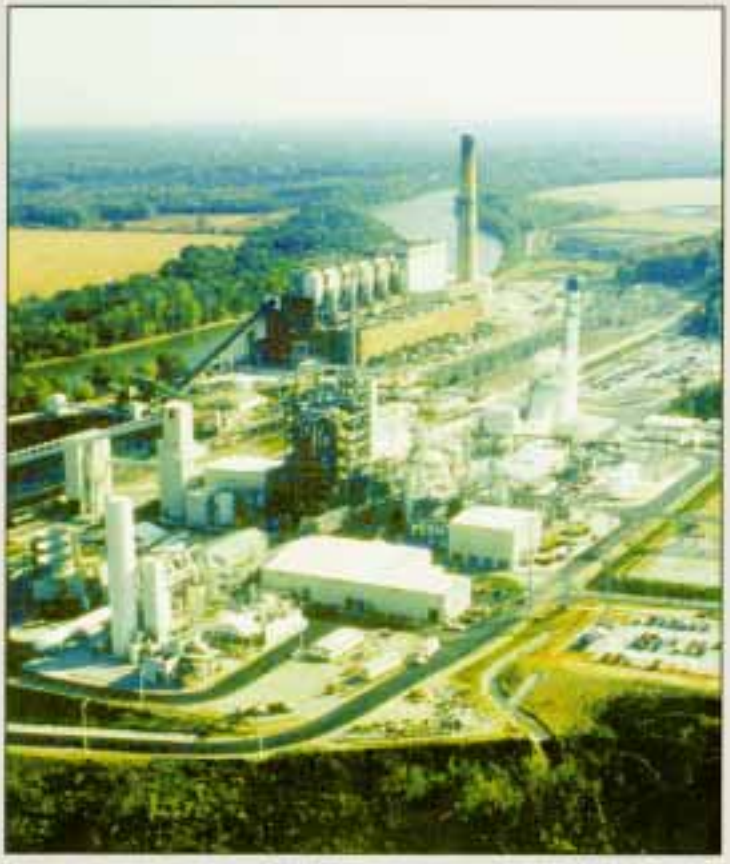
TOPICAL REPORT NUMBER 7

NOVEMBER 1996

CLEAN COAL TECHNOLOGY



The Wabash River Coal Gasification Repowering Project

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A 262 MWe Commercial Scale Integrated Gasification Combined Cycle Power Plant

A report on a project conducted jointly under a cooperative agreement between:

The United States Department of Energy
and Wabash River Coal Gasification Project Joint Venture

Cover Image: View of the Wabash River Coal Gasification Repowering project with the Wabash River and the flat terrain of west central Indiana in the background.

Preparation and printing of this document conforms to the general funding provisions of a cooperative agreement between Destec Energy Inc., PSI Energy, Inc., and the U.S. Department of Energy. The funding contribution of the industrial participant permitted inclusion of multicolored artwork and photographs at no additional expense to the U.S. Government.

CLEAN COAL TECHNOLOGY

The Wabash River Coal Gasification Repowering Project

Introduction and Executive Summary

Coal is America's most abundant fossil fuel. Its combustion creates the steam that produces 65 percent of this country's electricity. The burning of coal, however, liberates two types of gases that have been linked to the formation of acid rain: nitrogen oxides (NO_X) and sulfur dioxide (SO_2).

With the passage of each successive piece of clean air legislation over the years, the electric utility industry has been made increasingly aware that it would eventually have to reduce both types of emissions from existing and new power plants to environmentally acceptable levels.

The Clean Coal Technology (CCT) Demonstration Program is a government and industry co-funded program to furnish the U.S. energy marketplace with advanced, more efficient and environmentally responsible coal-utilizing technologies.

A multi-phased effort consisting of five separate solicitations was administered by the U.S. Department of Energy (DOE). Projects selected are a new generation of innovative coal utilization processes that are being demonstrated in "showcase" projects conducted across the country.

These projects are on a scale sufficiently large to demonstrate commercial worthiness and generate data for design, construction, operation and technical/economic evaluation of full-scale commercial applications.

Integrated Gasification Combined Cycle

Among the technologies being demonstrated in the CCT program is Integrated Gasification Combined Cycle (IGCC). IGCC is an innovative electric power generation technology that combines modern coal gasification with gas turbine and steam power generation technologies. Fuel gas produced by a gasifier is cleaned and burned in a gas turbine to produce electric power. Heat recovered from the hot turbine's exhaust produces steam that turns a steam turbine generator to produce more electricity.

IGCC power plants are environmentally acceptable and easily sited. Atmospheric emissions of pollutants are low. Water use is lower than conventional coal-based generation because gas turbine units require no cooling water, an especially important consideration in areas of limited water resources.

Due to their high efficiency, less coal is used per megawatt-hour of output, causing IGCC power plants to emit less carbon dioxide (CO_2) to the atmosphere, thereby decreasing global warming concerns. Less coal use also reduces disposal requirements for ash or slag if there is no market for these materials.

Repowering is an excellent application for IGCC. Such applications utilize an existing power plant site and are more economical than greenfield applications. Costs are lower because an existing steam turbine is used, less site development is required, and the permitting process is accelerated.

Both greenfield and repowering IGCC could provide the flexibility needed for utility compliance planning for SO_2 emissions in the next century. Providing 25 percent of coal-based electricity by IGCC would result in emissions of less than 0.4 million of the 11.8 million tons/yr of SO_2 allowable under the Clean Air Act Amendments (CAAA).

Modularity and fuel flexibility are other important attributes of IGCC power plants. Before the gasifier is constructed, the combined cycle unit can be operated on other fuels, such as natural gas or fuel oil, to provide early power. The size of gas turbine units can be chosen to meet specific power requirements. The ability to operate on multiple fuels allows continued operation of the gas turbine unit if the gasifier island is shut down for maintenance or repairs, or if warranted by fuel costs.

IGCC power plants use plentiful and relatively inexpensive coal as their fuel. In the United States there are several hundred years of reserves, and use of coal helps to reduce dependence on foreign oil.

IGCC has potential for significant reduction in capital costs over today's technologies, per kW of generation. These, in part, arise from higher possible efficiencies compared to today's impressive IGCC values.

Efficiency improvements are expected to result from design improvements which increase overall steam and thermal integration, use of higher firing temperature gas turbines, and other technology enhancements such as hot-gas cleanup. Other contributors to reduced capital costs are: economies of scale, reduced engineering costs, and improvements resulting from operating experience.

IGCC Advantages

- A Clean Environment
- High Efficiency
- Low Cost Electricity
- Potential for Low Capital Costs
- Repowering of Existing Plants
- Modularity
- Fuel Flexibility
- Phased Construction
- Low Water Use
- Low CO_2 Emissions
- Public Acceptability

Executive Summary

The Wabash River Coal Gasification Repowering Project (the Project) was selected in September 1991 by DOE as a CCT Program Round IV demonstration project. Demonstration of this advanced IGCC power plant was initiated in December, 1995.

The Participant is Wabash River Coal Gasification Repowering Project Joint Venture, formed in 1990 by Destec Energy Inc. (Destec), of Houston, Texas and PSI Energy, Inc. (PSI), of Plainfield, Indiana. They formed this joint venture to demonstrate coal gasification repowering of an existing PSI generating unit. The Cooperative Agreement with the DOE was signed in July 1992.

The Project is located at PSI's Wabash River Generating Station near West Terre Haute, Indiana. It is demonstrating utility repowering with a Destec two-stage, oxygen-blown gasification system, including advancements in the technology relevant to the use of high-sulfur bituminous coal.

The Project demonstrates the integration of Destec's gasification process with a combined cycle unit based on an advanced General Electric gas turbine generator to repower a refurbished steam turbine generator. Now in commercial operation, the Project is the world's largest single-train IGCC power plant. Local Indiana high-sulfur coal is processed to produce 262 MWe (net) of clean, low-cost, energy efficient baseload capacity.

A Destec gasifier in this IGCC power plant converts coal to a synthetic fuel gas that is cleaned of impurities and burned in a combined cycle unit to produce electricity. At least 98 percent of sulfur contaminants are removed. Sulfur is recovered and sold, as is the slag by-product of gasification. Emissions are lower than from conventional power plants operating on high sulfur coal.

The efficiency of the Wabash River IGCC power plant is a 20 percent improvement over the pre-project derated condition of the repowered steam turbine. This facility has the lowest capital cost in terms of $/kW of all past and current IGCC demonstration plants.

Due to the high gasifier operating temperature, only a single gasifier is needed to process the 2544 tons of coal per day required for the Wabash River Coal Gasification Repowering Project.

The repowered power plant is designed to be efficient, with a heat rate of about 9030 Btu/kWh (37.8 percent efficiency), higher heating value basis. The capital cost, including startup costs, is $417 million, or about $1585/kW.

The demonstration period began in December 1995, when the facility satisfied performance requirements specified by the lending institution and the commercial agreement between the Participants. Detailed performance, operating and maintenance data will be gathered during the three-year test period to demonstrate the effectiveness and economic viability of the technology in a commercial utility environment.

For its role in hosting, funding, and operating this "next-millenium" power plant, PSI, Destec and DOE were awarded *Power* magazine's 1996 Powerplant award.

The Wabash River Coal Gasification Repowering Project

Background

Coal gasification has been used worldide for many years. Primitive coal gasification provided town gas more than 100 years ago, and a gasification industry produced coal-based transportation fuels for Germany in World War 11.

Today, in Tennessee, a U.S. gasification technology proven in a CCT Round I program is used for methanol production. The Dakota Gasification plant in North Dakota produces synthetic natural gas and chemicals based on an advanced German gasification technology. Overseas, a major chemical and transportation fuel industry exists in The Republic of South Africa, mostly based upon advanced German gasification technologies. And an IGCC power plant is operation in The Netherlands.

Advanced gasification and IGCC technology development began in the U.S. about 25 years ago, the stimuli being the desire for: (1) development of a coal-based replacement for natural gas and oil due to shortages and price increases; and (2) more efficient, clean, coal-based power plants.

Modem IGCC technology is a response of U.S. government and industry to these needs. Such systems use advanced pressurized coal gasifiers to produce a fuel for gas turbine-based electric power generation; the hot gas turbine exhaust produces steam to generate additional electricity.

The Dow Chemical Company initiated development of its coal gasification technology in the early 1970s when it sought a low cost replacement for natural gas fuel for gas turbine generator units at its chlor alkali plants. After a development program involving several pilot plants, the 2400 ton

per day Louisiana Gasification Technology, Inc.(LGTI) facility was built at Dow's Plaquemine, Louisiana plant. Ownership of the technology and LGTI was transferred from Dow when Destec was formed by Dow in 1989. The facility was operated for about eight years and accumulated about 34,000 hours of operating experience.

Gas turbines for power generation have been one of the consequences of jet aircraft engine development. They have been increasingly used by electric utilities and by the end of 1994, gas turbines contributed about 12 percent (59,600 MWe) to the fossil fuel-based generating capability of U.S. electric utilities.

The Wabash River lGCC power plant. The gas cleanup system is on the left and the combustion turbine/HRSG unit is in the center. The Wabash River coal-steam plant is in the background by the Wabash River; repowered Unit 1 is on the left.

Gas turbine and combined cycle generation capability in the U.S. increased by 23 percent over the period 1990-1994 even though the total fossil-based generation capability increased by only one percent.

This increasing use is due to technology advances, relatively low cost per kW and shorter construction time than conventional generation. Advances in design and materials have led to major increases in the size and performance capability of gas turbine units.

Today's IGCC is efficient because of major improvements in coal gasification, gas cleanup, and gas turbine technologies—plus a high degree of system integration that efficiently recovers and uses waste heat. Atmospheric emissions are low due to availability of proven technologies for highly effective removal of sulfur and other contaminants from the fuel gas. Advancements demonstrated in the CCT program are expected to result in still better performance.

Participant

The Participant with DOE in this project is Wabash River Coal Gasification Project Joint Venture. Destec Energy, Inc. and PSI Energy, Inc. (PSI) are the partners in this joint venture. They have completed a Gasification Services Agreement that contains the commercial terms for development and operation of the Project. PSI, the host utility, is responsible for financing, constructing, and operating the power block and Destec for financing, constructing, and operating the gasification facility.

PSI is an investor owned utility whose service area covers 69 of the 92 counties

in Indiana. With Cincinnati Gas & Electric Company, it is owned by CINergy Corp. which was formed in October 1994. CINergy is one of the twenty largest electric utilities in the U.S. PSI is participating in this Project because it wants to demonstrate an alternative technology for new units and repowering of existing units.

Destec is a major independent power company that owns power generation and coal gasification facilities which produce, sell and market electricity, steam and synthetic fuel gas worldwide. Destec has operating and/or equity participation in over 5000 MWe of electric generation, much of which was developed and constructed by Destec. Dow formed and has a majority interest in Destec.

Destec is participating in the Project because it wants to enhance the competitive position of its gasification technology. It wishes to verify performance expectations and gain information about capital and operating costs. It seeks to obtain the data base and experience necessary to meet commercial markets for this technology.

Together, PSI and Destec seek to optimize the cost-effectiveness of the overall system including individual system elements. They seek to optimize operating, maintenance, and management disciplines, and otherwise advance the technology.

Gasification Services Agreement Provisions

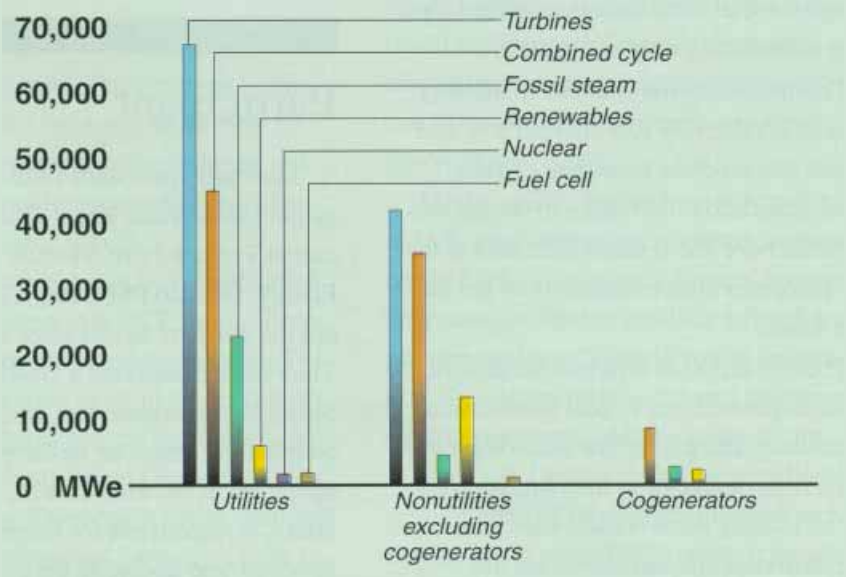
PSI:

- Build, own and operate the power generation facility
- Furnish Destec with a site, coal, electric power, storm water and wastewater facilities, and other utilities and services
- Pay a monthly fee to Destec for gasification services

Destec:

- Build, own and operate the coal gasification facility
- Guarantee operating and environmental performance
- Deliver syngas and steam to the power generation facility

New Generating Capacity Forecast 1994-2015



DOE projects that over the period 1994-2015, gas turbine and combined-cycle based generation will be 78 percent (197,000 MWe) of the total new capacity additions of utility plus non-utility generators (252,000 Me).

Source: U.S. Energy Information Administration, 1996

IGCC power plant. The Destec gasifier structure, gas cleanup system, and sulfur recovery plant are on the left. Gas turbine auxiliary fuel tanks are in the center. Right center is the GE MS 7001FA gas turbine and HRSG. The pipe rack exiting the HRSG passes under the bridge to the building containing the repowered steam turbine.

Project Description

This Project is demonstrating integration of Destec's gasification process with a GE model MS 7001FA gas turbine generator, a heat recovery steam generator (HRSG), and the refurbished Unit 1 (of 6) steam turbine generator of the Wabash River Generating Station.

This IGCC power plant is expected to function as a substantial element of PSI's plan to comply with the Clean Air Act Amendments of 1990 (CAAA) with sulfur dioxide (SO_2) emissions as low as 0.02 lb/million Btu of fuel. Emissions are expected to be less than the CAAA Phase II limits for the year 2000. The efficiency of the repowered unit is expected to be about 20 percent better than its pre-project derated condition.

Due to the anticipated low cost of electricity, CINergy plans to dispatch the output of the Wabash River Coal Gasification Repowering Project second behind its hydro facilities.

The electric utility industry will benefit from expected future improvements in the Project technology. Experience gained and improvements realized from this and future projects will result in still better power plant efficiency and lower operating and maintenance costs. A proven power plant technology will be available that is highly efficient, reliable, environmentally acceptable and cost effective.

Consumers and society will benefit through low cost electricity and reduced reliance on foreign energy sources. The environment will benefit through low emissions of atmospheric pollutants and reduced emissions of greenhouse gases.

Destec will benefit as owner of the gasification technology and potential owner/operator of all or part of future Destec-based IGCC power plants.

Project Team

Combined Cycle Facility

Project Management	PSI Energy, Inc.
Engineer	Sargent & Lund
Construction Management	PSI Energy, Inc.
Gas Turbine Vendor	General Electric Company
HRSG Vendor	Foster Wheeler Energy Corp.

Gasification Facility

Project Management	Destec Engineering, Inc.
Engineer	Dow Engineering Co.
Construction Management	Destec Engineering, Inc.
Gasification Vessel Vendor	Nooter Corp.
Syngas Cooler Vendor	Deutsche Babcock-Borsig
Air Separation Unit Vendor	Liquid Air Engineering Corp.

Wabash River gasifier/combustion turbine/HRSG train during construction. The pipe rack, foreground, connects to the repowered steam turbine Unit 1.

Project Subcontractors

Sargent & Lundy provided engineering services to PSI for the design and procurement of modifications to the existing station, the new power block equipment, and system integration interface to Destec. PSI managed the initial site work for both facilities, and the construction and startup of the power island block, including a water treatment facility, control building and coal handling system modifications.

Dow Engineering Company provided engineering services to Destec for the design and procurement of the gasification plant and the system integration interface to PSI. Destec developed the project, performed the process design work, and managed construction of gasification island facilities, including a control, administration and maintenance building and one of the largest air separation facilities in North America.

Site Description

The site is located in a predominantly rural area on the Wabash River near West Terre Haute, Vigo County, Indiana. PSI's Wabash River station was originally a mine mouth power plant, and much of the new facility is actually built over areas that were shaft mined earlier this century.

The area immediately surrounding the site includes the Wabash River to the east, woodlands and agricultural areas, a reclaimed strip mine and residential areas about 0.2 miles to the southwest and 1.5 miles to the north. The site is about eight miles north of downtown Terre Haute.

The new coal gasification repowering facilities are located immediately northwest of PSI's Wabash Generating Station on land donated by the Peabody Coal Company. The 15 acre plot containing the gasification island, air separation unit, water treatment facility, and gas turbine-HRSG tandem is on a hill overlooking the existing

IGCC Emissions are Substantially Less Than Pre-Repowering Values

Emissions, lb/Megawatt-hour	SO_2	NO_X	CO	PM	PM-10	VOC
Pre-Repowering Unit 1 Boiler	38.2	9.3	0.64	0.85	0.85	0.03
lGCC	0.21	0.75	0.47	0.07	0.06	0.02
Emissions, lb/Million Btu	**SO_2**	**NO_X**	**CO**	**PM**	**PM-10**	**VOC**
Pre-Repowering Unit 1 Boiler	3.1	0.8	0.05	0.07	0.07	0.003
lGCC	0.02	0.08	0.05	0.01	0.01	0.003

IGCC atmospheric emissions are lower than those from the pre-IGCC repowered boiler
The consequence is an improvement in air quality

station. New wastewater and storm water ponds are located nearby in an area previously used as an ash pond.

Environmental

Expected environmental impacts of the Project were analyzed by DOE according to National Environmental Policy Act (NEPA) requirements. PSI, Destec and two environmental consulting firms prepared a detailed environmental information volume which provided inputs to DOE's development of an Environmental Assessment for this Project. A favorable NEPA assessment resulted in DOE issuing a *Finding of No Significant Impact* in May 1993.

Required federal, state and local environmental permits and approvals have been obtained. A process and environmental monitoring program has been established in compliance with requirements.

The plant is designed to substantially outperform emission standards for the year 2000 established by the CAAA. The Destec gasification technology removes at least 98 percent of the sulfur in the coal. Compared to previous operation of the steam turbine, carbon dioxide (CO_2) emissions are reduced by approximately 20 percent on a per kilowatt-hour basis.

Even though power generation from the project is almost three times that of the original unit, emissions are reduced because of IGCC operation.

Coal Supply

The Wabash River IGCC Power Plant is designed to use a range of local coals with a maximum sulfur content of 5.9 percent (dry basis) and a higher heating value of over 13,500 l3tuAb (MAF). The coal selected for initial operation is a high sulfur midwestern bituminous from the number 6 seam at Peabody's Hawthorn Mine in Indiana. It is stored apart from

Coal Properties

Moisture	5-18%
Ash (as received)	5-15%
Sulfur (dry)	2.3-5.9%
Ash Fusion Temperature	1000-2500°F
Heating Value (MAF) (higher heating value basis)	Over 13,500 Btu/lb

Advanced Features of the Gasifier Island

- A single operating high throughput coal gasifier.
- Hot/dry particulate removal and recycle that enhances system efficiency.
- Production of steam in an HRSG at a pressure of 1,600 psia.
- Integration of the gasification facility with the HRSG to optimize efficiency and operating costs.
- Carbonyl sulfide hydrolysis, allowing a high level of sulfur removal.
- Recycle of waste water to minimize makeup water requirements.

the compliance coal burned in Units 2-6 of the existing station.

Alternative feedstocks may be tested for up to 60 days each year of the three-year demonstration period.

Review of Technology

The design of the Wabash River Coal Gasification Repowering Project gasifier is based on that of Destec's LGTI gasifier, which is similar in size and operating characteristics to the Project gasifier.

LGTI was operated for more than 34,000 hours from April 1987 through November 1995. Experience gained provided significant input to the design of the Wabash River coal gasification facility and eliminates much of the risk associated with scaleup and process variables.

A coal/water slurry feed is prepared and, with oxygen, fed to the first stage of the Destec gasifier. Partial combustion of the coal maintains a temperature of about 2500°F (1371°C). Most of the coal reacts chemically with steam to produce raw fuel gas; the ash melts and flows out of the bottom of the vessel as slag. Additional coal/water slurry added to the second gasification stage undergoes devolatilization, pyrolysis and partial gasification to cool the raw gas and enhance its heating value.

The raw gas is further cooled, with production of steam for power generation. Particles contained in the gas are removed by candle filters and recycled to the first stage for gasification of residual carbon. Only a single gasifier vessel is required to process the 2544 tons per day of coal required for operation of the IGCC power plant although two vessels, each of 100 percent capacity, have been installed.

The particle-free gas is further cooled to ambient temperature and at least 98 percent of sulfur contaminants are removed by a proven technology. High quality sulfur (over 99.9 percent pure) is recovered and sold for agricultural applications. The slag by-product of gasification can be used for applications such as road paving and roof shingles.

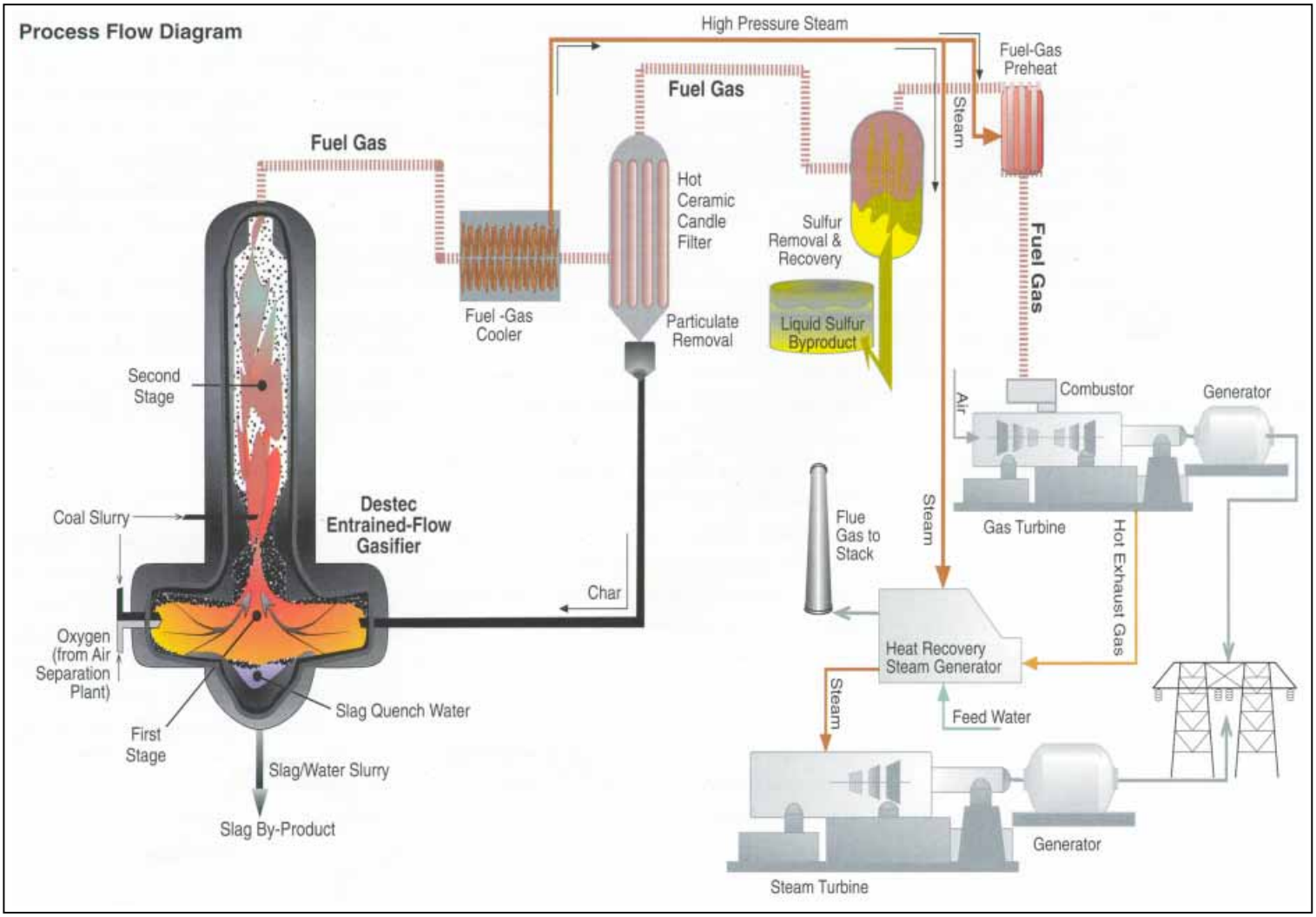
The heating value of the cleaned fuel gas is approximately 285 Btu/SCF (dry basis). The cleaned gas is moisturized to aid in control of NO_X emissions, heated and fed to General Electric's model MS 7001FA gas turbine where it is combusted. Gas turbine exhaust heat is recovered in an HRSG to produce steam for production of electricity. Flue gas is emitted to the atmosphere via a 225 foot stack.

(text continues on page 14)

Typical Operational Characteristics

Fuel Gas Burn Rate	442,000 lb/hr
Gas Turbine Output	192,000 kW
NO_X Control Steam	111,260 lb/hr
Exhaust Gas Rate	3,775,000 lb/hr
Exhaust Gas Temperature	1,100°F
Main Steam Flow	732,200 lb/hr
Reheat Steam Flow	560,000 lb/hr
Steam Turbine Generator Output	104,990 kW
Auxiliary Power	35,380 kW
Net Plant Output	261,610 kW
Net Plant Heat Rate, HHV	9030 Btu/kWh
Water Makeup	535 gpm

The gas cleanup system removes H_2S from the fuel gas; sulfur is recovered as a by-product and sold. Ammonia is also removed and recycled to the gasifier.



Process Description

Destec Coal Gasification

The Destec two-stage coal gasification technology features an oxygen-blown, entrained flow, continuous slagging, refractory lined gasifier. The first stage operates at about 2,500°F and 400 psia. The actual operating temperature depends upon the specific coal used. A 60/40 weight percent coal/water slurry is combined with oxygen and injected into the gasifier. The coal undergoes partial combustion, releasing heat that causes the coal gasification reactions to proceed very rapidly and the ash to melt and flow.

The molten ash exits through a taphole at the bottom of the first stage into a water quench, forming an inert vitreous slag. Oxygen of 95 percent purity is supplied by a turnkey, dedicated air separation unit.

The raw synthesis gas (syngas) flows upward into the second stage, a vertical refractory lined vessel, where added slurry reacts with the hot coal gas exiting the first stage; the coal devolatilizes, pyrolyzes and partly gasifies by reaction with steam.

In the second stage (1) the heating value of the syngas is increased, and (2) evaporation of water and endothermic (heat consuming) chemical reactions cause the temperature of the crude syngas to be reduced to about 1900°F (1038°C). Use of the second stage of gasification for both heating value enhancement and raw syngas cooling eliminates the need for a large, expensive radiant heat exchanger that would otherwise be required and creates a more efficient IGCC system.

Only a single gasifier is required to process the 2544 tons per day of coal re-quired for operation of the IGCC power plant, although two vessels, each of 100 percent capacity, have been installed.

The raw product gas exits the second-stage gasifier at 1900°F and is further cooled in parallel convection heat exchangers, producing high pressure (1600 psia) saturated steam.

Gas Cleanup

Gas cleanup equipment in an IGCC power plant is relatively inexpensive compared to flue gas cleanup in a conventional coal-steam power plant. Smaller equipment is required because a much smaller volume of gas is cleaned.

The gas volume is smaller because the coal gas is still pressurized before cleaning and subsequent combustion. In contrast, the volume of flue gas from a coal-steam power plant is greater because the fuel has been combusted at atmospheric pressure before the flue gas is cleaned.

Flyash and remaining char particles in the gas exiting the second stage are removed by a hot candle filter system and recycled to the first stage gasifier for gasification of residual carbon. Filter system operation was first tested at full scale at LGTI, and the design was advanced at the demonstration facility.

The "sour" gas leaving the particulate filter system consists mostly of hydrogen (H_2), carbon dioxide (CO_2), carbon monoxide (CO), water (H_2O), nitrogen (N_2), and smaller quantities of methane (CH_4), carbonyl sulfide (COS), hydrogen sulfide (H_2S), and ammonia (NH_3).

H_2S and COS are at concentrations of hundreds of parts per million, requiring a high level of their removal for the power plant to achieve the low design level of SO_2 emissions. H_2S is removed by an acid gas removal system; however, because COS is not readily removable it is first catalytically converted to H_2S in a hydrolysis unit.

The "sour" gas is cooled to about 100°F (38°C) before H_2S is removed. The cooling is accomplished by several heat exchangers where water in the syngas condenses; the condensate contains NH_3 and some of the H_2S and CO_2. The condensate is sent to water treatment.

The cooled syngas flows to the acid gas removal absorber column where H_2S is removed by a solvent, methyldiethanol amine (MDEA), to produce clean syngas. The solvent plus H_2S and some of the CO_2 flows to the H_2S stripper where the pressure is reduced and steam stripping removes the gases, which then flow to the sulfur recovery system. The "lean" amine is recycled.

Sulfur Recovery

In a series of catalytic stages, a Claus sulfur recovery unit converts H_2S removed from the fuel gas to sulfur. Part of the H_2S is burned in a thermal stage to produce SO_2 which reacts with the remaining H_2S to produce elemental sulfur and water. Unreacted H_2S is compressed and recycled to the gasifier, thereby retaining this sulfur compound within the system.

The particle-free gas is further cooled to near ambient temperature, and over 98 percent of sulfur contaminants are removed by conventional sulfur recovery technology. High quality sulfur (over 99.99 percent pure) is recovered and sold. The slag by-product of gasification is sold for agricultural and construction applications.

Water Treatment and Recycle

In the water treatment system, dissolved gaseous contaminants are removed. The CO_2 and H_2S are removed first and recycled to sulfur recovery; NH_3 (which is removed in a second column) is combined with the resultant water and recycled for coal/water slurry preparation. Excess water is treated and discharged to the pond for subsequent discharge to the river through the permitted discharge point.

Power Block

Key elements of the combined cycle power block are the General Electric MS 7001FA high-temperature gas turbine/generator, the heat recovery steam generator (HRSG), and the repowered steam turbine. The MS 7001FA is a dual-fuel machine (syngas for operations and No. 2 fuel oil for startup), capable of producing 192 MWe.

The advanced gas turbine technology incorporates redesigned air compressor and turbine stages, higher firing temperatures, and a higher pressure ratio. The HRSG is a single drum design capable of superheating 754,000lb/hr of high pressure steam at 1010°F 543°) and 600,820 lb/hr of reheat steam at 1010° (543°) when the gas turbine operates on syngas.

The repowered steam turbine unit No. 1, originally installed in 1952, was derated from 105 MWe to 90 MWe when a reduction in coal consumption was necessary to reduce stack emissions. The unit was refurbished to accept the increased steam flows and pressures associated with the combined cycle operation. Output has been restored to 105 MWe.

The auxiliary load for the Project is 35 MWe. This consists of power to operate the air separation unit, motors, pumps, and other electrical requirements.

The cleaned gas is moisturized to aid in control of NO_X emissions and fed to the gas turbine where it is combusted. Gas turbine exhaust heat is recovered to produce steam for production of electricity. Flue gas is emitted to the atmosphere via a 225 foot stack.

Typical Clean Syngas Composition

(After final moisturization—as delivered to gas turbine)

Component	Volume Percent
H_2	28
CO	38
CO_2	10
CH_4	1
N_2	1
H_2O	22
Sulfur compounds	100 ppmv
Higher heating value, dry	285 Btu/SCF
Lower heating value, dry	223 Btu/SCF

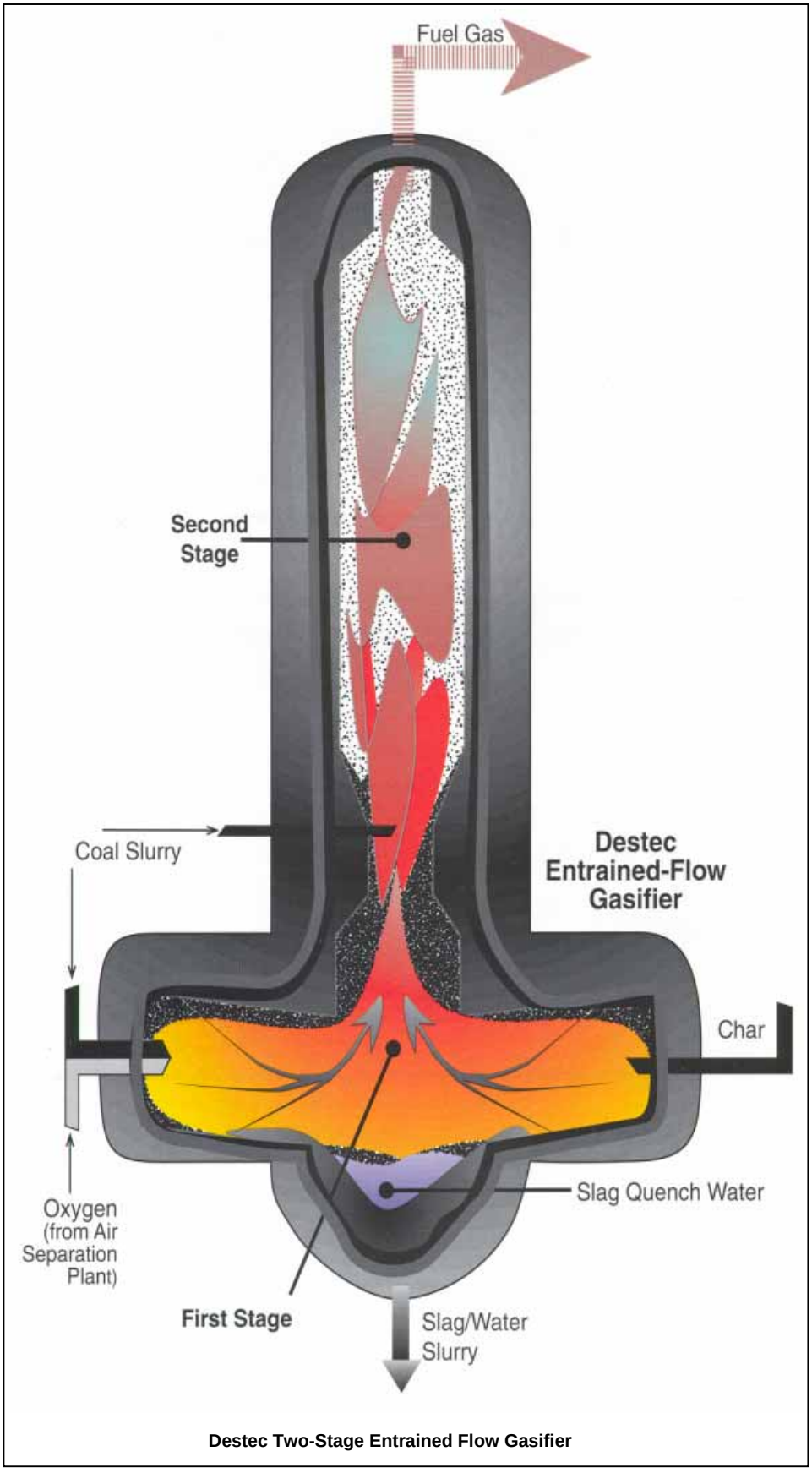
Simplified Destec Gasification Chemistry

First Stage

$$C\ (coal) + O_2 \rightarrow CO_2 + Heat$$
$$C\ (coal) + H_2O\ (steam) \rightarrow H_2 + CO$$
$$2S\ (coal) + H_2 + CO \rightarrow COS + H_2S$$

Second Stage

$$C\ (coal) + Heat \rightarrow \text{Cracked devolatilization products (CDP)}$$
$$CDP + H_2O \rightarrow H_2 + CO + CH_4$$
$$C(coal) + H_2O \rightarrow H_2 + CO$$
$$2S + H_2 + CO \rightarrow COS + H_2S$$



Destec Two-Stage Entrained Flow Gasifier

Project Efficiency and Cost

The repowered power plant is quite efficient, having a design heat rate of about 9030 Btu/kWh (37.8 percent efficiency), higher heating value basis.

The total cost for the Project is approximately $438 million, including escalation, environmental and permitting costs, startup costs, license fees and demonstration programs. Costs are equally shared by DOE and the joint venture. Repowering the Unit 1 steam turbine and reusing ancillaries from the existing plant has saved the Project about $30-$40 million.

Demonstration Project Costs

Demonstration Project Cost	$438.2 million
U.S. DOE	$219.1 million
Participant	$219.1 million

Demonstration project costs include permitting, engineering procurement, and construction, startup and pre-operations costs for the gasification, air separation and power generation facilities. Operating costs (except coal) during the three-year demonstration period are also included. The total capital cost of the IGCC power plant, including startup, is $417 million.

Schedule/Demonstration Milestones

Project Schedule

DOE's involvement in the Project extends over almost eight years, beginning June 1, 1991 with the definition of the scope in the Participant's proposal and concluding March 1, 1999 with the completion of the three-year demonstration period. The IGCC power plant will be operated for a total of 25 years.

Construction

Construction of foundations and steel erection commenced in September 1993 and was complete in October 1995. Construction activities in the first year were hampered by unusually severe weather conditions. To stay on schedule, both PSI and Destec selectively employed seven-day construction schedules. Peak construction activity brought over 1,300 workers to the site daily. Support from local labor unions and contractors was critical to maintaining the Project schedule.

Major equipment began arriving in early 1994 and all major pieces were in place by August. By mid-June 1995 virtually all of the 157 subsystems were turned over to operations personnel.

Turnover and Commissioning

A detailed turnover/commissioning plan was developed and implemented for each facility by separate teams of construction and operating personnel. Initially the combined cycle facility was tested alone, on No. 2 distillate. Gas turbine roll occurred on June 8, 1995 and synchronization to the grid occurred on June 21. Various startup problems were identified and corrected.

The first gasifier run (23 hours) took place without significant problems on August 25, 1995. First gas turbine operation on syngas took place October 3, 1995. Commercial operation of the gasification facility was

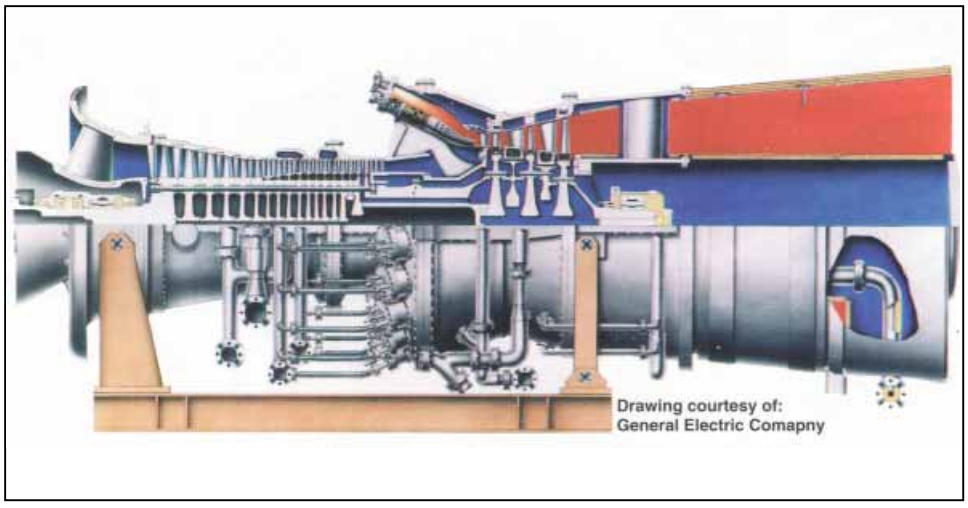
Wabash River Coal Gasification Repowering Project site during early construction.

Same view as above-well into construction.

Selected Achievements

May 1991	Clean Coal IV Proposal Submitted
September 1991	Project Selected
May 1993	Environmental Permitting Completed
September 1993	Construction Started
June 1995	CT/CC Synchronized on Fuel Oil
August 1995	First Gasifier Run
October 1995	CT/CC Synchronized on Syngas
November 1995	Completed Initial Testing Started Commercial Operation
December 1995	Started Demonstration Period
February 1996	Achieved 100% Capacity

General Electric model MS 7001FA Gas Turbine.



achieved November 18, 1995, kicking off the planned 25 year operating life of the facility.

Barely four months into the demonstration period, in mid-February 1996, the Wabash River Coal Gasification Repowering Project was operated continuously for over 12 consecutive days with all parameters at acceptable levels. The gasifier achieved 100 percent capacity for the first time and produced the most syngas ever from a single train gasification plant. The gas turbine also achieved 100 percent of rated load on syngas by generating 192 MWe.

Objectives

PSI's major objectives involve making this facility an effective part of their baseload capacity, and to demonstrate the operability, effectiveness and economic viability of the technology on a commercial scale and in a commercial environment. PSI desires to maintain or improve the dispatch status of the facility, while managing costs. PSI will separately track its operating and maintenance (O&M) costs according to labor, material, and fuel, capital expenditures, major overhaul expenditures, and preventable recurring costs.

Destec will closely monitor the performance of key subsystems and components. In addition, Destec plans to manage the gasifier island for continuous improvement, setting the stage and creating a standard for operation of the next Destec gasification facility.

Other focuses of the demonstration are to show operation on the PSI grid, demonstrate the operability of the thermal integration between the gasification and power blocks, define the boundaries of operability of the overall plant, and establish a baseline for O&M costs.

Together, the Participants will monitor the facility's ability to meet the requirements of its commercial environment. Monitoring includes startup and shutdown times and costs, ramp rates on load changes, turndown ratios, stability of the plant at various loads, optimization of maintenance cycles, factors that degrade

performance, and verification of dynamic system response and controls.

Since dispatch status is a function of both environmental and cost performance, the information representing such performance will be evaluated. Finally, since coal is the single largest energy cost component, PSI will continually pursue the lowest cost coal which meets the quality requirements.

Results

The Wabash River facility began commercial operation in November 1995. This section gives production statistics for the gasification and combined cycle facilities through October 1996.

Operations of most of the process units in the IGCC facility have met or exceeded expectations. The gas turbine generator's fuel consumption at design output is well below the design guarantee, causing the plant heat rate to be improved over design. The gasification facility has demonstrated outputs of up to 103% of design.

Sulfur emission rates of less than 0.1 lb/ million Btu (coal input basis) have been consistently demonstrated, which are better than the plant design point of 0.2 lb/ million Btu and greatly surpass the 1.2 lb/ million Btu guideline for the year 2000 as set by the CAAA.

In the gasification plant, the slurry preparation, gasification, high temperature heat recovery, acid gas removal and continuous slag handling systems have all functioned well. The combustion turbine, steam turbine and water treatment system at the power generation facility have also operated satisfactorily.

The early operation has been marked by significant problems in certain process units. As expected, the areas of the newest technology have produced the majority of the downtime for the plant. At the gasification

Early Performance

	Design	*Actual*
Plant Heat Rate, Btu/kWh (HHV)	9030	8910
Combustion Turbine Output, MWe	192	192
Steam Turbine Output, MWe	105	96
Auxiliary Power, MWe	35	36
Net Power Output, MWe	262	252
Sulfur Removal Efficiency, %	>98	>99

Production Statistics through October 1996

Gasification Plant Production Statistics

First Coal Gasified	August 17, 1995
Total Gasifier Hours on Coal	2035
Total Syngas Produced—10^6Btu (dry)	2,838,628
Total Coal Processed—tons	189,233
Highest Capacity Demonstrated—10^6 Btu/hr (HHV) % Nameplate	1825 103%
Longest Continuous Coal Run—hours	253
Cold Gas Efficiency—percent	>74

Combined Cycle Plant Production Statistics

First Syngas to Combustion Turbine (CT)	October 3, 1995
Total CT Hours	2536
Total CT Hours on Syngas	1061
MWh Produced on Syngas	175,269
Highest CT Capacity Demonstrated—MWe % Nameplate	192 100%
Longest Continuous Syngas Operation—hours	151

Air Separation Unit (foreground). Destec gasifier structure under construction (upper right).

facility, problems in the particulate removal system have resulted in repeated outages, constituting the majority of the plant's downtime, and prompting modifications to this process area. The gasification facility has also seen downtime due to metallurgical problems in the low temperature heat recovery systems.

The power generation facility has had few major problem areas since the start of commercial operation, although the gas turbine HRSG will require some modifications to allow the plant to achieve its best efficiency point.

Feedwater heating problems have required use of a portion of the high pressure steam for direct condensate heating in the deaerator rather than power production in the steam turbine. This has caused the maximum net output in the first eight months to be 252 MWe, instead of the design value of 262 MWe. The plant is expected to achieve the rated output when this problem is corrected.

The plant heat rate, already about one and one half percent better than the design point, is expected to improve to the 8600–8700 Btu/kWh range (39–40 percent efficiency), higher heating value basis, when plant systems are optimized.

Future

Results of the Wabash River Coal Gasification Repowering Project are expected to establish the basis for future power plants based upon the demonstrated technologies. Improvements in both performance and costs based upon experience gained in this project are likely. As the technology matures and power plant sizes increase, costs are expected to decrease further, and performance to improve. The performance improvements will stem from gasifier system enhancements, improved overall steam conditions and thermal integration, use of commercially available hot-gas cleanup, and advances in gas turbine technology.

Destec and DOE estimate that future IGCC greenfield power plants based upon mature and improved technology will cost $1000–$1350/kW (1995 basis), and will have a heat rate in the range of 7000–7500 Btu/kWh (46–49 percent efficiency), higher heating value basis. Costs will be further reduced if an existing steam turbine is repowered and existing site infrastructure utilized.

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The Clean Coal Technology Program

The Clean Coal Technology (CCT) Program is a unique partnership between the federal government and industry that has as its primary goal the successful introduction of new clean coal utilization technologies into the energy marketplace. With its roots in the acid rain debate of the 1980s, the program is on the verge of meeting its early objective of broadening the range of technological solutions available to eliminate acid rain concerns associated with coal use. Moreover, the program has evolved and has been expanded to address the need for new, high-efficiency power-generating technologies that will allow coal to continue to be a fuel option well into the 21st century.

Begun in 1985 and expanded in 1987 consistent with the recommendation of the U.S. and Canadian Special Envoys on Acid Rain, the program has been implemented through a series of five nationwide competitive solicitations. Each solicitation has been associated with specific government funding and program objectives. After five solicitations, the CCT Program comprises a total of 40 projects located in 18 states with a capital investment value of nearly $6.0 billion. DOE's share of the total project costs is about $2.0 billion, or approximately 34 percent of the total. The projects' industrial participants (i.e., the non-DOE participants) are providing the remainder—nearly $4.0 billion.

Clean coal technologies being demonstrated under the CCT Program are establishing a technology base that will enable the nation to meet more stringent energy and environmental goals. Most of the demonstrations are being conducted at commercial scale, in actual user environments, and under circumstances typical of commercial operations. These features allow the potential of the technologies to be evaluated in their intended commercial applications. Each application addresses one of the following four market sectors:

- Advanced electric power generation
- Environmental control devices
- Coal processing for clean fuels
- Industrial applications

Given its programmatic success, the CCT Program serves as a model for other cooperative government/industry programs aimed at introducing new technologies into the commercial marketplace.

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This report is available on the Internet
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List of Acronyms and Abbreviations

Btu	British thermal unit
CAAA	Clean Air Act Amendments of 1990
CCT	Clean Coal Technology
CT	combustion turbine
EIA	U.S. Energy Information Agency
EPA	U.S. Environmental Protection Agency
gpm	gallons per minute
HHV	higher heating value
HRSG	heat recovery steam generator
IGCC	integrated gasification combined cycle
kW	kilowatt
kWh	kilowatt hour
lb/hr	pounds per hour
MAF	moisture and ash free
MDEA	methyldiethanol amine
MWe	megawatt electric
MWh	megawatt hours
O&M	operating and maintenance
PM	particulate matter
PM-10	particulate matter less than 10 micrometers in diameter
psia	pounds per square inch absolute
SCF	standard cubic feet
VOC	volatile organic compounds