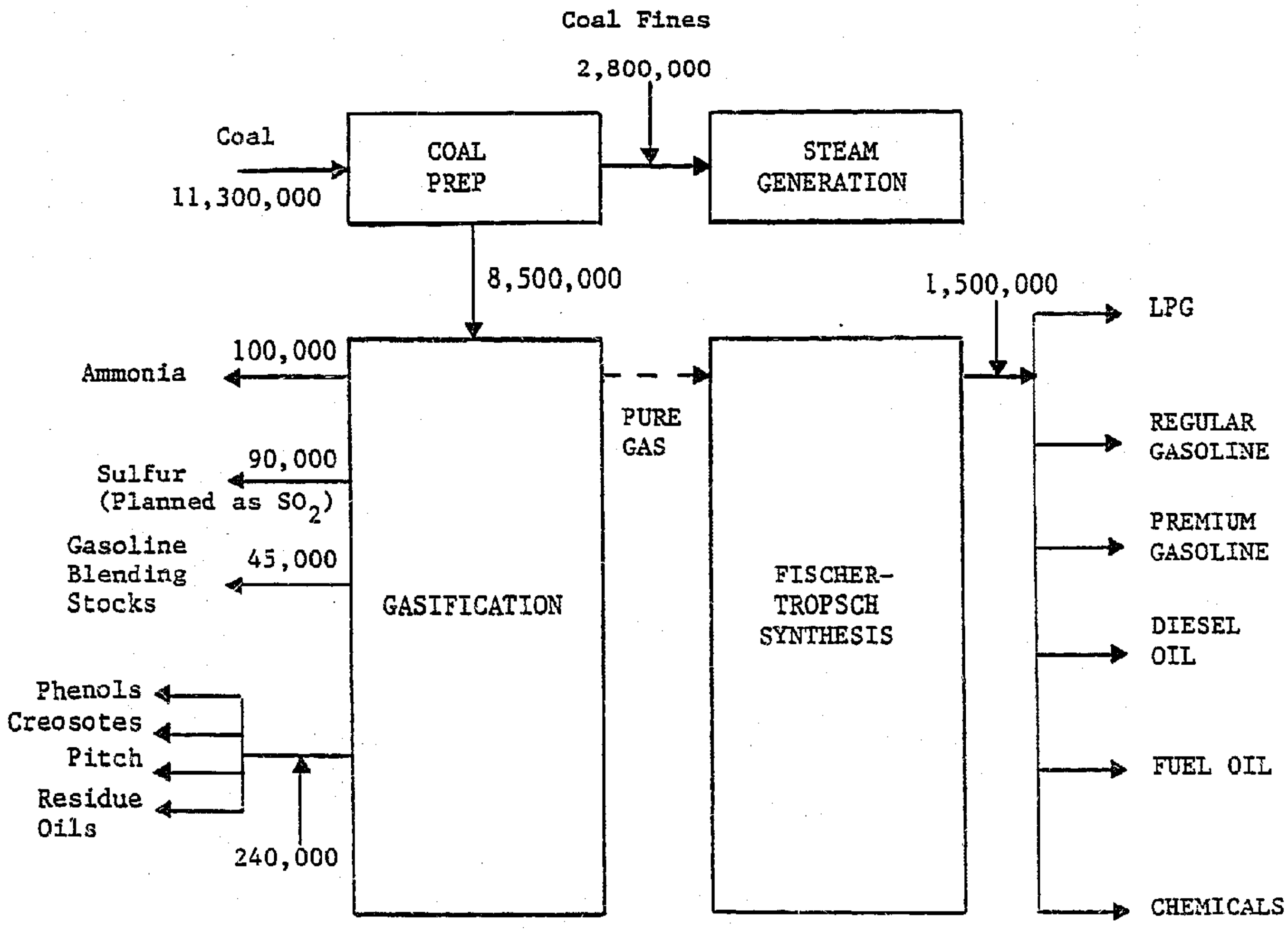
Design Mass Balance

Sasol I and Sasol II/III are sufficiently close to the coal mines that transport of the coal by belt conveyor is possible. The coal supply is expected to last for at least 40 years of operation at Sasol I and for 60 to 70 years at Sasol II.

A nominal mass balance of feedstock and products for Sasol II is shown in Figure 6-5. The current mass balance for Sasol I with all 17 gasifiers in operation is not available. The very high flexibility of the Sasol I production makes such a balance less meaningful.

Environmental Considerations

The impression was given that the air emission standards in South Africa can be met relatively easily; however, Sasol II faces more stringent regulations than Sasol I. Presently, all H_2S is flared in both plants. The altitude [about 1,525 meters (5,000 feet) above sea level] and a relatively sparse overall population apparently permits a higher local pollution level.



(All Numbers in Tons Per Year)

Source: Reference 62

Figure 6-5

SASOL II FEED AND PRODUCTS

The water pollution problem, however, is taken very seriously. The fact that the names of so many towns end with "fontein" (fountain) emphasizes the crucial importance of water availability for the early settlers. Today, water availability is often the limiting factor for industrial growth in South Africa. Sasol III and II claim near zero discharge, while Sasol I discharge is treated to meet high water quality standards. All internal wastewaters at Sasol II are recycled as cooling water. Storm water is the only accepted wastewater. The degree of water recycling was stated to be as much an economic decision as a technical decision.

Sasol Licensing and Consulting Services

Sasol and Lurgi have a cooperation agreement under which Lurgi licenses the Lurgi units and Sasol provides operating experience and consulting services.

Sasol itself licenses its own technology, including the Sasol Synthol process, and provides consulting services. An arrangement exists between Sasol and Fluor for the use by the latter of Sasol Information in conducting feasibility studies and performing engineering and construction.

Future Plants

Sasol managers have considered the direct liquefaction processes as a possible coal utilization technology; however, South African coals with more than 20 to 30 percent ash are ill-suited for direct liquefaction. Major losses of coal occur during the required coal preparation stage, decreasing the overall efficiency to about the same level as experienced for Sasol I or II. Furthermore, new devices, such as fluidized bed combustors for coal culm, would be needed to utilize those wastes.

Methanol (which could be produced via Lurgi gasifiers and conventional synthesis) could be used to extend gasoline supplies after all current technical problems (corrosion, vapor lock, etc.) have been overcome. Sasol personnel question the economics of such a step which would involve difficult distribution logistics. A more attractive measure would be a special engine developed for methanol as sole fuel to power local vehicles, such as city buses.

All three Sasol plants together will produce close to 50 percent of the total South African liquid fuel needs. The high flexibility of Sasol I allows for major exports in waxes and similar specialties. In view of (1) the relative percentage of synthetic motor fuels and crude-derived motor fuels, (2) the optimal product distribution for syncrude and for natural crude upgrading, and (3) the increased use of diesel engines, South Africa expects an abundance of gasoline, but a shortage of diesel and jet fuel in the near future. This makes Mobil's M-Gasoline process an unlikely candidate for a future Sasol plant. As a result, the feeling was expressed that any Sasol IV or V would most likely be based on the same synthesis methods as Sasol II.

Horizontal and Vertical Integration

The Sasol complexes at Sasolburg and Secunda demonstrate a high degree of vertical integration beginning with the mining of coal and production of catalyst and culminating with the refining and marketing of finished products. The Sasol organization also demonstrates a significant degree of horizontal integration in the form of an oil refinery which produces a wide range of finished products from imported naphtha and crude oil.

At both Sasol I and Sasol II/III, coal is the primary raw material and is supplied from large coal mines owned and operated by Sasol. Coal from the Sigma Colliery is used at Sasol I for gasifier feed, power generation, and steam generation at a rate of 5.5 million metric tons (6.0 million tons) per year. Sasol II and III will require coal from the Bossjesspruit Colliery at a rate of 27.0 million metric tons (30.0 million tons) per year when these plants reach full production. The other three major raw material requirements for the gasification facilities are steam, oxygen, and catalyst. Steam and oxygen are generated on-site from water and air, respectively. Sasol manufactures its own catalysts for the Fischer-Tropsch reactors.

The product slates for both Sasol I and Sasol II/III are quite broad. These products include ethylene (II/III only), propylene, butylene, propane, butane, fuel gas, gasoline, diesel fuel, jet fuel, furnace oil, phenols, methanol, ethanol, propanol, butanol, pentanol, acetone, MEK, tar products, and waxes (I only). These products are formed from chemical components generated during gasification and F-T synthesis. To reach their final form, they require processing in a number of units, including hydrocarbon refining and processing plants, wax fractionation and processing plants, oxygenated components processing plants, and tar products processing plants. All of these plants are located on-site and are owned and operated by Sasol.

The major products from the Sasol plants are gasoline, diesel fuel, and fuel gas. These and other products are marketed directly by Sasol. Through its wholly owned subsidiary, Sasol Marketing Company, Ltd. (SMC), Sasol distributes and markets liquid fuel products and petrochemicals. SMC uses both its own retail outlets to market motor fuels as well as pumps located at retail outlets operated by other oil companies. As in the United States, motor fuel stocks are interchangeable and are traded freely by petroleum product marketers.

Fuel gas from Sasol is distributed widely to industrial users by South African Gas Distribution Corporation, Ltd. (Gascor). Sasol holds 50 percent of the share capital in Gascor with the balance held by the Industrial Development Corporation (IDC), an arm of the South African Government.

Other operating companies which influence Sasol's horizontal and vertical integration include:

- National Petroleum Refiners of South Africa, Ltd. (Natref) - Refines imported crude oil and naphtha as well as streams from Sasol I. Sasol has a 52.5 percent interest in Natref's share capital.
- Tosos, Ltd. - Sasol holds 70 percent of share capital in Tosos which in turn has a 50 percent interest in FTS Binders, Ltd., a marketer of road binder material.
- Allied Tar Acid Refiners, Ltd. (Altar) - Sasol owns 75 percent of share capital in Altar which refines tar acids from Sasol I and markets phenols and cresylic acid through SMC.
- Sasol Townships, Ltd. (SDB) - SDB is a wholly owned subsidiary which was responsible for township development at Sasolburg.
- Sasol (Transvaal) Townships, Ltd. [SDB(Transvaal)] - Sasol owns 50 percent of SDB(Transvaal) which is undertaking township development at Secunda.

Capital Structure

Sasol I was originally conceived as a commercial operation in the late 1940's by Anglo Transvaal Consolidated Investment Company (Anglo Vaal), a private mining group. However, Anglo Vaal could not find the required financing to build a plant. The State of South Africa took over the project in 1950 by the creation of the South African Coal, Oil and Gas Corporation, Ltd. (Sasol). The company was registered in accordance with the Companies Act as an ordinary company with a profit motive. The State provided the capital investment required for construction of the plant in the form of share capital through the IDC, a government-owned organization designed to stimulate industrial development. Sasol I was constructed at Sasolburg and began to produce marketable products near the end of 1954.

During the 1960's, Sasol expanded its activities into petrochemicals, gas supply, and crude oil refining. In 1975, the decision was made to build a second and much larger oil-from-coal plant at Secunda. The estimated direct cost of completing the Sasol II project, including mining operations, is estimated at about $3.25 billion. The funds for construction were provided from the following sources: 19.7 percent in the form of export credits, 68.3 percent from the State Oil Fund, and 12.0 percent in the form of parliamentary grants. As indicated, the State provided over 80 percent of construction funds effectively in the form of an equity stake.

All revenue and cost figures associated with Sasol Ltd. and the Sasol operations have been converted to U.S. dollars at a rate of $1.30 per South African Rand.

In 1979, the State announced the plans for construction of a third oil-from-coal plant, Sasol III, adjoining the Sasol II plant at Secunda. The cost of construction for Sasol III is estimated to amount to $4.25 billion at completion of construction. Funds for construction are being provided as follows: 20 percent in export credit, 64 percent from the State by way of parliamentary grants and the SOF, and 16 percent from the sale of share capital to private investors. The last item amounts to $525 million, of which $490 million was raised in a private placement aimed at institutional investors and the remainder in a public issue.

Sasol Limited (Sasol) was incorporated on 26 June 1979 as the holding company of the Sasol group. Sasol presently holds a 100 percent share interest in Sasol I and a 50 percent share interest in each of Sasol II and III. The remaining share interest in Sasol II and III is held indirectly through the IDC and its subsidiary, Konoil, Ltd. After the final issue of public shares in Sasol Limited in April 1981, the public now holds 70 percent of issued shares, while the State holds 30 percent of shares. At the end of fiscal year 1980, Sasol's long-term debt-to-equity ratio was 0.13.

An agreement was reached on 20 July 1979 providing for the future acquisition by Sasol of the State's interest in Sasol II and III, which includes a 50 percent shareholding and substantial loans. According to the agreement, the government loans will be free of interest initially. After Sasol II and III each exceeds a profit level of over $130 million per year, one-half of the loans will bear interest at a rate not to exceed that applicable to 10-year Government Stock.

Capital Costs

Capital cost estimates for the Sasol I, II, and III plants have been widely publicized. For Sasol I, plant construction began in the middle of 1952 and was essentially complete by late 1955. The first capital cost estimate for the plant, developed prior to the start of construction, was $75 million. An end-of-job cost assessment in 1956 for the fully operating plant, including the capitalized cost of start up and essential modifications, but excluding the cost of later improvements, indicated a real cost of $142 million. The total capital cost of the present plant, including subsequent modifications, is estimated at $230 million.

The large difference in capital cost estimates before and after construction of Sasol I is in direct contrast to the cost estimating experience for Sasol II. The original estimate for the larger Sasol II facility was developed in 1975 on the basis of in-house cost information. The final end-of-job cost figure for the plant was $3.25 billion. This value was within 10 percent of the original estimate after allowing for inflation and currency adjustments. Site preparation for Sasol II began in March 1976. The first units were commissioned in July 1980.

Although the Sasol III complex is a near duplicate of the Sasol II facility, inflation and currency valuations have driven the expected construction cost to $4.25 billion, according to a 1979 estimate. The Sasol III plant is expected to be fully operational by 1983, about four years after start of construction.

It should be remembered that the capital cost estimates for Sasol III, as those for Sasol I and II, are for grass roots plants. The estimates include site acquisition and development, mine development, and all off-site and auxiliary equipment. Table 6-1 summarizes the capital costs for the three Sasol plants together with coal feed rates and estimated production output rates.

Operating Costs

While capital cost estimates for the Sasol facilities are widely publicized, operating cost data are not. One of the problems is that operating costs for Sasol I are generally lumped with operating costs for the Natref refinery and other operating subsidiaries of the Sasol I group. However, from financial reports, it is clear that in recent years Sasol I accounts for the greatest portion of the profits of the Sasol I group. For

Table 6-1

CAPITAL COST ESTIMATES FOR SASOL I, II, AND III

	Year of Estimate	Capital Cost ($ Million)	Coal Throughput (Million MT/Yr)	Production Output[1] (Million MT/Yr)	Normalized Capital Cost ($/Yearly MT Products)
Sasol I[2]	1956	142	2.7	0.32[3]	440
Sasol II	1975	3250[4]	12.8	2.14[3,5]	1520
Sasol III	1979	4250[4]	12.8	2.14[3,5]	1990

Notes:

[1] Includes motor fuels, ethylene, chemicals, tar products, ammonia, and sulfur.

[2] Original Sasol I plant before expansion.

[3] Assumed 0.12 MT product/MT coal for Sasol I and 0.17 MT product/MT coal for Sasol II and II (Reference 61).

[4] Currency conversion at a rate of $1.30 per Rand.

[5] Includes approximately 30,000 barrel/day motor fuels.

instance, in the period 1974 through 1978, Sasol I accounted for 79 percent of income from operations and 97 percent of net profits. During this same period, income from operations averaged 17 percent of total revenues for the Sasol I group. Net profit after depreciation and taxes averaged 7 percent of total revenues. These figures should be representative of Sasol I operations alone.

Although direct operating costs for the Sasol plants are not available, costs have been estimated by the Financial Mail at $18.60/barrel. This estimate assumes a 20-year life for amortization, $3.60/barrel for coal costs, and $6.50/barrel for labor maintenance and other costs.

Accounting Standards

As a profit-seeking company registered in accordance with the Companies Act, Sasol Limited must report its financial position at the end of each fiscal year (near the end of June) in accordance with standard accounting practices. Accounting practices in South Africa are quite similar to those used in the United States. However, there are a few special considerations that should be allowed for when reviewing Sasol's financial statements. These are summarized below:

- Depreciation: Fixed assets such as plant, equipment, and buildings are written off on a straight line basis over their useful life. Sasol officials stated that plant and equipment at Sasol I were were assigned a useful life of 20 years for accounting purposes.
- Inventory Valuation: In the 1975/1976 fiscal year, Sasol changed its basis of valuing crude oil, naphtha, and finished goods from the first-in-first-out (FIFO) basis to the last-in-last-out basis (LIFO). This change has also been made by many oil companies in the United States to avoid overstating profits during periods of rising prices.

- Inflation Accounting: In the fiscal year ending June 1975, Sasol began adding $16.3 million per year as additional depreciation to account for the effects of inflation. This change had the effect of essentially doubling the depreciation allowance for fiscal years 1975 through 1978. This practice has continued through 1980.

Tax Laws

During the period 1975 to 1978, Sasol's effective corporate tax rate ranged from 36.5 percent to 55.1 percent, with an average of 44.3 percent of profits. The tax rate in 1980 was 41.2 percent of profits. As a producer of liquid fuels from idigenous raw materials, Sasol is also eligible for an excise tax credit of 4.7 cents per liter for LPG, gasoline, diesel, kerosene, and jet fuel. Liquid fuel products from Sasol are priced on a parity basis with petroleum-derived products, allowing for crude oil purchase, ocean freight from the Middle East, refining, and distribution costs.

Sasol also receives undisclosed tax credits for capital investment and export sales.

Other Factors

The cost of coal production at Sasol is significantly lower than in the United States due to thick, easily minable seams and a high degree of mechanization. Sasol officials estimated coal production costs at approximately $13/metric ton, or $12/short ton.

7.0 CONCLUSIONS AND RECOMMENDATIONS

The purpose of this program is to assess the availability, applicability, and transferability of information obtained from foreign coal gasification plants to the U.S. synfuels effort. This assessment includes an analysis of the usefulness of further detailed case studies. In addition, some general conclusions with respect to the choices of commercially available coal gasification processes are presented as they emerged from the case studies.

Conclusions with Respect to Additional Case Studies

In determining whether additional case studies would be useful to the U.S. gasification development efforts, a conclusion was drawn from the information obtained from the two case studies already undertaken. It was shown that although general information on major problem areas, design philosophies, and operational experience (including air and water pollution) is available, specific data to be used for designing a gasifier in the United States are not. All users of coal gasification processes and all engineering/construction firms are contractually bound to keep detailed design data proprietary. In this case, the depth of information available at other facilities can be expected to be similar to the selected two case studies. Therefore, it is concluded that further general case studies are not cost efficient.

The most fruitful continuation of case studies would be direct contacts with the process developers at their technical development centers. Discussions with key technical staff members are expected to reveal more specific information on the design philosophy and on the fundamental process characteristics than discussions with sales staff members of these companies in this country. Such basic information is needed for selecting a commercial gasification process.

A different situation would occur if and when industrial concerns in the United States plan to erect a coal gasification plant at a specific site, based on an already operating foreign commercial technology. For example, after a specific coal feedstock type has been selected by choosing the actual plant site in the United States, additional foreign case studies at plants with similar feedstock would be expected to produce useful basic information. The American industrial developer would benefit from case studies performed on a specific operating technology similar to the one intended for installation in the United States. As an example, the Great Plains Project obtained most valuable information from a "case study" at Sasol.

General Conclusions

Lurgi and Koppers-Totzek gasifiers are well-proven technologies with some 40 years of commercial experience and development. There is no fundamental reason that either process should not work for many U.S. coal feedstocks. However, every gasifier is essentially custom designed. In order to obtain the important design parameters, full-scale testing of the available coal should be done extensively in spite of its high cost. Generally, coal is more difficult and complex in its handling than oil. Provided sufficient testing is performed, typical coal-related problems such as corrosion, erosion, and fouling in a commercial Lurgi or a Koppers-Totzek coal gasification plant in the United States can be expected to be similar to the problems encountered for a conventional coal-fired power plant. The difference, however, is the multiplicity common for all coal gasification plants (e.g., Sasol II operates 36 gasifiers). In other words, the majority of failures would be hardware problems related to valves, pipes, compressors, fans, etc. A certain percentage of any such complex equipment can be expected to fail during the initial start-up of a plant, as exemplified by the problems of Sasol II.

The aforementioned complexity of any larger coal gasification plant to be built in the United States also leads to the conclusion that the involvement of the developer (e.g., Lurgi or Krupp-Koppers) and an experienced engineering company like Fluor, cannot easily be substituted without going through painful and long learning experiences. Similarly, the real operational experience of a Sasol or AECI cannot easily be substituted. Generally speaking, the developers, the engineering company, and the operators--athough bound together by contracts-have only limited information exchange. The standard phrase is, "We tell them what they need to know." It is this interrelation that initiated the sharing of consulting fees between the Lurgi, Sasol, and Fluor Corporation. As a result, it might be concluded that licensing companies which have had access to some limited operating information, but which have never obtained hands-on experience, are not substitutes for the companies which actually developed the technology.

General conclusions have also been drawn about the economic and political considerations that played a role in the stimulation of the synthetic fuels industry in South Africa and may be factors influencing synfuels development in this country. These conclusions are summarized below:

- Capital costs for first generation plants are likely to be significantly underestimated. The cost estimates for second and third generation plants, however, are likely to be much more accurate owing to the experience gained during construction and operation of the first plant. No one will really know how much it costs to build and operate a commercial coal gasification plant in the United States until the first one is built.

- Modern commercial gasification plants are capital intensive, not labor intensive. Operating costs for U.S.-built plants will not be significantly different from the South African experience after adjusting for coal and electricity costs.

- Government support was provided in some form for both the Sasol complexes and the AECI ammonia-from-coal plant. It is unlikely that the Sasol plants could have been built without the equity stake, no-interest loans, and excise tax credits extended by the government. Similarly, the Modderfontein plant enjoys price supports and investment tax credits (as do other ammonia producers). The decision to build the Sasol factories was based on political and strategic arguments. AECI's decision to use coal as a feedstock was primarily an economic one. The U.S. Government would do well to imitate its South African counterpart in assuming different postures toward different industry segments but providing an overall environment of encouragement and cooperation.

- After the first government-assisted plant is built in the United States and proven feasible, traditional forms of debt and equity financing will become available for the second and third generation plants. The Sasol I plant required several years before operating at a profitable level but now has become a formidable cash generator. On the basis of Sasol I's success and the prospects for Sasol II and III, the recent public issue of Sasol stock was oversubscribed 31 times.

Recommendations for the Choice of Gasifiers

Time and again, it has been seen that the most important input for making a choice of various technologies is the nature of the available coal. Important coal properties are caking behavior, fines content, ash content, gasification reactivity, ash corrosivity, moisture, and ash fusion temperature. The Koppers-Totzek (or for that matter, most other entrained bed) gasifier is less sensitive to highly caking coal behavior and high fines content but more sensitive to the ash properties which influence corrosion and fusion temperature than is the dry-bottom-Lurgi gasifier. All gasifier types are affected by coal reactivity, though not to the same extent.

High ash content causes no problems for Lurgi units while the Koppers-Totzek units require increased fly ash removal capacity.

Overall plant size is another important parameter to consider when selecting a gasification process. Four-headed Koppers-Totzek gasifiers are presently limited to 820 metric tons/day (900 TPD) coal input design capacity. The Mark V Lurgi unit apparently operates with about a 1,810 metric ton/day (2,000 TPD) input design capacity. Turndown ratio for larger synfuel plants seems to be of little importance as all gasifiers are either on full load or shut down. At very large synfuel plants, the by-products (oils, tars, phenol, etc.) of a Lurgi unit can be an asset. For smaller plants, these by-products are a nuisance. Recycling of by-products into the gasifier or into the steam boilers can solve the waste clean-up problem. The higher overall thermal efficiency of a Lurgi gasifier becomes more important for larger synfuel plants. It is assumed here that the product gas must be cleaned and available at higher pressures. A Lurgi gasifier requires compression (by gas compressors) of the incoming oxygen alone, while atmospheric gasifiers need subsequent compression of the total product gas, which is a much larger volume of gas. The Lurgi process also requires more steam from a boiler and produces less steam from cooling than the higher temperature Koppers-Totzek process. The steam produced by cooling involves oxygen for combustion, which is thermally less efficient than steam produced from a conventional boiler. The Koppers-Totzek carbon conversion efficiency should be improved, or the fly ash should be fed into a fluidized bed combustor for more complete burnout. High carbon content of the disposed ash can lead to dangerous fire hazards.

The Lurgi gasifier seems to be of somewhat simpler construction with respect to corrosion/erosion potential (i.e., the lower operating temperature of the Lurgi gasifier, compared to all entrained bed gasifiers, does not require refractory-lined walls, but merely water-cooled steel walls).

The Lurgi gasifiers might have a built-in advantage concerning safety over the Koppers-Totzek or Winkler gasifiers insofar as a Lurgi has a one-hour coal supply but only an oxygen supply for less than a minute within the reactor at any time. This results in tremendous coal excess (fuel rich conditions) preventing breakthrough of oxygen into the raw product gas, a hazardous condition which could lead to an explosion. All entrained and fluidized gasifiers with this concurrent flow pattern have coal and oxygen supplies for less than a minute. Any plugging of the coal injection quickly results in sharp oxygen excess conditions.

Availability of Data

Table 7-1 presents the framework of questions on operations which were presented to AECI and Sasol engineers. The answers are indicated by yes (fully answered), no (no details available), and ld (limited answers). Detailed numbers for design capacity, steam or oxygen consumption have been published. However, these values are of very limited applicability due to their strong dependence on the specific feedstock and on the actual operating conditions. Sometimes, the numbers represent annual averages. In other words, these are approximate numbers not of sufficient accuracy to be used for detailed design. Lurgi or Krupp-Koppers especially, but also Fluor, Sasol, and AECI, do

Table 7-1

INTERVIEW QUESTIONS

1.	What is the gasifier design capacity? What is the actual capacity being realized?	1d
2.	What is the coal type and group? Is it caking or non-caking? What is the Free Swelling Index (crucible swelling number)? What percentage is ash? What is the ash-softening temperature? Moisture content?	Yes
3.	What type of coal crushers, pulverizers are used? What is the coal size?	Yes
4.	How is the coal stored?	Yes
5.	How is the coal fed to the gasifier (screw mechanism, lock hopper, etc.)?	Yes
6.	What is the turndown ratio?	Yes
7.	What is the grate or stirrer speed (if applicable)?	No
8.	How is the bed depth determined (e.g., by periodic poking)?	1d
9.	How much ash is removed?	1d
10.	What is the steam (water) consumption?	No
11.	What is the steam : air (or oxygen) ratio?	Yes
12.	What is the gasifier pressure?	Yes
13.	What is the pressure drop across the reactor?	No
14.	What is the gasifier temperature? Gasification temperature, gas exit temperature?	1d
15.	What type of refractory linings in the gasifier?	No
16.	What is the maintenance schedule (e.g., grate replacement, patching of the refractory lining, etc.)?	1d
17.	What is the gasifier diameter?	Yes
18.	What is the startup procedure? How long does it take?	No

Table 7-1 (Continued)

INTERVIEW QUESTIONS

19.	How is the gas cleaned (e.g., scrubber, cyclone)?	Yes
20.	How much tar and oil is produced? What is the composition? Is it sold or used in-plant?	1d
21.	How much wastewater (condensate) is produced? What are its characteristics (pH, dissolved solids, etc.)?	1d
22.	How is the wastewater treated?	Yes
23.	How often is the product gas sampled?	Yes
24.	How does product gas composition vary?	Yes
25.	What are the lifetime of major components?	1d
26.	How much land do the gasifiers occupy?	Yes
27.	How are the gasifiers integrated with the balance of the plant?	1d
28.	How much downtime is experience per year?	1d
29.	How many operators per shift? Per gasifier?	1d
30.	What are the wages paid to the operators?	1d
31.	Have there been any serious accidents, fires, or explosions?	1d
32.	How often does the manufacturer's representative visit the gasifier facility?	1d

not give away design details concerning the construction and operation of such plants without their involvement. General information is available on such questions as:

- Which are the most troublesome components?
- What should be changed in the present setup?
- Future plans.

Future Development Needs

All current coal preparation/beneficiation plants produce large amounts of coal containing wastes, called culm. Similarly, all atmospheric fluidized bed gasifiers (e.g., Winkler) and, to a lesser extent, all atmospheric entrained bed gasifiers (e.g., Koppers-Totzek), produce large amounts of fly ash with a substantial unburned carbon content. Effective use of unburned carbon has a double merit:

(1) Increased overall thermal efficiency and

(2) Elimination of the fire danger of the discarded ash.

All countries with large coal consumption, including South Africa, India, Germany, England, Poland, and the United States, are in great need of culm burning fluidized bed combusters or similar devices. Any such technology developed in the United States could be used for technology exchange with other countries, such as South Africa. Such an exchange would include proprietary information.

Anthracite culm burning fluidized bed combustors are being devloped by Curtiss-Wright, Pope-Evans-Robbins, and Fluidine, with support by the U.S. Department of Energy.

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APPENDIX A

MASTER LIST OF FOREIGN GASIFIERS

Location	Gasifier Type & Number	Dates	Coal Type	Product Gas (Application)	Capacity per Unit	References
Bulgaria						
Dimitroffgrad	Winkler 4	1951 to Present		Medium-Btu	16.1 MMSCFD	1, 3, 4
Stara Zagora	Winkler 5	1962 to Present		Medium-Btu	27 MMSCFD	1, 3, 4
Czechoslovakia						
Chomutov	Woodall-Duckham 14	? to Present	Lignite	Low-Btu (Metal Works)	Approx. 2 MMSCFD	1, 13, 24
East Germany						
Schwarze Pumpe	Lurgi 24	1966 to 1980	Lignite	Medium-Btu (Town Gas)	24 MMSCFD	1, 2, 12, 21, 64
Schwarze Pumpe	Winkler 6	1950 to Present	Lignite	Low-Btu	58 MMSCFD	1, 2, 12, 21, 30
Bohlen	Winkler 3	1938 to Present	Lignite/Coke	Syngas (Hydrogen)	27 MMSCFD	1, 2, 3, 12, 30
Bohlen	Lurgi 10	1940/43** to ?	Lignite	Medium-Btu (Town Gas)	Approx. 2.5 MMSCFD	2, 8, 12

*This list contains facilities which are currently operating or have been shut down for less than five years.

**Some units of this plant started operation in 1940, others in 1943.

Location	Gasifier Type & Number	Dates	Coal Type	Product Gas (Application)	Capacity per Unit	References
East Germany (Cont'd)						
Zeitz	Winkler 3	1941 to Present	Lignite	Syngas (Hydrogen)	20 MMSCFD	2, 3, 12, 30
Karl-Marx Stadt	Koppers-Totzek 2	1966 to Present	Oil Residue (Coke)	Syngas (Ammonia)	13.4 MMSCFD	3, 22
West Germany						
Luenen	Lurgi 5	1969/70 to 1979	Subbitum.	Low-Btu (Gas Turbine)	Approx. 65 MMSCFD	1, 2, 8, 12
Great Britain						
Westfield	Lurgi 5	1960/62 to 1974	Bitum./ Subbitum.	Medium-Btu (Town Gas)	9 MMSCFD	1, 2, 6, 8, 12
Greece						
Ptolemais	Koppers-Totzek 6	1959/69/ 70 to Present	Lignite	Syngas (Ammonia)	6 to 9 MMSCFD	1, 2, 3, 12, 24

Location	Gasifier Type & Number	Dates	Coal Type	Product Gas (Application)	Capacity per Unit	References
India						
?	Wellman-Galusha 6					1
Ramagundam	Koppers-Totzek (4 headed) 3	1980 to Present		Syngas (Ammonia)	19 MMSCFD	1, 2, 10, 12, 22, 31
Korba	Koppers-Totzek (4 headed) 3	1972* Construction Close to Completion		Syngas (Ammonia)	19 MMSCFD	1, 2, 10, 12, 22, 31
Talcher	Koppers-Totzek (4 headed) 3	1980 to Present		Syngas (Ammonia)	19 MMSCFD	1, 2, 10, 12, 22, 31
Jealgora	Lurgi 1	1961 to Present	Various			1, 2, 12, 31
Asansol	Riley-Morgan 2	1952/68 to Present	Bitum.			25
Madras	Winkler 3	1961 to 1979	Lignite (now oil)	Syngas (Ammonia)	17.8 MMSCFD	1, 3, 12

*Date of order.

Location	Gasifier Type & Number	Dates	Coal Type	Product Gas (Application)	Capacity per Unit	References
Portugal						
Lisbon	Koppers-Totzek	1956 to Present	Lignite/ Anthracite	Syngas (Ammonia)	Approx. 4 MMSCFD	1, 2, 12, 22
South Africa						
Sasolburg (Sasol I)	Lurgi 17	1954/58/ 66/73/80 to Present	Subbitum.	Syngas (Liquid Hydrocarbons), Ammonia, Fuel Gas	33 MMSCFD to 100	8, 10, 32
Secunda (Sasol II)	Lurgi 36	1979/80 to Present	Subbitum.	Syngas (Liquid Hydrocarbons)	33 MMSCFD	7, 8, 10
Modderfontein (Johannesburg)	Koppers-Totzek 6	1974 to Present	Bitum.	Syngas (Ammonia)	Approx. 14 MMSCFD	1, 3, 18, 22
Vaal Potteries	Wellman-Galusha 1	1955 to Present		Low-Btu (Furnace)		7
Union Steel	Wellman-Galusha 7	1951 to Present		Low-Btu (Metal Works)		7
Rand Brick	Wellman-Galusha 1	1949 to Present		Low-Btu (Brick-Kiln)		7

Location	Gasifier Type & Number	Dates	Coal Type	Product Gas (Application)	Capacity per Unit	References
South Africa (Cont'd)						
Scaw Metals	Wellman-Galusha 1	1955 to Present		Low-Btu (Metal Works)		7
Lydenberg	Stoic 1	1976 to Present	Bitum.	Low-Btu (Metal Works)		1
Driefontein	Stoic 1	1973 to Present	Bitum.	Low-Btu (Brick Kiln)		1
Pretoria	Riley-Morgan 7	1933/41 to Present	Bitum.	Low-Btu (Metal Works)	Approx. 2 MMSCFD	1, 25
Dundee	Riley-Morgan 2	1950 to Present	Bitum.	Low-Btu (Glass Works)	Approx. 2 MMSCFD	1, 25
Springs	Woodall-Duckham 2	? to Present	Bitum.	Low-Btu		1, 13, 24
Meyerton	Woodall-Duckham 1	? to Present	Bitum.	Low-Btu (Furnace)		1, 13, 24
Johannesburg	Woodall-Duckham 2	? to Present	Bitum.	Low-Btu (Steel Works)		1, 13, 24
Stewarts & Lloyds	Woodall-Duckham	? to Present	Bitum.	Low-Btu (Steel Works)		1, 13, 24

Location	Gasifier Type & Number	Dates	Coal Type	Product Gas (Application)	Capacity per Unit	References
South Africa (Cont'd)						
Escault	Woodall-Duckham 3	? to Present	Bitum.	Low-Btu (Furnace)		1, 13, 24
Mandini	Woodall-Duckham 2	? to Present	Bitum	Low-Btu		1, 13, 24
Driefontein	Woodall-Duckham 2	? to Present	Bitum.			1, 13, 24
Vereenigning	Woodall-Duckham 3	? to Present	Bitum.	Low-Btu (Refractory Works)		1, 13, 24
Stewarts & Lloyds	Wellman-Incandescent	? to Present	Bitum.	Low-Btu (Steel Works)		1, 13, 24
Cullinan	Wellman-Incandescent 4	1964/65/ 73 to Present	Bitum.	Low-Btu (?) (Refractory Works)		1, 7
Scaw Metals	Wellman-Incandescent 5	1963/68/ 75 to Present	Bitum.	Low-Btu (?) (Steel Works)		1, 7
Johannesburg	Wellman-Incandescent 6	1963/68/ 75 to Present	Bitum.	Low-Btu (?) (Metals Works)		1, 7
Alusaf	Wellman-Incandescent 6	1978 to Present	Bitum.	Low-Btu (?) (Metal Works)		1, 7

Location	Gasifier Type & Number	Dates	Coal Type	Product Gas (Application)	Capacity per Unit	References
South Africa (Cont'd)						
Grootfontein	Wellman-Incandescent 1	1970 to Present	Bitum.	Low-Btu (?) (Metal Works)		1, 7
South Cross Steel	Wellman-Incandescent 4	1968/76/80 to Present	Bitum.	Low-Btu (?) (Steel Works)		1, 7
Highveld Steel	Wellman-Incandescent 6	1968/76 to Present	Bitum.	Low-Btu (?) (Steel Works)		1, 7
USCO	Wellman-Incandescent	1973 to Present	Bitum.	Low-Btu (?) (Steel Works)		1, 7
Saiccor	Wellman-Incandescent	1973 to Present	Bitum.	Low-Btu (?) (Paper Works)		1, 7
Union Steel	Wellman-Incandescent 5	1965/68 to Present		Low-Btu (?) (Steel Works)		1, 7
Consolidated Glass	Wellman-Incandescent	1967 to Present		Low-Btu (?) (Glass Works)		1, 7
Thailand						
Lampang	Koppers-Totzek 5	1963/66 to	Lignite	Syngas (Ammonia)	Approx. 10 MMSCFD	1, 3, 12, 22

Location	Gasifier Type & Number	Dates	Coal Type	Product Gas (Application)	Capacity per Unit	References
Turkey						
Kutahya	Koppers-Totzek 4	1966 to Present	Lignite	Syngas (Ammonia)	Approx. 9 MMSCFD	1, 3, 12, 22
Kutahya	Winkler 2	1959 to Present	Lignite	Syngas (Ammonia)	Approx. 9 MMSCFD	3, 4, 6
Istanbul	Woodall-Duckham 1	?	Lignite			1, 13
U.S.S.R.						
Salawad	Winkler 7	1950 to Present		Medium-Btu	21 MMSCFD	1, 3, 30
Baschkirien	Winkler 4	1950 to Present		Medium-Btu	57 MMSCFD	1, 3, 30
Yugoslavia						
Jendinjenja	Wellman-Galusha 1					1
Gorazde	Winkler 1	1952 to Present	Subbitum.	Syngas (Ammonia)	6.3 MMSCFD	1, 3
Kosovo	Lurgi 6	? to Present	Lignite	Syngas (Ammonia)	11.2 MMSCFD	14

Location	Gasifier Type & Number	Dates	Coal Type	Product Gas (Application)	Capacity per Unit	References
Zambia						
Kafue	Koppers-Totzek 4	1967/74/75 to Present	Bitum.	Syngas (Ammonia Methanol)	Approx. 9 MMSCFD	1, 11, 22
		Under Construction/Engineering Design				
Brazil						
San Jeronimo	Koppers-Totzek 2	1984	Subbitum.		Approx. 34 MMSCFD	17, 18, 22
Campo Largo	Carbogas-Pentagano	1980	Subbitum.	Low Btu? (Fuel Gas)	3 MMSCFD	26
China						
Peking	Lurgi 4	1978 (order date)	Semi-Anthracite	Syngas (Ammonia)	Approx. 30 MMSCFD	8,29
Poland						
Katowice	Koppers-Totzek 3	1982/83	Subbitum.	Med. Btu (Fuel Gas)	35 MMSCFD	17
South Africa						
Secunda (SASOL III)	Lurgi 36	1984	Subbitum.	Syngas (Liquid Hydrocarbons)	33 MMSCFD	8

APPENDIX B

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APPENDIX B

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APPENDIX C

EXPANDED DISCUSSION OF TECHNICAL, ECONOMIC, AND POLITICAL FACTORS RELATED TO BASIS OF COMPARISON BETWEEN FOREIGN AND U.S. FACILITIES

VERIFICATION OF THE FOREIGN SYNFUELS
INDUSTRIALIZATION EXPERIENCE
FINAL REPORT
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APPENDIX C

EXPANDED DISCUSSION OF TECHNICAL, ECONOMIC, AND POLITICAL FACTORS RELATED TO BASIS OF COMPARISON BETWEEN FOREIGN AND U.S. FACILITIES

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APPENDIX C

EXPANDED DISCUSSION OF TECHNICAL, ECONOMIC, AND POLITICAL FACTORS RELATED TO BASIS OF COMPARISON BETWEEN FOREIGN AND U.S. FACILITIES

C.1 TECHNICAL FACTORS RELATED TO BASIS OF COMPARISON

Design Philosophy and Construction Codes

The bulk of engineering projects in the world, such as chemical process plants, are designed by European or American firms. They occupy 18 of the top 20 places of leading international design firms (only one company from a developing country, Lebanon, is among the top 20).[1] Because design work is dominated by these firms in developed European and North American countries, common design philosophies and practices have resulted. There are several differences, however, between U.S. and European philosophies. U.S. practice is typically to specify the performance of subsystems and contract out the detailed engineering for these items. On the other hand, European firms typically design subsystems in complete detail, even specifying bolt patterns and fastener sizes. U.S. firms also tend to design systems that extensively use automatic controls and computerized microprocessing; European designs generally specify less automation.[2]

In developed and developing foreign countries, chemical plants are designed more closely to the European philosophy. This is because of the usual abundance of unskilled workers, lack of skilled workers, or limited availability of capital (sophisticated equipment is more capital intensive). This would translate to the United States as a design that would probably require additions of automated ocntrols to the foreign design, fewer unskilled workers, and a greater number of skilled workers (for example, instrument technicians).

There are numerous codes involved in the construction of a major engineering project such as a coal gasification plant. Prominent codes in the United States are the Uniform Building Code and the ASME Pressure Vessel Code (American Society of Mechanical Engineers). Major foreign codes are those of DIN (Deutsches Institue for Normung e.v.) and ISO (International Organization for Standardization). The DIN standards mainly cover product specifications (for example, Standards for Clamping Devices [10050] or Standards for Steel Pipelines [10052]). The international earthquake-resistant regulations were investigated in an attempt to obtain an indication of the variability of building codes throughout the world.[3,4,5] The 15 countries that were analyzed are listed in Table C-1, along with the calculated design factor C (the numerical coefficient for base shear as described by the equation F = CW, where F is the total earthquake force at the base of the structure and W is the total vertical load considered for the seismic calculation, assuming a zone of greatest earthquake potential). The mean for this sample of countries is 0.17, and the standard deviation is 0.05. The U.S. value point is greater than one standard deviation away from the international mean (no interference can be made from this observation). These countires were grouped by their status as developing or developed countries, and the distributions of C coefficients compared. At the 90 percent confidence level, there is no significant difference in the mean C values of the two types of countries. Thus, a case could be stated that the building codes in developing countries are not different than those of

Table C-1

BASE SHEAR COEFFICIENTS FOR SELECTED COUNTRIES

Country	Coefficient, C
Bulgaria	0.24
Canada	0.21
France	0.20
Federal Republic of Germany	0.10
Greece	0.16
India	0.16
New Zealand	0.23
Portugal	0.20
Rumania	0.15
Spain	0.21
Turkey	0.15
USSR	0.10
USA	0.11
Venezuela	0.15
Yugoslavia	0.12
Mean =	0.17
Standard Deviation =	0.05

developed countries. Other important construction code parameters include wind pressure and frost heaving. These parameters are heavily dependent on local factors. Design requirements to prevent frost damage will require additional maintenance and utilities (for example, insulation replacement and steam tracing of pipes).

Sparing

Typical U.S. process plants spare such important equipment as pumps and compressors. The spare may be a complete backup or some percentage of total capacity (for example, 50 percent for a pair of pumps). Large pieces of equipment are generally not spared, although spare parts may be incorporated (for example, a spare rotor may be specified for a centrifugal compressor).[6] Large international plant designs probably adhere to this same philosophy on sparing. The Westfield, Scotland gasifier of the British Gas Corporation required two percent of its total capital costs for spare equipment.[7] The Sasol II plant in Secunda, South Africa spares six of its thirty-six reactors (this is 20 percent of its 30 gasifier design capacity).[8] The Talcher plant of the Fertilizer Corporation of India, Ltd., apparently planned to have one spare gasifier for the three constructed there; however, only three were built (this would have represented 33 percent of capacity as spare). In developing countries such as India where capital is usually scarce, we would expect less sparing of equipment. This lack of capital is evidenced by high rates of interest, such as in Taiwan, which have reached 30 percent.[9] Furthermore, import duties in developing countries make the often-needed foreign equipment additionally expensive. It appears that developed countries have a sparing philosophy similar to the United States, and designs would translate 1:1. On the other hand, designs in developing countries may specify fewer numbers of spares compared to standard U.S. design practices because of the apparent lack of capital. This would indicate longer periods of downtime for gasifiers in developing countries relative to the United States.

Scheduled Maintenance

All process plants require maintenance (for example, catalyst replacement and boiler tube inspection). By properly scheduling maintenance, unexpected downtime can be minimized and unit product cost of the plant kept at a low level. Developed countries have estimated annual maintenance cost of coal gasification and liquefaction plants to range from 1.6 to 10 percent of total capital investment.[10] These countries are Canada, the Federal Republic of Germany, the Netherlands, Sweden, the United Kingdom, and the United States. Estimates for on-stream factors range from 0.70 to 0.95 (that is, fractional time in operation or downtime for scheduled and unscheduled maintenance of about three to sixteen weeks per year).[10] It is interesting to note that the highest on-stream factors were estimated by the British Gas Corporation in the United Kingdom; they operated a Lurgi gasifier commercially from 1961 to 1974.

U.S. estimates for on-stream factors by the Department of Energy and the Electric Power Research Institute ranged from 0.70 to 0.90. A study completed by C. F. Braun for the American Gas Association on western coal commercial concepts assumed a 0.90 factor.[6]

Number of Trains

As process equipment reaches the limit of its size (that is, economics of scale no longer evolve), additional process streams or trains must be added if capacity is to be increased. Extra trains also offer process flexibility in the event of an outage in one train; this is important for plants supplying product downstream for additional processing where an outage involves extra costs, such as additional labor to turn down and restart hot equipment. Plant losses can often be minimized during downtime by temporarily increasing the throughput of the remaining train(s). Depending on the process, it may be feasible to add storage to acquire added flexibility (for example, a one-train system for producing oxygen may use gaseous or liquid storage prior to use in a gasifier). This is similar to the arrangement that existed at the Westfield, Scotland plant. Two streams of oxygen supplied the four gasifiers with pressurized gaseous storage as a buffer. The remainder of the plant was basically of two trains, except for the single waste heat boiler where gasifier streams were combined, the organics removal section where the absorber towers were used, and waste gas disposal and final cleanup where single trains were utilized. The Westfield plant is relatively small and probably could not benefit from fully duplicated parallel trains. We expect that process plants in the United States can generally be larger and would have greater benefits by using multi-train designs.

Plant Capacities

In 1972, Baranson reported that "typically, plants in less developed countries operate at 5 to 10 percent of the scale of internationally competitive plants."[12]

For ammonia plant capacities, there was a statistically significant difference at the 90 percent confidence level for the 12 plants in developed countries and the 63 plants in developing countries. The mean capacity for a plant in developed countries is 1,250 tons of ammonia per day compared to 910 tons per day in developing countries. The optimal size in India is reported to be 1,000 tons/day.

Designers and Contractors

Firms from developed countries dominate this work. The top 10 international designers and contractors for 1979 are listed in Table C-2. U.S. design firms had larger domestic staffs than foreign firms (320 versus 260), but generally kept smaller staffs overseas.[1] The difference between foreign and domestic staff is is not as apparent for international contractors; on the average, each firm employs about 1,300 expatriates.[15] There is a trend toward joint ventures on international construction. The major reasons for these ventures are manpower and technology availability, as well as government aid.[15]

In many cases, local firms may be preferred over top international designers and contractors. Design and construction problems in these cases would not be directly translatable to the U.S. situation (presuming U.S. firms will design and construct gasifiers in the United States). Even if international firms are involved in foreign process plants, the probable difference in expatriate costs, relative unfamiliarity with local regulations, customs, and languages may make translation to the United States difficult.

One indicator of the success of a project's design and construction is the length of time for the system to reach design capacity. These times for five foreign coal gasifiers (Sasol I and II, Modderfontein, South Africa; Westfield, Scotland; and Luenen, Federal Republic of Germany) ranged from 1 to 5 years, with a mean value of 3.1 years. The Koppers Company estimated three years as the time to reach design capacity for a coal gasification plant to be built in the United States.[16]

Table C-2

TOP TEN INTERNATIONAL DESIGN FIRMS AND CONTRACTORS, 1979[1,15]

Position	Design Firm	Contractor
1	Sir William Halcrow & Partners, U.K.	Fluor Corp., U.S.A.
2	SWECO AB, Sweden	Bechtel Group of Cos., U.S.A.
3	Louis Berger Group of Cos., U.S.A.	Davy Corp., U.K.
4	Norconsult, Norway	Chiyoda Chemical Engr. & Const. Co., Ltd., Japan
5	SOFRESID, France	Foster Wheeler Corp., U.S.A.
6	Planning Research Corp., U.S.A.	Hanyang Corp., Korea
7	NEDECO, Netherlands	The Parsons Corp., U.S.A.
8	The SNC Group, Canada	The Rust Engineering Co., U.S.A.
9	W. S. Atkins, U.K.	C. F. Braun & Co., U.S.A.
10	Gibbs & Hill, Inc., U.S.A.	Technip, France

Labor

There are important differences in industrial relations policies and practices between the United Sates and foreign countries. The most significant differences are:

- "The generally very strong political orientation of most unions;
- The opposition, real or doctrinaire, of most important unions against the capitalist system;
- The much greater coverage by law of many aspects of industrial relations, especially fringe benefits;
- The more extensive limitation by public authorities of many management perogatives;
- The scope of collective bargaining - wider in geography but narrower in substance;
- The lesser power of unions at the shop level; and
- The greater importance of class distinctions, customs, and, in some countries, resistance to technological change."[17]

These differences are more or less the same for both developed and developing foreign countries.[17]

Construction

Number of Workers

Construction at the Sasol II plant was essentially complete at the end of 1980. The peak work force totaled about 22,000 persons. During the peak engineering and procurement period, about 2,000 engineers, designers, and specialists were employed.[18] In comparing foreign construction forces to the United States, the following items need to be related, as they can affect the size of the work force:

- Wage rates,
- Skilled labor availability,
- Social and fringe benefits,
- Productivity,
- Weather conditions,
- Construction overhead, and
- Local engineering know-how.[19]

These items have a tendency for their effects to cancel each other; for example, low wages are often associated with low productivity. Specific projects also have to be normalized to the same size and construction duration. Estimates for the number of construction workers at large gasification plants have been made, which are also generally consistent with the construction of large electric power plants in the United States. A 250 billion Btu/day gasification plant in the United States which requires about 20,000 tons of coal/day is estimated to have a peak construction force of 3,200 workers during its four-year construction period.[20] The total number of personhours for construction of a high-Btu gasification plants is estimated at 15 million;[20] for the Sasol II plant, the total number of personhours was 115 million.[21] For comparison, the U.S. high-Btu base plant should be doubled in size. There is a general feeling that more labor is required to build these kinds of facilities in such foreign countries as South Africa, as would be the case in the United States. In India, personhour requirements for given tasks have been estimated to be four to eight times greater than in the United States.[22] This implies construction forces that are about six times larger than those in the United States.

Quality

No convenient measure of the quality of construction workers exists. Productivity values can give an indication of quality, but it is also a function of other variables (for example, weather, type of tools, and availability of construction machinery). Productivity is usually expressed as an index of previous years' levels. Comparisons between countries cannot be made from these indices. One may infer from the South African Sasol construction experience, which apparently required about four times the work for a similar U.S. construction, that foreign construction workers are less productive; however, this is by no means certain.

Costs

Costs are only meaningful if they can be used to assess productivity. Changes in productivities and costs over time have been compared within various countries, but comparisons between countries are scarce. Generally, wages in developing countries are considerably lower than those in developed countries.[23] We found these differences to be statistically significant at the 90 percent confidence level. The U.S. wages are significantly different at the 90 percent confdence level from those in other developed countries. Caution must be exercised when examining international wages; many countries have large social charges, other personal benefits, incentive plans, profit sharing, and bonuses. For instance, in India, wages consist of three components: a basic wage, a "dearness allowance" (comparable to a cost-of-living adjustment), and an annual bonus.[24]

Training Requirements

Where inadequate numbers of skilled construction workers exist or unique skills are required for a particular project, workers must be trained or migrated in. It is beneficial for a country to have its own supply of skilled workers; hence, most countries would choose to develop their populace through training programs. South Africa is doing this on a large scale for the Sasol II and III plants. What is said to be the largest training program in the world for welders is certifying students at the Sasol site. From January to June 1978, nearly nine welders per day were certified.[18] This training program undoubtedly is reflected in a higher cost of the plant. Presumably, there are sufficient skilled workers in the United States.

Availability

Availability of workers is related to unemployment rates. The quality of the unemployed workers, however, is difficult to determine. Unemployment in South Africa was about 10 percent in 1978,[25] in India 30 percent,[26] in Greece 2 percent,[27], and in the United States 6 percent. India is characterized by large numbers of unemployed skilled workers and under-employed workers. Many skilled and technically trained people leave the country to find more rewarding jobs.[26] Greece, with its low unemployment rate, suffers from a tight labor market and a scarcity of workers.[27] Conditions in the United States and South Africa are situated midway of these extremes. Another indicator of availabiltiy of construction labor is the relative percentage employed in construction compared to the remainder of the work force. In South Africa, about 8 percent of the employed work in construction;[25] in India, about 1 percent;[24] and in the United States, about 6 percent.

Miscellaneous Features

The current atmosphere in India makes it nearly impossible to terminate or lay off employees. Many other countries have strict laws restricting layoffs and prescribing remuneration in these cases. In South Africa, an unskilled worker or helper usually accompanies each skilled worker.[28] This may partially explain the large construction work force at the Sasol II plant.

Operation and Maintenance

Number of Workers

Operation of the Sasol I plant in South Africa requires about 3,700 workers; roughly 1,000 of these work in maintenance. The Sasol II plant is estimated to require a total O&M staff of about 8,000 (this plant is about three times larger than Sasol I). The Westfield, Scotland plant employed nearly 300 people during its operation; a breakdown of the staff by function is shown in Table C-3 (this plant was about one-twentieth the size of Sasol I).[7] Estimates for operating staffs in U.S. high-Btu gasification plants range from 580 to 890 (these plants would be one-half the size of Sasol II).

Cost

Indices for hourly wages in manufacturing for 11 developing countries are shown in Table C-4.

Training Requirements

The Westfield, Scotland plant required several months of training for the workers operating the oxygen production facility, the Lurgi gasifiers, and the Benfield process (acid gas

Table C-3

WESTFIELD OPERATION AND MAINTENANCE PERSONNEL[7]

Designation	Staff	Workmen
Works Engineer	1	--
Technical	14	--
Chemical	11	--
Mechanical	8	55
Electrical	2	15
Instrumentation	2	13
Operation	9	108
Day Workers	1	43
Clerical	15	--
	63	234

Total 297 persons

Table C-4

HOURLY COMPENSATION IN MANUFACTURING, NATIONAL CURRENCY BASIS, ELEVEN COUNTRIES, 1950-1979

(INDEXES: 1967=100)

YEAR (1)	UNITED STATES	CANADA	JAPAN	BEL-GIUM	DEN-MARK	FRANCE (2)	GERMANY	ITALY	NETHER-LANDS	SWEDEN (2)	UNITED KINGDOM (2)
1950	45.6	38.8	17.8		26.9	30.3	22.8	24.7	21.2	23.0	34.2
1951	50.2	45.6	22.8		29.8	38.8	26.3	27.1	23.5	26.9	37.1
1952	53.5	53.9	26.3		32.4	45.0	28.1	29.2	25.0	31.6	40.6
1953	56.4	56.3	27.6		33.4	46.3	29.5	31.3	25.8	33.4	43.0
1954	59.0	60.0	30.3		34.9	48.9	30.4	32.6	28.4	34.2	45.3
1955	61.2	61.2	31.7		36.7	52.7	32.3	35.3	30.9	36.5	48.3
1956	65.2	64.6	33.0		39.4	56.7	35.0	38.1	34.1	39.2	52.6
1957	69.0	70.7	34.7		41.8	50.9	39.2	39.5	38.0	41.9	55.9
1958	72.1	73.5	35.3		43.7	49.7	42.6	41.6	40.0	45.0	59.9
1959	74.9	77.2	39.3		46.8	51.8	46.3	43.2	41.8	47.0	61.7
1960	78.0	80.3	43.4	52.4	49.8	56.0	51.8	46.8	44.1	50.7	65.9
1961	80.2	78.9	50.3	55.6	55.8	61.7	60.5	51.8	52.3	55.6	78.8
1962	83.3	77.0	57.5	59.8	61.2	67.9	68.8	61.1	56.3	62.2	74.6
1963	85.8	79.0	64.1	66.1	66.5	75.0	73.6	72.3	62.0	68.3	77.9
1964	89.3	82.0	72.0	74.3	71.7	80.7	79.5	80.4	71.8	75.1	83.2
1965	91.1	86.2	81.1	82.5	79.6	86.9	85.7	86.0	80.5	82.6	91.2
1966	95.2	93.0	89.2	91.2	90.6	92.5	94.3	89.8	90.0	90.2	98.7
1967	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1968	107.1	107.4	116.9	105.8	103.8	112.6	105.9	106.8	111.2	108.6	93.3
1969	114.6	115.5	139.3	115.3	115.2	111.6	117.3	121.1	125.9	118.1	101.7
1970	122.4	128.2	165.9	131.3	135.0	117.2	145.9	145.0	145.6	129.6	115.3
1971	129.9	142.6	197.4	153.7	148.2	131.3	173.1	169.7	172.5	148.0	134.3
1972	136.9	156.6	261.2	197.1	176.8	159.9	210.8	206.0	215.0	181.6	154.4
1973	146.8	170.3	359.9	259.1	235.8	208.5	288.3	261.7	296.1	217.1	167.8
1974	162.4	200.6	439.5	315.7	281.1	231.3	340.9	291.6	365.4	248.7	197.8
1975	181.7	221.4	505.5	404.6	354.5	310.7	404.0	374.7	444.4	322.6	247.5
1976	196.3	261.0	542.6	431.1	374.8	319.0	422.9	352.7	476.9	367.7	235.6
1977	212.5	273.2	661.8	515.8	415.7	353.0	503.6	394.3	557.6	402.4	253.3
1978	230.1	273.8	904.2	629.7	499.7	435.2	631.6	469.9	682.1	447.7	321.8
1979	252.3	292.9	918.2	733.5	578.4	524.5	736.0	582.0	786.1	509.1	416.2

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(1) PRELIMINARY ESTIMATES FOR LATEST YEAR.
(2) COMPENSATION ADJUSTED TO INCLUDE CHANGES IN EMPLOYMENT TAXES THAT ARE NOT COMPENSATION TO EMPLOYEES, BUT ARE LABOR COSTS TO EMPLOYERS.

NOTE: THE DATA RELATE TO ALL EMPLOYED PERSONS (WAGE AND SALARY EARNERS, THE SELF-EMPLOYED, AND UNPAID FAMILY WORKERS) IN THE UNITED STATES AND CANADA, AND ALL EMPLOYEES (WAGE AND SALARY EARNERS) IN THE OTHER COUNTRIES.

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removal).[7] Current extensive experience in the United States with oxygen plants should obviate the need for operator training in this section of a U.S. gasification plant. Because large coal gasifiers are not in operation in the United States, operator training in this area will most likely be required.

Availability

As for construction labor, the availability of operating labor is also hard to assess without some accompanying measure of quality. An indication of availability might be gleened by examining the proportion of workers engaged in manufacturing for the various countries. In India, about 9 percent of the work force is engaged in manufacturing;[24] in South Africa, the figure is also about 9 percent;[25] and for the United States, about 23 percent of the work force is engaged in manufacturing.

Standard Operating Procedures

Times Worked

We compared the average number of hours worked per week during 1977 in manufacturing for 23 developed and 28 developing countries and found a statistically significant difference at the 90 percent confidence level.[29] The mean for developed countries was 38.6 hours/week compared to 44.2 hours/week. If shorter work weeks prevail for gasification plants in the United States and developed countries, a greater number of work shifts per week will be required for round-the-clock operation. Exactly 4.2 shifts are required for continuous operation and 40-hour work weeks. Four- and five-shift systems are common for power generation in developed countries. A report by the International

Energy Agency suggests a four-shift system for a coal gasification system in a developed country.[10] This implies a 42-hour work week.

Safety

Processes are designed to be shut down when safety hazards become apparent. This can be done by automatic controls or manual actions. The United States and developed countries tend to have more automatic controls. A drawback of controls is spurious shutdowns when the instruments fail but no safety problems exist. This is minimized by using a voting system and multiple sensors so that the process is not shut down unless a majority of controls indicate shutdown is required. Similar arrangements are utilized on U.S. plants, which generally are fully automated. U.S. plants usually have large numbers of automatic monitors and samplers on equipment, such as infrared analyzers for organic compounds, fluorescent analyzers for sulfur dioxide, chemiluminescent analyzers for nitrogen oxides and ozone, and gas chromatographs for hydrocarbons. Automatic sampling is safer than obtaining sampling manually. In fact, a laboratory assistant at the Modderfontein plant suffered a fatal anoxia by exposure to carbon monoxide while sampling a precipitator near a purge vent.[11]

Most countries have regulations limiting the concentrations of toxic substances to which plant workers can be exposed. In the United States, recommended concentration levels are published by the American Conference of Governmental Industrial Hygienists. Booklets listing these recommended concentrations (actually referred to as threshold limit values) have been requested by organizations in England, the Netherlands, the Federal Republic of Germany, Italy, and Japan.[30] These recommendations have become the bases for occupational health laws in the United States, which are enforced by the Occupational Safety and Health Administration.

There are at least two philosophies for setting allowable concentrations in the work place. The United States seeks to prevent permanent injury but allows reversible biological changes to take place. In the Soviet Union, any biological change is assumed deletarious and standards are set accordingly. Thus, Soviet standards are much stricter than those in the United States. They might better be called occupational health goals. Some Soviet standards call for such low concentrations of toxic substances as to defy detection by modern analytical methods.[30]

Developing countries are expected to have less stringent occupational health regulations because of their overriding need to first build an industrial base and viable economy.

Unscheduled Maintenance

Very little quantitative information exists in the open literature on unscheduled maintenance requirements. For the Westfield, Scotland plant, we determined that about 6 percent of their maintenance on gasifier No. 3 was for unscheduled items.[7] The other three gasifiers required slightly more maintenance, so we feel the 6 percent value may represent a minimum. Most of the unscheduled repair was for mechanical items (repairs to the stirring mechanism, lock hoppers). The Modderfontein plant reportedly had poor initial reliability, but unscheduled maintenance was not detailed.

Feedstock

Type

The United States is blessed with large reserves of coal of varying types. Coal can probably be found to operate satisfactorily with any commercial coal gasification process. European coals are being depleted and are generally of lower quality than U.S. coal. South Africa has significant reserves of coals, but they are mostly of low grade. Coals gasified there typically contain 20 to 30 percent or more ash and have lower calorific contents compared to U.S. coal. The inital start-up problems at the Modderfontein, South Africa coal-to-ammonia plant were blamed on the initial choice of coal. These problems were attack of the refractory lining of the gasifier, excessive amounts of fly ash, and low efficiency of carbon conversion. A switch in feedstock allowed the plant to increase its performance to that of an oil- or gas-based ammonia plant.[31]

Location

Coal gasification plants can be located next to the mine that serves them or remote from it. Minemouth siting of a plant reduces transportation costs of the coal. The Westfield, Scotland gasification plant is situated adjacent to a coal mine. Because the plant is located in a rural area, there have been some difficulties in obtaining the required number and quality of workers.[7] This is also expected to occur in western regions of the United States. The lack of manpower can be mitigated by bringing in workers; this requires additional expenditures of capital for housing and support services. The Department of Interior is studying these "extra" costs in conjunction with an analysis of away from the minemouth locations for coal liquefaction plants.

The Sasol I, II, and III plants are all located very near their respective coal mines. Indeed, the primary criteria for selecting the Sasol II site was the existence of an adequate coal field.[32] The Modderfontein plant, however, gets its coal from a mine 90 km (56 miles) away.[31]

Coal gasification plants proposed for the United States are usually sited adjacent to a mine. A 1977 sampling of electric utility projects showed that 8 percent of the planned coal-fired plants were located at the minemouth.[33] Electric power plant practice is not directly applicable to potential gasification plants, because power plants tend to be sited as near as possible to the load center they serve. This may not be as crucial for gasification plants.

Reserve Requirements

A cautious electric utility in the United States may store 120 days consumption of coal as a reserve, while the minimum in current practice is 45 days. Reserves by utilities typically average 50 to 60 days.[34] An International Energy Agency report references 60 days storage for power generation in the United States and 90 days in the United Kingdom. For gasification plants, estimates ranged from 14 to 60 days; 30 days was selected as a typical value for analysis in that study.[10]

Environmental Regulations

Environmental limitations placed on gasification plants affect their designs and operation. Most environmental regulations have been enacted in developed countries. A listing of ambient air quality standards is presented in Table C-5.[35] Performance standards have been formulated by various countries for coal-fired power plants; these standards are presented in

Table C-5

NATIONAL AMBIENT AIR QUALITY STANDARDS (mg/m^3)

Country	SO_2	TSP	NO_2	NO	CO
Australia	No national ambient standard	No national ambient standard	No national ambient standard	No national ambient standard	No national ambient standard
Denmark	0.75[a]	0.25[a]	No national ambient standard	No national ambient standard	No national ambient standard
Federal Republic of Germany	0.14[b] 0.40[c]	0.2[b] 0.4[c]	0.1[b] 0.3[c]	0.2[b] 0.6[c]	10.0[b] 30.0[c]
Italy	0.25[m] 0.10[f]	No national ambient standard	No national ambient standard	No national ambient standard	No national ambient standard
Japan	0.14[d]	No national ambient standard	0.4[d] 0.8-0.12[e]	No national ambient standard	No national ambient standard
Netherlands	0.075[b] 0.25[c]	0.03[b] 0.12[c]	No national ambient standard	No national ambient standard	No national ambient standard
Poland	0.075[f] 0.35[g]	0.075[f,h] 0.2[g,h]	0.05[f] 0.2[g]		0.5[f]
United Kingdom	No national abmient standard	No national ambient standard	No national ambient standard	No national ambient standard	No national ambient standard
United States	0.36[d,i] 1.3[e,j]	0.2[d,i] 0.15[e,j]	0.1[k]	No national ambient standard	10.0[l]

[a] monthly average;

[b] long term;

[c] short term;

[d] primary standards (protective of human health);

[e] secondary standards (protective of public welfare, i.e., materials, flora and fauna);

[f] daily average for sensitive areas;

[g] daily average for non-industrial areas;

[h] particles less than 20 μm;

[i] daily average;

[j] 3-hour average;

[k] annual average;

[l] 8-hour average;

[m] 30-min average.

Source: World Coal Study

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Table C-6.[35] Specific emission standards for gasifiers do not routinely exist. The U.S. Environmental Protection Agency is developing standards for coal gasification. Emissions from gasifiers can be different from power plants because gasifiers operate in a reducing atmosphere rather than an oxidizing atmosphere. Thus, gasifiers would emit sulfur and nitrogen in their reduced forms of hydrogen sulfide and ammonia rather than sulfur oxides and nitrogen oxides. The State of New Mexico has proposed emission standards for gasifiers; they are shown in Table C-7.[36]

During the initial operation of the Westfield, Scotland facility, customers complained of sooting problems with the gas. This was thought to be due to the presence of nickel carbonyl, a very toxic compound. The problem was eventually solved when the Benfield plant was put into operation. This was a unique problem, probably as a result of the relatively high concentration of nickel in the coal.[7]

The only environmental problem reported at the Modderfontein plant in South Africa was dust emission from the coal milling section,[11] which was above the normal value of 150 mg per m^3.

The Sasol II plant was designed to meet stringent environmental regulations. For example, the plant is self-sufficient in water; rain water is collected, process water is recycled, and no water is discharged to streams. This arrangement prevents contaminated water from entering the environment.

In 1969, an engineering firm reported that European environmental regulations were more severe than U.S. regulations and were becoming more stringent. At that time, regulations were adding 10 percent to the cost of process plants. In one refinery

Table C-6

NEW SOURCE PERFORMANCE STANDARD FOR COAL-FIRED POWER PLANTS (mg/m^3)

Country	SO_2	TSP	NO_x	CO
Australia	No standard	250	2,500	500
Denmark	No standard	150[a]	No standard	No standard
Federal Repulic of Germany	2,845[b]	100[c] 150[d]	State of the art considered	250
Italy	2,000	No standard	No standard	No standard
Japan 2,500[f]	500 400[f]	200[e]	767	No standard
Netherlands	No standard	No standard	No standard	No standard
Poland	No standard	No standard	No standard	No standard
United Kingdom	No standard	115	No standard	No standard
United States	1,800[g]	45[h]	950[i]	No standard

[a] mg/Nm^3

[b] converted from 275 g/kWh

[c] lignite

[d] hard coal

[e] urban

[f] rural

[g] converted from 1.2 lbs/10^6 Btu

[h] converted from 0.03 lbs/10^6 Btu

[i] converted from 0.6 lbs/10^6 Btu

Source: World Coal Study

Table C-7

COAL GASIFICATION EMISSION STANDARDS PROPOSED BY NEW MEXICO[36]

Emission Component	Regulation
Particulate Matter	0.03 $lbs/10^6$ Btu
Non-methane Hydrocarbons	nil
Sulfur (vapor)	0.04 $lbs/10^6$ Btu
Reduced Sulfur (sum of hydrogen sulfide, carbon disulfide & carbonyl sulfide)	100 ppm
Hydrogen Cyanide	10 ppm
Hydrogen Chloride and Hydrochloric Acid	5 ppm
Ammonia	25 ppm

project, regulations required that process water be returned to the Rhine River beter in quality than the river itself.[22] As seen in Tables C-5 and C-6, U.S. standards are more strict than some countries and less strict than others. We feel that generally, developing countries have less stringent regulations than developed countries. Actual translation of environmental regulations to U.S. operations depends on the country of comparison.

End-Use Requirements

Most common uses of gas from coal are for chemical synthesis, industrial fuels, and town gas. We feel that product requirements for synthesis gas would be similar for the United States and other countries because of the common designs of ammonia and methanol plants; the clean-up requirements for these types of plants are expected to translate 1:1. For industrial fuel gas or town gas, there may be differences in foreign burners that prevent direct translation. For example, the town gas at the Westfield facility contained 450 Btu per standard cubic foot (SCF) compared to estimates of 300 Btu per SCF for the U.S. gasification project by the Memphis Light, Gas and Water Division. The gas at Westfield was enriched with butane; these mixing requirements prevent a direct translation of operational results in this case for that portion of the process. For the Sasol facilities, direct translation is complicated by the difference in specifications of the final product (gasoline) from the United States. South Africa has, for example, different octane requirements and lead additive regulations.

Miscellaneous

Weather Conditions

Extreme high and low temperatures affect the construction and operation of process plants. High temperature and humidity would affect cooling towers and air coolers operation. Freezing temperatures require insulation, steam tracing of pipes and tanks, and special construction for freezing soils.

Fertilizer plants in India are typically built for temperatures between 0°C and 46°C (32°F and 115°F).[37] This would indicate that they do not design for freezing conditions in India; this must be taken into account when translating Indian experience to the United States.

Industrial Activity

Yen has pointed out an interesting ocurrence for products from developing countries compared to developed countries.[9] In developing countries, primary products tend to cost notably more to manufacture, secondary products tend to be more or less costly, and tertiary products tend to cost less. This tendency is shown in Figure C-1 for the route ethylene to polyvinyl chloride pipe (3 in. in diameter) using 1972 costs in Taiwan.

Imports

Project costs in foreign countries are often increased by difficulties in importing materials. For example, the following problems were reported in India.

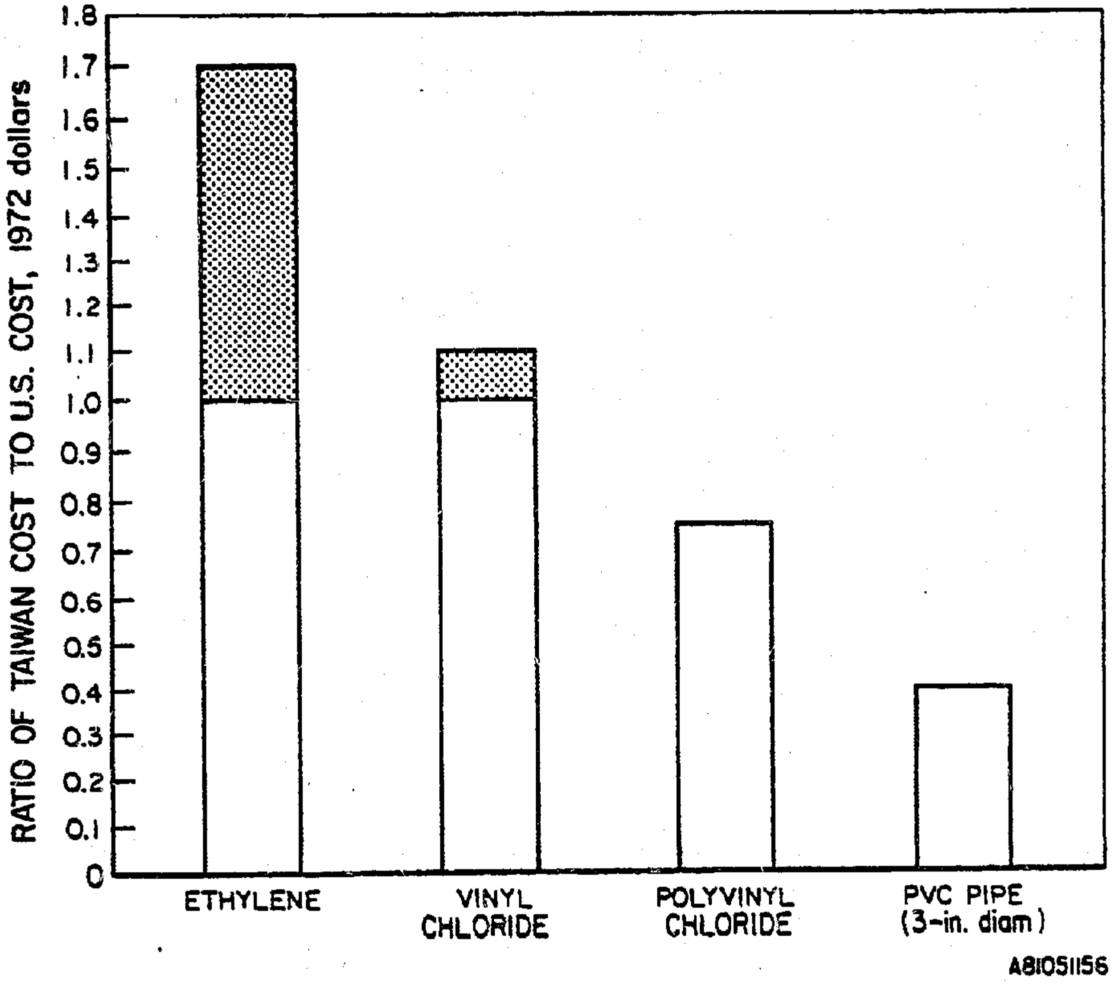

Figure C-1

RELATIVE COSTS OF PRODUCTS FOR TAIWAN AND UNITED STATES, 1972, POLYVINYL CHLORIDE PIPE AND PRECURSORS

> "When we import materials, the customs authorities are very strict. They follow regulations to the letter, and they require all kinds of documentation and certification. To mention one horrible little example, we issued a purchase order for 500 feet of eight-inch pipe. The vendor shipped us 501 feet instead of the 500 we ordered; his packing list and the invoice showed 501 feet. The customs people insisted that the numbers had to agree, so we had to issue a supplementary purchase order for one foot of pipe and submit this order all the way back to the vendor in the United States, Then we had to get it back signed; this took a little time. In the meantime, the 501 feet of pipe was sitting on the dock in India.
>
> Another problem is that duty rates are subject to change by the Indian Government without notice. One fairly large project, we started out with 16.5 percent rate. The next year, this was increased to 26.5 percent. Within six months after that, it was up to 45 percent. A little bit later, the rupee was devalued, and the rate came down to 27.5 percent. When you get involved in a situation of this type, it is pretty hard to meet budgets."[22]

Cost Indices

Indices have been developed for cost of plants located in different countries and built at different times. These indices are averages that generally reflect plant costs but cannot be applied to individual plants. They incorporate the effects discussed above as the basis of comparing foreign plants to those in the United States. Cost indices for 15 countries are presented in Table C-8.[38] Location indices can be approximated by taking the ratio of cost indices between the countries of interest. More exact location indices for the United Kingdom and the United States are shown in Table C-9.[38]

Table C-8

EPE PLANT COST INDEX (1970 = 100)

Year Beginning	Australia	Austria	Belgium	Canada	Denmark	France	Germany	Ireland	Italy	Netherlands	Norway	Spain	Sweden	U.K.	U.S.A.
1971	106	107	105	107	109	109	110	113	108	108	108	112	99	113	104
1972	116	114	117	115	116	120	118	126	123	129	118	24	103	126	107
1973	125	126	133	123	137	141	132	145	147	138	128	142	105	132	113
1974	143	156	162	135	170	168	144	176	187	154	142	175	108	148	119
1975	186	199	188	165	204	197	176	240	241	175	174	221	144	205	149
1976	214	217	214	189	236	218	174	296	292	197	215	271	162	245	149
1977	243	250	227	206	268	236	191	352	342	219	267	342	181	280	160

99(3000)/TaEPEP1

Table C-9

PROCESS PLANT LOCATION INDICES, U.K./U.S.
(U.S. = 100)

Year Beginning	U.K./U.S.
1970	83
1971	90
1972	98
1973	97
1974	103
1975	115
1976	136
1977	145