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Synopsis

SASOL Ltd. and Westinghouse Electric Corporation have jointly undertaken a project to demonstrate on a commercial scale the pressurized, ash-agglomerating, fluidized-bed gasification process developed by Westinghouse during the past ten years. The nominal 1,200-metric-ton-per-day demonstration plant will be built and operated at the SASOL Two coal-to-synthetic-fuels complex at Secunda. Consisting of a coal preparation and feed system, a gasifier, an ash removal system, a fines collection and recycle system, and heat recovery and gas quench systems, the plant will operate in the "slip-stream" mode to make use of existing facilities and services at SASOL Two. This approach facilitates the early commercialization of the technology at minimum cost. The commercial demonstration is the last step in a structured scale-up program implemented by Westinghouse, starting with laboratory-scale experiments and proceeding through the pilot plant stage and the large cold flow model stage to the present demonstration plant. When demonstrated, the technology could offer unique advantages for future synthetic fuel plants, including gasification of fine coal, with operational safety and minimal environmental impact. Potential advantages also include low capital and operating costs and high process efficiency and reliability.

Project Description

SASOL Ltd., a Republic of South Africa company which has established the largest coal-to-synthetic-fuels plants in the world, with more than 30 years of experience in commissioning, operating and developing these plants, and Westinghouse Electric Corporation, a United States of America corporation established as a leading supplier of high technology processes, products and services to the process, manufacturing and utility industries, have jointly undertaken a project to demonstrate the operability and commercial viability of the pressurized, ash agglomerating, fluidized-bed process (PAFB) developed by Westinghouse during the past ten years. As part of the project scope, the two firms will design, construct and operate a nominal 1,200-metric-ton-per-day demonstration plant at the SASOL Two coal-to-synthetic-fuels complex in

Secunda, Republic of South Africa. This Advanced Commercial-Scale Gasifier (ACSG) plant will operate in the slip-stream mode, utilizing existing coal supply and waste water treatment facilities, oxygen and other utilities and could feed gas to existing processing units. Utilizing existing facilities permits the project to proceed at a lower cost and on a shorter schedule than would be possible in a grassroots demonstration plant, either in the United States or elsewhere.

The project, conceived by the two sponsors as a means of fulfilling their commercial and technical requirements, affords unique benefits to each:

- Collaboration of the most respected and experienced coal conversion organization with the developer and designer of one of the leading second-generation gasification technologies.
- An opportunity for Westinghouse to achieve commercial demonstration of its technology on a short schedule and at moderate cost to permit early commercial application.
- An opportunity for SASOL to participate in the demonstration of a technology that could offer advantages for future applications and facilities, including the ability to handle coal fines and caking coals, as well as to produce super-heated steam in a process with minimal adverse environmental impact at high conversion efficiency and reasonable cost.
- Commercial benefits for both SASOL and Westinghouse from their own and other's future use of the process for power generation or synfuels production.

The project is planned in six phases: design, procurement, construction and commissioning, demonstration, optimization and commercial operation. These overlapping phases are shown on the project schedule (Figure 1). The design phase begun in 1982 ends in early 1984, when the detailed engineering drawings are completed. The procurement phase begins with the ordering of major hardware components in October 1982 and will continue until August 1984. Construction at the SASOL Two site commences in mid-1983 and will be completed by November 1984, at which time the plant will be commissioned and operational phases will begin to demonstrate and optimize the process.

Each of these project phases involves the joint participation of SASOL and Westinghouse to complete their respective scopes of work. These scopes of work responsibilities (Figure 2), as defined by the joint agreement, are described below.

Design, Procurement, Construction Phases

Westinghouse is responsible for the design and construction of the basic gasification plant within a designated battery limits boundary. This responsibility includes all aspects of project management, engineering, procurement, construction and construction management, as well as all temporary facilities required to complete the plant. The SASOL experience and know-how will be utilized in the design stage to ensure successful commercialization in scale-up from pilot plant to commercial scale. In addition, SASOL is responsible for integrating the unit with the existing SASOL Two complex. This includes the coal preparation, drying and feed systems, the ash disposal system, utilities, electricals, piping and certain buildings and permanent site facilities. The SASOL portion of the work also includes all aspects of project management, engineering, procurement and construction.

Demonstration, Optimization Phases

The planning and implementation of the test program required to achieve operational success criteria are the responsibility of Westinghouse. SASOL will participate in all decisions concerning plant operation and is responsible for operational overview to ensure that the operations of the Advanced Commercial-Scale Gasifier are in conformance with SASOL Two operational and safety requirements. Any plant modifications needed to operate or optimize the process will be determined by both partners.

During test operations, SASOL and Westinghouse will jointly supply plant management, engineers, technicians and operators. Key engineering and operations personnel from the Westinghouse pilot plant facility in Pennsylvania will be used to ensure the efficient transfer of technology and operational procedures. SASOL will provide a base of experience resulting from commissioning and operation of large-scale commercial coal conversion and hydrogen synthesis plants.

For the entire operating period, SASOL will provide coal, oxygen, start-up high pressure steam, nitrogen, electrical power, water and waste disposal and certain other operational services. The steam and gas produced from the plant will be available for use by SASOL on an as-needed basis to supplement existing capacity.

Commercial Operations Phase

Upon completion of the demonstration and optimization test program, the plant will be taken over by SASOL and subjected to commercial operating conditions. Operational control will be SASOL's responsibility; Westinghouse will continue to participate in the project technically and will be permitted to conduct coal tests, under SASOL control, for various commercial clients.

The project is a logical merging of two paths begun many years ago at Westinghouse and SASOL. The history of the SASOL development and application of fixed-bed gasification technology with the Fischer-Tropsch synthesis at SASOL One, and now at SASOL Two and Three, has been documented previously. In recent years, a widespread need has been recognized to consider an advanced coal gasification process for future applications -- one which can consume fine coal (6 mm and less) and bituminous coals, which cake when heated. These considerations evolved as new automated mining methods produced greater quantities of fines per ton of coal mined and as new bituminous reserves were targeted for utilization. SASOL, as a leader in new coal conversion technology, has a keen interest in developing newer, more efficient coal conversion technologies for use in the future.

Westinghouse views the demonstration project as the last step in the development and commercialization process, a long chain of events dating back to 1970 in which the PAFB coal gasification process was developed from a concept through laboratory and pilot-scale testing to a mature near-commercial technology. One needs to understand this logical and sustained developmental program -- its objectives and methodology -- in order to appreciate the significance of the demonstration project and the importance to Westinghouse of this collaboration with SASOL.

Westinghouse Developmental Program

The Westinghouse PAFB gasification process was conceived in 1970. At that time, it was realized that an efficient, environmentally non-degrading fuel gas producer, utilizing the vast reserves of coal available in the United States, would be an economical way to generate electrical power when coupled with high-temperature fuel cells or gas-turbine, combined-cycle electrical generation plants. The early version of the gasifier concept was a two-stage, fluidized-bed process (Figure 3) using air as the oxidant. The first stage was a coal devolatilizer which employed a draft tube along its center line to mix the fresh incoming coal with recirculating char in the bed to prevent agglomeration. The second stage was an air-blown gasifier and combustor to provide the heat for the process, as well as gases for fluidizing the first stage.

A pilot plant (Figure 4) was built at Waltz Mill, Pennsylvania, in 1973 and 1974 to embody the air-blown system, and this version of the process was successfully tested during the next three years in both single- and two-stage versions. The single-stage concept (Figure 5) evolved when it was shown in late 1977 that caking coals could be fed directly into a fluidized-bed gasifier without caking, and in 1978, the air-blown capability at the pilot plant was augmented by an oxygen-blown capability. From that time on, the single-stage oxygen- or air-blown system has been the primary concept under development.

The pilot plant developmental program has been jointly funded by Westinghouse, the Gas Research Institute and the United States Department of Energy and its precursor agencies, the Energy Research and Development Administration and the Office of Coal Research. Since its commissioning in 1975, the pilot plant has logged more than 8,000 hours of hot operation at pressures of up to 15.3 bar and at coal capacities of up to 30 metric tons per day (Figure 6). It has successfully processed coal and char feedstocks from nearly every major seam in the United States to produce ash agglomerates and quality synthesis and fuel gases (Figure 7). It has also been used to demonstrate the feasibility of the basic PAFB processing concepts, the component hardware and the operational techniques necessary to achieve stable, predictable performance at feed rates well beyond its initial design limits.

In addition to operations at the pilot plant, the Westinghouse program has been conducted in a number of other facilities to perform functions required for a well-structured, integrated developmental effort of this kind (Figure 8). The facilities of the Westinghouse Research and Development Center have been used to promote a basic understanding of gas-solid fluidized systems through the use of laboratory-scale cold flow models (Figure 9). In addition, bench-scale apparatus are used to study ash fusion and agglomeration mechanisms, coal gasification kinetics with steam and carbon dioxide, coal devolatilization behavior, particulate removal, gas desulfurization and high-temperature materials behavior. The cleaning and combustion of hot fuel gases have been studied in the combustion test passages of the Synthetic Fuels Division laboratories (Figure 10). Scale-up of fluidized-bed components and a more complete understanding of fluidized-bed and pneumatic-transport phenomena are being achieved in the commercial-scale three-meter-diameter cold flow facility (CFSF) at Waltz Mill (Figure 11). This versatile apparatus is a full-size replica of a coal gasifier, complete with solids feed and withdrawal systems. It permits full front-face viewing of a fluidized bed through a plastic window, allowing a detailed study of jet behavior, solids circulation, bubble velocity and frequency and related phenomena necessary to design a large coal gasifier.

To support and guide these experimental programs, the development effort includes a substantial engineering effort involving analysis and modeling. Analytical models of the gasification process were developed on the basis of small laboratory experiments and the literature, but corroborated during the successful operation of the pilot plant, which was designed largely from these models. Now, the models are being further validated at the three-meter model level. This methodology provides a cost-effective approach to scale-up and is the basis for the entire Westinghouse program: proceeding from small-scale cold and hot models to the pilot plant, verification of basic analytical models at the pilot plant, validation at the large cold flow stage, and finally, validation at the commercial-scale demonstration plant at SASOL Two (Figure 12).

This program structure underscores the importance of the ACSG demonstration project as the final "link" in the progression from laboratory concept to commercial reality. From the results of this program, Westinghouse will be able to design plants for a variety of applications (Figure 13) for coal conversion.

ACSG Process/Plant Design

The ACSG demonstration plant design is a direct application of the process and component designs developed in the program described above. In addition, the experience of SASOL is being used to optimize the design based on applicable experience at SASOL One and Two. The ACSG embodiment of the process consists of a gasifier and its coal feed and ash withdrawal systems, a heat recovery system, a fines collection and recycle system and a gas quench and recycle system (Figure 14).

In this process, sized coal is dried to five percent surface moisture and fed to a lockhopper system to boost its pressure from atmospheric to a system pressure of about 30 bar. The minus 6 mm size coal is metered by a rotary feeder and transported pneumatically to the gasification reactor using recycled product gas. The coal, along with steam and oxygen, is fed to the reactor through a feed tube assembly placed along the gasifier center line.

The jet formed at the end of the feed tube is a unique and important feature of the process (Figure 5). In this jet, coal is heated to a reaction temperature of 1010°C and is first devolatilized, rendering it non-caking. It then is combusted with oxygen to provide heat for the process and gasified with steam and carbon dioxide to form carbon monoxide and hydrogen, which are the main constituents of the synthesis gas project. The velocity and pressure fields around the jet cause a high rate of solids circulation from the upper bed to the jet zone, resulting in a well-mixed, essentially isothermal bed.

As the solids circulate through the jet, carbon and volatile matter are released from the char matrix, leaving particles richer in ash than the coal. Some ash constituents in the particles, particularly the low-temperature eutectics of iron, aluminum and silica, melt and moisten the surfaces of the char-ash particles. This causes adjacent particles to stick together or agglomerate by a sintering action. Eventually, the ash agglomerates become larger and denser than the other bed particles and defluidize. The defluidized ash-rich agglomerates are separated from carbon-rich particles by classification in the ash annulus, cooled by recycled product gas, and continuously removed from the gasifier to lockhoppers by a rotary valve. The lockhoppers let down the pressure and feed the ash to a belt conveyor for disposal.

Typically, the gasifier concept allows the bed ash content to remain at a value of 30 to 40 percent. With fines capture in the cyclone of 90 percent, the carbon utilization for the process for the Bosjesspruit coal is expected to be over 90 percent.

Operating at a freeboard temperature of about 1000°C, the raw product gas from the gasifier is free of tars or oils, which have been cracked or reacted to gaseous components, primarily carbon monoxide, hydrogen, carbon dioxide and methane. The gas contains particulate matter in the form of char particles composed of carbon (65 to 75 percent) and ash (25 to 35 percent). Very little free ash is present. Prior to entering the cyclone, this gas-solid stream is cooled in a radiant steam boiler to 700°C, producing saturated steam at 40 atmospheres. The steam is then superheated to 425°C in a second heat recovery unit downstream of the cyclone. Both heat recovery units are water-tube designs.

The cyclone removes the char particles, typically from 10 to 300 microns in size, which are fed to a dip leg for recycle to the gasifier. The fines are consumed in the gasifier, along with the coal, by gasification and combustion.

Venturi scrubbers cool the gas leaving the second heat recovery unit from 370°C to 160°C prior to final scrubbing in a quench tower. The remaining particulate matter is scrubbed out of the gas, concentrated in a filter system and disposed as a wet cake. A portion of the clean, cooled product gas is recompressed for use in gasifier reactor fluidization, ash cooling and solids transport. The majority of the gas is either flared or sent to the SASOL Two raw gas stream for further processing.

A summary of the design conditions for the unit to be built at SASOL Two (Figure 15) illustrates its performance advantages as a producer of synthesis gas:

- It can utilize fine-sized, run-of-mine coal of widely differing ash characteristics, reactivities and sulfur contents.
- It produces little to no tars, oils or liquid hydrocarbons as by-products, simplifying gas cleaning operations.
- It produces a granular, dry ash product that can be used as a safe, non-leaching landfill or as a construction material.
- Its low use of steam, moderate use of oxygen, moderate operating temperature, high carbon utilization and use of waste heat make it an efficient and economical process.
- It is a simple, safe and controllable process with considerable operating range and flexibility because of its large carbon inventory.
- Its use of carbon steel components, with minimum exotic or high technology materials, provides a reasonable capital cost.

Conclusion

The joint Westinghouse/SASOL demonstration will provide an early, minimum-cost opportunity to demonstrate the efficiency and economy of a second-generation gasification process on a commercial scale under commercial operating conditions. The work, when successfully completed, will make available for wide commercial application a process with unique technical, economic and environmental advantages.

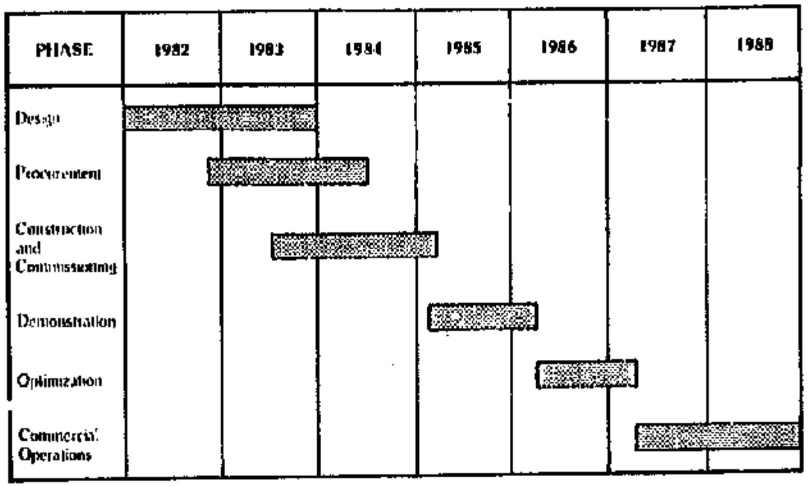

Figure 1. ACSG Demonstration Project Schedule

PHASE	WESTINGHOUSE	SASOL
Design, Procurement, and Construction	• Battery Limits of Plant • Construction Services and Facilities	• Interconnections to SASOL II • Commercial Operating Experience • Utilities • Site Facilities and Buildings • Coal Preparation Facility
Demonstration and Optimization	• Technical Operations • Test Program • Plant Modifications • Engineering and Technician Support	• Utilities • Feedstocks • Operational Overview • Use of Gas Produced • Engineering and Operator Support
Commercial Operations	• Technical Participation • Coal Tests	• Operational Control • Production Operations

Figure 2. ACSG Projet Scopes of Work

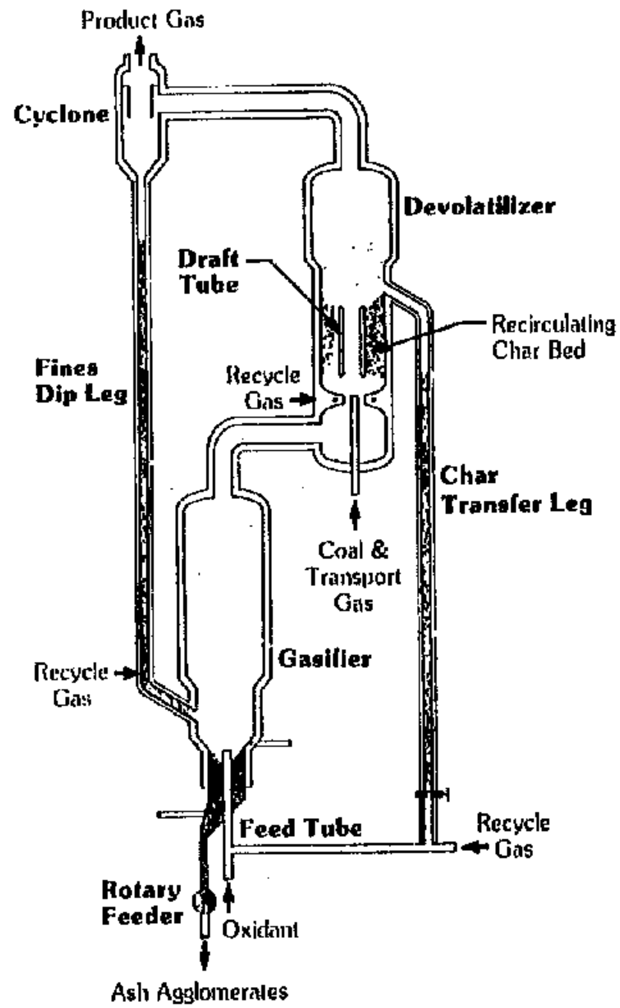

Figure 3. Two-Stage Coal Gasifier

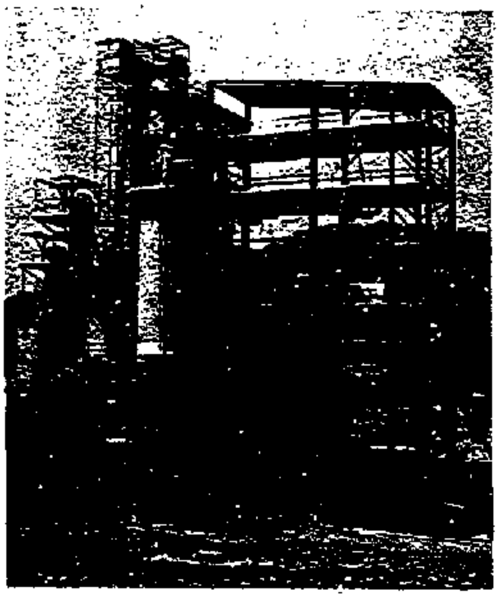

Figure 4. Westinghouse PAFB Gasifier Pilot Plant

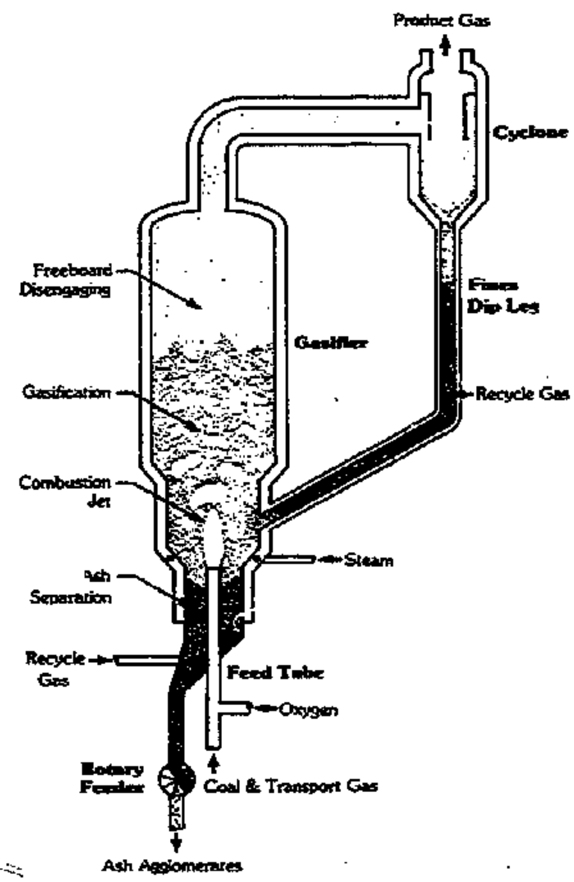

Figure 5. Single-Stage Coal Gasifier

PARAMETER	AIR BLOWN	OXYGEN BLOWN
Coal Feed Rate, kg/hr	300-700	400-1400
Steam to Coal, kg/kg (MAF)	0-0.5	0.5-1.0
Oxidant to Coal, kg/kg (MAF)	3.0-4.0	0.7-1.0
Temperature, °C	850-1070	850-1070
Gauge pressure, Bar	8.6-15.3	8.6-15.3

Figure 6. Pilot Plant Operating Conditions

Feedstock	Preparation	Caking Tendency	Relative* Reactivity	Ash Content
West Virginia Coal	W	High	12	9
Pittsburgh 8 Coal	W, ROM	High	5	10
Upper Freeport Coal	W, ROM	High	4	11
Ohio 9 Coal	ROM	High	5	13
Kittanning Coal	W	High	5	9
Illinois 6 Coal	ROM	Med	5	12
Kentucky 9 Coal	W	Med	6	9
Indiana 7 Coal	W	Med	8	11
Bosjesspruit (RSA) Coal	ROM	Low	50	18
Utah Sub-C Coal	W	Low	30	3
Montana Rosebud Coal	W	Low	70	8
Wyoming Sub-C Coal	W	Low	60	8
Texas Lignite	ROM	Low	28	22
FMC COED Chars	—	Nil	12	13
Pittsburgh Coke Breeze	—	Nil	1	12
Westinghouse Chars	—	Nil	2 to 10	18
Petroleum Coke	—	Nil	1 to 2	0.2 to 0.4

W = Washed ROM = Run of Mine *TGA Measurement

Figure 7. Feedstocks Successfully Processed in the Westinghouse Pilot Plant

FUNCTION	FACILITY
Basic Phenomena Research	Bench-Scale Experiments
Ash and Coal Characterization	Bench-Scale Experiments
Fluidization Research	5, 10, 30 cm Models
Combustion Research	20 Bar Combustion Passages
Process Development	30 Tonne Per Day Pilot Plant
Component Development	30 Tonne Per Day Pilot Plant
Procedures Development	30 Tonne Per Day Pilot Plant
Hydrodynamic Scale-Up	3-m Cold Flow Facility
Process Analysis	—
Analytical Model Development	—
Component Design	—
Process Design	—
Reference Plant Design	—
Demonstration Plant	SASOL TWO ACSG

Figure 8. Components of the Westinghouse Development Program

Figure 9. Cold Flow Fluidization Research Model (30 cm)

Figure 10. Combustion Test Passage Utilizing Pilot Plant Coal - Derived Gas

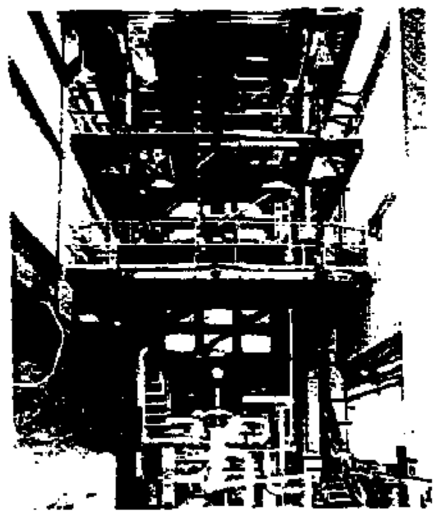

Figure 11. Three-Meter Cold Flow Fluidization Facility

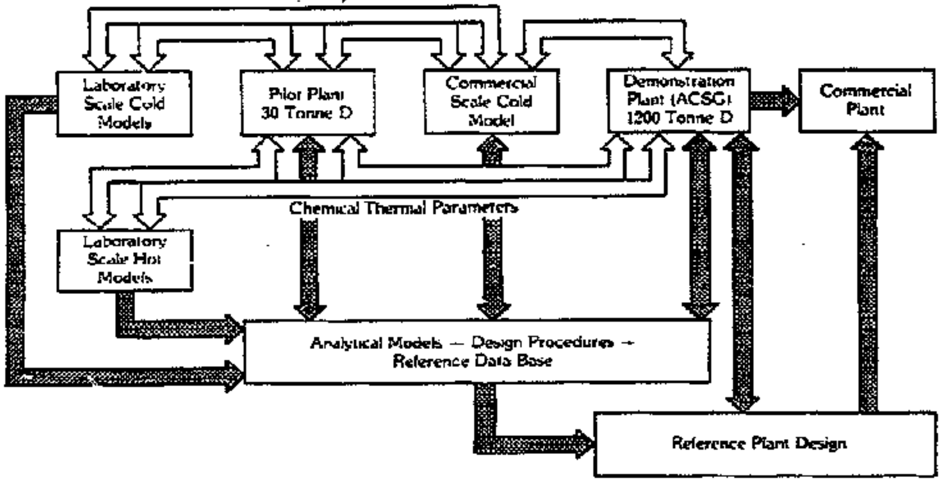

Figure 12. Structure of the Westinghouse Development Program

Power Generation Fuel

- Boiler Fuel
- Combined Cycle
- Fuel Cells

Fuel and Synthesis Gas

- Industrial Fuel Gas
- Methanol Synthesis
- Liquid Hydrocarbon Synthesis
- Synthetic Natural Gas
- Hydrogen

Figure 13. Applications of the Westinghouse Process

Stream	Flow Rate tonne/hr	Temperature °C	Gauge Pressure Bar	Composition %
Coal Feed	47.6	27	0	(WT%)
—Carbon				50.2
—Ash				18.2
—Volatiles				22.6
—Moisture				9.0
Oxygen Feed	25.4	150	33	
Steam Feed	22.4	390	37	
Recycle Gas	17.6	96	30	
Fines Recycle	33.0	704	30	
Ash Removal	9.2	100	0	(WT%)
—Ash				85.0
—Carbon				15.0
Net Dry Product Gas	65.5	171	27	(VOL%)
—CO				42.8
—H_2				31.5
—CH_4				5.8
—CO_2				17.4
—Other				2.5
Net Steam Product	19.6	427	40	

Figure 15. ACSG Operating Conditions

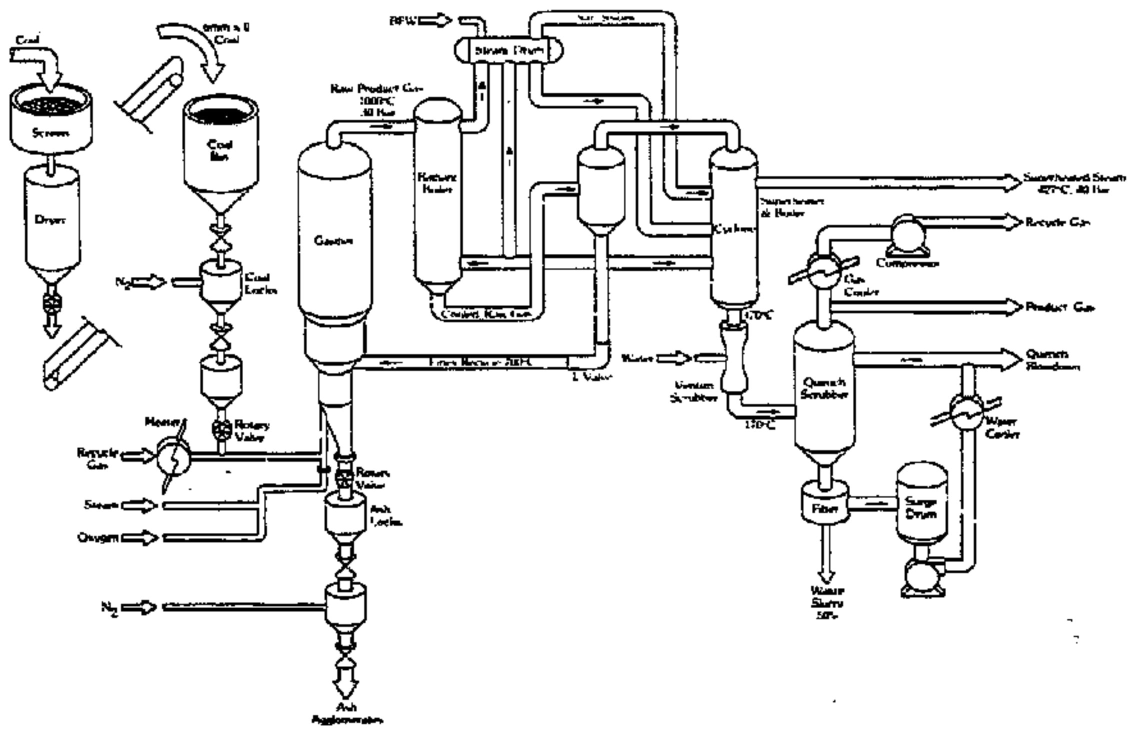

Figure 14. ACSG Demonstration Plant Process Flow Schematic