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WESTINGHOUSE GASIFICATION TECHNOLOGY DEVELOPMENT AND PROJECTS STATUS

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ABSTRACT

A joint program between Westinghouse, the Department of Energy, and the Gas Research Institute has shown, through the use of a 35 ton-per-day coal feed process development unit (PDU), that the fluidized bed gasifier is technically feasible and economically attractive. The process has been shown to be simple, controllable, and safe in converting many types of coals, including reactive western coals, caking eastern coals, high ash coals, and run-of-mine coals. The process is efficient because it utilizes many coals at high conversion efficiency with relatively low use of oxidant and steam. Because of its simplicity, its use of available hardware technology, and the absence of tars in the product gas, the system has low capital and operating costs. It can be employed with little adverse environmental impact because of its efficiency, low pollutant output, low water usage, and disposable ash product.

Process advantages have been confirmed by independent conceptual designs and cost estimates for commercial-scale applications, including substitute natural gas (SNG), industrial fuel gas, liquid synfuels, and combined cycle power generation.

The development program includes unique cost-effective integration of hot and cold small-scale experimental models, a commercial-scale cold flow model, and analytical modeling, together with the PDU, to provide commercial design procedures. Westinghouse commercial designs are utilizing these design tools and the process is now being scaled-up for a commercial-scale demonstration facility.

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TECHNOLOGY PROGRAMS

Program Perspective

Under the joint sponsorship of the Department of Energy, the Gas Research Institute and Westinghouse Electric Corporation, a comprehensive technology development program has been pursued since 1972. References 1 through 8 summarize program components. Briefly:

- More than 8000 hours of hot operation have been accumulated at the process development unit at (PDU) Waltz Mill, Pennsylvania. Fluid dynamics, process control, component development, equipment design, and product characterization have all been studied at the PDU.
- Fundamental investigations of the unit process and mechanisms involved in the gasification process have been carried out in bench-scale experimentation at the Westinghouse Research and Development Center at Churchill, Pennsylvania.
- A commercial-scale fluidization simulator (CFSF) was built and operated at Waltz Mill to study fluidization at the commercial scale. This cold flow model is semicylindrical and permits direct viewing of fluidization behavior.
- Experimental results are being integrated into a detailed design of a commercial-scale demonstration unit exceeding 1000 tons per day of coal feed. Cost estimates and project economics are being evaluated for several projects.

Development History

The Westinghouse single-stage process evolved from a two-stage process comprised of a devolatilizer and a gasifier-agglomerator. Development began in 1972 under the sponsorship of the Office of Coal Research. During these early years of the program, emphasis was directed primarily to the two-stage, air-blown system for direct integration with Westinghouse combined cycle plants based on the W501D combustion turbine.

In 1975, the Energy Research and Development Administration redirected the program. From 1976 to 1978 the gasification process was extended to encompass medium-Btu fuel and synthesis gas applications. Oxygen-blown gasifier experiments were initiated.

In 1979, the Gas Research Institute became a part of a joint program with the Department of Energy and Westinghouse. The medium-Btu, oxygen-blown process for SNG applications was emphasized. The program was also expanded to include scale-up methods and systems-oriented or "balance-of-plant" issues such as heat recovery.

Currently, efforts are being directed toward expanding the data base for the design of a commercial-scale coal gasification process. Reactor scale-up is being studied by correlating the results of laboratory modeling with PDU test results and with the results acquired from the CFSF. Component development leading to improved process efficiency is being performed.

The effort through 1979 emphasized gasifier development, with systems and component development as required to demonstrate the complete process. Table 1 outlines PDU test accomplishments. Future activities are directed toward scale-up of the technology for various applications and process improvements.

Process Development Unit Operations

The PDU facility is the primary vehicle used to demonstrate the technical feasibility of the process. The PDU comprises all unit operations, from coal crushing and drying through quench scrubbing of the coal gas. Downstream units, such as acid gas removal, shift, methanation, or power generation, are not included in the current capabilities of the PDU, since these are processes that have been demonstrated elsewhere. Figure 1 is a flow schematic of the facility.

The PDU gasifier, which is an ash agglomerating fluidized bed, has processed run-of-mine coal with steam and either air or oxygen to produce a low- or medium-Btu gas and ash agglomerates. Typical operating ranges for this unit are as follows: freeboard temperature - 1650 to 1850°F, pressure - 130 to 230 psig, coal feed rate - 1000 to 1600 pounds per hour for bituminous coals, 1600 to 3500 pounds per hour for subbituminous coal and for lignites.

As shown in Figure 2, the reactor vessel consists of four functional zones: (1) an expanded freeboard section to separate char fines from exiting raw gas; (2) a gasifier bed to permit char particles to react with steam; (3) a combustor to devolatilize coal, combust carbon for the heat source, and produce ash agglomerates; and (4) a char-ash separator to separate ash agglomerates from char, to cool the ash with recycle gas, and to discharge solids into the lockhoppers.

Coal and recycled fines are pneumatically conveyed and injected into the gasifier. Oxygen and steam are preheated and introduced through the feed tube. A lean-phase turbulent jet forms at the exit of the feed tube assembly. Coal is rapidly devolatilized in an oxidizing environment; the jet induces a vigorous recirculation of the char solids, thus promoting heat transfer into the upper regions of the fluidized bed.

Run-of-mine coal is received in lump form and prepared in a crusher-dryer, providing a feedstock size of minus 1/4 inch plus 0 with a surface moisture content between 5 and 10 percent.

Coal feeding is performed by pressurized lockhoppers and pneumatic transport of dry feedstock using recycled product gas as the transport medium. The feed material is batched from storage bins by belt conveyors and bucket elevators to a transfer lockhopper that cycles between atmospheric pressure and system pressure. Batches of coal are then transferred to the pressurized feed lockhopper, where a rotary feed valve discharges the material into a pneumatic transport feed line.

The ash produced in the gasifier is removed in a dry granular form as agglomerates. The discharge is controlled by a starwheel feeder, which feeds a set of parallel pressurized lockhoppers, mounted at the bottom of the fluidized bed.

Fines-laden raw gas from the gasifier flows through two cyclones, which separate the elutriated char, and then to a quench scrubber, where the gas is cooled to its adiabatic saturation temperature by water spray.

A slipstream of quenched gas is further scrubbed in a direct contact cooler and recompressed for recycle to the gasifier. This recycle gas is used for penumatic transport of solids, ash cooling and separation, and gasifier grid aeration. The bulk of the product gas is incinerated in a thermal oxidizer.

The water-fines slurry from the scrubber bottoms is processed through a clarifier pit and the clear water is recirculated by high pressure pumps into the scrubbers. Sludge from the pit is periodically removed to a contract landfill facility.

Ancilliary units include an oxygen storage dewar, air compressor, and an electric steam generator. All systems are extensively instrumented to monitor and record process performance data. Gas characterization equipment includes two on-line gas chromatographs for the analysis of product gas trace and bulk constituents, an infrared analyzer, a calorimeter, and a gas chromatograph specially devised for estimating the moisture content in the raw gas exiting the gasifier. Fines entrained by the gas are measured by isokinetic probes and sample conditioning trains. Digital data are recorded by a DEC PDP-11 computer.

Testing Experience

To date, the Westinghouse process and operating data base extends to more than 8000 hours of hot operation with coals and chars in both the air-blown mode, producing low-Btu gas, and the oxygen-blown mode, producing medium-Btu gas. Table 2 lists the feedstocks that have been processed in the unit. The flexibility of the gasifier in processing a wide variety of feedstocks can be easily gauged in Table 3, which reports the entire range of feedstock coal and ash properties. Table 4 summarizes developments that have been demonstrated in the PDU.

Laboratory Support

The PDU was designed on the basis of laboratory studies. Only minor modifications in the PDU have been needed, indicating that the analytical models used for scale-up to PDU-size are basically sound.

However, it was clear that the PDU could not be used to supply all of the information needed to scale-up the gasifier to commercial size with minimum risk. Accordingly, experimental and theoretical work has been included in the development program to study the chemical kinetics, hydrodynamics, and fluidization characteristics of the gasifier.

Cold flow models can be used to predict the effects of changing such items as reactor configuration, gas flows, and fluidized bed velocities. Also, such factors as distributor design, feed tube location, jet penetration, and char-ash separation geometry have been studied. The cold model studies were performed in a variety of two- and three-dimensional models of various scale, including a 10-foot diameter full-scale cold flow semicylindrical model. In addition, investigation was initially aimed at understanding the history of coal particles fed to the gasifier, a phenomena important in developing an effective model of the process.

Bench-scale gasification tests were used to develop information on the rates of devolatilization, burning, and gasification of coal. The reactivities of various coals and char were determined in a fluidized bed. The thermogravimetric analyzer (TGA) was used to measure gasification reaction rates for different coals. Conditions needed to obtain comparability between the TGA and fluidized bed tests were established. Work to obtain reactivities and those factors that affect them are continuing. This information was used in the design of the scaled-up gasifier.

A bench-scale ash agglomeration test facility was constructed with the objective of determining chemical and physical factors that affect ash agglomeration, and seven different coals were tested. Only a few of the tests using coal resulted in the formation of satisfactory agglomerates. However, these tests were useful in determining the limits of the parameters for successful operation with a Pittsburgh seam coal.

Table 5 summarizes laboratory support activities.

Commercial-Scale Fluidization Simulator (CFSF)

The CFSF located at Waltz Mill, Pennsylvania, is shown in Figure 3. The test facility is a vessel with a semicircular cross-section and a 10-foot inside diameter. Transparent Plexiglas plates at the front (flat side) and transparent windows at the back (circumferential side) allow direct viewing of the bed fluidization characteristics. Various fluidization regimes and hardware configurations can be simulated. There is also provision for continuous solid fines recycle back into the bed. The model can be operated continuously with solids feed and withdrawal.

CFSF Results

The CFSF became fully operational in late 1980 and was used to verify critical hydrodynamic phenomena developed from smaller laboratory-scale units. Jet behavior, solids circulation, and other phenomena within the bed are clearly observed through the front face.

The CFSF tests that have been conducted include series of shakedown tests, to check out components, instruments, utilities and to calibrate each process subsystem, and system operability tests to evaluate bed velocity profiles and bed materials separation.

Experimental data on jet penetration depth, bubble diameter, and bubble frequency obtained at the CFSF during the test program were compared with the different correlations available in the literature and those developed by Westinghouse.

The data on jet penetration depth obtained at the CFSF are correlated within plus or minus 25 percent by Yang (Reference 9). Other popular correlations available in the literature show errors of more than 100 percent.

These results provide confidence in the use of the CFSF as a preferred method of reducing scale-up risk. A summary of CFSF activities is given in Table 6.

PROJECT STATUS

Commercial-Scale Design

The technology programs outlined above have brought the Westinghouse process to the point of being ready for a commercial-scale demonstration. The PDU has shown the basic process is successful, and scale-up efforts have produced a design basis for the commercial-scale unit. Detailed mechanical design is under way for a demonstration facility. Technology programs to reduce risk, improve process efficiency, and optimize component design are proceeding in parallel with the demonstration design.

The Westinghouse process has several inherent advantages. In the Westinghouse fluidized bed, virtually any coal can be processed; caking or noncaking, high or low ash, high or low sulfur, reactive or nonreactive, lignite through bituminous. Other second generation processes, such as the high temperature entrained bed and the slagging moving bed, have limited application. They are not able to effectively handle many coals; for example, those having high moisture, excess fines, or undesirable caking or ash fusion properties. The Westinghouse process has modest steam requirements when compared to both fixed and entrained beds. This results in a low product gas cost.

The reactor itself is a carbon steel pressure vessel. It is lined with refractories commonly used in intermediate temperature (1800°F) processes. The coal storage bins also employ standard valves and other components in an arrangement that have been tested through thousands of cycles at the

Westinghouse facilties. Also, the gasifier operates at moderate temperatures when compared to the entrained or slagging gasifiers. Here, the Westinghouse gasifier has the advantage of less materials selection problems, an extended refractory life, and more efficient operation because less carbon is combusted to produce the heat required for gasification. The Westinghouse gasifier has an advantage over low temperature fixed bed gasifiers, such as moving dry ash gasifiers, because the fluidized bed operates at a temperature above which most toxic phenols, tars and oils are produced. This avoids the in-plant toxicity hazard and a loss in efficiency because of tar-oil cleanup systems.

The ash is depressurized and collected as a dry, granular, and environmentally benign material, rather than as a slag that can quickly develop into hot-spot deposit growths and plug the ash outlets, causing severe operational problems. Other gasification systems must deal with hot ash systems that are water quenched and handled as a slurry. Finally, fluidized bed operation, with its large inventory of carbon, is inherently more stable and easier to control than entrained bed operation, yet responds readily to process load demand changes and can readily be operated at partial load conditions.

In addition to the commercial-scale design, detailed feasibilty studies are under way for three other commercial applications: Keystone coal-to-methanol project, Gulf States Utilities medium-Btu gas project, and Fiat-Ansaldo low-Btu project. Each of these projects is reviewed below.

Keystone Project

The Keystone project is being evaluated through a feasibilty study funded by the Department of Energy. Westinghouse Synthetic Fuels Division, Davy-McKee Corporation, Air Products and Chemicals, Inc., AmeriGas, Inc., Dravo Engineers and Constructors, Bethlehem Steel Corporation, Energy Impact Associates, Johnstown Area Regional Industries, and Lehman Brothers Kuhn Loeb, Inc., are participating in the evaluation.

Most methanol today is produced from reacting natural gas with steam in the presence of a catalyst. This produces a syngas containing carbon monoxide and hydrogen, which is then converted to methanol. In the Keystone plant, the syngas will be produced by the gasification of coal in a facility containing two parallel Westinghouse systems.

Most of the gasification system features of the Keystone project are directly applicable to substitute natural gas (SNG) production. The only significant difference between a coal-based methanol plant and a coal-based SNG plant is the final processing step; to make SNG, the syngas would be fed to a methanation unit rather than to methanol synthesis and purification units.

Process Description

The Keystone project will produce fuel-grade methanol from coal at a site near Cairnbrook, Pennsylvania, in Somerset County. Elemental sulfur and liquid anhydrous ammonia will be recovered as plant by-products. Part of the carbon dioxide removed from the gasification system will be recovered and sold for food processing and enhanced oil well recovery applications.

The ultimate plant capacity will be determined by the market growth for methanol. Additional capacity will be added in a modular fashion as demand increases. The first module will produce approximately 13,000 barrels per day of methanol from 2300 tons per day of local, run-of-mine, high sulfur coal. Site selection is based on an ultimate capacity of about 65,000 barrels per day.

Figure 4 shows the units that make up the Keystone facility.

For the first module, coal can be most economically delivered by truck. The coal being used has a sulfur content that makes it unattractive for steam coal markets. The ash level chosen is high enough that beneficiation is not needed for the incoming coal. Sufficient coal meeting these specifications is available within a 20-mile radius of the plant. Table 7 shows the average coal properties.

Two parallel gasification trains operating at 500 psi were chosen for the first module. Scale-up risks will be mitigated by the operating data from the commercial-scale demonstration gasifier, which will commence startup one to one and a half years before startup of the Keystone module.

The ratio of hydrogen to carbon monoxide in the reactor product must be adjusted to approximately 2.4:1 before being fed to the methanol unit. (For an SNG application, the required ratio would be about 3.2:1.) The adjustment is done by adding steam to the product gas and passing it through a shift conversion unit.

The quench system is followed by a Selexol acid gas removal system to remove carbon dioxide and sulfur impurities to below 10 ppm in the syngas. Two streams exit the Selexol unit. The first stream contains nearly all of the sulfur and is concentrated enough to feed a Claus-type sulfur recovery unit. The second is mainly CO_2, with less than 10 ppm sulfur impurities, and serves as feed to a CO_2 recovery unit. The sulfur is recovered in the elemental form and will be shipped in the molten form. The methanol synthesis unit uses ICI low pressure technology and will produce a product targeted for fuel use.

The startup for the Keystone project is scheduled to commence early in 1986, with full-commercial production achieved by the beginning of 1987. Figure 5 presents the schedule for the project.

Gulf States Utilities Project

Westinghouse, with support from the U.S. Department of Energy, has begun a multiphase program to evaluate the feasibility of applying coal gasification to a Gulf States Utilities Company combustion turbine power plant in Lake Charles, Louisiana.

Concurrent with the construction and installation of a Westinghouse W501D combustion turbine generator (nominal rating 100 MW) at this site is the Phase I engineering, economic, and environmental impact evaluations of using medium-Btu gas from two coal gasification modules to fuel this turbine. The preliminary design will be complete in mid-1983, and the proposed gasification plant should be ready for integration with the combustion turbine by 1987.

The participants in the project include: Gulf States Utilities Company, owner and operator of the Roy S. Nelson Power Station in Lake Charles; Stone and Webster Engineering Corporation; Dravo Engineers and Constructors; Energy Impact Associates; and Arthur Andersen and Company.

The GSU project has important implications for SNG plants, as it will be oxygen-blown and will process a reactive coal such as those found in large amounts in the western United States. Development of an SNG plant processing western coal could draw on Westinghouse experience with the GSU project.

Fiat and Ansaldo Project

Fiat TTG and Ansaldo, a subsidiary of IRI Finnecannica, in cooperation with the European Economic Community and ENEL, the Italian state utility, have undertaken a multiphase program for the design and demonstration of a 140-MW coal gasification combined cycle plant. Fiat and Ansaldo have awarded the Westinghouse Synthetic Fuels Division a contract for the first phase of the project, which includes a preliminary design study defining the technical and economic parameters of the low-Btu coal gasification system. This preliminary design will be finished during the first quarter of 1983, and the proposed plant could be ready for startup as early as 1986. This gasifier is air-blown and is being designed to handle coals of widely varying conditions.

The Fiat, Ansaldo and Westinghouse team is the first to have been awarded funding by the European Economic Community for this type of project.

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TABLE 1

PDU TEST ACTIVITY SUMMARY

Activity	Period	Function
PDU construction startup	1973-1975	Design/construction
Air-blown devolatilizer operations	1976	Operability and performance characterization at 225 psig
Air-blown gasifier operations	1977	Operability tests with coke breeze and char at 225 psig
Air-blown gasifier operations	1978	Initial coal testing
Oxygen-blown gasifier operations	1978	Operability and feedstock characterization at 130 psig
Air-blown gasifier operations	1979	Integrated two-stage operability testing at 130 psig
Oxygen-blown gasifier operations	1979	Operability and feedstock characterization at 130 psig
Oxygen-blown gasifier operations	1980-1981	Process data base and feedstock characterization at 230 psig
Remaining test activity		Complete transient/turndown performance, process data base, and environmental data at 130-230 psig

TABLE 2

FEEDSTOCKS PROCESSED IN WESTINGHOUSE GASIFIER

Lignite:	Texas lignite
Subbituminous coals:	Wyoming Wyodak, Montana Rosebud, Bosjesspruit
Bituminous coals:	Pittsburgh No. 8, Indiana No. 7, West Virginia, Illinois No. 6, Ohio No. 9, Upper Freeport No. 8
Chars:	Metallurgical coke breeze, petroleum cokes, FMC (COED) char, devolatilizer chars

TABLE 3

COAL GASIFICATION PILOT PLANT FEEDSTOCK PROPERTIES

Heating value, as received (Btu/lb)	7300 - 12700
Ash content (%)	0.5 - 22
Ash deformation temperature (°F)	1970 - 2520
Moisture (%)	3 - 24
Geiseler plasticity (dial division/minute)	0 - 28000
Free swelling index	0 - 9

TABLE 4

PROCESS ADVANTAGES DEMONSTRATED BY PDU OPERATION

- Processing of a wide variety of feedstocks (14) without pretreatment
- Effective automatic control of ash removal with no clinkering or sintering
- Simple, controllable process - automatic control of freeboard temperature, alternate startup with oxygen in lieu of air, and capable of handling transient upsets
- Safe, reliable process with air or oxygen at 130 psig and 230 psig
- Low steam demand and low oxygen demand
- Virtually no tars or oils in product gas
- High thermal efficiency, including operation with heat recovery
- High carbon conversion - greater than 90 percent with two stage fines recycle
- Minimum environmental impact - disposable ash, minimal waste water treatment, and low air pollutant emissions

TABLE 5

LABORATORY SUPPORT ACTIVITIES

- Cold flow models
  - Fluidized bed dynamics
  - Jet penetration
  - Solids circulation

- Bench-scale gasification
  - Gasification kinetics
  - Devolatilization kinetics
  - Feedstock reactivity

- Bench-scale ash agglomeration

- Coal and ash chemical phenomena
  - Relationships of coal and ash composition and operational performance
  - Ash leaching tests

TABLE 6

CFSF SUPPORT ACTIVITIES

Cold Flow Model - 10 Foot ID

- Fluidized bed dynamics
- Jet penetration
- Bubble characteristics
- Solids circulation
- Single vs. multitube feeders

TABLE 7

KEYSTONE DESIGN BASIS COAL

Proximate Analysis	Design Basis
Volatile matter (%)	19.09
Fixed carbon (%)	61.91
Ash (%)	14.00
Moisture (%)	5.00*

Ultimate Analysis**	Design Basis
Carbon (%)	85.35
Hydrogen (%)	4.93
Oxygen (%)	3.83
Nitrogen (%)	1.30
Sulfur (%)	4.52
Chlorine (%)	0.07

Heating value: 12,300 Btu/lb
Ash fusion: 2420°F - softening
Free swelling index: 8.5
Hardgrove grindability index: 95

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* Total moisture. Comprised of 4% surface moisture and 1% inherent moisture.

** Dry, ash-free basis.

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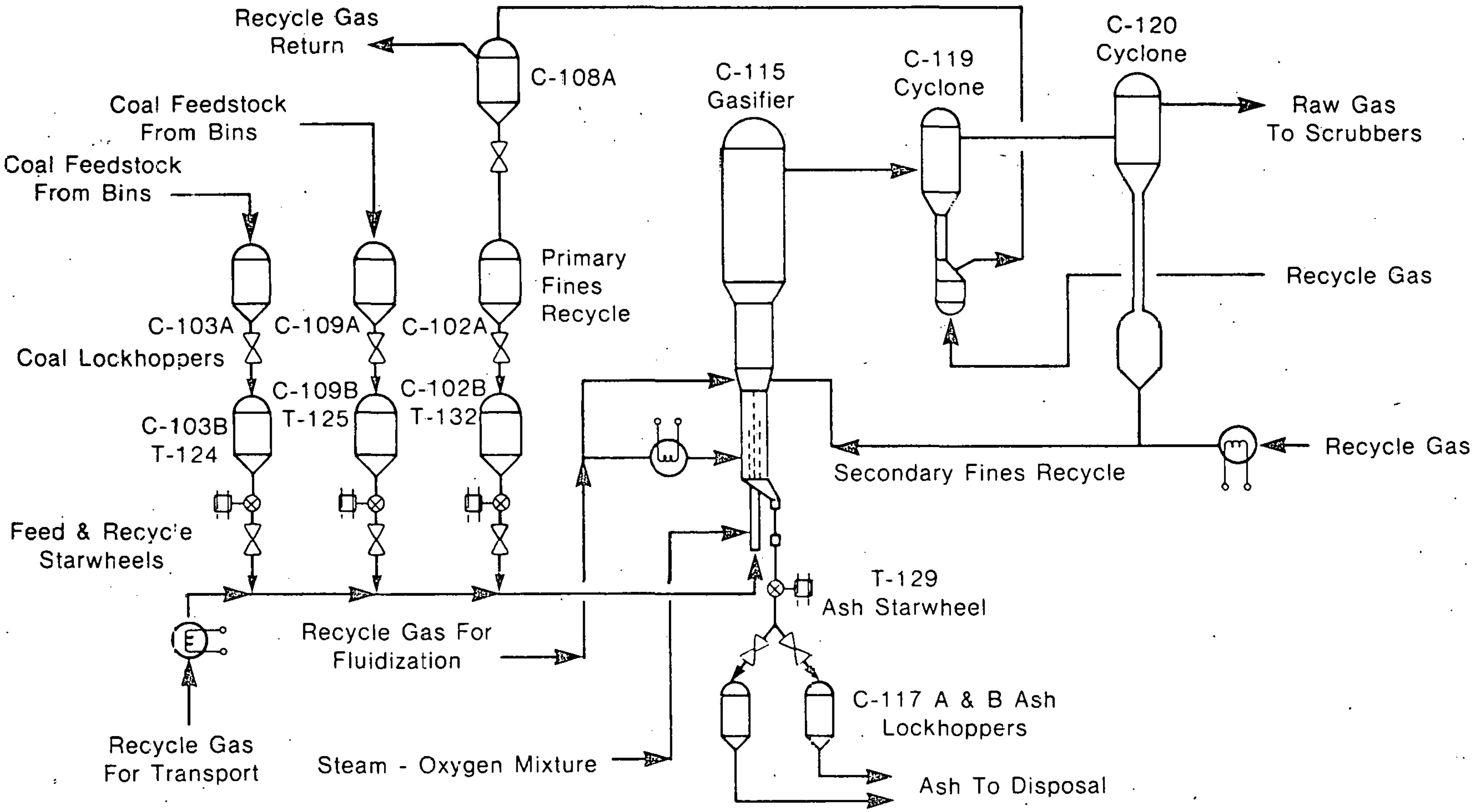

Figure 1. Westinghouse Coal Gasification PDU Schematic

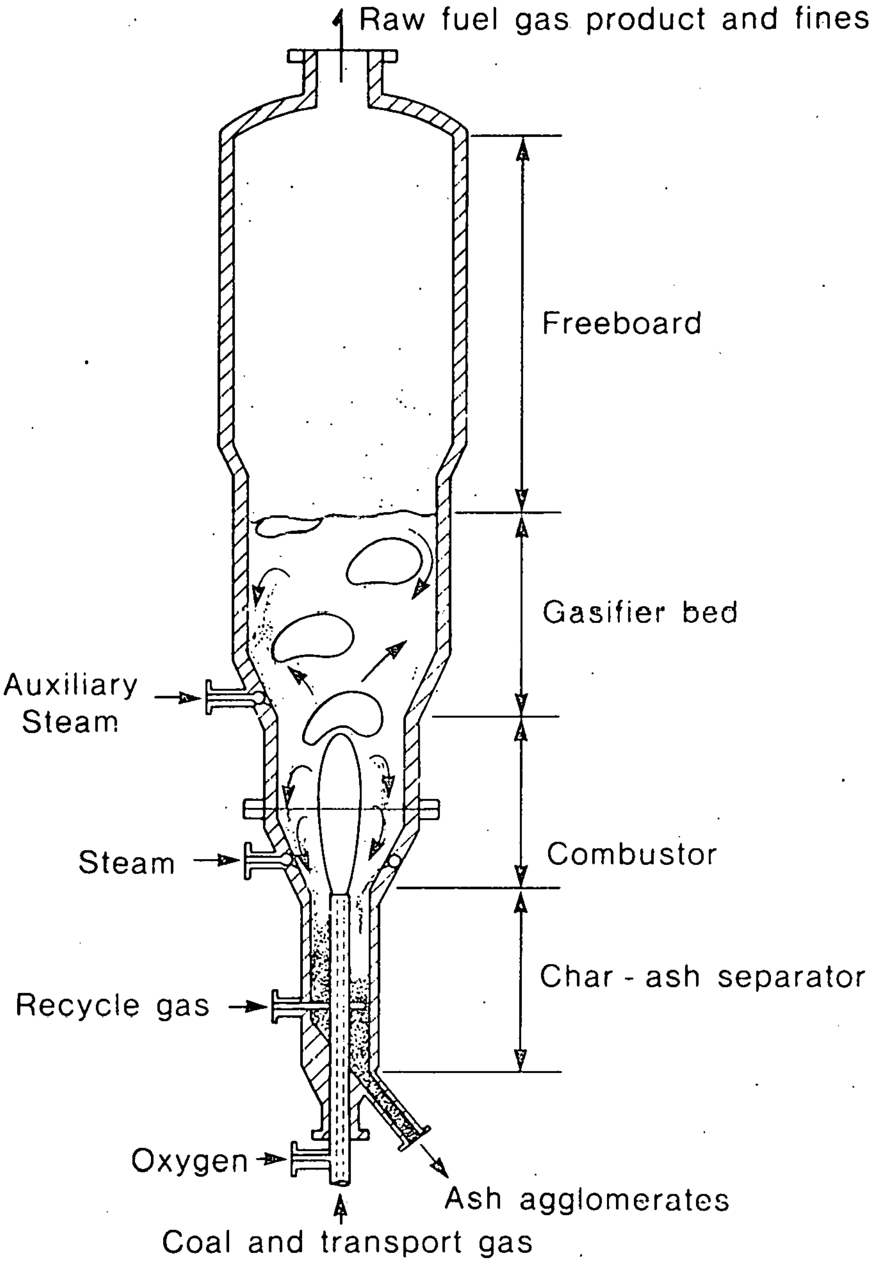

Figure 2. Functional Schematic of the Westinghouse Gasifier

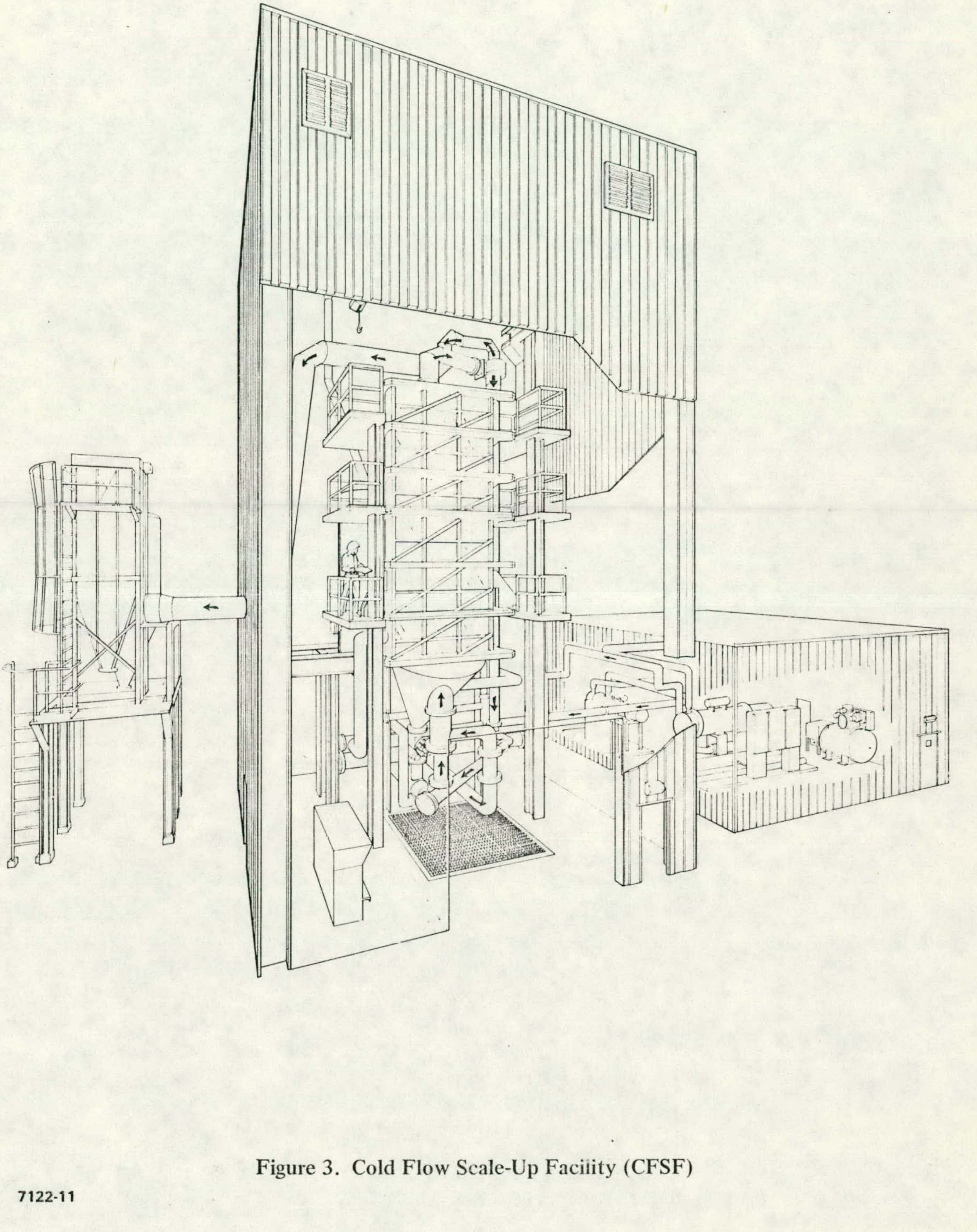

Figure 3. Cold Flow Scale-Up Facility (CFSF)

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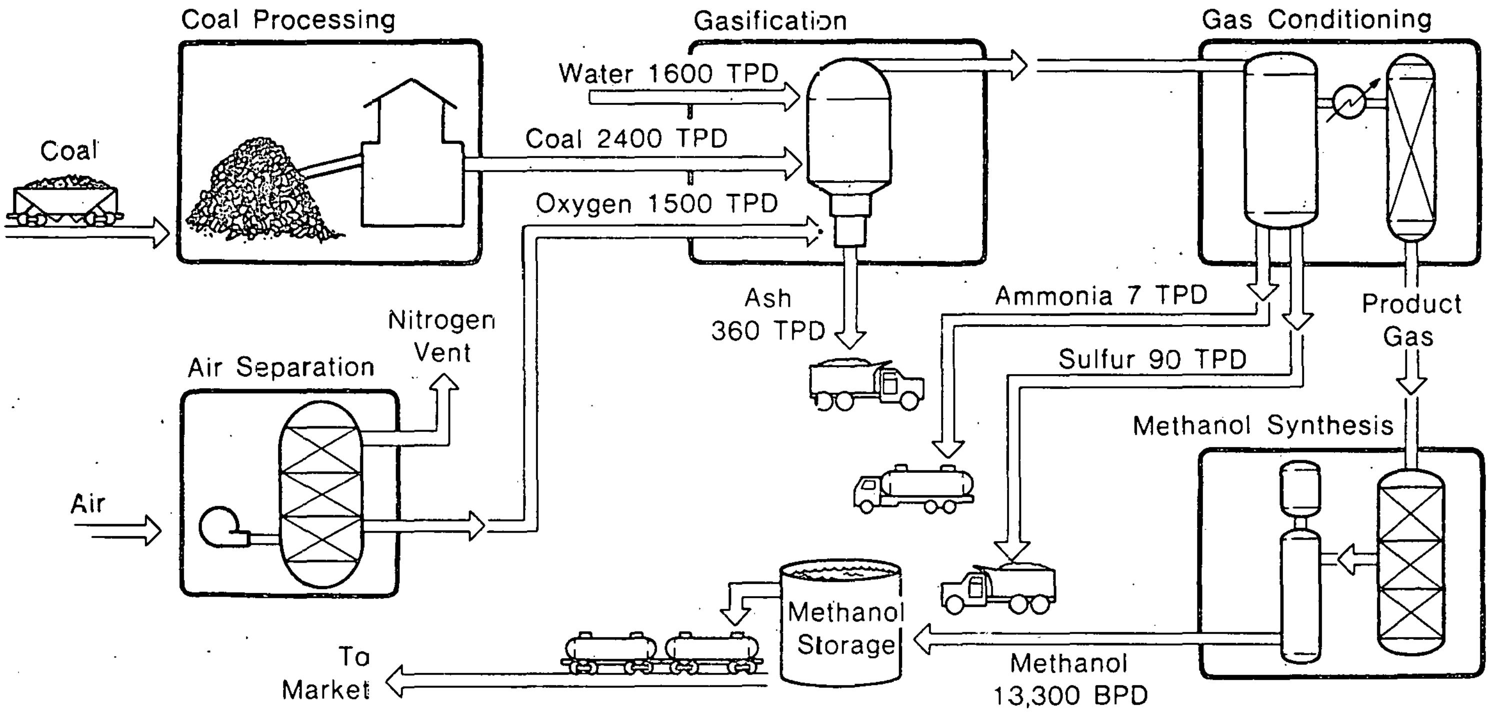

Figure 4. Keystone Commercial Prototype Module

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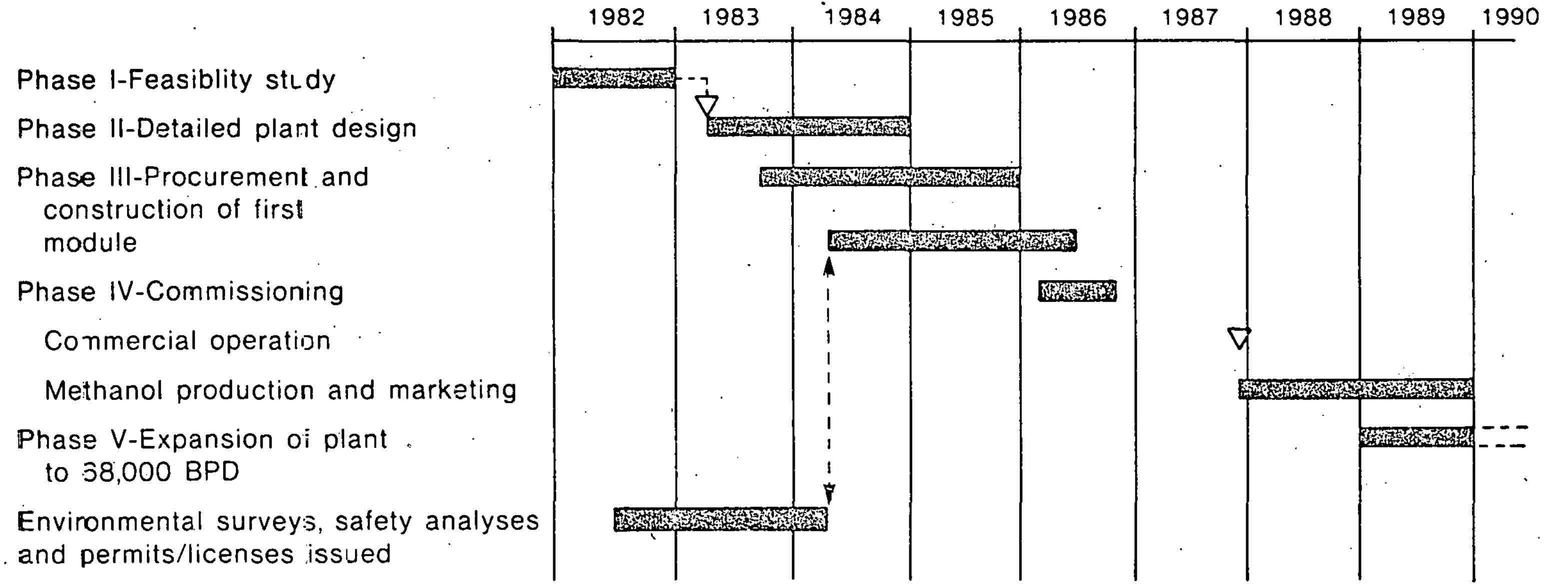

Figure 5. Keystone Project Schedule and Milestones