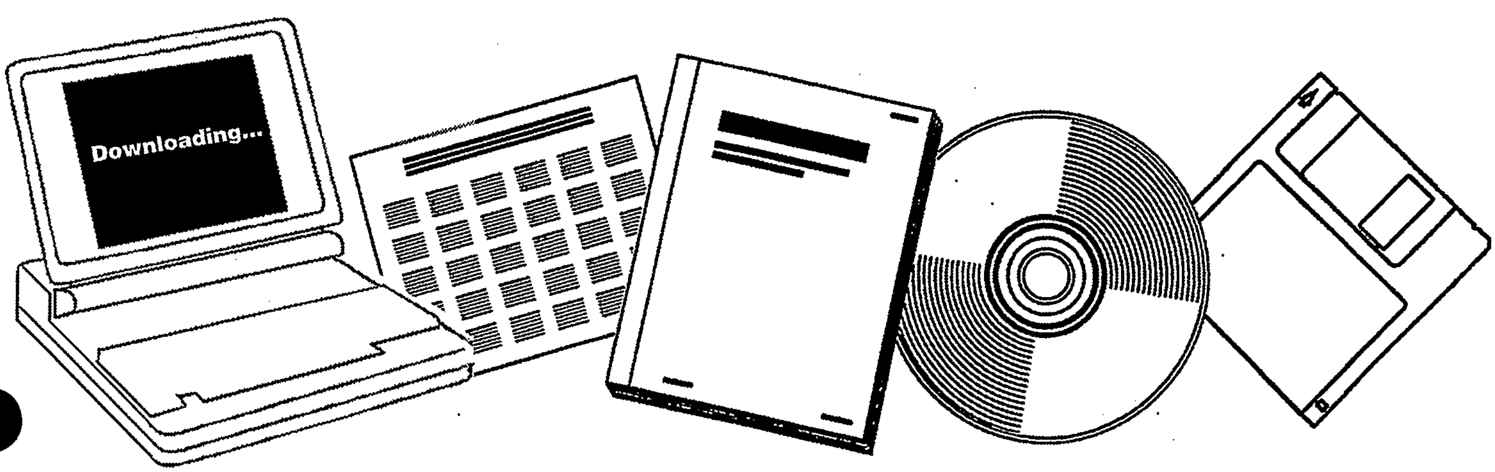
ADVANCED COAL GASIFICATION TECHNICAL ANALYSES. APPENDIX 1: TECHNOLOGY REVIEWS

KELLOGG RUST SYNFUELS, INC.
HOUSTON, TX

JAN 1986



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ADVANCED COAL GASIFICATION TECHNICAL ANALYSES

FINAL REPORT:

APPENDIX 1 — TECHNOLOGY REVIEWS

(DECEMBER 1982—SEPTEMBER 1985)

GAS RESEARCH INSTITUTE
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16. Abstract (Limit: 200 words)

The work reported here is a result of KRSI's activities to support the GRI/Advisors Planning and Strategy (GAPS) Committee thru the duration of the contract. It provides an overview of the gasification, shift/methanation, acid gas removal and sulfur recovery technologies for use in coal-to SNG plant design.

For selected processes in each technology area, "Status Summary" reports are presented. The non-proprietary information contained in these reports was utilized to assess the characteristics, efficiencies and other performance variables of each process relative to criteria developed for each technology area. The results of the assessment are presented in tables which can be utilized for selection of a process best suited for a given application.

In coal gasification area, status summaries were prepared for Lurgi, GKT, Texaco, BGC/Lurgi, Westinghouse (now KRW), Exxon CCG, Shell and U-Gas processes. The Conventional Shift/Methanation, Combined Shift/Methanation, Direct Methanation and Comflux Methanation processes were selected for review of shift/methanation technology. In the acid gas removal technology area, evaluation of Selexol,Rectisol,Benfield and CNG processes has been presented. For the sulfur recovery technology area, Claus,Amoco Direct Oxidation,LO-CAT, Selectox,Stretford and Unisulf processes, were selected for assessment.

17. Document Analysis a. Descriptors

Substitute Natural Gas, Technology Review, Coal Gasification, Shift, Methanation, Acid Gas Removal, Sulfur Recovery

b. Identifiers/Open-Ended Terms

Lurgi Gasification, GKT Gasification, Texaco Gasification,BGC/Lurgi Gasification, Westinghouse Gasification, KRW Gasification, Exxon CCG, Shell Gasification, U-Gas Gasification, Conventional Shift/Methanation, Combined Shift/Methanation, Direct Methanation, Comflux Methanation, Selexol, Rectisol, Benfield, CNG, Ryan-Holmes, Claus, Amoco Direct Oxidation, LO-CAT, Selectox, Stretford, Unisulf.

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ADVANCED COAL GASIFICATION TECHNICAL ANALYSES

FINAL REPORT

Project Summary

APPENDIX 1: TECHNOLOGY REVIEWS

Appendix 2: Coal Fines Disposal

Appendix 3: Technical/Economic Evaluations

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Job 6440

For
GAS RESEARCH INSTITUTE

Contract No. 5082–222–0754

GRI Project Manager
HOWARD S. MEYER
FOSSIL FUELS GASIFICATION

JANUARY 1986

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ADVANCED COAL GASIFICATION TECHNICAL ANALYSIS
FINAL REPORT: APPENDIX 1
TECHNOLOGY REVIEWS

FOREWORD

This document is a compilation of task reports prepared by KRSI, as evaluation contractor for GRI during the December 1982 through September 1985 period. The general purpose of the work reported in these studies was to provide GRI technical assessments of the potential advantage of various processes in order to facilitate GRI management and planning of research programs for production of Substitute Natural Gas from Fossil Fuels. The design assumptions and gas costing procedures used in these reports are based on methodology contained in a GRI report entitled "Guidelines for Evaluation of Commercial Fossil Fuels Gasification Concepts", published in March 1983. (GRI-83/0003, NTIS PB84-132570)

Specifically this document contains the following reports prepared under the topic "Technology Reviews":

- Review of Selected Coal Gasification Processes for SNG Production
- Review of Selected Shift and Methanation Processes for SNG Production
- Review of Selected Acid Gas Removal Processes for SNG Production
- Review of Selected Sulfur Recovery Processes for SNG Production

These reports were prepared as an ongoing support to the GRI/Advisors Planning and Strategy (GAPS) committee throughout the contract. This committee, which is chartered to prepare long-range plans for research and development efforts directed toward the most economical and technically feasible methods of SNG production, developed a procedure for evaluating the competing processes for a given function within an SNG plant. KRSI assisted in the detailed assembly and the testing of that procedure, with much of its input being the accumulation, organization and presentation of information regarding the processes of interest.

KRSI produced "Status Summary" reports for processes in the areas of coal gasification, shift/methanation, acid gas removal and sulfur recovery. The status summary reports became the principal input for the process evaluation procedure. The initial step in the procedure was to assess the characteristics, efficiencies and other performance variables of each process relative to criteria which were developed for each technology area. The tables which were the product of this assessment then became the input for further comparison and analysis. This volume contains all of the status summary reports for the four technology areas.

REVIEW OF SELECTED COAL GASIFICATION PROCESSES FOR SNG PRODUCTION

FINAL REPORT

Prepared by

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FOSSIL FUELS GASIFICATION

JULY 1985

REVIEW OF SELECTED COAL GASIFICATION PROCESSES FOR SNG PRODUCTION

DISCLAIMER

REVIEW OF
SELECTED COAL GASIFICATION PROCESSES
FOR SNG PRODUCTION

TABLE OF CONTENTS

1.0 INTRODUCTION AND SUMMARY

Kellogg Rust Synfuels, Inc. (KRSI) has assembled background information for use in evaluating technologies for coal gasification, as part of work with the GRI/Advisors Planning and Strategy (GAPS) Committee under GRI Contract No. 5082-222-0754. Initially, KRSI accumulated a list identifying most of the available technologies for coal gasification. Then, "Status Summary" reports were prepared for eight selected processes: Lurgi, GKT, Texaco, BGC/Lurgi, Westinghouse, Exxon CCG, Shell and U-Gas. With the list of processes, these documents comprised a body of background information for use in further work.

A large number of technologies for coal gasification is known to exist; many have been abandoned in relatively early stages of development due to technical inadequacies or due to prediction of uncompetitive economics. Of those technologies which remain active, the stage of development spans the range from small-scale research facilities to full-scale commercial plants. Using pertinent references and in-house information from previous studies, KRSI developed a list of 56 technologies for coal gasification. The listing has been subdivided as to stage of development, as:

- Commercial: Processes which are fully-developed and have been operated in full-scale production units.
- Near-Commercial: Processes which have been proven in research facilities of substantial scale and which are ready to be applied in demonstration/commercial plants in the near future.
- Developmental: Processes which are currently under active investigation but which cannot be viewed as prospects for near-term commercialization.
- Inactive: Processes for which development has been terminated; typically, probability of commercialization appears minimal if not nil.

Within each of these subdivisions the processes are grouped, for convenience, as fixed-bed, fluidized-bed, entrained-bed and other techniques. The listings in Section 2., by subdivision, show for each process its name, the name and location of the developer, a capsule description of the process, typical operating conditions, acceptable feedstocks, specifics of existing units and other comments.

The 56 technologies are distributed among the various categories as follows:

	Fixed Bed	Fluid Bed	Entrained Bed	Other Tech	Total
Commercial	7	1	1	0	9
Near-Commercial	2	3	3	1	9
Developing	1	4	5	4	14
Inactive	5	12	4	3	24
Total	15	20	13	8	56

The GAPS committee chose eight representative technologies for further evaluation. These were:

- Lurgi: Fixed-bed, pressurized, non-slagging.
- GKT: Entrained-bed, atmospheric, dry-feed, slagging.
- Texaco: Entrained-bed, pressurized, slurry-feed, slagging.
- BGC/Lurgi: Fixed-bed, pressurized, slagging.
- Westinghouse: Fluidized-bed, pressurized, ash-agglomerating.
- Exxon CCG: Fluidized-bed, pressurized, non-slagging, catalytic.
- Shell: Entrained-bed, pressurized, dry-feed, slagging.
- U-Gas: Fluidized-bed, pressurized, ash-agglomerating.

KRSI proceeded to prepare a "Status Summary" report for each of the eight technologies mentioned above. The direction taken as a basis for assembly of these reports was to summarize pertinent, recent information within a concise report for each process. Each of the Status Summary reports is divided into the following sections, as applicable.

- General Information
- Past/Present Development Activities
- Process Descriptions and Flowsheets
- Process Characteristics
- Advantages and Limitations
- Existing/Planned Commercial Applications
- Technical/Economic Evaluation
- References

The Status Summary reports appear in Sections 3 through 10 for, respectively, the Lurgi, GKT, Texaco, BGC/Lurgi, Westinghouse, Exxon CCG, Shell and U-Gas processes.

2

COMMERCIALIZED GASIFICATION TECHNOLOGIES

- Fixed Bed Gasifiers
  - Lurgi
  - Riley-Morgan
  - STOIC
  - Wellman Galusha
  - Wellman Incandescent
  - Wilputte
  - Woodall Duckham/Gas Integrale
- Fluidized Bed Gasifiers
  - Winkler
- Entrained Bed Gasifiers
  - Koppers-Totzek (GKT)

COMMERCIALIZED GASIFICATION TECHNOLOGIES: FIXED BED

LURGI (DRY-BOTTOM)
LURGI KOHLE UND MINERALOELTECHNIK

- The fuel bed is supported on a rotating grate; a stirrer is attached to the coal distributor. Water jacketed gasifier shell. Coal fed from the lockhoppers is mounted at top. Ash removed from the grate. Oxygen and steam are fed at bottom. Mark IV gasifier is approximately 13 feet I.D., 900 TPD coal capacity.
- 350 - 450 psig, 700 - 2500°F
- All coals, sized to 1/4" x 2" (possibly up to 4").
- Produces oils and tars. Can process only small fraction of fines in ROM coal.
- There are 16 plants around the world; one is Great Plains Project in North Dakota.

RILEY-MORGAN
RILEY STOKER COMPANY, MASSACHUSETTS

- Coal is fed at top and spread evenly by the action of the rotating barrel and the pivoting leveler arms. No grate; the ash bed performs the function of grate. Ash is removed radially by means of a helical plow located in the ash pan and discharged through a water seal. A full size gasifier is 10.5 ft I.D. and approximately 72 TPD capacity.
- Atmospheric pressure, 1000 - 2000°F
- All coals, sizes to 1/2" X 2"
- Careful sizing, even coal distribution and coal swelling index are critical in optimum design/operation of the unit.
- Over 9,000 units built during the first half of the 20th century. A 150 TPD pilot plant was built in 1974 at Worcester, MA to update technology to current practices.

STOIC
FOSTER WHEELER ENERGY CORPORATION, NEW JERSEY

- Two stage fixed bed gasifier with the top stage being the devolatization zone, the bottom stage being the gasification zone. Coal is fed from the top using a feeder. Gas is recovered from each zone separately. Ash is removed from the grate via a water seal. The gasification zone is jacketed for steam production. The gasifier is available in 12.5', 10.0', 8.5' and 6.5' I.D. with capacities of 108, 72, 53, 31, TPD respectively.

- Atmospheric pressure, 750 - 1700°F
  Top gas at 250°F, bottom gas at 1200°F

- Suitable for sub-bituminous, anthracite and bituminous coal with free swelling index less than 3, sized to ½" x 1½", or 1-½" x 3".

- Air blown gasifier. Produces tarred gas. Tar-oils are removed by cyclone and electrostatic precipitators.

- 35 units in operation in South Africa. A 300 TPD demo unit was installed at University of Minnesota.

WELLMAN GALUSHA
DRAVO CORPORATION, PENNSYLVANIA

- Standard or agitated type (for caking coals and higher capacity). The gasifier does not use refractory. The agitator arm, its drive shaft and the gasifier shell are water cooled. Coal is fed by gravity through vertical feed pipes. A revolving eccentric step-type grate is mounted at the bottom, which discharges the ash. Gas passes through a cyclone where ash and char are removed. A 10 foot I.D. gasifier has a capacity from about 30 TPD for anthracite to 150 TPD for lignite in air-blown mode.

- Atmospheric pressure, 600 - 2400°F

- All coals, 1" x 2" for bituminous coal, 5/16" x 9/16" for anthracite.

- Small amounts of tar are produced. Mainly used in air-blown mode. Anthracite and coke have been gasified with steam/oxygen, and it is conceivable that bituminous coal could be gasified with oxygen.

- 14 gasifiers are in operation within the U.S.A. There are over 150 units operating worldwide. A 36 TPD demo unit is at Twin Cities Research Center in Minneapolis, Minnesota.

WELLMAN INCANDESCENT
WELLMAN THERMAL SYSTEMS INCORPORATION, INDIANA

- Coal is fed by gravity in this two stage (devolatilization and gasification) gasifier. The gasifier is not refractory lined. The bottom section is surrounded by a water jacket. Gas is removed from each stage. A mixture of steam and air is injected through the rotating grate at the bottom from where the ash is also discharged. Gasifier of 12 ft. I.D. has a capacity of approximately 100 TPD.

- Atmospheric pressure, 900 - 2200°F. Top gas at 250°F, bottom gas at 1000°F.

- Wide range of bituminous coals sized 1-½" x 2-½", with maximum undersize at 15% - 5/16".

- Over 30 gasifiers installed in South Africa since 1963. One commercial unit at Caterpillar Tractor Company, PA, started up in 1978.

- Black, Sivalls & Bryson (BS & B) is the licensor in the U.S.A. Gasifier produces tar oils of quality comparable to #2 fuel oil.

WILPUTTE
WILPUTTE CORPORATION, NEW JERSEY

- The gasifier is agitated, partially-jacketed, non-slagging and brick lined. Agitation is accomplished by a rotation of the grate at the bottom and water cooled leveler near the top. A 10' 2" Wilputte producer has a capacity of (air blown) 60 TPD.

- Atmospheric pressure, 1150 - 2200°F

- All types of coals, sized 1/4" to 4". 10% fines can be used.

- Approximately 0.1 pound of tar is produced per pound of coal.

- Only a few installations exist in stand-by condition. A 12-producer plant built in 1942 is operating in Kingsport, TN.

6

WOODALL-DUCKHAM/GAS INTEGRALE
IMPIANTI GAS INTERNAZIONALE, SPA, ITALY

- A two-stage gasifier with a rotating grate. The gasification zone is water jacketed and refractory lined. Coal is fed at the top through a lockhopper system. Ash is quenched with water after removal from grate. A 12 foot gasifier can process up to 200 TPD of coal.
- Atmospheric pressure, 1200 - 2200°F. Top gas at 250°F.
- Suitable for coals with free swelling indices up to 2-1/2. Sized coal required.
- Tars and oils equal approximately 13% of product heat.
- There are over 100 installations in Europe.

7

WINKLER
DAVY MCKEE CORPORATION, OHIO

- Cylindrical shell with refractory lining. Coal is fed radially using screw feeders. Steam and oxidant are injected at several levels. Ash is discharged at the bottom. An 18 ft. I.D. by 75 ft. T.T. gasifier can process approximately 1100 TPD.
- 1 to 4 atmospheres, $1800^{\circ}F$.
- Coals with free swelling index less than 4. Sizes to 0 x 3/8".
- Carbon content of ash is usually 15 - 30%.
- There are 16 commercial plants in Europe and Asia, but process has not been demonstrated with U.S. coals.

KOPPERS-TOTZEK
GKT, C/O KRUPP WILPUTTE, NEW JERSEY

- o Two or four headed, double-shelled, refractory lined, slagging gasifier. Coal, steam and oxygen are injected radially through burners. Molten slag flows down the reactor and is quenched by circulating water. A two-headed gasifier has a capacity of 400 TPD. A four headed gasifier has a capacity of 850 TPD.
- o Atmospheric pressure, 2700 - 3500°F
- o Coal must be dried between 2 - 8%, and pulverized to about 70-90% through 200 mesh. Flux addition may be required.
- o Does not produce tars and oils.
- o 25 plants installed worldwide.

NEAR COMMERCIAL GASIFICATION TECHNOLOGIES

- Fixed Bed Gasifiers
  - BGC/Lurgi
  - Ruhr-100
- Fluid Bed Gasifiers
  - High Temperature Winkler
  - U-Gas
  - Westinghouse
- Entrained Bed Gasifiers
  - KBW
  - Shell
  - Texaco
- Other Techniques
  - Allis-Chalmers KILnGAS

NEAR-COMMERCIAL GASIFICATION TECHNOLOGIES: FIXED BED

BGC/LURGI
BRITISH GAS CORPORATION, ENGLAND

- Similar to a Lurgi dry-ash gasifier; ash is withdrawn as slag. Fuel bed rests on a refractory hearth that is surrounded by a number of tuyeres for steam/oxygen injection. Slag accumulates at the base of the hearth and exits through a tap.
- 60 - 450 psig, 900 - 2700°F
- Can handle coking coals, 1/8" x 2" size, with up to 35% - 1/4" fines. Flux addition may be required.
- Steam requirement and liquor production claimed to be significantly lower than dry-ash Lurgi.
- A modified 6' I.D. Lurgi gasifier is operational at Westfield, Scotland. An 8' I.D. (600 TPD) gasifier to be operational in 1984.

RUHR-100
RUHRGAS-RUHRKOHLE, WEST GERMANY

- Basically a large, Lurgi-type gasifier with modifications for high pressure operation. The product gas can be tapped at two points: from the gasification zone, and from the top of the reactor. Coal is fed via alternating lockhoppers, and ash is removed at bottom via lockhoppers.
- Has been operated at 1015 psig. 1450 psig planned. 750 - 2000°F.
- Non-caking coals have been gasified successfully. Coal size is 95% - 1.2" with almost 20% fines.
- A 5' I.D. gasifier, operated at Dorsten, West Germany, has accumulated 1850 operating hours.
- Principal advantages claimed over Lurgi are: higher methane production and throughput, accompanied by lower liquid make.
- All pilot plant activities are dormant now.

NEAR-COMMERCIAL GASIFICATION TECHNOLOGIES: FLUID BED

HIGH TEMPERATURE WINKLER
RHEINISCHE BRAUNKOHLENWERKE AGR, WEST GERMANY

- HTW is an extension of existing Winkler technology to accommodate higher temperature and pressure operation. The higher temperature results in higher carbon conversion and lower liquid byproduct make. High pressure increases the gasifier throughput.
- 13 - 130 psig, 1700°F operation demonstrated; 2000°F planned.
- All types of coal. Drying may be required.
- Limestone addition with coal has resulted in significant decrease in H_2S content of raw gas.
- 30 TPD PDU (2' ID) in West Germany. Oxygen gasification test runs being conducted.

U-GAS
INSTITUTE OF GAS TECHNOLOGY, ILLINOIS

- A vertical cylindrical reactor with two external cyclones to return the elutriated fines. A sloped grid at bottom with an inverted cone serves as oxidant and steam distributor and the agglomerated ash outlet. Coal is fed radially to the grid. PDU gasifier is 4' I.D.
- 50 (PDU) - 350 (Commercial) psig, 1750 - 1900°F.
- All types of coal, sized to 0" x 3/16". Drying may be required.
- Produces gas with relatively high methane content and no oils and tars.
- 18 TPD PDU at Chicago, Illinois; Detailed engineering is underway for a 200 MTPD demo gasifier to be installed at Mazingarbe in Northern France by Charbonnages de France (CdF), the French National Coal Company. Startup is scheduled for late 1986.

WESTINGHOUSE
WESTINGHOUSE ELECTRIC CORPORATION, SYNTHETIC FUELS DIVISION, MADISON, PA

- Similar to U-Gas gasifier, except fresh coal is fed axially at the bottom of the gasifier through a central injection tube along with oxygen and steam. The ash agglomerates are removed from the annulus around the feed tube.

- 130 - 230 psig, 1550 - 1850°F in PDU., 400-600 psig commercial.

- All types of coal, sized to 0" x 3/16". Drying may be required.

- Produces gas with relatively high methane content and no oils and tars.

- A 15 TPD (air-blown) PDU at Waltz Mill, PA is in operation since 1976.

- Proprietorship of Westinghouse Gasification Technology was assumed by Kellogg Rust, Inc., in early 1984 with the formation of its subsidiary, KRW Energy Systems, Inc.

NEAR-COMMERCIAL GASIFICATION TECHNOLOGIES: ENTRAINED BED

KBW
KBW GASIFICATION SYSTEMS, INC., PITTSBURGH, PA.

- o Upflow, refractory lined, water-jacketed, slagging gasifier similar to Koppers Totzek.
- o Atmospheric pressure. Gasification zone is 200°F higher than ash softening temperature. Gas exits gasifier at 1800°F.
- o All types of coal, sized to 70 - 85%, less than 200 mesh. Drying is necessary.
- o PDU does not exist; however, gasifier is based on technologies that have been commercial.
- o KBW is an extension of K-T technology, coupled with Babcock & Wilcox's input in design of the waste heat recovery system which is an integral part of the reactor.

SHELL
SHELL INTERNATIONALE PETROLEUM MAATSCHAPPIJ B.V., NETHERLANDS

- o Pressurized version of Koppers-Totzek gasifier. Coal is fed via lockhoppers into the gasifier pneumatically. The reactor is two-headed and the shell is protected by a thin layer of refractory material. Product gas is quenched by coal gas recycle.
- o 410 psig, 2500 - 3500°F
- o All types of coal, sized to 90% less than 90 microns. Drying to 1-6% moisture necessary.
- o Gasifier produces less than 2% CO_2 (dry basis) and raw gas is free of any liquid byproducts.
- o A 150 TPD pilot plant in Germany. A demo plant (400 TPD) planned in Texas.

TEXACO
TEXACO DEVELOPMENT CORPORATION, WHITE PLAINS, NEW YORK

- Pressurized, downflow, refractory lined cylindrical vessel. Slag flows down the reactor into a water bath at bottom. Gas leaving the gasifier is either directly quenched or cooled to generate steam. Gasifier produces little or no methane and is free of any heavier hydrocarbons.

- 300 - 1200 psig, 2200-2900°F

- All types of coal, size to 100% - 14 mesh and slurried with water. Drying will be required with lignites to avoid excessive oxygen consumption.

- 15 and 20 TPD PDU's in California and a 165 TPD demo plant operated in West Germany.

- A 900 TPD gasifier for Tennessee Eastman on stream in Kingsport, TN.

- A 190 TPD gasifier at TVA, Muscle Shoals, AL, has operated successfully.

- A large demonstration scale (1000 TPD) gasifier is tested at Cool Water, Daggett, CA.

ALLIS-CHALMERS KILnGAS
ALLIS-CHALMERS CORPORATION, MILWAUKEE, WISCONSIN

- Raw coal is fed at the free end of a rotary kiln. The kiln is sloped and the coal is driven to the other end by the tumbling action of the bed. The coal is first dried, preheated, and devolatilized by the exiting gas before it enters the gasification zone where a mixture of air and steam is injected. Some ash is discharged at the other end of the kiln while most of the ash, entrained with product gas, is removed by physical separation.

- 60 psig, 2000°F.

- Any type of coal. Does not require pretreatment.

- Tars and oils are produced in the kiln. Process at present produces only low Btu gas.

- 600 TPD demo unit is operational at East Alton, Illinois. Kiln is 13 feet in diameter and 170 feet long.

16

DEVELOPING GASIFICATION TECHNOLOGIES

- o Fixed Bed Gasifiers
  - KGN
- o Fluid Bed Gasifiers
  - Exxon Catalytic
  - Hydrogasification Rheinbraun AG
  - Stone and Webster
- o Entrained Bed Gasifiers
  - Bell Aerospace High Mass Flux Gasifier
  - Mountain Fuel Resources
  - Rockwell Hydrogasifier
  - Ruhrchemie-Ruhrkohle Coal Gasification
- o Other Techniques
  - Humbolt
  - Rockwell Molten Salt
  - Rummel-Otto
  - Saarberg Otto.

DEVELOPING GASIFICATION TECHNOLOGIES: FIXED BED

KGN
KOHLEGAS NORDRHEIN GmbH, WEST GERMANY

- Gasifier consists of a rotary-grid water-gas generator with a superimposed distillation zone.
- Precarbonizing the coal in the distillation zone and simultaneously recycling the carbonized gases into the hot coke-bed is the heart of the process.
- Temperature: 1450°F, pressure: atmosphere (?)
- Raw gas contains 90 percent ($CO + H_2$) and traces of dust, CO_2, H_2S and hydrocarbon.
- 50 TPD capacity pilot plant operated near Dusseldorf, West Germany with anthracite.

18

DEVELOPING GASIFICATION TECHNOLOGIES: FLUID BED

EXXON CATALYTIC
EXXON RESEARCH AND ENGINEERING COMPANY, BAYTOWN, TEXAS

- Reactor does not use oxygen. Coal is fluidized using recycled syngas and steam and converted to CH_4 and CO_2, in the presence of KOH/K_2CO_3 catalyst. Catalyst is recovered and recycled; char is typically not recycled. After cryogenic separation, CO and H_2 are recycled to gasifier. PDU gasifier is 10" ID and 80' tall.

- 500 psig, 1300°F.

- Coal drying, pre-oxidation will be required. Coal is sized to -16 to 100 mesh size. Four coal types tested.

- 1 TPD PDU at Baytown, Texas. 100 TPD pilot plant was planned for late 1980's in Rotterdam, Netherlands. Fully integrated PDU operation not demonstrated.

- Coal pretreatment, catalyst recovery and consumption are key issues that can determine success of the process.

HYDROGASIFICATION
RHEINBRAUN AG, WEST GERMANY

- Two stages - in the upper bed; hydrogen is used as fluidizing agent. Standard HTW is used as lower bed to generate hydrogen.

- 825 - 1425 psi, 1500 - 1740°F.

- Lignite.

- 28 TPD Pilot Plant.

STONE & WEBSTER
STONE & WEBSTER CORPORATION

- Heat is supplied by high temperature gas cooled nuclear reactor; heat transfer tubes inside gasifier.

- 1530°F, 600 psia.

- Lignite, German hard coal.

- Gasification rate is controlled by heat transfer and temperature of the reactor.

- 18 TPD pilot plant in Essen, West Germany.

BELL AEROSPACE HIGH MASS FLUX
BELL AEROSPACE, BUFFALO, NEW YORK

- This is a pressurized slagging gasifier with 4 zones. The first is coal - O_2 gasification; the second is char-steam gasification; the third is secondary coal-syngas reaction; and the fourth is water quench.
- 3000°F, 735 psig.
- All types of coal, 70% - 200 mesh size; drying required.
- Short superficial residence time (less than one second). No tars or oils produced.
- 12 TPD PDU at Buffalo, New York.

MOUNTAIN FUEL RESOURCES
MOUNTAIN FUEL RESOURCES, INC., SALT LAKE CITY, UTAH

- Dry pulverized coal with steam in entrained flow operating at slagging temperatures.
- 2850°F, 185 psig.
- All types of coals, finely ground.
- 0.5 TPD bench scale unit at Eyring Research Institute, Utah. 30 TPD PDU has been constructed and a few test runs have been made.

ROCKWELL HYDROGASIFIER
ROCKWELL INTERNATIONAL, CANOGA PARK, CALIF. & CITIES SERVICES R & D

- Dry coal feed with hot hydrogen in entrained bed; reaction is by flash hydropyrolysis; residence time is approximately 1 to 2 seconds.
- 1800°F, 985 psig.
- All types of coals, sized 70% through 200 mesh.
- Flash hydrolysis has rapid kinetics which allow reaction to occur in milliseconds. BTX are produced.
- 18 TPD PDU testing completed. 18 TPD IPDU under construction.

RUHRCHEMIE RUHRKOHLE
RUHRCHEMIE AG, AND RUHRKOHLE, WEST GERMANY

- An extension of Texaco coal gasification process. Coal grinding, heat recovery, and slag/ash treatment units are RCRK's own developments.
- 2450 to 2800°F, 600 psig.
- Slurry of 70 wt%, 60% below 90 microns.
- No tars or oils are formed.
- 144 TPD pilot plant operated from 1978 to 1981.

DEVELOPING GASIFICATION TECHNOLOGIES: OTHER TECHNIQUES

HUMBOLDT, KLOECKNER AND SUMITOMO
KHD HUMBOLDT AG, COLOGNE, WEST GERMANY

- Refractory lined vessel containing a molten iron bath. Coal is injected through cooled triple-flow tuyeres with lime and oxygen.
- 2450 - 2550°F.
- Up to 3mm size coal.
- Syngas consists mainly of CO and H_2; sulfur is removed in molten slag.
- Bench scale unit. 240 TPD demo unit under construction.

ROCKWELL MOLTEN SALT
ROCKWELL INTERNATIONAL

- Stainless steel vessel lined with fused alpha-alumina refractory. Gasification in a pool of molten Na_2CO_3.
- 1800°F, 0 - 280 psia.
- All coals, 40% moisture, 1/4" x 0 size.
- Air blown.
- 1 TPD PDU at Santa Susana, CA, operational since November 1978.

RUMMEL-OTTO
DR. C. OTTO & COMPANY, WEST GERMANY

- Atmospheric version of Saarberg-Otto; two versions: single shaft and double shaft.
- Temperature: 2800°F
- Operated 250 TPD single shaft gasifier by Union Kraftstoff at Wesseling, West Germany in 1956 with Lignite.
- A 20 TPD double shaft gasifier was installed at Bromley, England in 1962 but never operated satisfactorily. The project was abandoned in 1964.

SAARBERG-OTTO
SAARBERGWERKE AG & DR. C. OTTO & CO., W. GERMANY

- Entrained flow slag bath, with three stages: slag chamber, reaction zone, and gas cooling section. The first two zones have an outer pressure shell and an inner shell of water cooled tubes.
- 2700 - 3100°F, 370 psi.
- All coals.
- No tars or oils are produced. O_2 blown. High pressure version of Rummel-Otto single shaft.
- 220 TPD demo plant in West Germany.

23

INACTIVE GASIFICATION TECHNOLOGIES

- Fixed Bed Gasifiers
  - Chevron
  - GEGAS
  - GFERC
  - METC Stirred-Bed
  - MORGAS

- Fluid Bed Gasifiers
  - Battelle/Carbide
  - BCR Low BTU
  - BGC Hydrogasifiation
  - Chemically Active Fluid Bed
  - CO_2 Acceptor
  - COGAS
  - HRI
  - Hydrane
  - Hygas (Steam-Oxygen)
  - Hygas (Steam-Iron)
  - Synthane
  - U. of Wyoming Catalytic

- Entrained Bed Gasifiers
  - BI-GAS
  - Combustion Engineering
  - Foster Wheeler
  - ORC (Garrett)

- Other Techniques
  - ATGAS
  - Electrofluidic
  - Kellogg

INACTIVE GASIFICATION TECHNOLOGIES: FIXED BED

CHEVRON
CHEVRON RESEARCH COMPANY, CALIFORNIA

- Feedstock is reacted with steam in a fixed bed reactor in the presence of a catalyst (e.g., K_2CO_3). Ash removal is via a grate and catalyst is added to the feedstock, removed with ash, recovered and recycled.
- 1200 - 1400°F, 300 - 800 psig.
- Tested with lignite only.
- No details of the gasifier are published. Process is protected by U. S. Patents 3759677 and 3775072.
- Small laboratory bench-scale unit.

GEGAS
GENERAL ELECTRIC COMPANY, SCHENECTADY, NEW YORK

- Steel shell in four sections, protected by two layers of castable refractory. Inside equipment includes a grate, a movable upper bed stirrer, and a coal feed auger. Ash is discharged at the bottom.
- 2100°F, 300 psig. Exit gas temp = 1000°F.
- All coals, sized 1/8" x 2".
- Steam/air enters at the base of the gasifier. Tars and oils are produced.
- A 24 TPD PDU has been in operation since 1976. No current plans to scale up to a demonstration size.

GFERC
GRAND FORKS ENERGY RESEARCH CENTER, NORTH DAKOTA

- Slag drains continuously from refractory hearth through a water cooled taphole. Slag breakers and burners remove slag plugs.
- 80 - 400 psig.
- Western (non-caking), Sub-bituminous and Lignite.
- O_2 blown.
- 18 TPD PDU at Grand Forks, N. D.

METC STIRRED BED
U.S. DOE, MORGANTOWN, WEST VIRGINIA

- o Vertical cylindrical gasifier with vertical stripper in the center and rotating grate at the bottom. Coal is fed from a storage lockhopper to gasifier via a rotary screw feeder. It is a pressurized version of Wellman-Galusha gasifier.

- o Atmospheric - 285 psig, 1800 - 2500°F. Gas temperature = 800-1300°F.

- o All types of coals, no drying required.

- o Tars and oils are produced.

- o 24 TPD pilot scale unit.

MORGAS
MORGANTOWN ENERGY RESEARCH CENTER, MORGANTOWN, WEST VIRGINIA

- o Stirred bed; twin coal lockhoppers; water-cooled agitator rotates and reciprocates within fuel bed.

- o Same as METC stirred-bed, except for the coal feeding system.

INACTIVE GASIFICATION TECHNOLOGIES: FLUID BED

BATELLE/UNION CARBIDE
BATTELLE MEMORIAL INST., COLUMBUS, OHIO

- This is a two stage fluidized bed system. The first stage is combustion (burner). The second stage is steam gasification (gasifier). Refractory lined solids transfer system from burner to gasifier. Agglomerated ash formed in the burner acts as a heat carrier to gasifier.
- 1600 - 2300°F, 100 - 300 psig.
- All types of coals, <100 mesh for burner and +100 mesh for gasifier.
- No oxygen required. Low C content in ash. Minute quantities of oils and tars are produced. Feedstock pretreatment is necessary.
- A 25 TPD PDU at West Jefferson, Ohio operated from 1976 to 1978.

BCR LOW BTU (TRI-GAS)
BITUMINOUS COAL RESEARCH, INC., MONROEVILLE, PA

- Three stage fluidized bed: first stage is devolatilization of coal feed; second stage is coal and char gasification; third stage is char combustion. Air is introduced in Stages 2 and 3. Stage 1 coal is fluidized by hot gas from Stage 3.
- Temperature, °F - Stage 1: 600 - 1200; Stage 2: 1700 - 2000; Stage 3: 2100. 250 - 300 psig.
- All types of coals: 60% + 200 mesh, 40% - 200 + 325 mesh.
- No oils or tars are produced.
- A 1.2 TPD PDU was operated at Monroeville, PA until 1980. Illinois #6 coal was tested.

BGC HYDROGASIFICATION
BRITISH GAS CORP., ENGLAND

- Two stage fluidized bed: first stage is coal hydrogasificaiton and devolatilization; second stage is char hydrogasification. There is internal recirculation of solids in bed.

- 1st Stage: 1470 - 1560°F. 2nd Stage: 1650 - 1740°F. 750 psig.

- O_2 used in steam. O_2 gasification of residual char to produce hydrogenerating gas.

- There was a 40 TPD demonstration plant a Solihull, England. The program was terminated in 1965.

CHEMICALLY ACTIVE FLUID BED
FOSTER WHEELER CORP., LIVINGSTON, NEW JERSEY

- Two fluidized beds: first is the gasifier and regenerator; second is partial oxidation and pyrolysis of coal. CaO captures S from pyrolysis, resulting in a SO_2 rich stream from regenerator.

- Gasifier 1600°F. Regenerator 1900°F. 15 psia.

- Air is used. No steam is required.

- Developed by Exxon; licensed since 1979 by Foster Wheeler.

- A 288 TPD pilot plant at San Benito, Texas was terminated in 1981.

INACTIVE GASIFICATION TECHNOLOGIES: FLUID BED

CO_2 ACCEPTOR
CONOCO COAL DEVELOPMENT CO., LIBRARY, PA

- Two fluidized beds -- gasifier and regenerator; uses steam gasification in the presence of limestone or dolomite.
- 1500 - 1850°F, 150 - 200 psia.
- Lignite and sub-bituminous coal; +100 to -8 mesh size.
- No O_2 required. Air is used in the regenerator only. Reaction of CaO with Co_2 supplies heat and enhances H_2/CO production.
- 40 TPD pilot plant at Rapid City, South Dakota. This program was terminated in 1979.

COGAS
COGAS DEVELOPMENT CO., PRINCETON, NEW JERSEY

- Combination of a 3 to 4 stage pyrolyzer with steam-blown gasifier and air-blown combustor. Ash is discharged from the combustor as molten slag via a water quench system.
- Liquids are produced in the pyrolyzer.
- Gasifier - 1600°F. Combustor - 3500°F. 50 psig.
- All types of coal are acceptable; 1/8" x 0.
- A 50 TPD pyrolysis pilot plant was operated in New Jersey.
- A 36 TPD char gasification/combustion pilot plant was operated at Leatherhead, England and a 1.2 TPD PDU was operated at Princeton, New Jersey. The Program was terminated in 1981.

HRI
HYDROCARBON RESEARCH INSTITUTE, TRENTON, NEW JERSEY

- Fast fluidized bed gasifier, gas velocity 7-20 ft/sec, solids loading 10-20 lb/ft^3, low BTU gas.
- 2400°F, 150 psi.
- All coals.
- High gasifier capacity. No tar formation.
- 7 TPD PDU at Trenton, New Jersey.

HYDRANE
U.S. D.O.E., MORGANTOWN, WEST VIRGINIA

- Two stages: first stage is a free-fall dilute phase reactor; second stage is a char hydrogasification in a fluidized bed. Residual char is gasified with steam and oxygen to produce hydrogen.
- Free board temperature = 1800°F. Hydrogen entering FB temperature = 1000°F. 1000 psig.
- Can accept all types of coals; 70% through 200 mesh size.
- About 94-95% of required methane for pipeline gas is produced in gasifier. A forerunner to the Cities Service/Rockwell process.
- 12 lb/hr bench scale unit was operated at Bruceton, PA. Full integration of two zones was not achieved. No work done since 1978.

HYGAS (STEAM OXYGEN)
INSTITUTE OF GAS TECHNOLOGY, CHICAGO, IL.

- Cylindrical vessel with four internal stages: coal slurry drying (I), low-temperature hydrogasification (II), high-temperature hydrogasification (III), steam-oxygen gasifier (IV). Feed is coal slurry in byproduct oil.
- 500-1000 psig., Stage I: 600°F, Stage II: 1200-1400°F, Stage III: 1600-1700°F, Stage IV: 1750°-1840°F.
- All coal types accepted, sized - 14 mesh.
- Tars and oils produced, residence times are 1-10 sec. for second stage, 20-40 min. for third stage.
- 75 TPD pilot plant in Chicago; testing terminated in 1980.

HYGAS (STEAM-IRON)
INSTITUTE OF GAS TECHNOLOGY, CHICAGO, IL.

- Same as the Hygas steam-oxygen in upper section. Separate steam-iron H_2 production system required, has producer, reducer and oxidizer sections. Spent solids from the oxidizer recycle to the reducer via the vertical lift pipe.
- Producer 2000°F. Reducer and oxidizer 1500°F. 1,100 psig.
- All types of coals.
- Air is used.
- 50 TPD pilot plant at Chicago, IL; program was terminated in 1978.

SYNTHANE
U.S. D.O.E., PITTSBURGH, PA

- Refractory lined with an internal cyclone; single-stage fluid bed. Char cooler and removal at base.
- 1500 - 1800°F, 1000 psig
- All coals: < 200 mesh, < 14% moisture.
- O_2 blown operation. The project was terminated before process problems were resolved.
- A 72 TPD pilot plant operated bewten 1976 and 1979 at Bruceton, PA by the Lummus Company.

UNIVERSITY OF WYOMING CATALYTIC
UNIVERSITY OF WYOMING AND BABCOCK & WILCOX

- Fluidized bed: Ni and K_2CO_3 as catalyst. Overall reaction is autothermal.
- 1200 - 1400°F, 30 psig.
- Lignite, sub-bituminous coals.
- Laboratory scale.

INACTIVE GASIFICATION TECHNOLOGIES: ENTRAINED BED

BI-GAS
BITUMINOUS COAL RESEARCH, INC., MONROEVILLE, PA

- Two-stage reactor with slag quench zone in bottom. Char burners at stage 1, coal feed injection at stage 2. Stage 1 and 2 are connected by a throat inside the gasifier body. Coal is injected through nozzles at the throat. Steam is introduced at the same point through the annulus. Char produced in Stage 2 is recycled to Stage 1.
- Stage 1: 2700 - 3000°F. Exit gas 1500 - 1700°F. 750 - 1500 psig pressure.
- All types of coals (only two types tested). Slurried with water. 5% +10 mesh size.
- No oils or tars produced. Oxygen is used. Relatively high methane make is claimed.
- 120 TPD pilot plant at Homer City, PA. since 1976.

COMBUSTION ENGINEERING
COMBUSTION ENGINEERING, INC., WINDSOR, CT

- Two sections in the gasifier: lower combustor and upper reductor. Reaction sections separated by a reduced cross section throat or diffuser zone. Water-cooled, refractory lined walls around the gasification reactor produce steam.
- Combustion zone - 3200°F. Exit gas - 1700°F. Atmospheric pressure.
- All types of coals; 70% through 200 mesh. 1 - 2% moisture.
- Air blown operation. Heat is supplied by combustion of pulverized coal and recycled char. Molten slag is drawn off at the bottom.
- There has been a 20 TPD pilot plant at Windsor, CT since 1978, with 3700 hours of operation. The operations were terminated in June 1981.

FOSTER WHEELR
FOSTER WHEELER ENERGY CORP., LIVINGSTON, NEW JERSEY

- This is an air blown version of Bi-Gas.
- Stage 1: 2500 - 2800°F. Stage 2: 1800 - 2100°F. 350 psig pressure.
- 70% through 200 mesh, dried to 2% moisture.
- A 480 TPD pilot plant was planned, but was not constructed. No progress since 1978.

ORC (GARRETT)
OCCIDENTAL RESEARCH CORP.

- Entrained flow. Flash hydrolysis of pulverized coal by hot recycled char. Distribution of gas/liquid products is set by pyrolysis temperature. Dry ash.
- Gasifier 1600 - 1650°F, quench - 1350°F. 50 psi
- Sub-bituminous coal.
- Air is used in a separate char heater.
- 50 lb/hr pilot plant in La Verne, CA.

INACTIVE GASIFICATION TECHNOLOGIES: OTHER TECHNIQUES

ATGAS
APPLIED TECHNOLOGY CORP.

- This is a molten iron bath, refractory lined, cylindrical vessel with oil cooled injected lances. Slag is continously removed.
- 2500 - 2600°F, 65 psi.
- Primarily H_2 and CO in the syngas; sulfur leaves in slag.
- Bituminous coal.
- Molten iron bath reactor of 2 tons capacity.
- O_2 is used. Limestone is injected with coal to remove sulfur.
- Now rights of this technology have been bought by Kloeckner of West Germany.

ELECTROFLUIDIC
IOWA STATE UNIVERSITY, AMES, IOWA

- Fluidized bed. Heat is supplied electrically by graphite electrodes. The reactor lining is high alumina refractory.
- 1530°F, 600 psig.
- Lignite, German hard coal.
- Gasification rate is controlled by heat transfer and the temperature of the reactor.
- 18 TPD pilot plant in Essen, W. Germany.

KELLOGG
THE M. W. KELLOGG COMPANY, HOUSTON, TEXAS

- Molten Na_2CO_3 bath; castable alumina reactor lining. Slag removed from bottom.
- 1700°F, 1200 psi
- Western sub-bituminous coal.
- O_2 or air can be used.
- Lab work on bench scale gasifiers.

STATUS SUMMARY:

LURGI (DRY BOTTOM) GASIFICATION

LURGI

1.0 GENERAL INFORMATION

- The Lurgi process is a commercially proven, fixed bed pressurized gasification method to produce fuel gas or synthesis gas and other by-products from a variety of coals.

- Developer: Lurgi Kohle und Mineralotechnik GmBH of Frankfurt, West Germany

- Licensor (within USA): American Lurgi Corporation
  660 Kinderkamack Road
  River Edge, NJ 07661

- All ranks and most types of coal can be gasified in present gasifier designs; caking coals require special stirrer designs.

- Coal sized 1/4" - 2" preferred

- Ash contents up to 30 wt. percent are acceptable; the ratio of ash to feed carbon normally should not exceed 0.7 lb/lb.

- Moisture content is not crucial, provided it does not reduce the temperature of the gases leaving the fuel bed below the dew point. Limit is usually 35-40%.

- A typical Mark IV gasifier (13 ft. ID) can gasify approximately 900 TPD of coal at 400 psig.

- More than 20 plants with about 150 gasifiers have been constructed. A list of the installations is in Section 6.0.

2.0 PAST/PRESENT DEVELOPMENTAL ACTIVITIES

- The process was commercially proven with successful operation of the first full-scale coal gasification plant at Hirschfelde, Germany, in 1936.

- In 1946, bench scale Lurgi gasifiers of 4", 6" and 13.5" ID were built at the Central Experimental Station of the Bureau of Mines to test Alabama caking coals.

- In 1953, a pilot-scale plant was erected at Holten, Germany, to test the Lurgi gasifier for various high-volatile coals and weakly caking coals.

2.0 PAST/PRESENT DEVELOPMENTAL ACTIVITIES (CONTD.)

- The ability of the Lurgi dry ash gasifier to handle strongly caking, less reactive Eastern U.S. coals was demonstrated at the plant in Dorsten, W. Germany, in 1963.

- In 1973-1974, special trials were carried out on the U.S. coals at the Westfield, Scotland plant.

- Between 1974 and 1982, a number of U.S. coals were tested at the SASOL, South Africa plant. A chronological list of all U.S. coals tested is presented in Table 2.1.

- With the support of the West German Government, a consortium including Ruhrgas, Ruhrkohle, Lurgi Kohle and Mineralotechnik GmBH are to build an experimental gasifier at Dorsten to investigate operation at pressures up to 1,500 psig, called the Ruhr 100 process.

- The British Gas Corporation, under the sponsorship of 15 U.S. companies, tested slagging operation of the Lurgi gasifier at Westfield, Scotland. The capacity of this 6 ft. ID semi-commercial unit is 400 tpd.

3.0 PROCESS DESCRIPTION

The Lurgi process utilizes a fixed bed, pressurized gasifier with a vertical, cylindrical construction (figure 3.1). The gasifier shell is surrounded by a water jacket and boiler feedwater is circulated through the jacket to recover part of the heat evolved during coal gasification reactions as steam. A coal lockhopper system is mounted on top of the gasifier and a distributor spreads the incoming coal evenly onto the coal bed. A motor driven grate at the bottom of the gasifier is used to withdraw the ash.

Coal, sized at the storage area, is fed in batches into the gasifier via a system of belt conveyors and lockhoppers.

Fines generated during the sizing are removed and are available for use in the plant or for export. Steam and oxygen are introduced at the bottom of the gasifier into the coal bed through the rotating grate. The grate supports the coal bed and is continuously rotated to assure a constant and even withdrawal of the ash.

TABLE 2-1

LURGI GASIFICATION TESTS OF U.S.A. COALS

LOCATION	DATE	SPONSOR	PROJECT	COAL	TEST GASIFIER
Westfield, Scotland	1973-4	American Gas Association/Office of Coal Research	Trials	Montana Rosebud	Mark II
				Illinois 5	Mark II
				Illinois 6	Mark II
				Pittsburgh 8	Mark II
Sasolburg, Republic of South Africa	1974	ANG Coal Gasification	Great Plains Gasification	North Dakota Lignite	Mark III
	1977	Carter Oil	Exxon East Texas	East Texas Lignite	Mark III
	1981	Panhandle Eastern Pipeline	WyCoal Gas	Wyoming Sub-Bituminous	Mark IV
	1981	Texas Eastern Texas Gas	Tri-State Synfuels	Kentucky 9	Mark IV Modified
	1982	Phillips Coal	Texas Gasification	East Texas Lignite	Mark IV

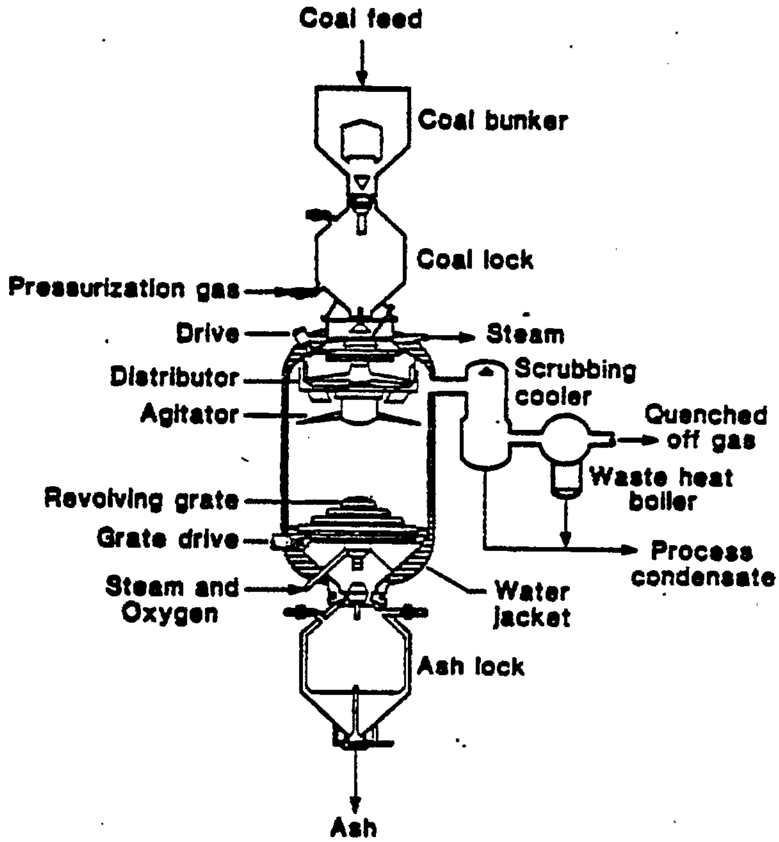

FIGURE 3.1 LURGI DRY ASH GASIFIER

3.0 PROCESS DESCRIPTION (CONTD.)

In the upper part of the coal bed, coal entering the gasifier is dried and is then subjected to low temperature distillation by the heat in the rising gases. In the lower part of the bed, the gasification reactions, initially between the steam/oxygen mixture and the descending semi-coke, produce a mixture of carbon monoxide and hydrogen, together with significant quantities of methane (most of which is produced in the upper pyrolysis zone). The ash is withdrawn from the bottom of the gasifier into the ash lockhopper and then sent to disposal.

The raw gas formed in the gasifier leaves from the top and flows through a wash cooler where it is quenched with a flow of recirculated liquor (see Figure 3.2). Heavy tars and dust are removed from the gas stream in the wash cooler and in the waste heat boiler sump with lighter tar and liquor condensing in the boiler tubes. Oil, tar and liquor accumulating in the sump are discharged to the tar/liquor separator. The gas exiting the waste heat boiler is further cooled by three water-cooled heat exchangers in series. A part of the condensate recovered from this cooling is sent to the tar/liquor separator, and the remainder is sent to an oil/liquor separator.

Tar and the aqueous tar liquor are decanted in the tar/liquor separator. Similarly, tar oil and the aqueous oil liquor are decanted in the oil/liquor separator. The gas liquor is fed to a Phenosolvan unit and an ammonia plant, where crude phenols and anhydrous ammonia are recovered.

By-product naphtha is recovered from the condensate collected in a cooling step prior to acid gas removal. Gases from the final cooler are desulfurized in an acid gas removal unit. The final product gas is a desulfurized medium-BTU gas.

4.0 PROCESS CHARACTERISTICS

4.1 Operating Conditions

- Pressure: 350 to 450 psig
- Temperature: 1,800 to 2,500°F (combustion zone)
  1,150 to 1,500°F (gasification zone)
  700 to 1,100°F (exit gas)

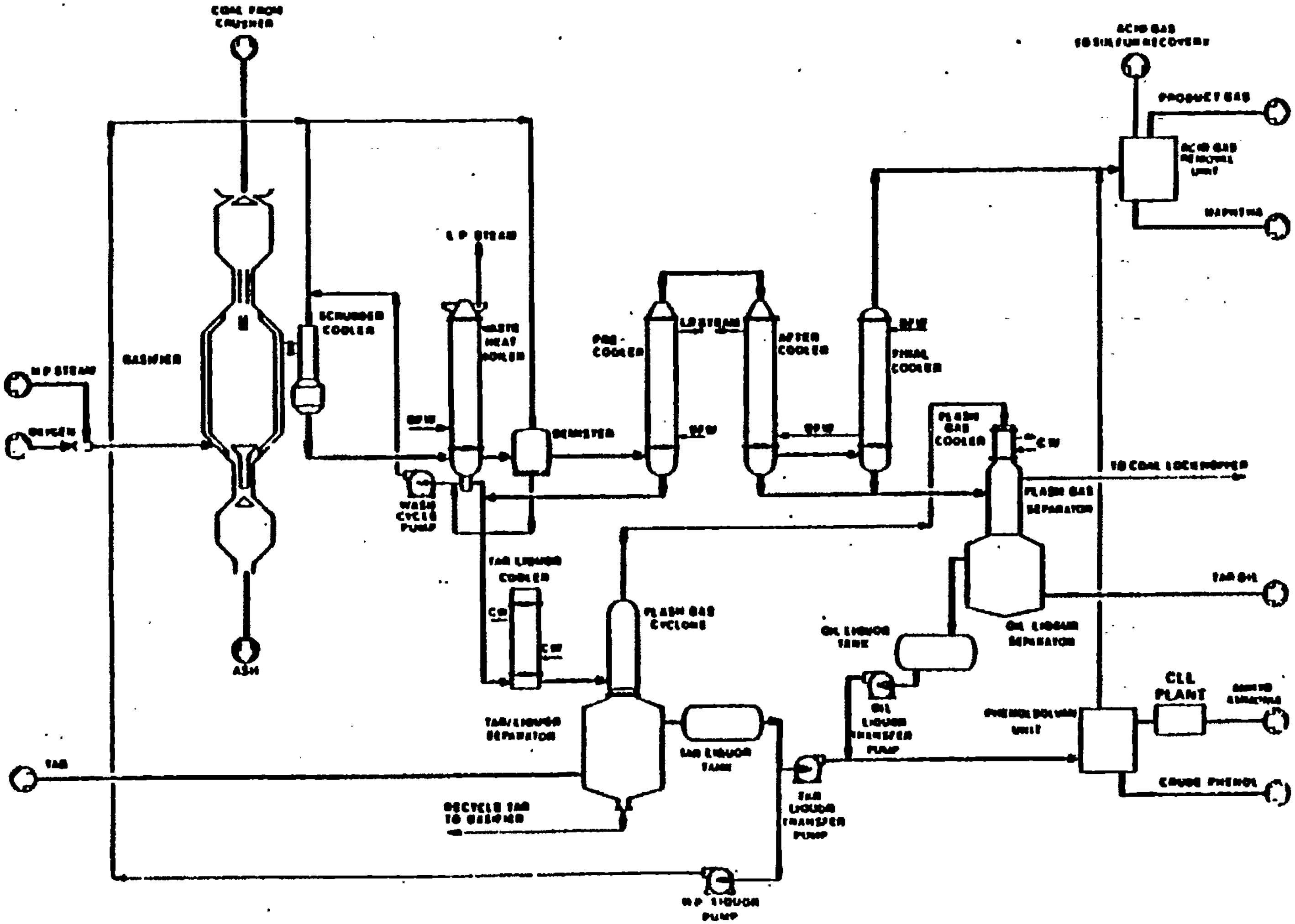

FIGURE 3.2 LURGI (DRY ASH) GASIFICATION SYSTEM

4.0 PROCESS CHARACTERISTICS (CONTD.)

- The operating temperature is strongly dependent on type of coal:
  - Higher moisture = lower temperature
  - Higher reactivity = lower temperature
- Residence time up to one hour.

4.2 Reactants

- Can be operated in oxygen-blown or air-blown mode
- Steam and oxygen requirements are dependent on coal type.

	Oxygen Ton/Ton Coal (MAF)	Steam Ton/Ton Coal (MAF)
Examples: Pittsburgh #8 (Ref 2)	0.71	3.70
Illinois #6 (Ref. 3)	0.43	1.92
Wyoming (Ref 4)	0.36	1.34
N.D. Lignite (Ref 5)	0.36	1.79

4.3 By-products

- Tar oil, crude phenols, naphtha, ammonia and sulfur.

4.4 Gas Produced

Typical gas compositions after gas scrubbing and cooling are presented in Table 4-1.

5.0 ADVANTAGES AND LIMITATIONS

- Commercialization: Lurgi has had many years of successful operation with nearly 3,800 MM scfd of gas production capacity in operation.
- Operating conditions: High pressure technology is proven. Low exit temperature operation decreases the need for waste heat recovery but increases liquid hydrocarbon production.

TABLE 4-1

SUMMARY OF LURGI GASIFICATION TRIALS ON AMERICAN COALS AT WESTFIELD

	Fuel and Size (in.)			
	Rosebud, 0.25–1.5	Illinois No. 5, 0.5–1.5	Illinois No. 6, 0.5–1.5	Pittsburgh, 0.25–1.5
Proximate analysis (wt %)				
Volatile matter	29.2	35.2	34.7	37.4
Fixed carbon	36.4	44.7	46.0	50.3
Moisture	24.7	12.0	10.2	4.6
Ash	9.7	8.1	9.1	7.7
HHV (Btu/lb, maf)	13,130	14,330	14,210	15,330
Caking index	0	15	15	30
Free-swelling index	0	2–2½	3	7½
Ash-fusion point (°F)				
Oxidizing	2300	2370	2490	2480
Reducing	2150	1940	2100	2140
Total sulfur (wt %, maf)	1.61	3.88	3.44	2.87
Operating conditions				
Pressure (psia)	371	356	350	365
Gas offtake temperatures (°F)	709	1148	1121	1195
Steam/oxygen ratio (molar)	9.1	8.6	9.8	9.8
Products				
Crude gas composition (vol %)				
CO	15.1	17.6	17.3	16.9
H_2	41.1	38.3	39.1	39.4
CH_4	11.2	9.2	9.4	9.0
C_2H_6	0.5	0.5	0.7	0.7
C_nH_m	—	0.3	—	0.1
H_2S	0.5	1.1	1.1	0.8
CO_2	30.4	31.0	31.2	31.5
N_2	1.2	1.5	1.2	1.6
HHV (Btu/scf)	298	291	290	285
Tar and oil (wt % coal, maf)	6.1	6.13	4.21	5.39
Liquor (wt % coal, maf)	148.7	221.2	262.2	296.5
Specific data				
Consumption				
Oxygen				
scf/lb coal (maf)	4.39	6.88	6.64	7.95
scf/10^6 Btu gas	418	620	618	688
Steam				
lb/lb coal (maf)	1.91	2.81	3.11	3.70
lb/10^6 Btu gas	182	253	289	320
Fuel (lb/hr-ft^2 maf)	138	135	127	83.6
Crude gas				
scf/lb coal (maf)	35.2	38.2	37.2	40.5
10^6 Btu/ton (maf)	21.0	22.2	21.6	23.1
10^6 Btu/hr-ft^2	1.45	1.50	1.37	0.96

43

5.0 ADVANTAGES AND LIMITATIONS (CONTD.)

- Countercurrent operation provides for preheating of steam, oxygen and coal inside gasifier, thus leading to significant CH_4 production and high thermal efficiency.

- Most types of coals, including highly caking, have been gasified with the addition of an agitator to the gasifier. Less-reactive coals require higher consumptions of oxygen and steam.

- Coal size: Run-of-mine coal (1/4" x 2", up to 4") and feeds with up to 7 to 10% fines (-1/4") have been successfully gasified.

- Up to 35% moisture can be tolerated in the feed coal; therefore, predrying is necessary only for feedstocks with very high moisture levels.

- Excessive amounts of coal fines cannot be processed in the gasifier; therefore, extra handling of excess fines is required, i.e., either export power/steam, disposal as fuel or gasification in a different type of gasifier.

- To maintain the lower temperature in bottom of the gasifier to avoid ash fusing and clinker formation, excess steam must be added and, when recovered, gas liquor must be treated.

- All the liquids produced in the process must be treated unless used as in-plant fuel.

6.0 LIST OF LURGI GASIFIERS

Date of Order	Location	Feedstock	Product	Gasifier ID, FT.	Gasifier TYPE	Capacity Nm^3/day	Number of Gasifiers
1936–1949	5 Plants Germany, CSSR	Lignite	Town Gas		MARK I	ca. 1 Mio	18
1952	Netherlands	Coke	Synthesis Gas			1,800,000	3
1952	Republic of South Africa	Coal, medium volatile, high ash	Fischer-Tropsch Products	12.1	II	4,300,000	9
1953	Germany	Coal, high volatile caking	Town Gas	8.75	II	1,500,000	6
1954	Australia	Lignite	Town Gas	8.75	II	600,000	6
1955	Pakistan	Coal, Sub. Bit high sulfur	Synthesis Gas for ammonia synthesis	8.75	II	110,000	2
1958	Scotland	Coal, high volatile, bituminous, low caking	Town Gas	8.75	II	1,000,000	4
1961	Great Britain	Coal, high volatile, bituminous, caking	Town Gas	8.75	II	1,350,000	5
1961	Korea	Anthracite	Synthesis Gas for ammonia synthesis	10.5	II	400,000	3
1964	Republic of South Africa	Coal, medium volatile, high ash	Synthesis Gas	12.1	III	2,000,000	4

6.0 LIST OF LURGI GASIFIERS (CONTD.)

Date of Order	Location	Feedstock	Product	Gasifier ID, FT.	Gasifier TYPE	Capacity Nm^3/day	Number of Gasifiers
1969	Germany	Coal, medium volatile high ash	Fuel Gas for gas turbine	11.33	III	4,400,000	5
1974	Republic of South Africa	Coal, medium volatile, high ash	Synthesis Gas for Fischer-Tropsch Products	12.33	III	5,000,000	3
1975	USA	Coal, high volatile, bituminous	Fuel Gas for gas turbine		III	1,150,000	2 (Not Built)
1977	Republic of South Africa	Coal, medium volatile, high ash, sub-bituminous	Synthesis Gas for Fischer-Tropsch Products	13.0	IV	26,400,000	36
1972-1974	Design of 4 SNG-from-Coal Plants for 5 U.S. Gas Companies	Subbit. coal and lignite	SNG		IV	7,400,000 each	(Not Built)
1977	Germany	Coal, high volatile, caking	Town Gas and Synthesis Gas			350,000	1
1977	Germany	Lignite	Pipeline Gas			380,000	1
1978	China	Coal, low volatile	Synthesis Gas for ammonia	13.0	IV	2,700,000	4

46

6.0 **LIST OF LURGI GASIFIERS** (CONTD.)

Date of Order	Location	Feedstock	Product	Gasifier ID, FT.	Gasifier TYPE	Capacity Nm^3/day	Number of Gasifiers
1979	Republic of South Africa	Coal, medium volatile, high ash, sub. bituminous	Synthesis Gas for Fischer-Tropsch Products	13.0	IV	26,400,000	36
1979	USA (Exxon)	Lignite	SNG		IV	3,700,000	(Not Built)
1980	USA (ANR)	Lignite	Synthesis Gas	13.0	IV	11,000,000	14
1980	Netherlands (GazUnie)	Sub-bituminous Coals	Methanol and Medium BTU-Gas		IV	6,800,000	
1981	Republic of South Africa	Coal, medium volatile high ash, sub-bituminous	Synthesis Gas for Fischer-Tropsch Products	13.0	IV	6,600,000	9

47

7.0 SUMMARY OF TECHNICAL/ECONOMIC EVALUATIONS

- Results from technical and economic evaluations of Dry-bottom Lurgi Coal Gasification Process for production of 250 billion Btu/day SNG.

List of Tables

List of Figures

TABLE 7.1

DESCRIPTION OF CASES

Coal Type/Case	Eastern	Western	Lignite
Location Basis	Eastern	Western	Western
Evaluating Contractor	CF Braun	CF Braun	KRSI
Date Published	March 1983	Dec. 1982	Oct. 1984
Coal Properties			
Proximate Analysis, As Received, wt%			
Moisture	6.0	22.0	34.3
Volatile Matter	31.9	29.4	29.0
Fixed Carbon	51.5	42.6	30.5
Ash	10.6	6.0	6.2
	100.0	100.0	100.0
HHV, Btu/lb	12,400	8,800	7,140
Ultimate Analysis, Dry Basis, wt%			
Carbon	71.50	67.70	65.98
Hydrogen	5.02	4.61	4.20
Nitrogen	1.23	0.85	1.30
Oxygen	6.53	18.46	17.90
Sulfur	4.42	0.66	1.20
Ash	11.30	7.72	9.40
Chlorides	*	*	0.02
	100.0	100.0	100.0
HHV, Btu/lb	13,190	11,290	10,870

* not reported

TABLE 7.2

PLANT OVERALL MATERIAL BALANCE
(Mlb/Hr)

Case	Eastern	Western	Lignite
INPUTS:			
Coal (MF) to Gasifiers	1,204.5	1,263.6	1,420.5
to Export	---	181.7	737.7
to Boilers	229.2	144.6	59.9
Moisture in Coal	91.6	448.4	1,158.0
Oxygen to Gasifiers	640.1	405.0	461.7
Air to Boiler	3,566.4	3,116.8	2,616.8
to Sulfur Plant	*	*	56.8
Nitrogen to AGR	---	---	236.0
Raw Water Supply	5,538.8	1,217.0	1,323.2
TOTAL	11,270.6	6,777.1	8,070.6
OUTPUTS:			
SNG Product	460.3	487.2	441.3
Sulfur from Acid Gas	58.3	7.6	4.0
from Flue Gas	*	*	10.0
Ammonia Byproduct	10.3	11.7	18.2
Coal Fines Export	---	230.4	1,122.8
Vent/Stack Gases:			
AGR Vent	1,492.6	1,548.0	1,287.5
Gas Drying	*	*	1.3
Sulfur Recovery	*	*	3.5
Flue Gas Treatment	4,273.9	3,398.8	3,561.3
Evaporation Losses:			
Raw Water Pond	*		21.2
Cooling Tower	4,396.6	463.0	1,192.5
Bio-Oxidation	*	1.2	23.8
Solids to Landfill	180.6	126.0	276.3
Miscellaneous Losses	398.3	456.5	106.9
TOTAL	11,270.6	6,777.1	8,070.6

* Included in other items of same category or under miscellaneous.

TABLE 7.3

PLANT OVERALL ENERGY BALANCE

Case	Eastern MM Btu/Hr*	Western MM Btu/Hr*	Lignite MM Btu/Hr*
ENERGY INPUTS:			
Coal to Gasifiers	15,888	14,289	15,457
Coal to Boilers	2,370	1,632	6,510
Coal Fines (Export)	-	2,054	8,018
TOTAL	18,258	17,975	24,106
ENERGY OUTPUTS:			
SNG Product	10,417	10,592	10,417
Sulfur Byproduct	233	39	56
Ammonia Byproduct	99	113	176
Coal Fines (Export)	-	2,054	8,018
Subtotal	10,749	12,798	18,668
Consumption & Losses	7,509	5,177	5,438
TOTAL	18,258	17,975	24,106
Cold Gas Efficiency, % Fines Export Excluded	57.1	65.5	64.7
Plant Thermal Efficiency, % Fines Export Excluded	58.9	66.6	66.2
ROM Coal Conversion Efficiency, %	57.1	58.9	43.2

*HHV Basis

TABLE 7.4

GASIFIER MATERIAL BALANCE AND OPERATING CONDITIONS

Lignite Case

INPUTS	#/HR	PSIG	°F
Sized Coal	2,162,089	430	85
Oxygen	461,648	480	290
Steam	2,207,044	600	750
BFW	203,534	600	375
Quench Water	192,776	600	200
	5,227,091		
OUTPUTS			
Gas, Water, Condensibles	4,892,449	415	1100
Ash	334,642	415	600
	5,227,091		

Notes:

1. Data not available for Eastern and Western Coal Cases.
2. Number of Lurgi gasifiers: 24 (Operating)
3. Data shown are for all the gasifiers.

TABLE 7.5

GASIFIER RAW GAS COMPOSITION

Lignite Case

	RAW GAS FROM GASIFICATION		LIQUOR FROM GASIFICATION	
	VOL %	LBS/HR	WT%	LBS/HR
GASES:				
Carbon Monoxide	9.19	485,165		
Hydrogen	22.81	86,614		
Carbon Dioxide	19.13	1,585,998		
Methane	6.36	192,092		
Ethylene	0.04	2,177		
Ethane	0.29	16,496		
Propylene	0.04	3,266		
Propane	0.05	3,907		
i-Butene	0.04	4,354		
Butane	0.02	2,581		
Argon	0.03	2,213		
Nitrogen	0.04	2,174		
Oxygen				540
Ammonia	0.56	18,082		
Hydrogen Sulfide	0.21	13,216		
Carbonyl Sulfide	0.005	667		
Water	41.18	1,397,519		
Organic Sulfur	0.005	353		
Total Gases	100.00	3,816,874	0.05	540
LIQUIDS:				
Tars		9,200	6.37	66,203
Oils		12,714	0.43	4,443
Naphtha		8,577		
Phenols		5,042	0.92	9,571
Fatty Acids		1,516	0.25	2,604
Water			90.67	941,554
HCN/HCl		8	0.03	300
Total Liquids		37,057	98.67	1,024,675
Total Solids			1.28	13,303
Total Flow		3,853,931		1,038,518

TABLE 7.6

SUMMARY OF TOTAL PLANT INVESTMENT
(MM, Mid '82)

	LURGI		
	Eastern *	Western *	Lignite*
ONSITE UNITS			
Coal Storage and Reclaiming	17.5	19.8	37.0
Coal Preparation	7.3	40.5	31.0
Lurgi Process Area*	474.3	354.9	427.0
Coal Feeding	Included	Included	Included
Gasification	Included	Included	Included
Raw Gas Quench	Included	Included	Included
Shift Conversion	Included	Included	32.0
Acid Gas Removal	110.8	141.2	95.0
Methanation and Gas Compression	59.3	81.4	65.0
Sulfur Recovery	97.0	45.1	11.0
Sour Water Stripping	27.6		8.0
Product Gas Drying	2.8	2.9	Included in Methanation
Ammonia Recovery	Included	Included	15.0
Oxygen Plant	171.9	116.1	107.0
General Facilities	139.9	116.7	Included in Offsites
Onsite Subtotal	1,108.4	918.6	828.0
OFFSITE UNITS			
Flue Gas Desulfurization	Included	22.2	75.0
Solids Disposal	44.6	29.8	14.0
Steam and Power	287.2	322.5	230.0
Plant Water System	94.1	49.3	25.0
General Facilities	59.6	59.3	184.0
Offsite Subtotal	485.5	483.1	528.0
Total Installed Cost	1,593.9	1,401.7	1,356
Project Contingency	239.1	210.3	203.0
Engineering and Design Cost	110.0	96.7	93.0
Contractor's Overhead and Profit	110.0	96.7	93.0
Total Facilities Investment	2,053.0	1,805.4	1,745.0

* Total Lurgi process area consists of Coal Feeding, Gasification, Gas Cooling, Shift Conversion, Phenol Extraction, Gas-Lurgi Separation, and Ammonia Recovery Units

TABLE 7.7

SUMMARY OF CAPITAL AND OPERATING COSTS
(WITHOUT APPLICATION OF PDA)

	LURGI		
	Eastern	Western	Lignite
CAPITAL COSTS, $MILLIONS			
Total Facilities Construction Investment	2,053.0	1,805.4	1,745.0
Initial Charge of Catalysts and Chemicals	58.7	51.8	23.0
Paid-Up Royalties	5.2	5.4	22.0
Start-Up Costs	86.4	57.5	83.0
TOTAL PLANT INVESTMENT	2,203.3	1,920.1	1,873.0
OPERATING COSTS, $MILLIONS/YEAR			
FUEL (Coal)	205.44	84.37	133.1
Ash and Solid Waste Disposal	2.85	2.04	1.8
Catalysts and Chemicals	20.22	20.83	7.3
Purchased Water (Raw Water)	3.93	1.44	1.7
Direct Labor			
Process Operating Labor	5.41	5.41	9.0
Maintenance Labor	52.71	46.85	43.1
Overhead Costs			
Benefits	14.53	13.07	13.0
Supervision	14.53	13.07	13.0
General Plant	26.15	23.52	23.5
Corporate	17.43	15.68	15.6
Supplies	2.91	2.61	2.6
Maintenance Supplies	35.14	31.23	28.8
Local Taxes and Insurance	30.79	27.08	26.1
TOTAL VARIABLE OPERATING COSTS/YEAR	226.60	202.83	185.5

55

TABLE 7.7 (CONTD.)

SUMMARY OF CAPITAL AND OPERATING COSTS
(WITHOUT APPLICATION OF PDA)

	Eastern *	LURGI Western *	Lignite
TOTAL GROSS OPERATING COSTS/YEAR	432.04	287.20	318.6
TOTAL BY-PRODUCT CREDITS	26.49	16.75	17.4
TOTAL NET OPERATING COSTS/YEAR	405.55	270.45	301.2
WORKING CAPITAL - CONSUMABLES, $MILLIONS			
Coal Storage - 44 Days	27.52	11.30	16.0
Material and Supplies	18.48	16.25	15.7
Spare Parts	9.18	7.54	14.5
TOTAL	55.18	35.09	46.2
LEVELIZED GAS COST, $/MMBtu (PDA = 0)	8.20	5.66	6.10

TABLE 7.8

CALCULATION OF CONTRIBUTION TO GAS COST
LURGI GASIFICATION

Coal Type	N.Dakota lignite
Evaluator	Kellogg Rust Synfuels, Inc.
Project Report No.	None
Date Published	None
Plant Capacity	250 Billion Btu/day SNG

CAPITAL COSTS :	$ MM (Mid-1982)
Installed Equipment	279.0
Contingency @ 15%	41.9
Direct Facility Constr Investment	320.9
Home-Office costs @ 12%	38.5
Total Facility Constr Investment	359.4
Royalties	20.0
Total Plant Investment	379.4

OPERATING COSTS :			$/hr
Steam(600 psig)	2,207,000 #/hr	@ $ 5.50/ 1000 lb.	12138.5
Oxygen	461,600 #/hr	@ $36.00/ 2000 lb.	8308.8
Electricity	1,119 Kw	@ $ 0.05/ Kwh	56.0
Cooling water	5,927 Gpm	@ $ 0.10/ 1000 Gal	35.6
Steam Credit(100 psig)	935,700 #/hr	@ $ 3.95/ 1000 lb.	-3696.0
TOTAL			16842.8

Total Operating Cost, $ MM/yr at 100 % Stream factor = 6.1 MM $/Yr

CONTRIBUTION TO GAS COSTS :	Specific Cost, $/MM Btu-Yr	Charge Rate, Year	Contribution, $/MM Btu
Capital Related	4.62	0.089	0.41
Operating	0.07	1.000	0.07
Total			0.49

57

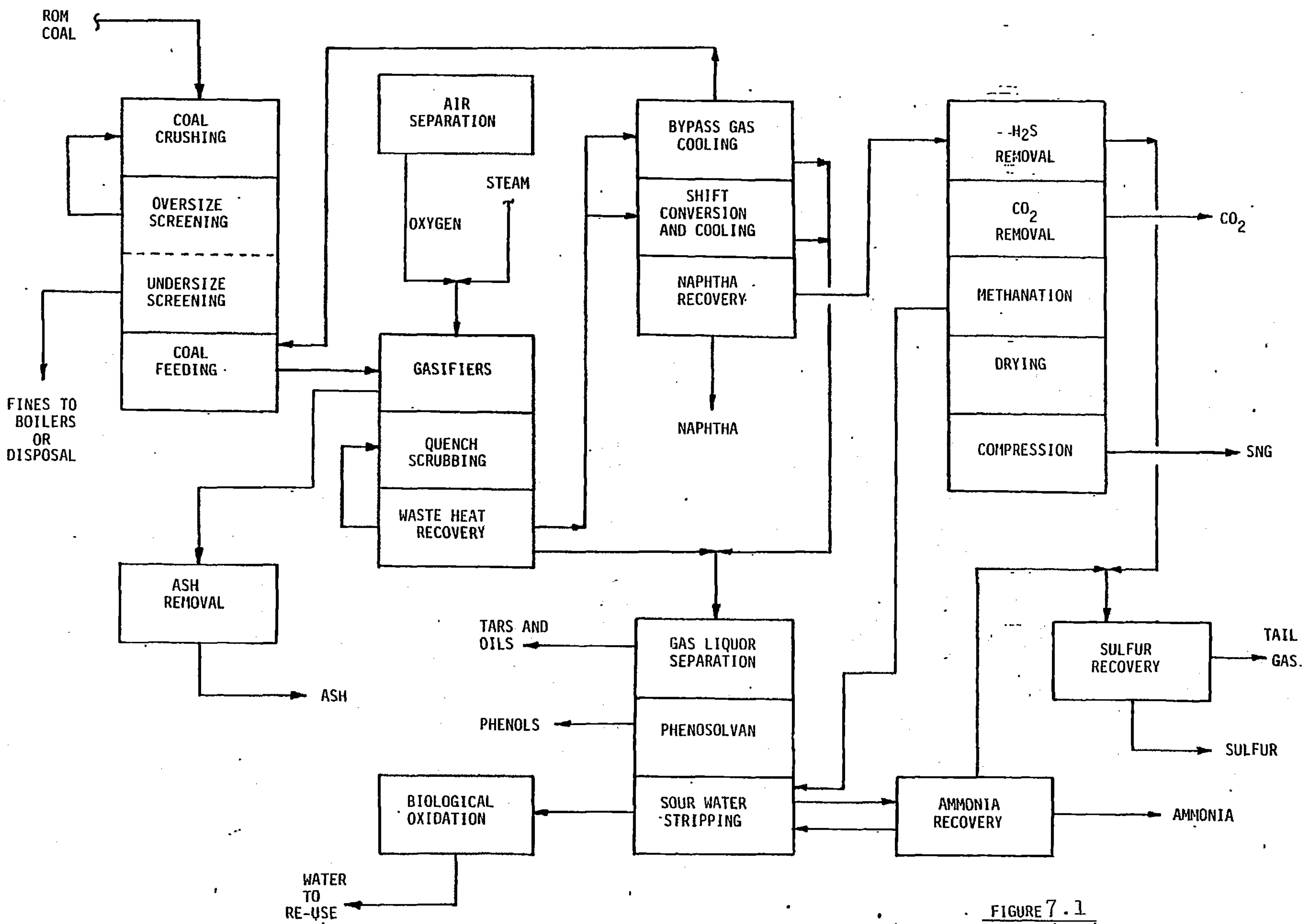

FIGURE 7.1

COAL-TO-SNG WITH LURGI GASIFICATION

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STATUS SUMMARY:
KOPPERS-TOTZEK GASIFICATION

KOPPERS-TOTZEK

1.0 GENERAL INFORMATION

- Developer: GKT Gesellschaft fuer Kohle-Technologies mbH
  c/o Krupp Wilputte
  152 Floral Avenue
  Murray Hill, NJ 07974

- Type: Atmospheric, entrained-bed, upflow, slagging ash gasifier. Reactor has two or four conical heads, double-walled construction lined with a thin layer of refractory. Low-pressure steam is generated between the shell walls.

- Conditions: Gasifier operates at slightly above atmospheric pressure. The reaction temperature in front of the burner port is 3,300-3,500^{o}F. As a result of endothermic reactions and radiation losses, the gas temperature decreases to about 2,750^{o}F at the gasifier exit.

- Coal Type: Gasifier can process virtually any type of coal (conversion is typically lower for less-reactive coals.) Coal is dried to 2 to 8% moisture, depending on rank, and pulverized to 80% below 150 mesh (0.1 mm).

- Products: High temperature in gasifier prevents formation of hydrocarbons higher than methane.

- Applications: Considered less competitive for fuel gas production than for synthesis gas production.

- Status: About 25 commercial installations in operation. Number of applications of K-T for production of fuel gas were announced during '79 -'81 (see Section 7.0). Koppers Company, USA, in venture with Babcock-Wilcox is presently marketing KBW gasifier which is modified version of K-T gasifier.

1.0 GENERAL INFORMATION (CONTD.)

Shell is developing a high pressure slagging gasifier based on the atmospheric K-T process. Plans were announced in 1974 to develop a six-head gasifier that would have twice the capacity of a four-head gasifier.

2.0 PROCESS DEVELOPMENT

- In the late 1930's/early 1940's, Dr. Friedrich Totzek of Heinrich Koppers GmbH (parent company of GKT), Germany, developed the Koppers-Totzek gasification process.

- During 1938 - 1944, three pilot plants were built by Heinrich Koppers GmbH and operated at various locations in Germany.

- In 1948, a demonstration plant was designed by Heinrich Koppers GmbH, constructed by Koppers Company, U.S.A. and operated jointly by the two companies at Louisiana, Missouri for the U.S. Bureau of Mines. The purpose of this installation was to generate synthesis gas for production of liquid hydrocarbons via the Fischer-Tropsch process.

- In 1949 - 1950, the first commercial two-headed K-T gasifier was installed in France by Heinrich Koppers GmbH.

- Between 1952 - 1956, six plants were installed in Finland, Japan, Spain, Belgium, and Portugal. Each gasifier had a capacity of approximately 4.5 MM scfd of $(CO+H_2)$ gas.

- Between 1959 - 1969, seven more plants were installed in Greece, Egypt, Thailand, Turkey, East Germany and Zambia with gasifier capacity increased to 10 MM scfd $(CO+H_2)$ gas.

- In 1969, the four headed gasifier was first introduced and installed in India. Since then, the gasifier capacity has been increased to approximately 45 MM scfd per unit.

- In mid 70's Krupp-Koppers GmbH (formerly Heinrich Koppers) using their experience on the atmospheric

2.0 PROCESS DEVELOPMENT (CONTD.)

pressure K-T began developing with Shell a high pressure slagging coal gasifier. In November 1978, a 150 tpd pilot plant, engineered and constructed by Krupp-Koppers GmbH was commissioned in West Germany and has accumulated a series of runs ranging from few to over 200 hours duration.

- o Also in mid-70's Krupp-Koppers GmbH announced plans for developing a six-headed gasifier, which to date has not been commercialized.

3.0 FEEDSTOCKS TESTED

Gasifier can process virtually any type of coal. Coal is dried to 2 to 8% moisture, depending on rank, and pulverized to 80% below 150 mesh (0.1 mm). Commercial gasifiers built in 14 countries have demonstrated ability to process a wide range of coal compositions.

4.0 PROCESS DESCRIPTION

- o Coal is pulverized in a single operation using ball, rod or roller mills, with hot flue gas circulating through the mill. The gas flow dries, entrains, and transports the coal to a classifier, where the finer particles continue to a cyclone separator and the oversize particles return to mill. The system permits the utilization of entire mine output.

- o The pulverized coal is fed via a screw feeder to a mixing head, where it is entrained in a mixture of steam and oxygen. The particles are accelerated through a nozzle at velocities above the speed of flame propagation to prevent flashback.

- o In the gasifier, burners (two or four), are positioned directly opposite, each pointing slightly down. This improves turbulence and ensures that any unburned particle in one flame region is gasified in the opposing flame. The central part of the gasifier has the highest temperature region, thus refractory problems are minimized.

- o The reaction temperature of 3,300-3,500^{o}F decomposes the coal rapidly before it can agglomerate. Thus any coal can be gasified irrespective of caking properties, ash content or ash fusion temperature. Carbon reacts very rapidly with oxygen and steam. Tars, condensable

4.0 PROCESS DESCRIPTION (CONTD.)

hydrocarbons or phenols are not produced. Little or no methane is formed. Most of the sulfur from the coal appears in the gas, 80-90% as H_2S and the remainder as COS.

- For most coals, more than 50% of the ash flows down the gasifier walls as molten slag and drains into a quench tank. The quench tank temperature is carefully controlled by rapid water circulation, since excessive flash steam could cause the downflowing slag to solidify. Addition of fluxing agent is required when ash fusion temperature is greater than 2,400°F. Rejection of ash at high temperature means lower gasifier efficiency with high-ash coals, although lignites with up to 40 wt% ash have been used in commercial applications. Erosion of the refractory lining occurs if the slag is too fluid.

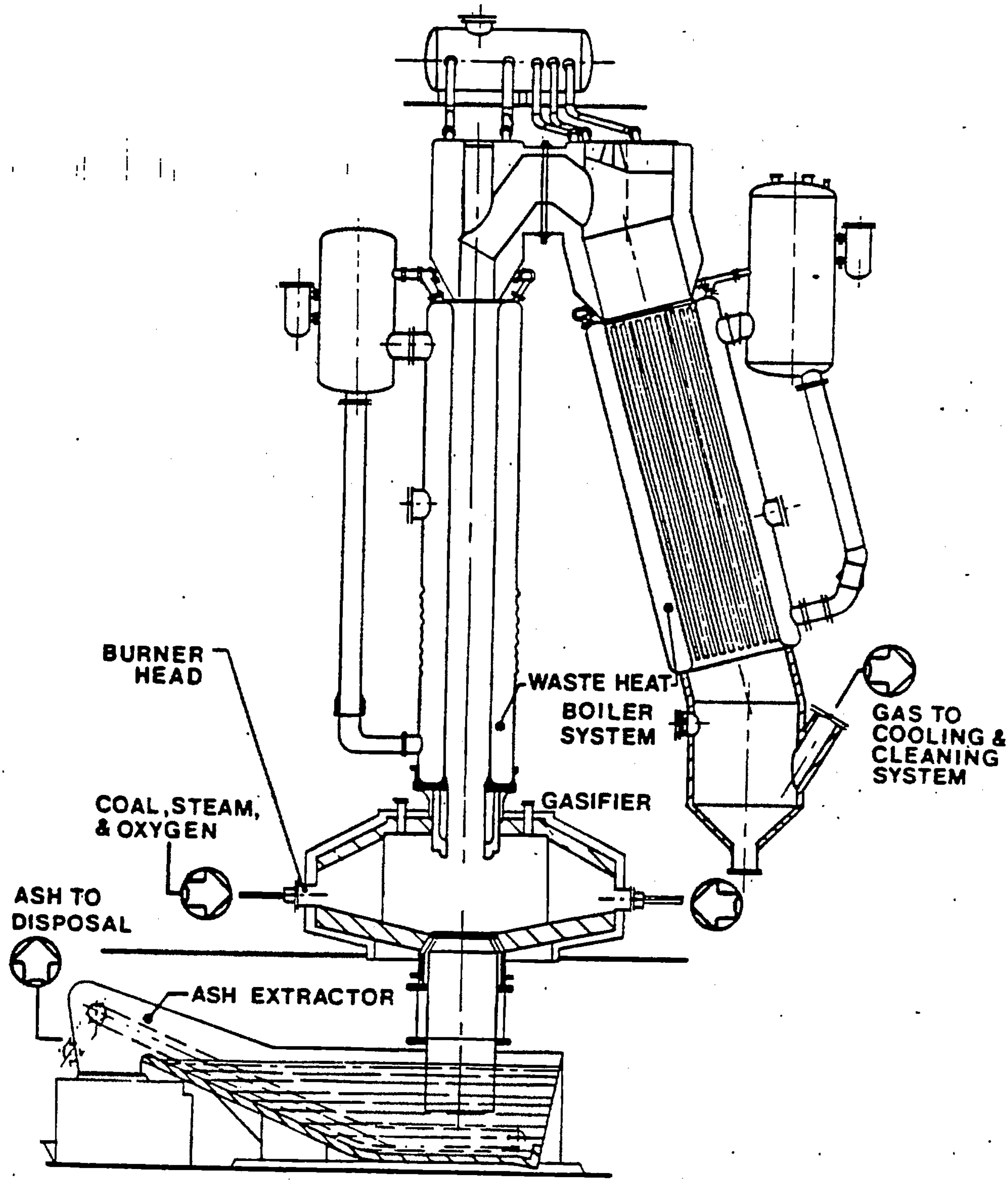
- The gas exiting the gasifier carries remainder of the slag out as fly ash. Endothermic reactions and steam generation in the double-shell lowers the gas temperature to about 2,750°F. The gas is quenched with water at exit to solidify the entrained slag particles, and then enters a waste heat reboiler. Next the gas is treated in a refractory lined spray washer, where about 90% of the particles are removed and gas is cooled from 350-500°F to 95°F. Further reduction in particulate matter from 5×10^{-7} lbs/scf to 1.5×10^{-8} lb/scf is achieved using electrostatic precipitators, so that the gas can be compressed before further processing.

- Figure 4.1 shows the Koppers-Totzek two-headed gasifier and Figure 4.2 illustrates the K-T coal gasification system.

5.0 PERFORMANCE DATA

- Typical Operating Data: See Table 5.1

- Capacity: A two-headed gasifier can process approximately 400 TPD coal and produces 21.6 million scf/day gas. The gasifier head is 10-12 ft. in diameter tapered to 6.8 ft. at either end with an overall length of 25 ft. The four-headed gasifier has approximately twice the capacity of a two-headed gasifier.



KOPPERS–TOTZEK TWO–HEADED GASIFIER

FIGURE 4.1

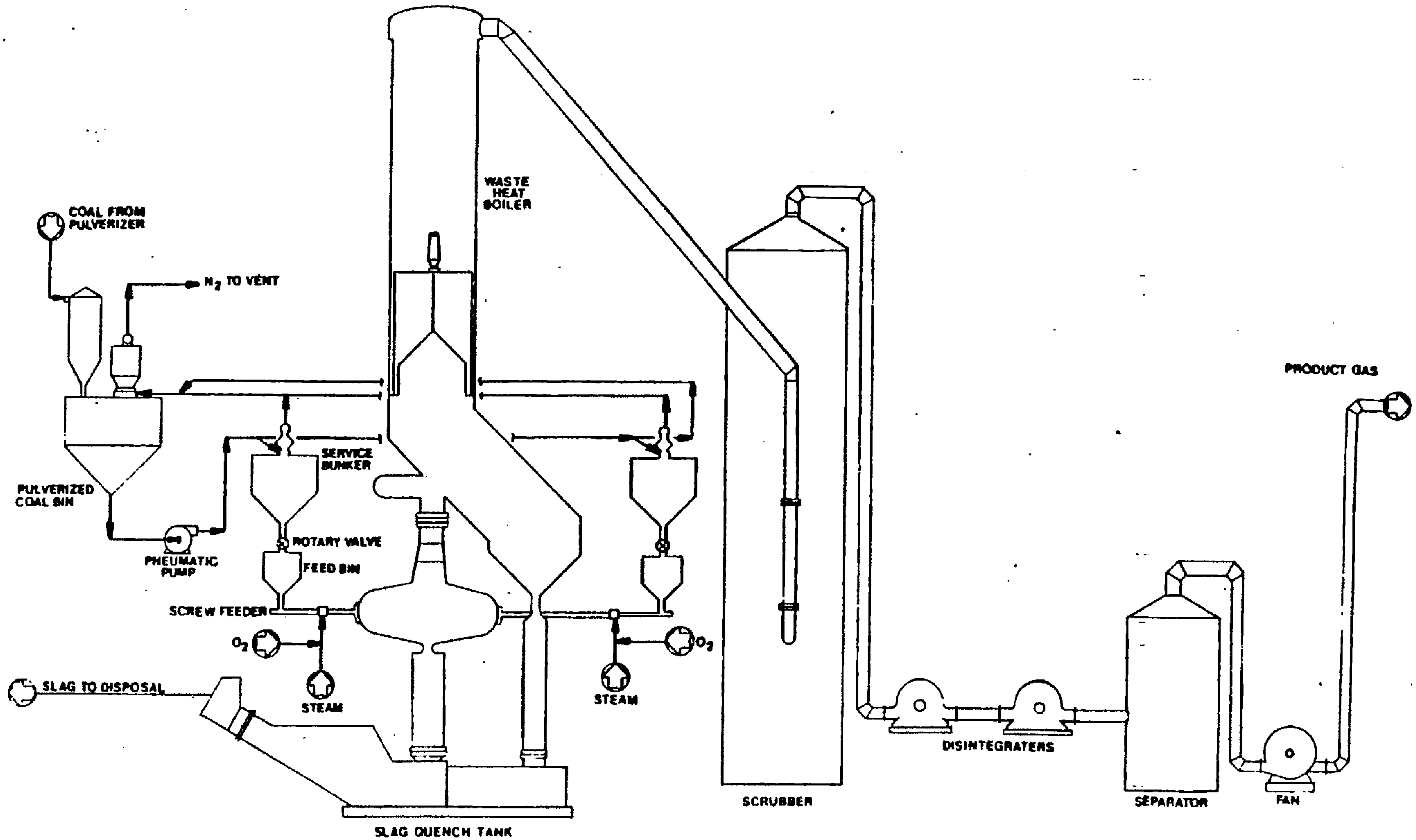


FIGURE 4.2

KOPPERS–TOTZEK COAL GASIFICATION SYSTEM

5.0 PERFORMANCE DATA (CONTD.)

- Carbon Conversion: Approximately 88% for bituminous coal and 98% for lignite.
- Power Requirement: Gasification area power requirement is approximately 34 KWh/ton.

TABLE 5.1

K-T GASIFIER DATA FOR U.S. COALS

Type of Coal	Western Coal	Illinois Coal	Eastern Coal
GASIFIER FEED			
Dried Coal to Gasifier Analysis - Wt. %			
C	56.76	61.94	69.88
H	4.24	4.36	4.90
N	1.01	0.97	1.37
S	0.67	4.88	1.08
O	13.18	6.73	7.05
Ash	22.14	19.12	13.72
Moisture	2.00	2.00	2.00
Higher Heating Value Btu/lb.	9,888	11,388	12,696
Oxygen, lb/lb Dried Coal	0.649	0.704	0.817
Purity-%	98.0	98.0	98.0
Process Steam, lbs/ton Dried Coal	272.9	541.3	587.4
GASIFIER PRODUCTS			
Jacket Steam, lbs/ton Dried Coal	347.8	404.9	464.9
High Press. Steam, lbs/ton Dried Coal	2147.1	2292.2	3023.6
Raw Gas Analysis (Dry Basis) Vol. %			
CO	58.68	55.38	55.90
CO_2	7.04	7.04	7.18
H_2	32.86	34.62	35.39
N_2	1.12	1.01	1.14
H_2S	0.28	1.83	0.35
COS	0.02	0.12	0.04
TOTAL	100.00	100.00	100.00
Gross Heating Value, Btu/SCF	295.1	290.2	294.4
Gas Make-SCF/ton Dried Coal	51,783.	59,489.	66,376.
Slag Make - ton/ton Dried Coal	0.222	0.190	0.138
Cold Gas Efficiency	77.3	75.8	77.0

6.0 BY-PRODUCTS AND ENVIRONMENTAL IMPACTS

- Oils and tars are not produced.
- The unconverted carbon is occluded in the slag particles that have been fused. In landfill disposal, the slag would be covered with soil to support vegetation growth.
- Pressurized nitrogen from the oxygen plant is used to transport the pulverized coal. It can be vented to the atmosphere after passage through bag filters.

7.0 COMMERCIAL DESIGN PLANS

Listing of commercial projects completed and announced recently is shown in Table 7.1. The six-headed gasifier announced in mid 70's has not been commercialized. No detailed techno/economic evaluations have been found in literature for SNG. A block flow diagram for coal-to-SNG using GKT gasification process is presented in Figure 7.1.

TABLE 7.1
PLANTS FOR THE GASIFICATION OF ALL KINDS OF FUELS BY GKT'S COAL GASIFICATION PROCESS

	Feedstock	Number of gasifiers	Capacity (V_n) m^3 CO + H_2 per day	Use of synthesis gas	Year of order
Charbonnages de France, Paris, Mazingarbe Works (P.d.C.), France	Bituminous coal, coke oven gas, tail gas	1	75000–150000	Ammonia and methanol synthesis	1949
Typpi Oy, Oulu, Finland	Bituminous coal, oil, peat	3	140000	Ammonia synthesis	1950
Nihon Suiso Kogyo Kaisha, Ltd., Tokyo, Japan	Bituminous coal	2 1 stand-by	210000	Ammonia synthesis	1954
Empresa Nacional "Calvo Sotelo" de Combustibles Liquidos y Lubricantes S.A., Madrid, Nitrogen Works in Puentes de Garcia Rodriguez, Coruña, Spain	Lignite	2 1 stand-by	242000	Ammonia synthesis	1954
Typpi Oy, Oulu, Finland*	Bituminous coal, oil, peat	2	140000	Ammonia synthesis	1955
S.A. Union Chimique Belge, Brussels, Zandvoorde Works, Belgium	Bunker C oil, plant convertible for coal gasification	2	176000	Ammonia synthesis	1955
Amoniaco Português S.A.R.L., Lisbon, Estarreija Plant, Portugal	Heavy gasoline, plant convertible for lignite and anthracite gasification	1	169000	Ammonia synthesis	1956
The Government of the Kingdom of Greece, The Ministry of Coordination, Athens, Nitrogenous Fertilizers Plant, Ptolemais, Greece	Lignite, bunker C oil	3 1 stand-by	629000	Ammonia synthesis	1[illegible]
The General Organization for Executing the Five Year Industrial Plan, Cairo, Nitrogen Works of Société el Nasr d'Engrais et d'Industries Chimiques, Talkha, Egypt	Refinery off-gas, L.P.G., and light naphtha	3	778000	Ammonia synthesis	1963
Chemical Fertilizer Company Ltd., Thailand, Synthetic Fertilizer Plant at Mae Moh, Lampang, Thailand	Lignite	1	217000	Ammonia synthesis	1963
Azot Sanayii T.A.S., Ankara, Kütahya Works, Kütahya, Turkey	Lignite	3 1 stand-by	775000	Ammonia synthesis	1966
Chemieanlagen Export-Import GmbH, Berlin, for VEB Germania, Chemieanlagen und Apparatebau Karl-Marx-Stadt, VEB Zeitz Works, GDR	Vacuum residue and/or fuel oil	2	360000	Hydrogen for hydrogenation	1966
Kobe Steel Ltd., Kobe, Japan, for Industrial Development Corp., of Zambia, Kafue near Lusaka, Zambia	Bituminous coal	1	214320	Ammonia synthesis	1967
Nitrogenous Fertilizers Industry S.A., Athens, Nitrogenous Fertilizers Plant, Ptolemais, Greece*	Lignite	1	165000	Ammonia synthesis	1[illegible]

TABLE 7.1 (Cont.)

	Feedstock	Number of gasifiers	Capacity (V_n) m^3 CO + H_2 per day	Use of synthesis gas	Year of order
The Fertilizer Corporation of India Ltd., New Delhi, Ramagundam Plant, India	Bituminous coal	3	2000000	Ammonia synthesis	1969
The Fertilizer Corporation of India Ltd., New Delhi, Talcher Plant, India *	Bituminous coal	3	2000000	Ammonia synthesis	1970
Nitrogenous Fertilizers Industry S.A., Athens Nitrogenous Fertilizers Plant, Ptolemais, Greece *	Lignite	1	242000	Ammonia synthesis	1970
The Fertilizer Corporation of India Ltd., New Delhi, Korba Plant, India *	Bituminous coal	3	2000000	Ammonia synthesis	1972
AECI Ltd., Johannesburg, Modderfontein Plant, South Africa	Bituminous coal	6	2150000	Ammonia and methanol synthesis	1972
Indeco Ltd., Lusaka, NCZ Nitrogen Chemicals of Zambia Ltd., Kafue Works, Zambia *	Bituminous coal	1	220800	Ammonia and methanol synthesis	1974
Indeco Ltd., Lusaka, NCZ Nitrogen Chemicals of Zambia Ltd., Kafue Works, Zambia *	Bituminous coal	2	441600	Ammonia and methanol synthesis	1975
PETROBRAS Petroleo Brasileiro S.A., Rio de Janeiro, São Jeronimo Plant/Rio Grande do Sul, Brazil	Bituminous coal	2	1500000	Fuel gas	1979
KOPEX Przedsiębiorstwo Budowy Zakladów Górniczych za Granicą, Eksport-Import, Katowice, Collective Combine JANINA, Libiaz, Poland	Bituminous coal	3	3070000	Fuel gas	1980
ICRC International Coal Refining Company, Solvent Refined Coal (SRC-1), Demonstration Plant, Newman, Kentucky, USA	Bituminous coal, hydrogenation residues	3 1 stand-by	2076000	Hydrogen for hydrogenation	1980 ***
TVA Tennessee Valley Authority, Chattanooga, Tennessee, Murphy Hill Plant, Alabama, USA	Bituminous eastern US coal	16 2 stand-by	14726000	Medium-BTU gas, High-BTU gas (SNG), Methanol	1981

* REPEAT ORDER

*** PROJECT SUSPENDED

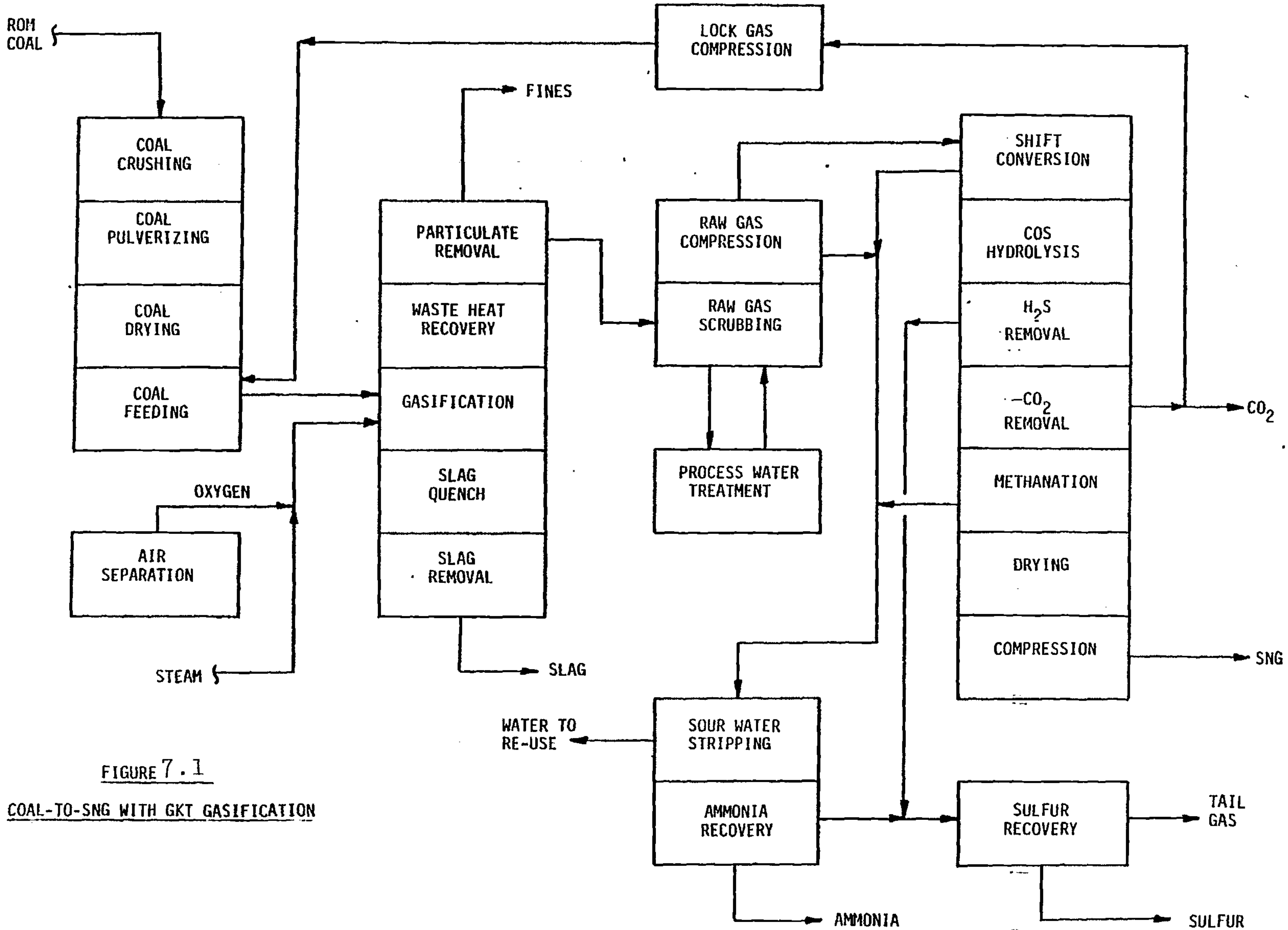


FIGURE 7.1

COAL-TO-SNG WITH GKT GASIFICATION

8.0 ADVANTAGES & DISADVANTAGES

- Advantages
  - Gasifier can be in full operation in 45 minutes.
  - Coal screw feeders allow operation at 60% of design capacity. With four-headed gasifier, turndown to 30% is possible by shutting off one pair of nozzles completely.
  - Oils and tars are not produced.

- Disadvantages
  - High oxygen consumption.
  - Coal must be dried to low moisture levels.
  - Near atmospheric operation results in handling and then compressing of a large volume of gas.
  - High entrainment resulting in lower carbon conversions for less reactive coals.
  - Oxygen leakage is reportedly an operating problem.

9.0 REFERENCES

1. Elliott, M. A. (Editor), "Chemistry of Coal Utilization, Second Supplementary Volume," John Wiley & Sons, 1981, pages 1713-1716.

2. UOP/SDC, "Handbook of Gasifiers and Gas Treatment Systems," prepared for U.S. Department of Energy, September 1982, page 2C-23.

3. Franzen, Dr. Johannes, E. and Goeke, Eberhard K., "SNG Production Based on Koppers-Totzek Coal Gasification," presented at the Sixth Synthetic Pipeline Gas Symposium, October 28-30, 1974.

4. Farnsworth, J. Frank, Leonard, Howard F., Mitsak, D. Michael, and Wintrell, Reginald, "The Production of Gas from Coal through a Commercially Proven Process," Koppers Company, Inc., August 1973.

STATUS SUMMARY
TEXACO GASIFICATION

TEXACO

1.0 GENERAL INFORMATION

o Developer:	Texaco Development Corporation 2000 Westchester Avenue White Plains, New York 10650
o Type:	The Texaco coal gasification process uses a pressurized, down-flow entrained bed, slagging gasifier. It involves partial oxidation of a concentrated slurry of coal to form synthesis gas.
o PDU Facility:	Two 15 to 20 TPD pilot units at Montebello, CA in operation since 1974. Demonstration unit of 165 TPD capacity in operation since 1978 at Ruhrchemie Chemical Plant Complex in Oberhausen-Holten, West Germany.
o Conditions:	Pilot units runs between 300-1200 psig were successful. The Ruhrchemie unit has been designed and operated at 600 psig. Operating temperatures range between 2,200-2,900°F, hot enough to melt ash to form slag.
o Coal Type:	Pulverized coal, 100% through -14 mesh. Gasifier can process a wide variety of caking and non-caking bituminous and sub-bituminous coals. Coal is slurried in water and fed to gasifier; thus, coal of virtually any moisture content can be handled. But high moisture coals incur higher oxygen consumption.
o Application:	Considered more suitable for production of syngas than SNG.
o Status	o A 400 TPD gasifier is operational since 1979 at Dow Chemical Company, Plaquemine, Louisiana plant site for use in producing electric power.

1.0 GENERAL INFORMATION (CONTD.)

- A 190 TPD Texaco gasifier to produce syngas to feed an ammonia plant for Tennessee Valley Authority (TVA) was started up in October 1981. However, technical problems resulted in syngas not being fed to the ammonia plant until November 1982. In February 1983, the facility was shut down because of financial reasons, and a slump in the ammonia market. However, since this time, the unit has been operated on several occasions to test various coal feedstocks.

- A 150 TPD demo gasifier is in operation since January 1978 at Ruhrchemie/Ruhrkohle's Oberhausen-Holten plant site. More than 36,000 tons of coal have been converted to synthesis gas.

- Two 900 TPD gasifiers (one standby) are in operation at Tennessee Eastman, Kingsport, Tennessee to provide syngas for captive use in a chemical complex.

- A letter of intent (120 million dollars in price guarantees) was issued by Synthetic Fuels Corporation in April 1983 to Cool Water Coal Gas Project. The project, which employs two 1,000 TPD (one standby) gasifiers to produce 100 megawatts of electricity, was started up in May 1984.

2.0 PROCESS DEVELOPMENT

The Texaco Coal Gasification Process (TCGP) is an extension of the commercial Texaco Synthesis Gas Generation Process (TSGGP). In the early 1950's, the TSGGP was commercialized to produce medium, or low Btu synthesis gas from a wide variety of liquid and gaseous hydrocarbon feeds. Since the first commissioning of a TSGGP plant in 1953, at least 75 plants with a total capacity in excess of a billion cubic feet per day have been started up in 22 countries. The initial plants had a capacity of 5 to 10 MM scfd of synthesis gas in several trains. Recently, plans having a single train of more than 10 MM scfd capacity have been built.

In the first stage of TCGP development, technological experience from TSGGP was utilized to run a 100 TPD, 300 psig pilot plant at Morgantown, West Virginia during 1956-1958. Current development on TCGP is being conducted at the Montebello Research Laboratory in California with two 15 to 20 TPD pilot units operated at pressures ranging from 300 to 1,200 psig.

The current thrust of development is mainly to make improvements in existing technology and run different types of coal. The current development program includes:

- Optimization of coal/water slurry feed concentrations.
- Optimization of gasifier operation with coals of high moisture contents.
- Increasing the life of materials of construction.
- Improvements in the design of the syngas cooler for steam generation.
- Optimization of particle grind size relative to maximum slurry concentration.
- Improvement of gasifier instrumentation and controls.
- Determination of scale-up parameters for gasifier modules of 1,000 TPD coal capacity.
- Evaluation of the economic benefits of the gasifier design features.

3.0 FEEDSTOCKS TESTED

o Types of coals gasified in the Montbello pilot plant include the following:

- **Bituminous Coals**

  Kentucky (3 mines)
  Illinois
  Utah (2 mines)
  Tennessee
  Arkansas
  Pennsylvania
  Germany
  Australia
  South Africa (2 mines)
  Canada
  Italy

- **Sub-Bituminous Coals**

  Wyoming (2 mines)
  Arizona
  Utah
  Japan

- **Lignites**

  Texas
  North Dakota
  Greece

- **Petroleum Cokes**

  Fluid
  Delayed
  Calcined
  Fluid Coke From
  Tar Sands Oil

3.0 FEEDSTOCKS TESTED (CONTD.)

- **Coal Liquefaction Residues**

SRC-I:	Keer McGee Ash Concentrates (Illinois #6) Filter Cake (Kentucky) High Ash SRC-I materials (Kentucky)
SRC-II:	Vacuum Tower Residues (Kentucky #9/14, Powhatan)
H-Coal:	Vacuum Tower Bottoms (Illinois #6, Wyodak) Settler Underflow (Illinois #6)
Synthoil:	Centrifuge Underflow (Kentucky)
Exxon Donor Solvent:	Vacuum Tower Bottoms (Illinois #6)
USS Clean Coke:	Stripper Bottoms (Illinois #6)

o 13 types of coals have been tested in the Ruhrchemie demonstration plant as of June 1982, including the following:

- German Ruhr
- Illinois No. 6
- Pittsburgh No. 8
- Utah
- South Africa
- Coal Liquefaction Residue

o Properties of coals tested vary over a wide range as shown below:

COMPOSITION RANGE, WT % (MF BASIS)

Carbon	60 - 83
Hydrogen	3.5 - 5.0
Nitrogen	1.1 - 1.6
Sulfur	0.6 - 3.6
Ash	5.6 - 27.9
Volatiles	16.0 - 43.6

3.0 FEEDSTOCKS TESTED (CONTD.)

HARDGROVE GRINDABILITY INDEX 47 - 100

ASH COMPOSITION, WT%

SiO_2	25 - 60
Al_2O_3	16 - 33
TiO_2	1 - 5
Fe_2O_3	4 - 32
CaO	3 - 11
MgO	1 - 3
Na_2O	0.2 - 4
K_2O	0.3 - 4
SO_3	2 - 7
P_2O_5	0.1 - 2.4

FUSION TEMPERATURE, °F 2300 - 2750

4.0 PROCESS DESCRIPTION

- Coal is ground and mixed with water to form a pumpable slurry of about 60% solids. It is then fed to the burner together with the oxidant (generally high purity O_2). Proprietary additives are added to control the slurry viscosity.

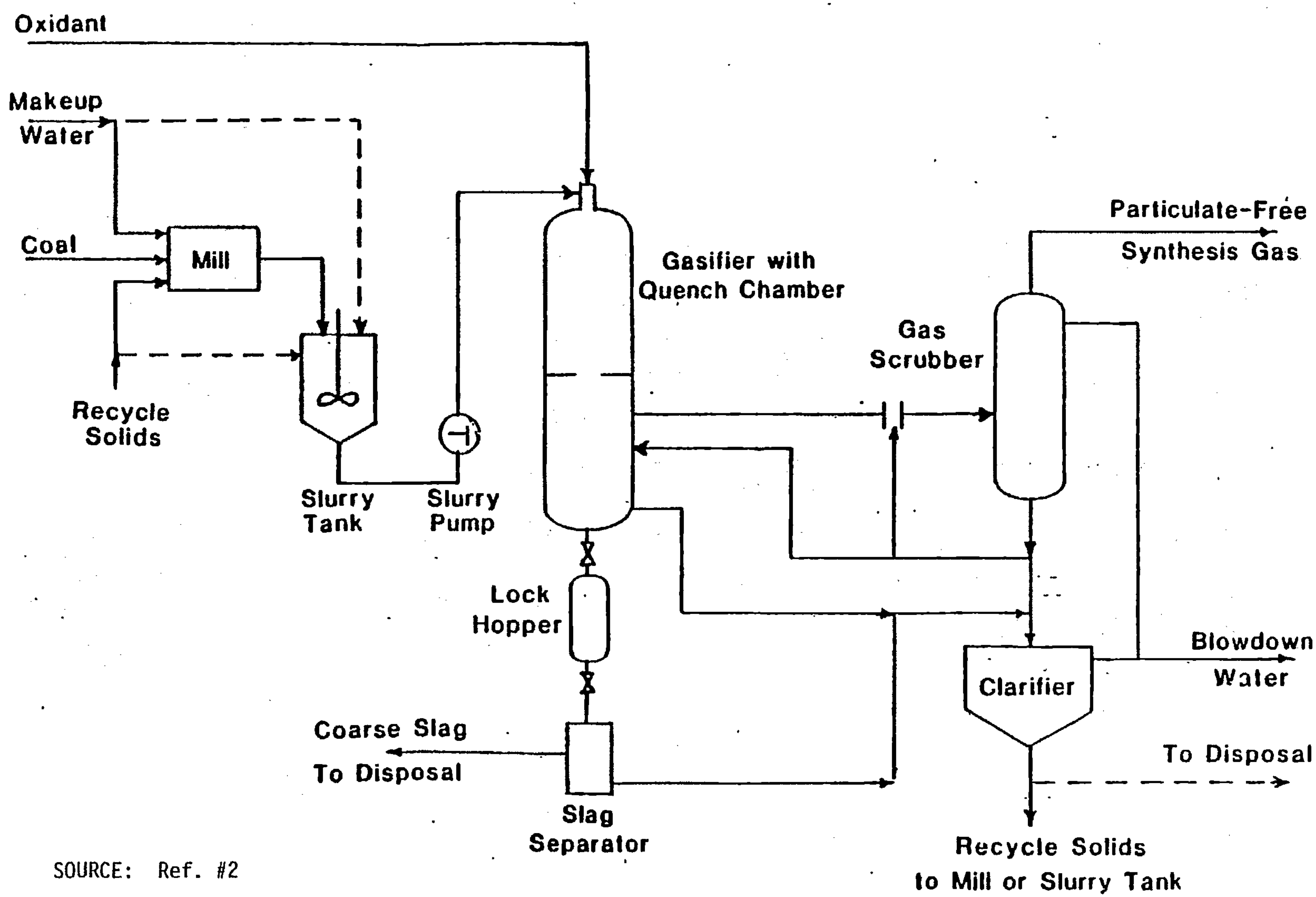
- Gasifier is a vertical steel vessel with an internal refractory liner and no internal moving parts:

  - Short residence time.
  - Carbon in the coal reacts with steam to produce CO and H_2.
  - O_2 burns part of the coal to provide heat for the endothermic reactions.
  - Sulfur compounds are gasified to form H_2S and COS.
  - Carbon conversion is controlled by the amount of O_2 fed and generally maintained above 90%.
  - Gasifier operates above fusion temperature of ash, but is kept below the limit of the refractory lined vessel by the water present in the slurry feedstock.

- In the direct quench mode, the hot gas and molten slag flow downward to a water spray chamber, thus producing a large quantity of steam. The gas temperature in this zone is low enough to allow unlined steel equipment to be used.

FIGURE 4.1

TEXACO COAL GASIFICATION PROCESS
Direct Quench Mode



SOURCE: Ref. #2

FIGURE 4.1

4.0 PROCESS DESCRIPTION (CONTD.)

- In the direct quench mode, the hot gas and molten slag flow downward to a water spray chamber, thus producing a large quantity of steam. The gas temperature in this zone is low enough to allow unlined steel equipment to be used.

- The solidified slag is removed through a series of lockhoppers and is taken away for disposal while the steam-saturated raw synthesis gas is water quenched and scrubbed to remove particulate matter before further processing.

- The water streams containing ash and soot are sent to a settler where clarified water is received for recycle. To prevent the buildup of dissolved solids, a blow-down stream is taken and sent to a wastewater treatment facility.

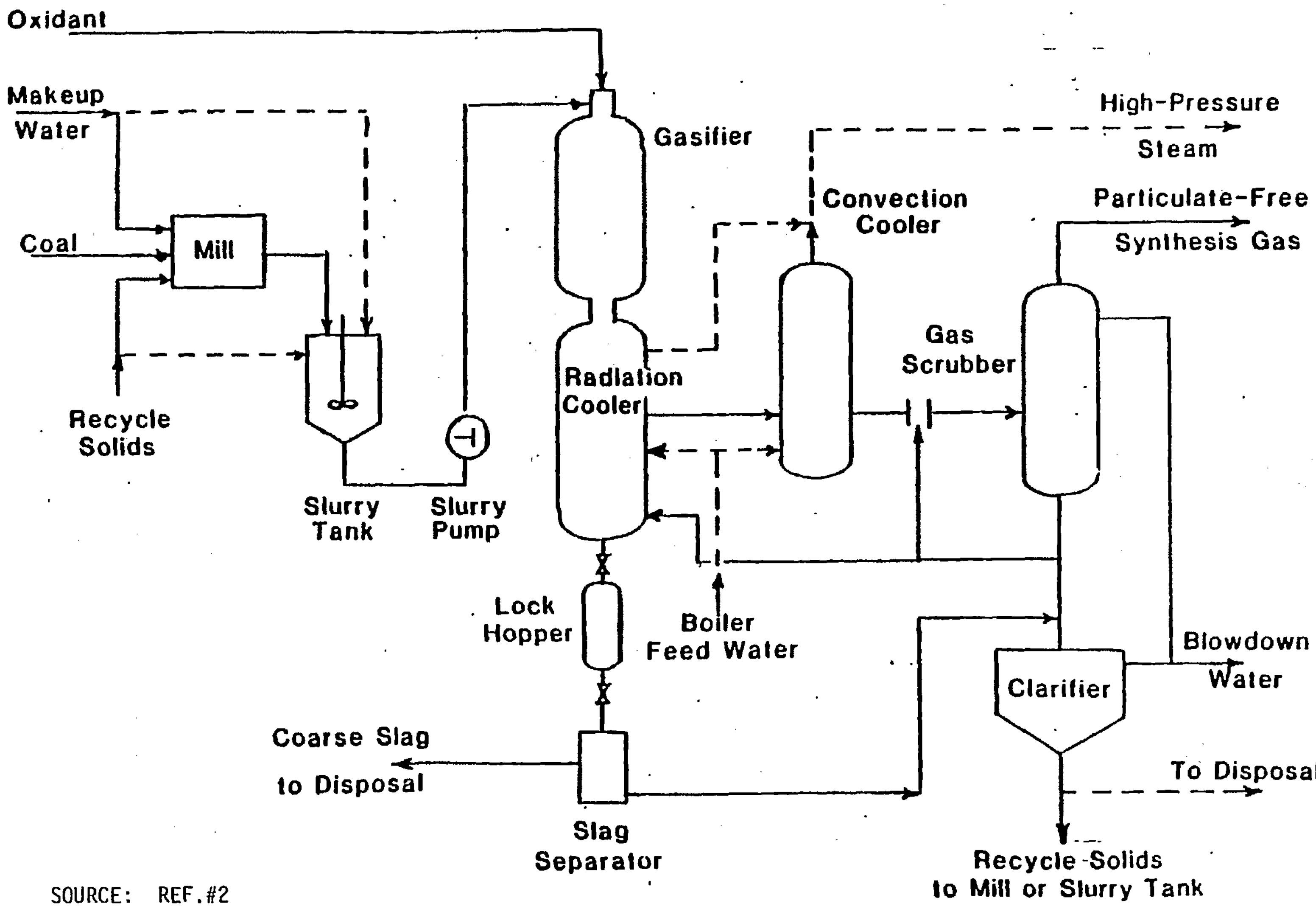
- In the gas cooler mode (Figure 4.2), the raw synthesis gas, after separation from the molten slag, is sent to a gas cooler where high pressure steam is produced.

- The raw synthesis gas in this operating mode requires a more thorough water scrubbing since it usually contains a higher level of particulates.

- The remainder of the gasification system of the gas cooler operation mode is similar to that of the direct quench mode.

FIGURE 4.2

TEXACO COAL GASIFICATION PROCESS
Gas Cooler Mode



SOURCE: REF.#2

TABLE 5.1

TEXACO COAL GASIFICATION PROCESS
BITUMINOUS COAL GASIFICATION

Coal Type	Kentucky No. 9	Illinois No. 6	Pittsburgh No. 8	South African	Polish
Feed Rate, Dry Short Tons/Day	1000	1000	1000	1000	1000
Dry Analysis, Wt Pct					
C	67.00	68.70	74.79	65.60	72.15
H	4.80	4.80	4.96	3.51	4.37
N	1.20	1.10	1.29	1.53	1.27
S	3.90	3.80	3.49	0.87	1.15
O	6.50	9.60	6.10	7.79	5.95
Ash	16.50	12.00	9.37	20.70	15.11
High Heating Value, Btu/Lb	12400	12400	13600	11200	12800
Pure Oxygen, Short Tons/Day	920	940	1010	870	980
Water, Lb/Hour	52500	55600	68200	44900	48900
Product Composition Mol Pct					
CO	34.33	32.92	31.08	36.534	38.28
H_2	28.34	27.03	27.69	26.01	27.95
CO_2	14.02	15.16	14.97	15.67	13.91
H_2O	21.59	23.23	24.88	20.82	18.94
CH_4	0.16	0.19	0.08	0.02	0.08
N_2+A	0.50	0.46	0.47	0.68	0.53
H_2S+COS	1.06	1.01	0.83	0.27	0.31
H_2+CO, MMSCF Per Operating Day	54.6	53.7	58.4	47.7	57.6

SOURCE: Ref.#3

TABLE 5.1 (Cont.)

TEXACO GASIFICATION PROCESS
COAL LIQUID RESIDUE AND HEAVY PETROLEUM GASIFICATION

Source Feed Type	Coal Lurgi Tar and Oils	Coal SRC II Vacuum Residue	Coal EDS Vacuum Residue	Petroleum Middle East Vacuum Residue
Feed Rate, Dry Short Tons/Day	1000	1000	1000	1000
Dry Analysis, Wt Pct				
C	84.16	62.59	71.7	83.8
H	8.28	3.59	4.9	10.5
N	0.70	1.12	1.2	0.5
S	0.33	2.86	2.3	5.1
O	6.38	1.23	3.9	-
Ash	0.13	28.16	16.0	0.1
High Heating Value, Btu/Lb	16400	11300	13200	17500
Pure Oxygen, Short Tons/Day	1010	700	800	1100
Water, Lb/Hour	16700	41200	37500	29200
Product Composition, Mol Pct				
CO	54.34	43.26	46.87	44.82
H_2	37.94	32.67	35.67	40.82
CO_2	2.68	9.28	7.40	4.44
H_2O	4.43	13.08	8.97	8.60
CH_4	0.19	0.26	-	0.05
N_2+A	0.33	0.52	0.42	0.13
H_2S+COS	0.09	0.93	0.67	1.14
H_2+CO, MMSCF Per Operating Day	85.3	55.7	75.2	98.0

SOURCE: Ref.#3

TABLE 5.1 (Cont.)

TEXACO COAL GASIFICATION PROCESS
PETROLEUM COKE GASIFICATION

Feed Type	Delayed Petroleum Coke	Fluid Petroleum Coke	Fluid Petroleum Coke from Tar Sands Bitumen
Feed Rate, Dry Short Tons/Day	1000	1000	1000
Dry Analysis, Wt Pct			
C	88.50	85.98	78.89
H	3.90	2.00	1.65
N	1.50	0.98	1.35
S	5.50	8.31	7.88
O	0.10	2.27	2.08
Ash	0.50	0.46	8.15
High Heating Value, Btu/Lb	15400	13800	12600
Pure Oxygen, Short Tons/Day	1080	1030	920
Water, Lb/Hour	53500	54400	48900
Product Composition Mol Pct			
CO	46.20	47.14	48.12
H_2	28.69	24.33	24.13
CO_2	10.68	13.16	12.79
H_2O	12.37	12.67	11.97
CH_4	0.17	0.09	0.09
N_2+A	0.55	0.42	0.59
H_2S+COS	1.34	2.19	2.31
H_2+CO, MMSCF Per Operating Day	73.3	64.2	58.3

SOURCE: Ref.#3

5.0 PERFORMANCE DATA

- Typical operating data from process development facilities are as shown in Table 5.1.

- Test results from the Ruhrchemie demonstration plant are:

  - Run Length Data (as of June 1982)
    Total time on stream, Hrs: >11,000
    Total Coal gasified, Tons: >66,000
    Total Gas Produced, MMSCF: 3,700

  - Gasifier Throughput
    Coal, Ton/hr: up to 9.0
    Gas, SCF/hr : up to 567,000

  - Gasifier Performance

Pressure psig	:	up to 600
Temperature, ^{o}F	:	2200 to 2900
Carbon Conversion	:	up to 99
Cold Gas Efficiency	:	77%
Gas Thermal Efficiency	:	94%
Gas Composition	:	vol %
CO	:	55.0
H_2	:	33.0
CO_2	:	11.0
CH_4	:	0.1
H_2/COS	:	0.3
N_2	:	0.6

6.0 BY-PRODUCTS AND ENVIRONMENTAL IMPACTS

- No phenols, tars or other heavy materials produced.

- Most water streams are recycled to slurry the feedstock such that those impurities get cracked to extinction.

- Slag from the gasifier exhibits low levels of leachability and can be disposed of by landfill.

7.0 COMMERCIAL DESIGN PLANS

A number of demonstration and commercial projects are complete, under construction or at design phase. A listing of the most promising projects worldwide are shown in Table 7.1. No detailed techno/economic evaluations have been found in literature for SNG. A block flow diagram for coal-to-SNG using Texaco coal gasification process is presented in Figure 7.1.

TABLE 7.1

TEXACO COAL GASIFICATION PROCESS LICENSED PROJECTS

Project	Location	Design Feed	Design Capacity, Short Tons Dry Feed/Day	Startup Date	End Product
Olin-Mathieson	Morgantown, W. VA	Hi-sulfur Bituminous Coal	100	1956	Ammonia
Ruhrchemie/ Ruhrkohle	Oberhausen, Germany	German (Ruhr) Semi-Anthracite Coal	165 (220 after "Debottlenecking")	1978	Oxo-chemicals
Dow Chemical	Plaquemine, LA	Ill. No.6 Coal	400	1979	Electricity
TVA	Muscle Shoals, AL	Ill. No.6 Coal	200	1982	Ammonia
Tennessee Eastman	Kingsport, TN	Hi-Sulfur Bituminous Coal	900	1983	Methanol plus CO (for acetic acid)
Cool Water	Daggett, CA	Utah (low-sulfur) Bituminous Coal	1000	1984	Electricity
SRC II	Morgantown, W. VA	SRC II Vacuum Bottoms from Pitt. No.8 coal	-	***	Hydrogen
WyCoalGas	Wyoming, USA	Lurgi Liquid By-Products	-	***	SNG
Alsands	Alberta, Canada	Tar-Sand-Derived Fluid Petroleum Coke	4200	***	Refinery Hydrogen
Ube Ammonia	Ube City, Japan	Imported Coal	1650	1984	Ammonia

*** Project suspended

SOURCE: Ref.#3

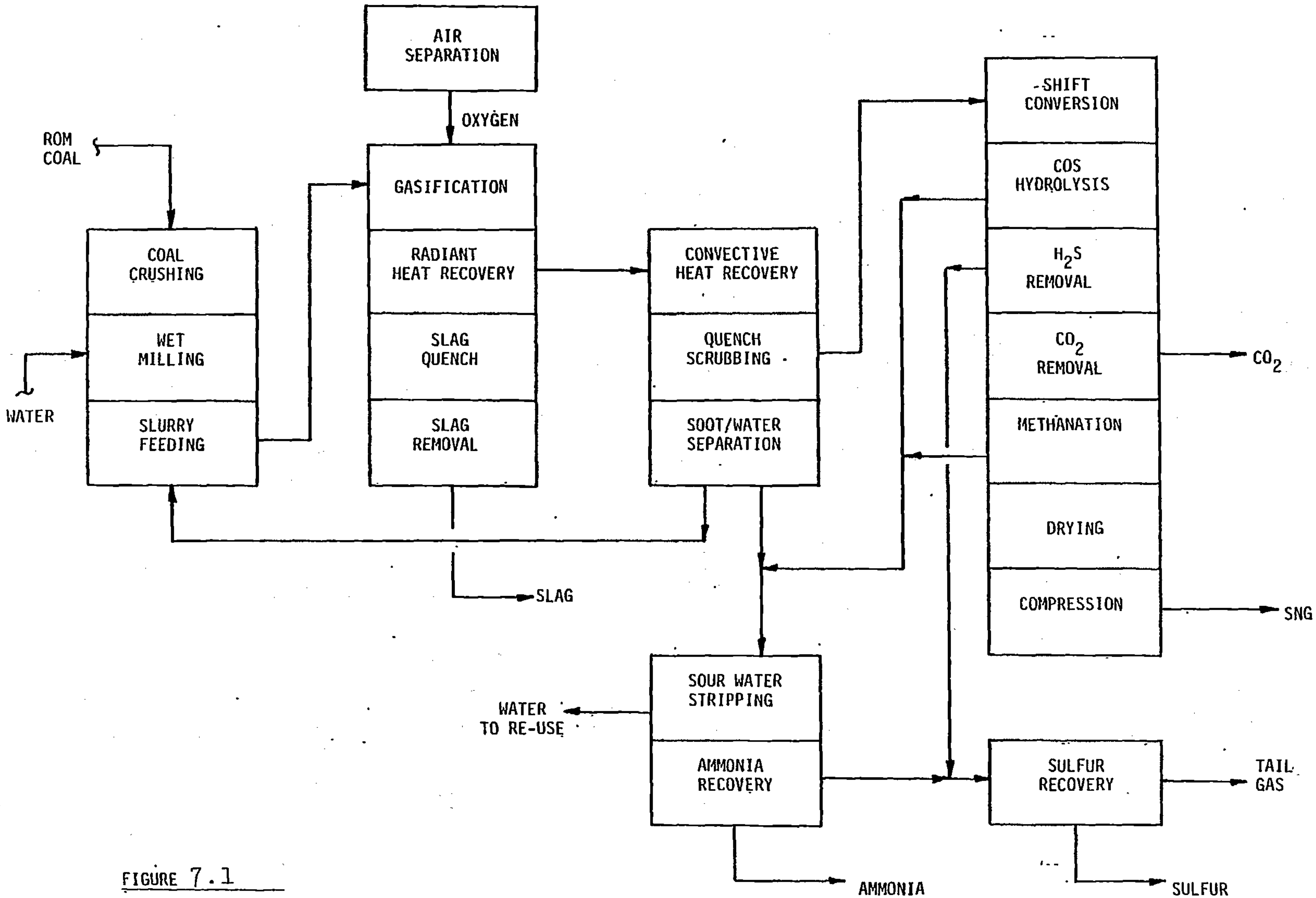


FIGURE 7.1
COAL-TO-SNG WITH TEXACO GASIFICATION

8.0 ADVANTAGES/DISADVANTAGES

- Advantages
  - Wide range of feedstocks
  - Pressure flexibility
  - Rapid process response
  - No liquid byproducts
  - Low impurities in product gas
  - Alternate process configurations
  - Direct use of coal from slurry pipeline

- Disadvantages
  - Water slurry feed results in high oxygen and feedstock consumption
  - Relatively short life (≤ 1 year) of refractories in gasifier due to slagging conditions
  - High-moisture coals (e.g., lignite) cannot be processed without pre-drying since vaporization of inherent moisture would otherwise lower temperature below that required for slagging.

9.0 REFERENCES

1. "Handbook of Gasifiers and Gas Treatment Systems," prepared for DOE by UOP/SDC, Report # WD-TR-82/008-010, September 1982.

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3. Crouch, W. B., "The Texaco Coal Gasification Process -- Synthesis Gas for Chemical Feedstocks," International Coal Conversion Conference, South Africa, August 1982.

STATUS SUMMARY:

BGC/LURGI (SLAGGING) GASIFICATION