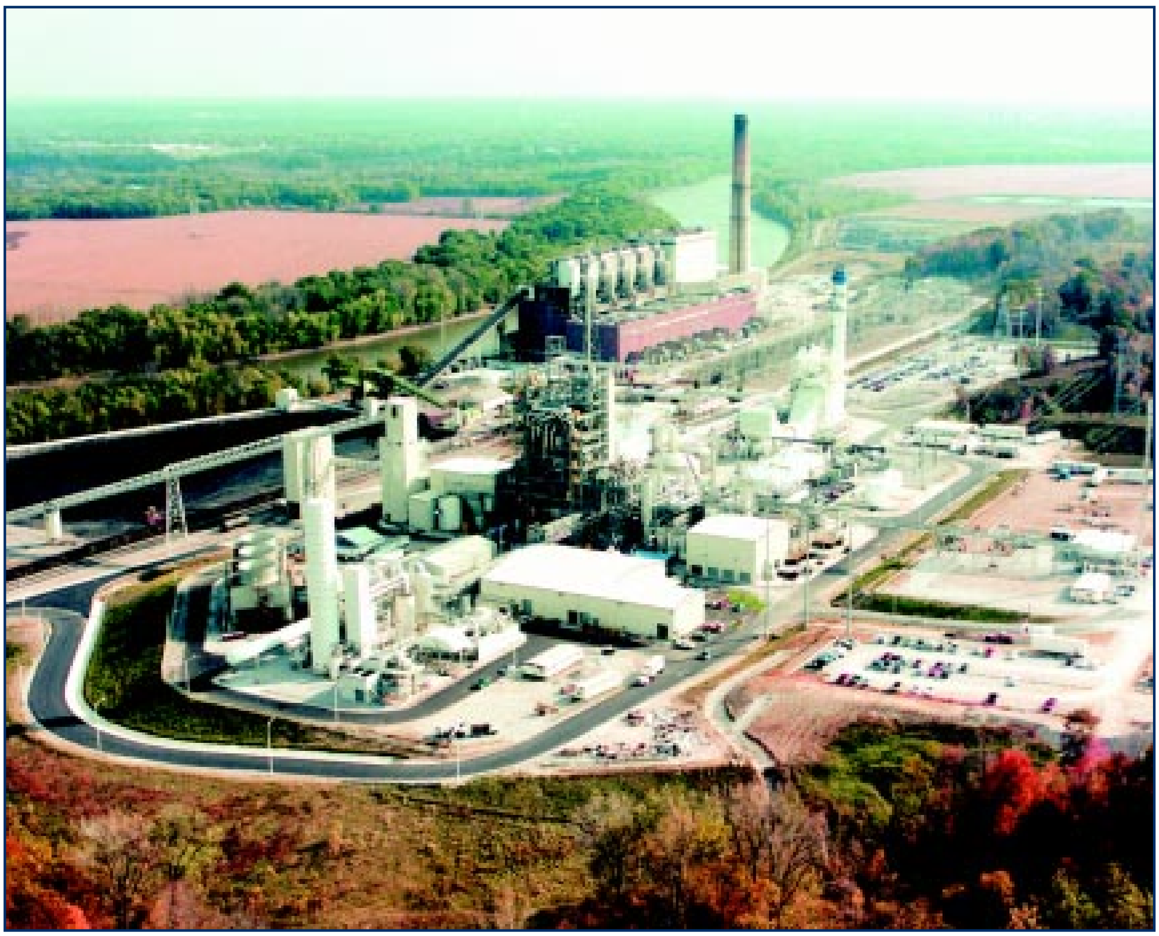
CLEAN COAL TECHNOLOGY



The Wabash River Coal Gasification Repowering Project

An Update

The Wabash River Coal Gasification Repowering Project

A 262 MWe Commercial Scale Integrated Gasification Combined Cycle Power Plant

An Update

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

The U.S. 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.

CLEAN COAL TECHNOLOGY

The Wabash River Coal Gasification Repowering Project

Executive Summary 1
Background 2
Integrated Gasification Combined-Cycle 2
Project Description 4
Power Plant Description 7
Cost/Schedule 12
Project Objective 13
Plant Modifications/Improvements 13
Results 14
Awards 15
Commercial Applications 15
Future Developments 16
Market Potential 17
Conclusions 18
Bibliography 22
Contacts for CCT Projects and U.S. DOE CCT Program 23
List of Acronyms and Abbreviations 24

Executive Summary

The Clean Coal Technology (CCT) Demonstration Program is a government and industry co-funded effort to demonstrate a new generation of innovative coal utilization processes in a series of facilities built across the country. These projects are conducted on a commercial scale to prove technical feasibility and provide the information required for future applications.

The goal of the CCT Program is to furnish the marketplace with a number of advanced, more efficient coal-based technologies that meet strict environmental standards. These technologies will mitigate the economic and environmental barriers that limit the full utilization of coal, thereby reducing dependence on foreign oil.

To achieve this goal, beginning in 1985, a multi-phased effort consisting of five separate solicitations has been administered by the U.S. Department of Energy's (DOE) National Energy Technology Laboratory (NETL), formerly the Federal Energy Technology Center. Projects selected through these solicitations have demonstrated technology options with the potential to meet the needs of energy markets while satisfying relevant environmental requirements.

This report discusses the Wabash River Coal Gasification Repowering Project. In this project, coal is gasified in an oxygen-blown, entrained-flow gasifier with continuous slag removal and a dry particulate removal system. The resulting synthesis gas is used to fuel a gas combustion turbine generator, whose exhaust is integrated with a heat recovery steam generator to drive a refurbished steam turbine generator. The gasifier uses technology initially developed by Dow (the Destec Gasification Process) and now offered commercially by Global Energy Inc. as the E-GAS™ technology.

This demonstration was completed in December 1999, having achieved all of its objectives. The facility built for this project is located at PSI Energy's Wabash River Generating Station near West Terre Haute, Indiana. Sulfur removal exceeds 97%. Sulfur is recovered and sold, as is the slag byproduct of gasification.

The Wabash River CCT project successfully demonstrated commercial application of the E-GAS™ coal gasification technology in conjunction with electric power generation. Operating time exceeded 15,000 hours, with over 1.5 million tons of coal processed and about 4 million MWh of power produced. The combustion turbine generated 192 MWe and the repowered steam turbine generated 104 MWe. With the system's parasitic load of 34 MWe, net power production was 262 MWe, which met the target goal. Carbon conversion exceeded 95%. The plant operated successfully on baseload dispatch in the PSI power grid, and continues to operate as a privately owned facility providing power to PSI Energy.

Gasification is an environmentally superior means of utilizing domestic coal resources for power production. It also offers the opportunity to use lower quality, less expensive feedstocks such as petroleum coke. Operation on petroleum coke was also demonstrated at Wabash River.

Emissions of SO_2 and NOx were far below regulatory requirements. SO_2 emissions averaged about 0.1 lb/million Btu, compared with the allowable limit of 1.2 lb/million Btu. NOx emissions were 0.15 lb/million Btu, which met the current target for coal-fired power generation plants. Particulate emissions were less than the detectable limit. The Wabash River facility is one of the cleanest coal-based power plants in the world.

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

The Wabash River Coal Gasification Repowering Project

Background

The Clean Coal Technology (CCT) Demonstration Program, sponsored by the U.S. Department of Energy (DOE) and administered by the National Energy Technology Laboratory (NETL), has been conducted since 1985 to develop innovative, environmentally friendly coal utilization processes for the world energy marketplace.

The CCT Program, which is co-funded by industry and government, involves a series of commercial-scale demonstration projects that provide data for design, construction, operation, and technical/economic evaluation of full-scale applications. The goal of the CCT Program is to enhance the utilization of coal as a major energy source.

The CCT Program has also opened a channel to policy-making bodies by providing data from cutting-edge technologies to aid in formulating regulatory decisions. DOE and the participants in several CCT projects have provided the Environmental Protection Agency (EPA) with data to help establish targets for nitrogen oxide (NOx) emissions from coal-fired boilers subject to compliance under the 1990 Clean Air Act Amendments (CAAA).

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 process that combines modern coal gasification with gas turbine and steam power generation technologies. IGCC is one of the most efficient and cleanest of available technologies for coal-based electric power generation. This technology offers high system efficiencies compared with conventional pulverized-coal power generation, reduced costs, and very low pollution levels.

IGCC power plants offer excellent environmental performance. Gasification breaks down virtually any carbon-based feedstock into its basic constituents, enabling the separation of pollutants to produce clean gas for efficient electricity generation. As a result, atmospheric emissions of pollutants are very low.

Due to their high efficiency, less coal is used, causing IGCC power plants to emit less carbon dioxide (CO_2) to the atmosphere, thereby decreasing concerns about climate change. Less coal use also results in less ash requiring disposal.

Modularity and fuel flexibility are important attributes of IGCC power plants. The

combined-cycle unit can be operated on other fuels, such as natural gas or fuel oil, before the gasifier is constructed, to provide early power. The size of gas turbine units can be chosen to meet specific power requirements. Ability to operate on multiple fuels also permits continued operation of the gas turbine unit if the gasifier island is shut down for maintenance or repairs, or if warranted by changes in fuel costs.

An additional benefit of IGCC is product flexibility, permitting production of alternatives such as chemicals or transportation fuels. Market forces, which are replacing regulatory structures, are resulting in expanded IGCC applications. As a result of both feedstock and product flexibility, traditional steam-powered electricity generation using single feedstocks is being supplanted by more versatile integrated technologies.

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

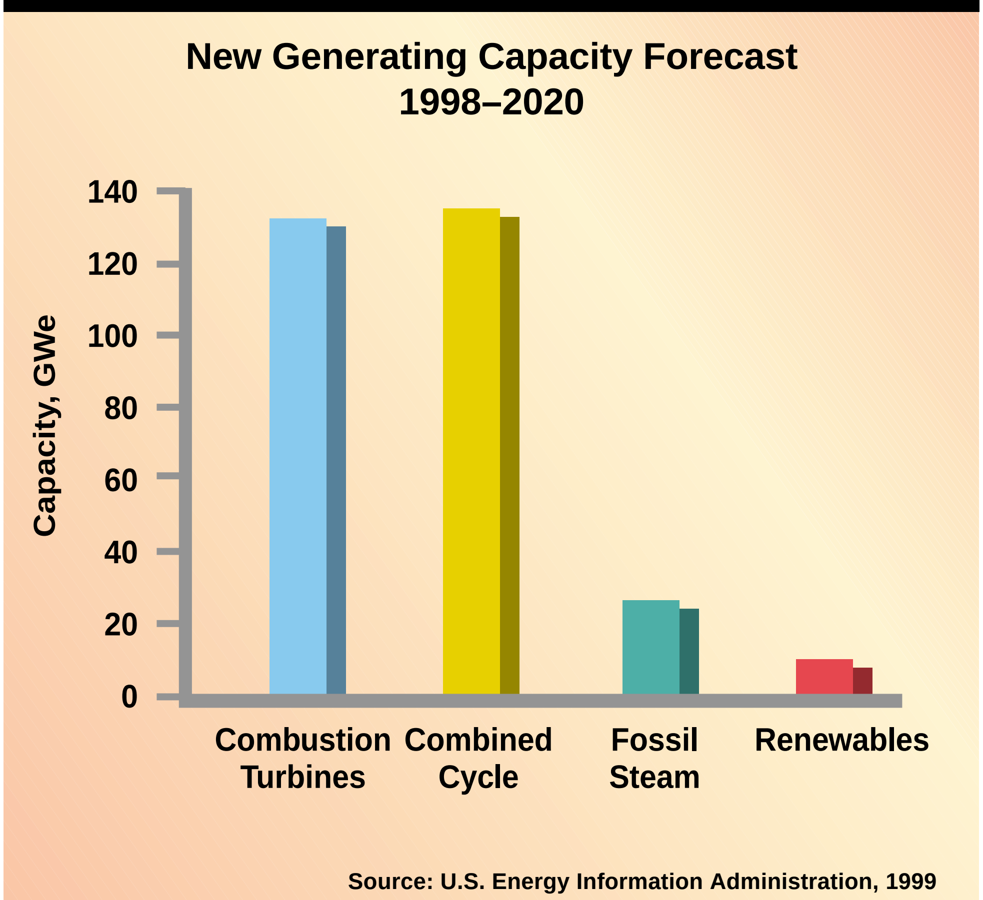
Four IGCC demonstration projects are included in the CCT Program: (1) the Piñon Pine IGCC Power Project, (2) the Tampa Electric Integrated Gasification Combined-Cycle Project, (3) the Wabash River Coal Gasification Repowering Project, and (4) the Kentucky Pioneer Energy Project. This Topical Report describes the Wabash River Project.

IGCC power plant. The 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

The Wabash River Project was selected by DOE in September 1991 as a CCT Program Round IV demonstration project. Construction was started in July 1993 and commercial operation began in November 1995. The demonstration was completed in December 1999.

The Wabash River Project demonstrated use of the Global Energy E-GAS™ coal gasification process to fuel a combustion turbine generator, whose exhaust is integrated with a heat recovery steam generator (HRSG) to drive a steam turbine generator. Sulfur removal exceeds 97%. Elemental sulfur is recovered and sold, as is the slag byproduct of gasification.



The demonstration facility is located at the Wabash River Generating Station near West Terre Haute, Indiana, owned and operated by PSI Energy, Inc. of Plainfield, Indiana.

The power block consists of an advanced General Electric MS 7001 FA gas turbine unit that produces 192 MWe (gross), a Foster Wheeler HRSG, and a 1953 vintage Westinghouse reheat steam turbine. The steam turbine, which was refurbished as part of this CCT project, produces an additional 104 MWe (gross). Parasitic power is 34 MWe, giving a total power output of 262 MWe (net).

Project Participant

The Participant in the CCT project was Wabash River Coal Gasification Project Joint Venture, formed in 1990 by Destec Energy, Inc. of Houston, Texas and PSI Energy. PSI is an investor-owned utility whose service area covers 69 of the 92 counties in Indiana. Along with Cincinnati Gas & Electric Company, PSI is owned by Cinergy Corporation, which was formed in October 1994. Cinergy is one of the largest electric utilities in the United States.

In 1997, Destec was purchased by Houston-based NGC Corporation, which changed its name to Dynegy, Inc. in 1998.

In December 1999, Global Energy Inc. completed the purchase of Dynegy's gasification assets and technology. The purchase included Dynegy's syngas facility at the Wabash River Coal Gasification Repowering Project as well as the right, title and interest in Dynegy's proprietary gasification technology, including its gasification-related patents. The sale also included the rights to Dynegy's gasification projects in development.

The gasification technology, originally developed by the Dow Chemical Company, was first applied to power applications at its Plaquemine, Louisiana chemicals complex. The technology was

Air separation unit during construction

later transferred to Destec, a partially held subsidiary of Dow Chemical.

Global Energy will license the gasification process under a new name, E-GAS™ Technology, reflecting the efficiency, economy, and superior environmental performance of this process. A newly created Global Energy subsidiary, Gasification Engineering Corporation, plans to market the E-GAS™ technology worldwide from offices in Houston, Texas.

Global Energy is a founding member of the Washington, D.C.-based Gasification Technologies Council along with several leading industrial companies. Global Energy is focused on gasification technology projects designed to improve environmental and economic results for the power, refining, chemical, and pulp and paper industries. The company has more than 2,000 MWe of project activity in development, construction and operation in the United States and the United Kingdom, with business development interests worldwide.

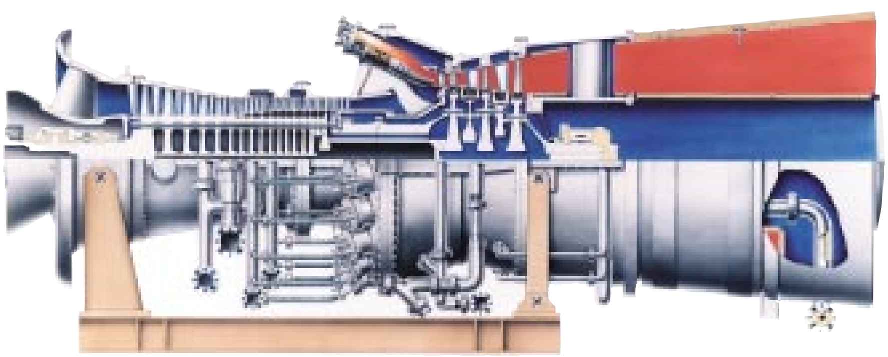
Project Subcontractors

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. 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 the gasification island facilities, including a control, administration and maintenance building and the air separation plant, one of the largest such facilities in North America.

Project Team

Combined Cycle Facility	
Project Management	PSI Energy, Inc.
Engineer	Sargent & Lundy
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.



General Electric model MS 7001FA gas turbine

Site Description

The CCT demonstration site is located in a predominantly rural area on the Wabash River near West Terre Haute, Indiana. PSI's Wabash River Station was originally a mine mouth plant, and much of the new facility is built over areas that were shaft mined in the early 20th 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. There are no nearby wilderness areas or national or state parks.

The coal gasification repowering facility is 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 adjacent to the existing station. New wastewater and storm water ponds are located nearby in an area previously used as an ash pond.

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% (dry basis) and a higher heating value of 13,500 Btu/lb (moisture- and ash-free). The coal selected for initial operation was a high-sulfur midwestern bituminous from the No. 6 seam at Peabody's Hawthorn Mine in Indiana. Coal for the project is stored apart from the compliance coal burned in Units 2-6 of the existing station.

Alternative feedstocks, including petroleum coke and blends of coal and coke, were tested during the three-year demonstration period.

Emissions from Wabash River IGCC Plant

Emissions, lb/MWh	SO_2	NOx	CO	PM-10	VOC
Pre-Repowering Unit 1 Boiler	38.2	9.3	0.64	0.85	0.03
IGCC	1.35	1.09	0.37	ND*	0.02

Emissions, lb/million Btu	SO_2	NOx	CO	PM-10	VOC
Pre-Repowering Unit 1 Boiler	3.1	0.8	0.05	0.07	0.003
IGCC	0.10	0.15	0.03	ND*	0.003

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

* *non-detectable*

Power Plant Description

The design of the project gasifier was based on Destec's Louisiana Gasification Technology, Inc. (LGTI) gasifier, which was similar in size and operating characteristics. LGTI was operated for more than 34,000 hours from April 1987 through November 1995. Experience gained in that project provided significant input to the design of the Wabash River coal gasification facility and eliminated much of the risk associated with scale-up and process variables.

Coal is slurried with water and fed, along with 95% oxygen from the air separation plant, to the first stage of the 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, producing steam for power generation. In this project, the steam is generated at a pressure of about 1,600 psia, whereas Dynegy's LGTI facility operated at about 600 psia. The Wabash River syngas cooler has met expectations with respect to thermal performance and durability.

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/day of coal feed, although two vessels, each of 100% capacity, were installed.

The particle-free gas is further cooled, scrubbed to remove chlorides, and passed through a catalyst bed that converts carbonyl sulfide (COS) to H_2S. Sulfur contaminants are removed by conventional processing using an amine solvent. High-quality sulfur (99.99% pure) is recovered and sold off-site for agricultural applications. The slag byproduct of gasification can be sold for use in road paving and roof shingles.

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.
- Continuous slag removal from the gasifier.
- 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.
- Recycle of sulfur removal unit tail-gases to the gasifier to further reduce emissions.

The cleaned gas is moisturized to aid in control of NOx emissions and fed to a General Electric model MS 7001FA gas turbine, where it is combusted to generate electricity. Moisturization reduces the amount of steam injection required for NOx control.

Advanced gas turbine design allows for the combustion of syngas at a firing temperature of 2350°F (1222°C), which is significantly higher than previously demonstrated. Wabash River features the first "F" machine to operate on syngas. Blade temperatures are monitored on a real time basis, using optical pyrometry.

Gas turbine exhaust heat is recovered in the HRSG to produce steam for generation of more electricity. Repowering of the existing steam turbine involved upgrading the unit to accommodate the increased steam flow generated by the HRSG. Flue gas is emitted to the atmosphere through a 225-ft stack.

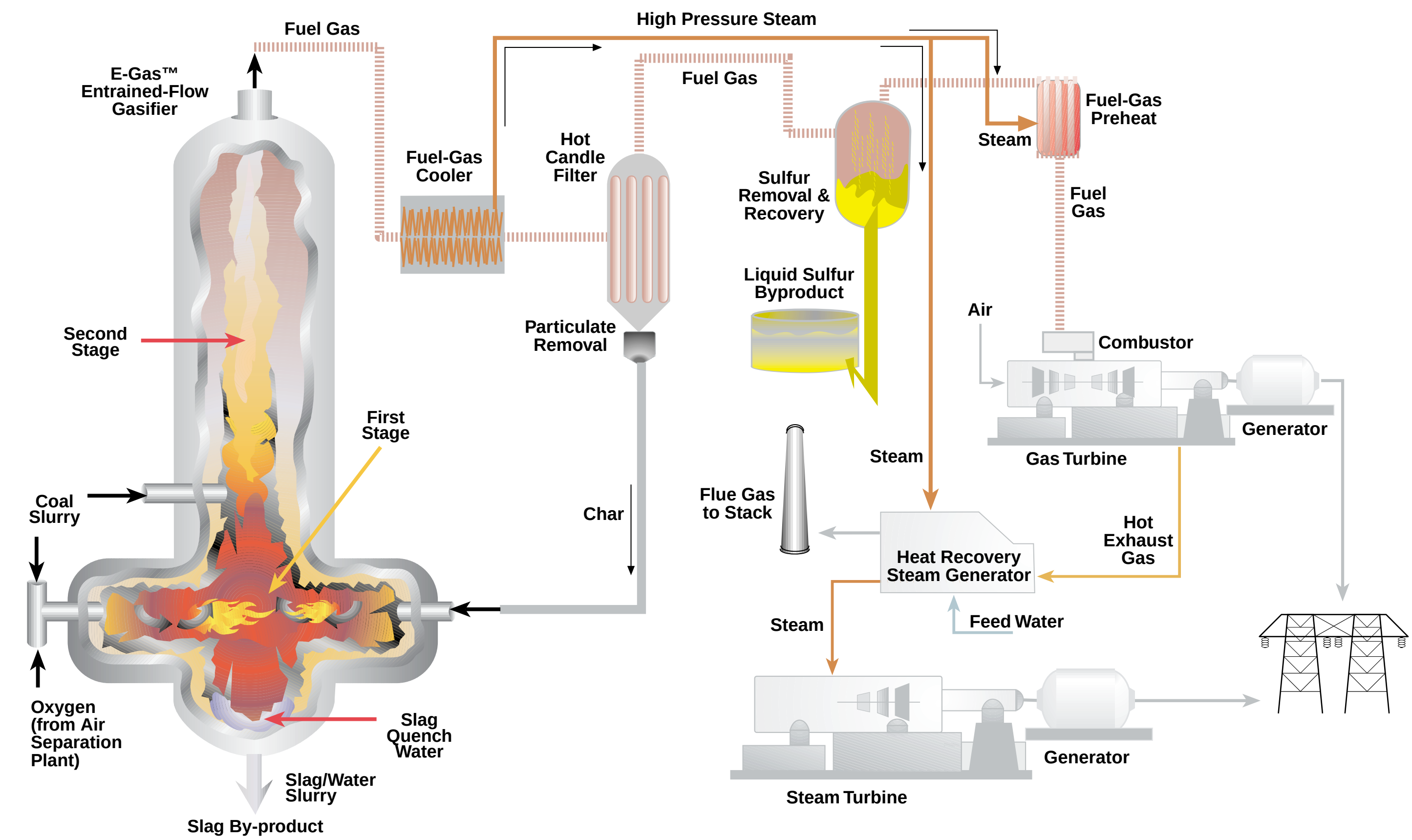
Environmental Considerations

Expected environmental impacts of the CCT 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 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 were obtained. A process and environmental monitoring program was established in compliance with permitting requirements.

The plant was designed to substantially outperform the CAAA emission standards, which include an SO_2 limit of 1.2 lb/million Btu of fuel input and a NOx limit of 0.15 lb/million Btu. As discussed subsequently, demonstrated emissions are far lower than these target values. Compared

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 Flow Diagram

Process Description

Coal Gasification

The E-GAS™ two-stage coal gasification technology features an oxygen-blown, entrained-flow, refractory-lined gasifier with continuous slag removal. The first stage operates at about 2500°F and 400 psig. The actual operating temperature depends upon the specific coal used. A 60/40 wt % coal/water slurry is combined with oxygen and injected into the gasifier. Oxygen of 95% purity is supplied by a turnkey, dedicated air separation unit. The coal undergoes partial combustion, releasing heat that causes the 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 which is sold for various construction applications.

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 as a method 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 system than otherwise would be obtainable.

The raw product gas exits the gasifier at 1900°F and is further cooled in a firetube boiler, producing high-pressure (1600 psia) saturated steam.

Gas Cleanup

Flyash and remaining char particles in the gas are removed by a hot metallic 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 degree of removal for the power plant to achieve the low design level of SO_2 emissions. H_2S is removed in an acid gas removal system; however, because COS is not readily removable it is first catalytically converted to H_2S by hydrolysis.

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.

Acid Gas Removal

The cooled syngas flows to the acid gas removal absorber column, where H_2S is removed by a solvent, methyldiethanol amine (MDEA). 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 the 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.

The particle-free gas is further cooled to near ambient temperature, and over 97% of the sulfur in the coal is removed by conventional recovery technology. High-quality sulfur (> 99.99% pure) is recovered and sold for agricultural 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 then 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 with activated carbon and discharged to the pond for subsequent discharge to the river through the permitted discharge point. The NH_3 content of the effluent is below the permit level.

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 gas turbine is currently being converted to use natural gas as a secondary fuel instead of fuel oil.

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 754,000 lb/hr of high-pressure steam at 1010°F (543°C) and 600,820 lb/hr of reheat steam at 1010°F (543°C) when the gas turbine operates on syngas.

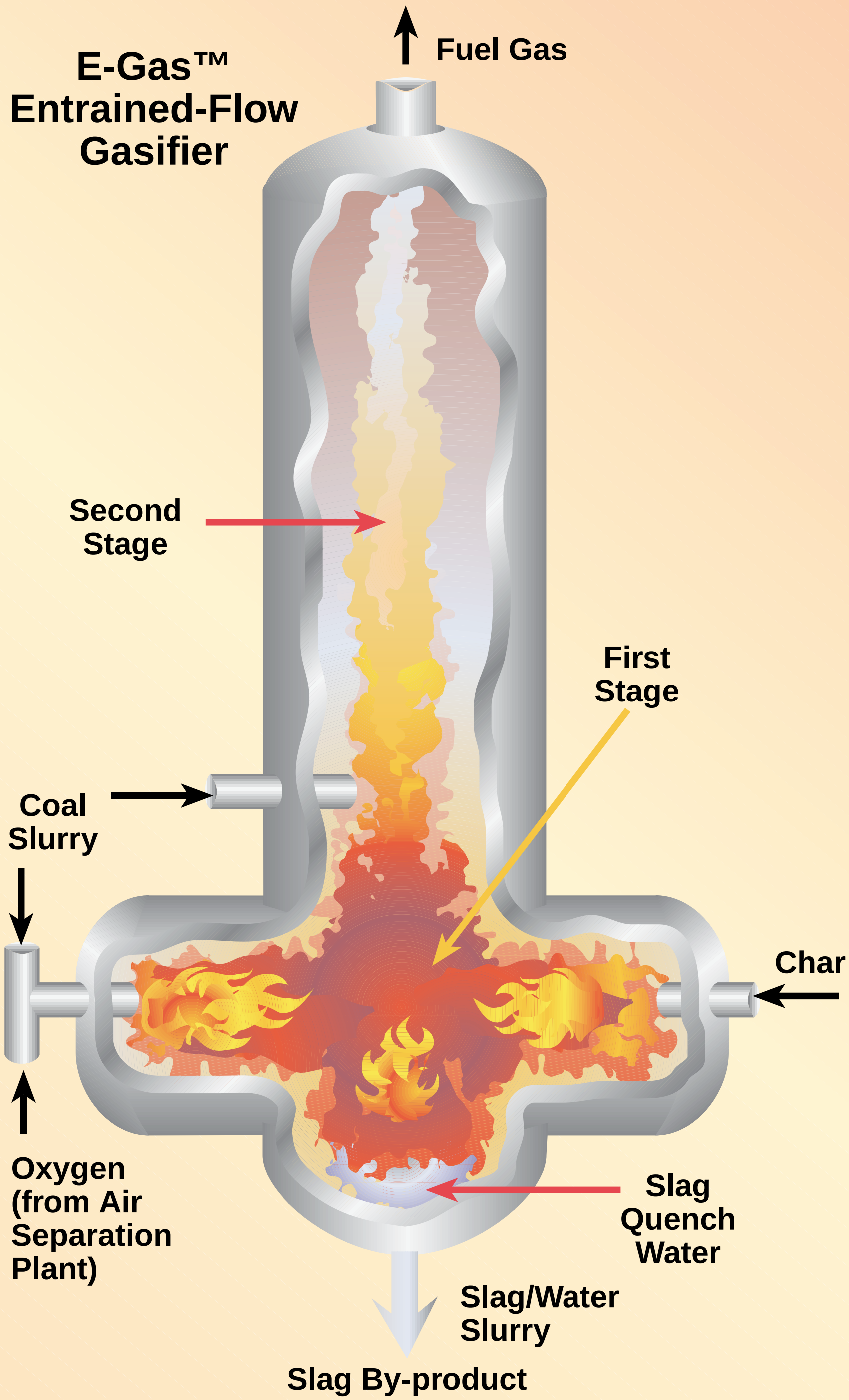
The repowered steam turbine unit number 1, originally installed in 1953, had been derated from 104 MWe to 90 MWe when reduced coal consumption was necessary to reduce stack emissions. As part of the CCT project, the unit was refurbished to accept the increased steam flows and pressures associated with the combined-cycle operation. Output has been restored to 104 MWe.

Parasitic electric consumption is 34 MWe, consisting of power to operate the air separation unit, motors, pumps, and other requirements of the project. Total net power production is 262 MWe.

The cleaned gas is moisturized to aid in control of NOx 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-ft stack.

Air Separation Unit

A conventional air separation unit provides 95% pure oxygen for the gasifier operation.



Product Syngas Analysis

Analysis	Typical Coal	Petroleum Coke
Nitrogen, vol %	1.9	1.9
Argon, vol %	0.6	0.6
CO_2, vol %	15.8	15.4
CO, vol %	45.3	48.6
H_2, vol %	34.4	33.2
CH_4, vol %	1.9	0.5
Total Sulfur, ppmv	68	69
HHV, Btu/SCF	277	268

Fuel Analysis

Component	Typical Coal	Petroleum Coke
Moisture, %	15.2	7.0
Ash, %	12.0	0.3
Volatile Matter, %	32.8	12.4
Fixed Carbon, %	39.9	80.4
Sulfur, %	1.9	5.2
HHV (as received), Btu/lb	10,536	14,282

Production Statistics

From startup in 1995 through project completion at end of 1999

Operating time on coal, hours	15,067
Coal processed, 10^6 tons	1.55
Syngas produced, 10^{12} Btu	23.9
Steam produced, 10^6 lb	6.38
Power produced, 10^6 MWh	3.91
Sulfur produced, 10^3 tons	33.4
Equivalent SO_2 captured, 10^3 lb	133.4

with previous operation of the steam turbine, CO_2 emissions are reduced by approximately 20% on a per kWh basis.

Even though power generation at Wabash River is almost three times that of the original unit, total emissions are a fraction of the pre-repowering values as a result of IGCC operation.

Cost/Schedule

Project Cost

The total cost of the Wabash River Project was $438 million, including construction and operation during the four year demonstration period. The DOE provided $219 milion (50%) of the total cost. Capital investment for a commercial unit of this size would be considerably lower than this figure.

Project Schedule

The cooperative agreement between Wabash River and DOE was signed in July 1992. Construction started in July 1993, and operation began in November 1995. The demonstration was completed in January 2000.

Construction

Construction activities in the first year were hampered by unusually severe weather. To stay on schedule, 7-day construction schedules were employed. Peak construction activity brought over 1,000 workers to the site daily. Support from local labor unions and contractors was critical to maintaining the project schedule.

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.

Commercial operation of the gasification facility was achieved November 18, 1995. Barely four months into the demonstration period, in mid-February 1996, the facility was operated continuously for over 12 consecutive days with all parameters at acceptable levels. The gasifier achieved 100% capacity and produced the most syngas ever from a single-train gasification plant during this period. The gas turbine also achieved 100% of rated load on syngas by generating 192 MWe of power.

Project Objective

The major project objective was to demonstrate utility repowering with a two-stage, pressurized, oxygen-blown, entrained-flow IGCC system, including advancements in the technology relevant to the use of high-sulfur bituminous coal, and to assess long-term reliability, availability, and maintainability at a commercial scale. Another goal was to evaluate the performance of all major process components, including the coal slurry feed system, the gasifier, the gas cleanup system, the modified combustion turbine utilizing medium-Btu gas, and the repowered steam turbine.

Plant Modifications/ Improvements

Initial operations were hampered by several problems, most of which have been addressed successfully.

Although the gasifier and slag handling facilities have performed well, carbon content in the slag was initially higher than desired, about 10%. Improvements in rod mill operation and installation of a new burner resulted in increased carbon conversion, reducing the carbon content of the slag to below 5%. The new burner design also improved burner life and greatly reduced the time required to change out burners.

Problems were experienced initially with syngas cooling, particulate removal, and hydrolysis of COS. Ash deposition at the inlet to the firetube boiler was corrected by modifying the hot gas path flow geometry and velocity. There was significant breakthrough of particulates in the barrier filter system, primarily due to movement and breakage of the ceramic candle filter elements. Replacing the ceramic elements with metallic candles remedied this problem.

Poisoning of the COS hydrolysis catalyst by chlorides and metals led to early replacement of the catalyst. This problem has been addressed successfully by installation of a wet chloride scrubber system and introduction of a different catalyst.

A new method of mechanically cleaning boiler tubes was developed, resulting in reduced corrosion and decreased filter blinding. Acid gas removal performance was improved significantly by expanding the capacity of the system for removing heat-stable salts from the circulating amine solution.

Gasifier structure

The combustion turbine system required improvements in several areas. The expansion bellows between the syngas module and the turbine required redesign and replacement to eliminate cracking in the flow sleeves. Solenoid valves in the syngas purge lines have been redesigned and replaced. Cracking of the combustor liners was remedied by replacement of the fuel nozzles. Failure of the air compressor rotor and stator of the combustion turbine assembly resulted in a prolonged shutdown in 1999; causes for this failure are under investigation but have been determined to be unrelated to syngas operation.

Results

Operation

Upon completion of the demonstration program on January 1, 2000, the Wabash River Project had processed over 1.5 million tons of coal, producing about 4 million MWh of electric power. Overall thermal efficiencies were 39.7% on coal and 40.2% on petroleum coke (HHV basis). Plant availability averaged 70% in 1998-99, reaching as high as 77% on a 9 month average. The plant demonstrated stable operation on the utility grid, successfully operating on baseload dispatch in the PSI system.

The employees for the project were hired for and function with the flexible worker concept, in that there is only one job classification on site. All employees have been trained to work multiple disciplines.

Emissions

Environmental performance was excellent. Average emissions are 0.1 lb/million Btu for SO_2, which is less than one-tenth of the permitted limit. Emission rates as low as 0.03 lb/million Btu have been achieved. NOx emissions are 0.15 lb/million Btu, which meets the target for 2003 specified under Title I of the CAAA. Particulate emissions are less than the detectable limit.

For SO_2, the New Source Performance Standards (NSPS) for fossil-fuel fired electric generating units call for 1.2 lb/million Btu of heat input and 90% reduction from the uncontrolled emissions rate. The SO_2 emissions rate for Wabash River of 0.1 lb/million Btu represents a reduction of 97%; therefore, both criteria are amply met. For NOx, the NSPS has recently been revised to an output-based regulation, at 1.6 lb/MWh of electric power generated. The Wabash River emissions figure of 1.09 lb/MWh meets this criterion as well as the former limit of 0.15 lb/million Btu. For particulate matter, the NSPS is 0.03 lb/million Btu. With particulate emissions below the detectable limit, Wabash River clearly meets this requirement.

High-quality elemental sulfur (99.99% pure) is recovered and sold. From startup through the end of 1999, the Wabash River project produced over 33,000 tons of marketable sulfur.

The COS hydrolysis system proved effective at achieving a conversion efficiency of 98%, allowing a high percentage of sulfur removal from the system. Syngas sulfur content has been well below the gas turbine manufacturer's requirements.

Repayment

Upon completion of the sale of the Wabash River IGCC facility and the Destec/Dynegy gasification technology to Global Energy, the Participants provided a $550,000 repayment to DOE on the technology sale. This represents the single largest repayment to date under the CCT Program, bringing total repayments to slightly over $1.3 million. While that represents only a small fraction of DOE's $1.8 billion investment in the $5.3 billion CCT Program, the advances in gasification technology and increasing utilization in both power and refining markets promise to bring further repayment, as CCTs are commercialized.

Cost and Efficiency Targets for IGCC
DOE's Vision 21

Year	Capital Cost, $/kW	Efficiency, % (HHV)
2000	1,250	42
2008	1,000	52
2015	850	>60

Awards

In their September/October 1996 issue, *Power* Magazine editors named the Wabash River Project as one of five Powerplant award winners for 1996–the fourth time since 1991 that a DOE-sponsored CCT project had been cited for this prestigious award. *Power* described the Wabash Project as demonstrating “a technology to bridge the millennium…being proven under the rigors of commercial service.” The Powerplant awards are given annually to recognize “leadership in the application of fresh ideas and new technology and equipment to minimize environmental impact and maximize efficiency.” *Power* revisited Wabash in March 2000 by naming it to the magazine’s “Power Plant Hall of Fame.”

The Wabash River plant has also earned the Indiana Governor’s Award for Excellence in Recycling.

Sargent & Lundy, engineer for the combined-cycle facility, won the American Consulting Engineers Council’s 1996 Engineering Excellence Award.

Five Powerplant Awards Presented to CCT Projects by *Power* Magazine

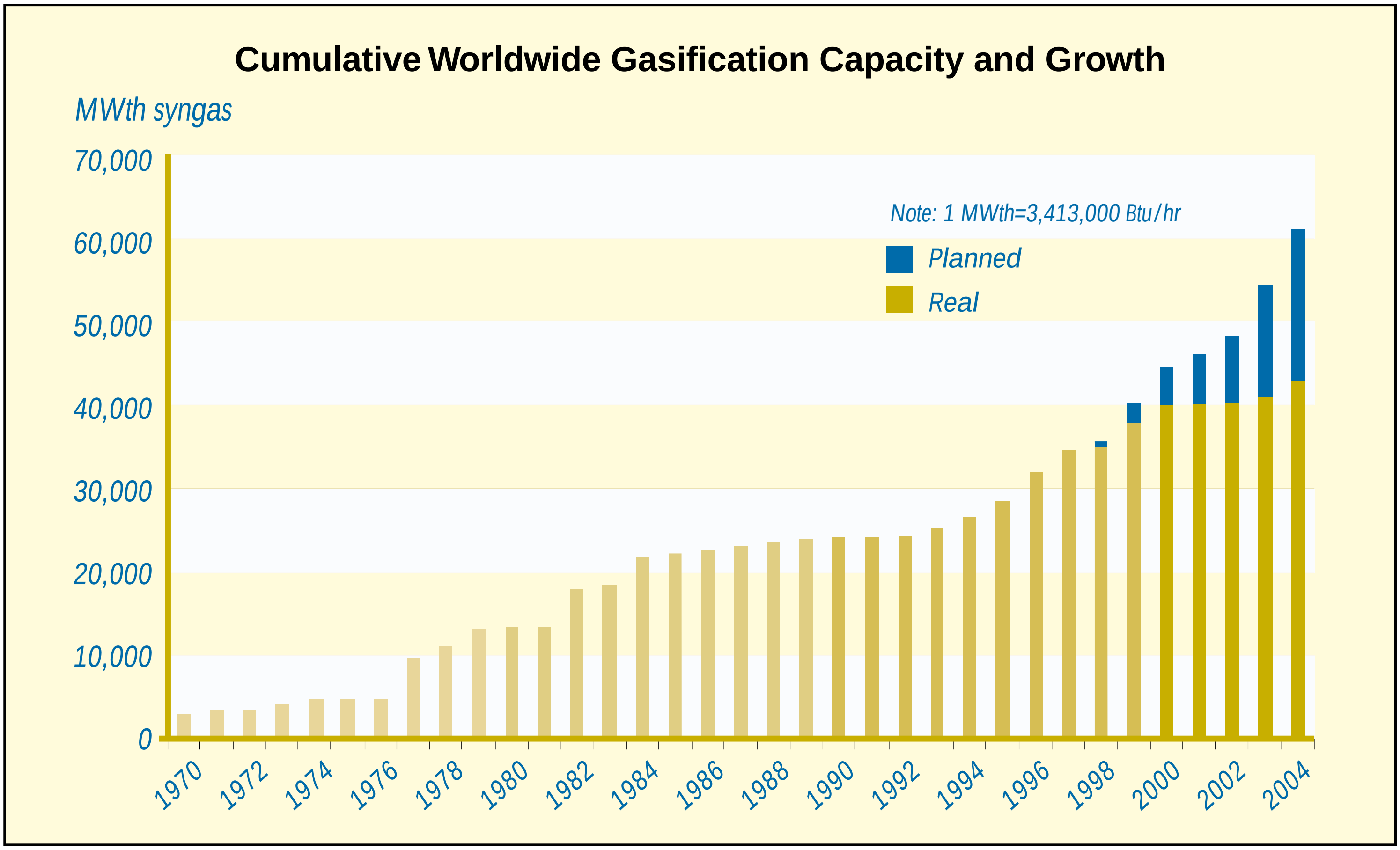
- Tampa Electric Integrated Gasification Combined-Cycle Project (Tampa Electric Company) - 1997
- Wabash River Coal Gasification Repowering Project (Cinergy Corporation/PSI Energy Inc.) - 1996
- Demonstration of Innovative Applications of Technology for the CT-121 FGD Process (Southern Company Services, Inc.) - 1994
- Advanced Flue Gas Desulfurization Demonstration Project (Pure Air on the Lake, L.P.) - 1993
- Tidd PFBC Demonstration Project (The Ohio Power Company) - 1991

Commercial Applications

In addition to generating power, the IGCC process can also be modified to produce value-added chemicals or transportation fuels from coal by chemical processing of the gas produced, as opposed to using the gas to drive a combustion turbine. It may be that the near-term market niche for IGCC lies not only in the production of electricity, but also in the generation of multiple products, where electricity, steam, and chemicals are economically bundled as products from a fully integrated complex. Such plants are envisioned in forward-thinking concepts such as the DOE’s “Vision 21” initiative.

In 1999, DOE selected a team led by Global Energy Inc. to evaluate producing power and methanol from an E-GAS™ plant fueled with coal and petroleum coke or other feedstocks. In this scenario, coal is gasified to generate feedstock for a liquid phase methanol plant, using the LPMEOH™ process developed by Air Products and Chemicals, Inc. Unreacted syngas flows to a combined-cycle unit for power production. If the concept is feasible, the team will develop an engineering package for a demonstration plant to be built at the Wabash River site.

In the past, the manufacture of syngas to produce chemicals has been the dominant market for IGCC technology. Worldwide, syngas-to-chemical applications currently include 89 projects, accounting for over 18,000 MWth. Power generation, which currently accounts for approximately 11,000 MWth, is growing quickly and represents most of the recent and planned capacity additions, with 20 new projects planned to generate over 10,000 MWth. Much of this growth is in gasification-based power generation at oil refineries.



Future Developments

Demonstrated results of the Wabash River project are expected to establish the design basis for future power plants. Improvements in both performance and costs are likely based upon experience gained in this project. As the technology continues to mature and power plant sizes increase, costs are expected to decrease further. Performance improvements are expected as a result of enhancements in gasifier system and gas turbine technology.

Operation of the Wabash River IGCC continues even though the CCT demonstration period has ended. The facility provides syngas to the PSI power plant under a market based agreement that allows the power produced from the syngas to compare favorably year-round to PSI's alternate sources for on-peak and off-peak power.

Future operation will continue to include coal as a feedstock, but will also feature opportunity fuels such as low cost petroleum coke. Introduction of biomass feedstocks is also being evaluated. Potential new products for the syngas facility, methanol for instance, are also being evaluated.

Market Potential

A number of factors are converging that contribute to the growth of gasification-based power generation worldwide. These factors include advances in gasification technology; improved efficiency and reduced cost of gas turbines; fuel flexibility, permitting use of lower quality, lower cost feedstocks; and deregulation of the power industry. This growth adds to an already important role gasification technologies have played in the production of chemicals and transportation fuels.

Currently there are over 160 existing or planned gasification projects worldwide, representing a total of more than 410 gasifiers with a combined syngas output of over 60,000 MWth. Conversion of all of this syngas to electricity by means of IGCC equates to over 33,000 MWe of power equivalent. Of the total worldwide capacity, gasification facilities currently operating or under construction account for about 130 plants with a total capacity of about 43,000 MWth. The current annual growth in gasification is about 3,000 MWth of syngas, or about 7% of the total operating worldwide capacity. Planned projects indicate that this growth will likely continue through the next five years, mostly in Western Europe, Asia, Australia, and North America.

At present, the use of syngas to produce chemicals is the dominant market for IGCC technology worldwide. Power generation is gaining quickly, and represents most of the recent and planned capacity additions. Much of this growth is in gasification-based power generation at oil refineries.

Throughout the United States, there are over 95,000 MWe of existing coal-fired utility boilers that are more than 30 years of age. Many of these plants are without air pollution controls and are candidates for repowering with IGCC. Repowering these plants with IGCC systems would improve plant energy efficiencies and reduce SO_2, NOx, CO_2, and particulate emissions. Similar opportunities exist in foreign markets. The Wabash River CCT Project represents a prime example of repowering an older power plant with IGCC. Gasification is also experiencing increased utilization in refineries, where it can utilize low cost feedstocks like petroleum coke and other bottom-of-the-barrel products to produce power, steam and hydrogen.

IGCCs offer the advantages of modularity, rapid and staged on-line generation capability, high efficiency, flexibility, environmental controllability, and reduced use of land and natural resources. For these reasons, IGCC technology is a strong contender in the market for new electric power generation, and coproduction of power, chemicals and fuels will become increasingly viable in a deregulated market.

Thermal Performance

	Design Coal	Actual Fuel	
		Coal	Petroleum Coke
Throughput, tons/day	2550	2450	2000
Syngas capacity, million Btu/hr	1780	1690	1690
Combustion turbine output, MWe	192	192	192
Steam turbine output, MWe	105	96	96
Parasitic power, MWe	35	36	36
Net power generation, MWe*	262	261	261
Overall thermal efficiency (HHV basis), %	37.8	39.7	40.2

*Failure of a feedwater heater at the combined cycle facility has resulted in less steam available to the steam turbine generator, reducing its output. The net power and thermal efficiency numbers shown in the table are corrected for this abnormal operation.

Conclusions

The Wabash River CCT project has successfully demonstrated commercial application of the E-GAS™ coal gasification process in conjunction with electric power generation. Power production met the target goal of 262 MWe (net). Carbon burnout exceeds 95%, and emissions of SO_2, NOx and particulates are far below regulatory requirements. Overall thermal efficiency is about 20% higher than that of the station prior to repowering.

The Wabash River gasification facility is the largest single-train gasification plant currently in operation in the Western hemisphere. Along with other IGCC projects demonstrated in the CCT Program, it is one of the cleanest coal-based power generation facilities in the world.

Project Milestones

July 1990	Wabash River Joint Venture Project formed by Destec Energy and PSI Energy
May 1991	CCT IV proposal submitted to DOE by Wabash River Joint Venture
September 1991	CCT project selected by DOE
July 1992	Cooperative Agreement awarded
May 1993	Environmental permitting completed
July 1993	Construction started
October 1994	Cinergy Corporation formed, merging PSI with Cincinnati Gas & Electric Co.
August 1995	First gasifier run
November 1995	Construction completed and commercial operation started
February 1996	Achieved 100% capacity
June 1997	Destec Energy purchased by NGC Corporation (renamed Dynegy Inc. in 1998)
September 1998	Completed 14 months of OSHA recordable-free operation
September 1998	Began operation with blended feeds of coal and petroleum coke
December 1999	Dynegy's gasification facility and technology purchased by Global Energy Inc.
December 1999	4 year demonstration completed

Project Accomplishments

- World’s largest commercial single-train coal gasification combined-cycle plant when built.
- Successfully demonstrated IGCC technology to repower a 1950’s-vintage coal-fired power plant. The repowered steam turbine operates as an integral part of the steam cycle.
- Repowering the existing steam turbine involved upgrading to accept increased steam flows. Required modifications to refurbish and boost the capacity of the steam turbine have proven successful.
- Wabash River features the first “F” machine to operate on syngas. Advanced gas turbine design allows for the use of higher firing temperature (2350 °F).
- The hot raw gas is cooled by producing steam at a pressure of up to 1,600 psia, compared with previous operation at about 600 psia.
- Syngas recycle provides fuel and process flexibility while maintaining high efficiency.
- The IGCC system delivers 262 MWe (net) to the Cinergy/PSI grid. Operation on the grid is stable. Successfully operates on baseload dispatch.
- Overall thermal efficiency is 39.7%, which is about 20% higher than the existing station before repowering.
- High-sulfur (2.0 to 3.5 %) bituminous coal and 5.5% sulfur petcoke is used successfully for power generation.
- Use of COS hydrolysis, sour water treatment, and tail gas recycling technologies enables the project to be the cleanest coal-fired power plant in the world.
- Product syngas sulfur content is well below the gas turbine manufacturer’s requirements.
- Acid gas treatment removes over 99% of the sulfur in the syngas, with overall sulfur recovery at better than 97%. Sulfur byproduct is 99.99% pure.
- SO_2 emissions are 0.03-0.10 lb/million Btu, less than one-tenth of the CAAA limit for 2000.
- Fuel gas moisturization reduces steam injection required for NOx control.
- NOx emissions are 0.15 lb/million Btu, meeting the Title I CAAA target for 2003.
- Particulate emissions are less than the detectable limit.
- Sour water treatment and tail gas recycling allow more complete recycling of combustible elements, thereby increasing efficiency and reducing wastewater and emissions.
- Cinergy/PSI employees function as flexible workers. Only one job classification on site. All employees trained to work multiple disciplines.
- Integration of the steam turbine, gas turbine and other systems with Westinghouse WDPF distributed control system and GE Mark V controls was a first in the PSI system.
- An on-site simulator sponsored by EPRI was installed for use in operator and maintenance training.
- Optical pyrometry is used to monitor gas turbine blade temperatures on a real time basis.
- Named to *Power* Magazine’s “Power Plant Hall of Fame.”

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 38 projects located in 18 states with a capital investment value of over $5 billion. DOE's share of the total project costs is about $2 billion, or approximately 34 percent of the total. The projects' industrial participants (i.e., the non-DOE participants) are providing the remainder—nearly $4 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.

Coal Gasification

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

Today, coal gasification is seeing increasing use. In the U.S., a Texaco gasifier is utilized in commercial operation at the Tennessee Eastman chemical plant in Kingsport, Tennessee to produce synthesis gas for production of methanol. The Dakota Gasification plant in North Dakota produces substitute natural gas and chemicals based on an advanced World War II gasification technology.

Overseas, a major chemical and transportation fuel industry exists in The Republic of South Africa, mostly based upon advancements of World War II gasification technologies. An IGCC power plant is in operation in The Netherlands. There are several German gasifiers that are commercially available. Texaco gasifiers are in commercial operation, or planned operation, in the People's Republic of China and other nations.

Advanced gasification and IGCC technology development began in the U.S. in the 1960s, the stimuli being the desire for (1) development of coal-based replacements for natural gas and oil due to shortages and price increases; and (2) more efficient, clean coal-based power plants. Modern 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 first commercial scale use of a gasifier in a U.S. IGCC project was the Cool Water Project in California, which was based upon the Texaco coal gasification technology. The Cool Water Project, which received major support from the U.S. Synthetic Fuels Corporation, Southern California Edison Company, EPRI (formerly the Electric Power Research Institute), and others, was instrumental in proving the feasibility of IGCC, including their exceptional environmental performance.

Gas turbines for power generation have been one of the consequences of jet aircraft engine development. Initially utilized for peaking purposes by utilities, their reliability, efficiency and output have improved to the extent that they now also provide intermediate and baseload electric power. It is projected that gas turbines and IGCCs will contribute significantly to future increases in power generation.

Today's IGCC is efficient because of major improvements that have taken place in coal gasification and gas turbine technologies, and a high degree of system integration that efficiently recovers and uses waste heat.

Gas cleanup in an IGCC power plant is relatively inexpensive compared with flue gas cleanup in conventional coal-fired steam power plants. Smaller equipment is required because a much smaller volume of gas is cleaned. This results from the fact that contaminants are removed from the pressurized fuel gas before combustion. In contrast, the volume of flue gas from a coal-steam power plant is much greater because of the presence of nitrogen diluent from the air and because the flue gas is cleaned at atmospheric pressure.

Atmospheric emissions are very low due to proven technologies for highly effective removal of sulfur and other contaminants from the syngas. Advancements being demonstrated in the CCT program are expected to result in still better efficiencies.

Bibliography

Comprehensive Report to Congress, "Wabash River Coal Gasification Repowering Project," proposed by Wabash River Coal Gasification Project Joint Venture, June 1992.

D.G. Sundstrom, "The Wabash River Coal Gasification Repowering Project," *First Annual Clean Coal Technology Conference* (Cleveland OH), September 1992.

P. Amick et al., "Wabash River Coal Gasification Repowering Project," *Twelfth Annual Gasification and Gas Stream Cleanup Conference* (Morgantown WV), September 1992.

Clean Coal Today, "Promise of Coal Gasification Power Draws 400 Representatives to Wabash River Site," p. 4, Summer 1993.

P. Amick and J. Cook, "The Wabash River Coal Gasification Repowering Project Update," *Second Annual Clean Coal Technology Conference* (Atlanta GA), September 1993.

Clean Coal Today, "Largest U.S. Single Train IGCC Facility," pp. 4–5, Winter 1993/1994.

J.J. Cook and L.A. Lednicky, "The Wabash River Coal Gasification Repowering Project—An Investment in the Future," *Third Annual Clean Coal Technology Conference* (Chicago IL), September 1994.

P.A. Pritchard and G.J. Starheim, "Turbine Developments for IGCC Applications," *Eleventh Annual International Pittsburgh Coal Conference* (Pittsburgh PA), v. 2, pp. 1543–1550, September 1994.

U.S. Department of Energy, Wabash River Coal Gasification Repowering Project, Public Design Report, DOE/MC29310-5260, July 1995.

M.R. Woodruff, "Wabash River Project Moves into Commercial Operation," *Fourth Annual Clean Coal Technology Conference* (Denver CO), September 1995.

Clean Coal Today, "O'Leary Heralds Wabash Startup," pp. 1–2, Winter 1995/1996.

Clean Coal Today, "Wabash Plant Begins Operating," pp. 1–3, Spring 1996.

"Startup of Large-Scale Projects Casts Spotlight on IGCC," *Power*, June 1996.

"Compare Air-Blown to Oxygen-Blown Gasification," *Power*, June 1996.

E.J. Troxclair et al., "Wabash River Coal Gasification Repowering Project—Early Commercial Operating Experience," *Thirteenth Annual International Pittsburgh Coal Conference* (Pittsburgh PA), v. 1, p. 436, September 1996.

"Wabash Proves Out Next-Generation Gasifier, Next-Century Power Plant," *Power*, pp. 34–40, September/October 1996.

Topical Report No. 7, "The Wabash River Coal Gasification Repowering Project," U.S. DOE, November 1996.

E.J. Troxclair and J. Stultz, "Wabash River Coal Gasification Repowering Project—First Year Operation Experience," *Fifth Annual Clean Coal Technology Conference* (Tampa FL), January 1997.

"Clean Coal Technology Breakthroughs are Expected to Keep Coal a Viable Option," *Power Engineering*, May 1997.

"IGCC Technology Offers Fuel Diversity, Coproduction for Competitive Generation," *Power Engineering*, September 1997.

"IGCC Offers Diversity for Competitive Generation," *Power Engineering*, November 1997.

C.G. Keeler and J. Stultz, "Operating Experience at Wabash River Coal Gasification Repowering Project," *Sixth Clean Coal Technology Conference* (Reno NV), April 1998.

"Preparing for the Millennium," *Power Engineering*, November 1998.

S.L. Douglas, "Wabash River in its Fourth Year of Commercial Operation," *Seventh Clean Coal Technology Conference* (Knoxville TN), June 1999.

C.G. Keeler, "Wabash River in its Fourth Year of Commercial Operation," *1999 Gasification Technology Conference* (San Francisco CA), October 1999.

"IGCC Gathers Pace," *Power Engineering*, November 1999.

U.S. Department of Energy, Energy Information Administration, "Annual Energy Outlook 2000 with Projections to 2020," December 1999.

"Cleaning Up on Economics," *Power Engineering*, December 1999.

U.S. Department of Energy and the Gasification Technologies Council, "Gasification—Worldwide Use and Acceptance," January 2000.

"Merchant Power Projects Push for Competitive Edge," *Power*, pp. 32-39, January/February 2000.

Clean Coal Today, "Wabash River Coal Gasification Repowering Project Completes Fourth Year of Commercial Operation," pp. 1-3, Spring 2000.

P. Amick, "Commercial Operation of the Wabash River Coal Gasification Repowering Project," *Electric Power 2000* (Cincinnati OH), April 2000.

U.S. Department of Energy, "Clean Coal Technology Demonstration Program, Program Update," April 2000.

Wabash River Coal Gasification Repowering Project—Final Technical Report, September 2000.

Contacts for CCT Projects and U.S. DOE CCT Program

Participant Contact

Phil Amick
Vice President, Commercial Development
Global Energy Inc.
1000 Louisiana St., Suite 1550
Houston TX 77002
(713) 374-7252
pramick@globalenergyinc.com

U.S. Department of Energy Contacts

Victor Der
Director, Office of Power Systems
U.S. Department of Energy, FE-24
Germantown MD 20874-1290
(301) 903-2700
(301) 903-2713 *fax*
victor.der@hq.doe.gov

Leo E. Makovsky
Project Manager
National Energy Technology Laboratory
P.O. Box 10940
Pittsburgh PA 15236-0940
(412) 386-5814
(412) 386-4775 *fax*
leo.makovsky@netl.doe.gov

To Receive Additional Information

To be placed on the Department of Energy's distribution list for future information on the Clean Coal Technology Program, the demonstration projects it is financing, or other Fossil Energy Programs, please contact:

Robert C. Porter
Director, Office of Communication
U.S. Department of Energy, FE-5
1000 Independence Ave SW
Washington DC 20585
(202) 586-6503
(202) 586-5146 *fax*
robert.porter@hq.doe.gov

Otis Mills Jr.
Public Information Office
U.S. Department of Energy
National Energy Technology Laboratory
P.O. Box 10940
Pittsburgh PA 15236-0940
(412) 386-5890
(412) 386-6195 *fax*
otis.mills@netl.doe.gov

This report is available on the Internet at U.S. DOE, Office of Fossil Energy's home page: www.fe.doe.gov and on the Clean Coal Technology Compendium home page: www.lanl.doe.gov/projects/cctc

List of Acronyms and Abbreviations

Btu	British thermal unit
CAAA	Clean Air Act Amendments of 1990
CCT	Clean Coal Technology
CH_4	methane
CO	carbon monoxide
CO_2	carbon dioxide
COS	carbonyl sulfide
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
EPRI	formerly the Electric Power Research Institute
HRSG	heat recovery steam generator
H_2S	hydrogen sulfide
IGCC	integrated gasification combined-cycle
kWh	kilowatt hour
LGTI	Louisiana Gasification Technology, Inc.
LPMEOH™	Liquid Phase Methanol process
MWe	megawatts of electric power
MWh	megawatt hour
MWth	megawatts of thermal power (1 MWth = 3.413×10^6 Btu/hr)
ND	non-detectable
NETL	National Energy Technology Laboratory
NH_3	ammonia
NOx	nitrogen oxides
NSPS	New Source Performance Standards
O_2	oxygen
PM	particulate matter
ppmv	parts per million by volume
psia	pressure, pounds per square inch (absolute)
psig	pressure, pounds per square inch (gauge)
SO_2	sulfur dioxide
syngas	synthesis gas
vol %	percent by volume
wt %	percent by weight