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CLEAN COAL TECHNOLOGY

The Tampa Electric Integrated Gasification Combined-Cycle Project

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Demonstration of an Advanced 250 Megawatt Integrated Gasification Combined-Cycle Power Plant

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

The U.S. Department of Energy and Tampa Electric Company

Cover image: The Polk Power Plant site as seen from across the lake in early evening.
Photography courtesy of Lee Schmoe, Bechtel Power Corporation.

TAMPA ELECTRIC
A TECO ENERGY COMPANY

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CLEAN COAL

TECHNOLOGY

The Tampa Electric Integrated Gasification Combined-Cycle 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 ($S0_2$).

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 modem coal gasification with gas turbine and steam power generation technologies. Syngas 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 (C02) 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 applications could provide the flexibility needed for utility compliance planning for sulfur dioxide ($S0_2$) emissions in the next century. Providing 25 percent of coal-based electricity by IGCC would result in emissions less than 0.4 million of the 11.8 million tons/yr of $S0_2$ emissions 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 and nitrogen injections. Other contributors to reduced capital costs are: economies of scale, reduced engineering costs, and improvements resulting from operating experience.

Executive Summary

The Tampa Electric Integrated Gasification Combined-Cycle Project (the Project) was selected by DOE as a CCT Program Round III demonstration project. Demonstration of this advanced IGCC power plant was initiated in October, 1996.

The Participant is Tampa Electric Company (TEC), headquartered in Tampa, Florida. TEC signed a Cooperative Agreement with DOE to conduct the Project in July 1992. Its service area includes the city of Tampa and covers a 2000 square mile area in west-central Florida.

The greenfield site is located south of Lakeland, Polk County, Florida. The Project is demonstrating use of Texaco's coal gasification process to fuel an advanced General Electric gas turbine generator whose exhaust is integrated with a heat recovery steam generator (HRSG) and a steam turbine generator to produce electric power.

About 96 percent of sulfur contaminants are removed by a combination of advanced hot-gas cleanup and conventional cold-gas cleanup technologies. Ninety percent of the gasification product gas, termed syngas, is cleaned by cold-gas cleanup and 10 percent by hot-gas cleanup. Sulfur is recovered as sulfuric acid and sold, as is the slag by-product of gasification.

TEC is demonstrating an advanced moving bed hot-gas desulfurization technology because of its potential for improving IGCC performance and costs.

A primary potential advantage of hot-gas cleanup is an increase in power plant efficiency because cleaning does not require the syngas to be cooled to near-ambient temperature (used for cold-gas cleanup) and resultant energy losses are eliminated. Further, there is no process waste water condensate.

The hot moving bed desulfurization system being demonstrated in this Project captures residual dust contained in the fuel gas, and downstream sintered metal barrier filters capture the balance.

In contrast to cold-gas cleanup, the hot-gas cleanup technologies have not yet been commercially demonstrated.

The combined cycle unit is based on an advanced General Electric gas turbine unit that produces 192 MWe. The steam turbine produces 121 MWe. Parasitic power consumes 63 MWe with the net power output being 250 MWe.

The demonstration also includes integration of nitrogen from the air separation plant with the gas turbine. Steam produced at various gas cooling stages is integrated with the HRSG and supplies various process needs. The facility processes approximately 2300 tons per day of Pittsburgh No. 8 bituminous coal, with a sulfur content of 2.5—3.5 percent.

$S0_2$ emissions will be 0.21 lb/million Btu input; NO_X emissions will be 0.27 lb/million Btu input. The design heat rate of the plant is an impressive 8600 Btu/kWh (40 percent net thermal efficiency) on a higher heating value basis. The cost of the Project including land acquisition, site development and allowance for funds used during construction (AFUDC) is about $506 million. DOE is providing about $142 million.

The first two-year demonstration period began in October, 1996 and will involve testing four Eastern U.S. bituminous coals. The following two-year period will involve continued development of operating/maintenance and reliability data on fuels selected by TEC.

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 $C0_2$ Emissions
- Public Acceptability

The Tampa Electric Integrated Gasification Combined-Cycle Project

Background

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 United States, Texaco's gasification technology is utilized at Eastman Chemical's Kingsport, Tennessee facility. The product is a synthesis gas for production of methanol. The Dakota Gasification plant in North Dakota produces synthetic 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. about 25 years ago, 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.

Modem IGCC technology is a response of the 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 turbine exhaust produces steam to generate additional electricity.

Texaco coal gasification technology stems from its partial oxidation technology that was developed following World War II, in which natural gas and refinery bottoms were partially oxidized at high temperatures to produce a synthesis gas for refinery use.

The first commercial scale use of a Texaco gasifier in a U.S. IGCC project was the Cool Water project. This project received major support from the U.S. Synthetic Fuels Corporation, Southern California Edison Company, U.S. DOE, Electric Power Research Institute, Bechtel Power Corporation, and others. The Cool Water project was instrumental in proving the feasibility of IGCC, including its exceptionally good performance in reducing atmospheric emissions.

Gas turbines for power generation have been one of the outgrowths of jet aircraft engine development. At the end of 1994, gas turbines contributed about 12 percent (59,600 MWe) of the fossil fuel-based generating capability of U.S. electric utilities. Gas turbine generation capability increased by 23 percent over the period 1990-1994 even though the total fossil-based generation capability increased by only one percent.

The Texaco gasifier is in the largest structure, which also contains the radiant syngas cooler. The hot gas cleanup system is installed in the smaller of the two large structures. In the foreground is the air separation unit.

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. Still more efficient models are expected to be available in the near future.

DOE projects that, over the period of 1994-2015, the proportion and amount of gas turbine and combined-cycle based generation will increase. These will constitute 78 percent (197,000 MWe) of the projected total new capacity of utility plus non-utility generators (252,000 MWe).

IGCC technologies demonstrated in the CCT program are expected to provide a significant share of this new 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.

Atmospheric emissions are low due to the availability of proven technologies for highly effective removal of sulfur and other contaminants from the fuel gas.

The sulfuric acid plant is located in the foreground and the gasifier and radiant syngas cooler are in the tall midground structure.

Project Benefits

The Tampa Electric Integrated Gasification Combined-Cycle Project is expected to demonstrate very low environmental impacts and will be one of the most efficient power plants operating in the United States.

The 250 MWe output of the power plant will help Tampa Electric Company (TEC), the participant in this project with the U.S. Department of Energy (DOE), meet its customers' needs and provide low-cost base load power. Benefits will be realized by both the customers and the environment—customers through low-cost reliable power and the environment because of very low emissions and relatively low use of natural resources.

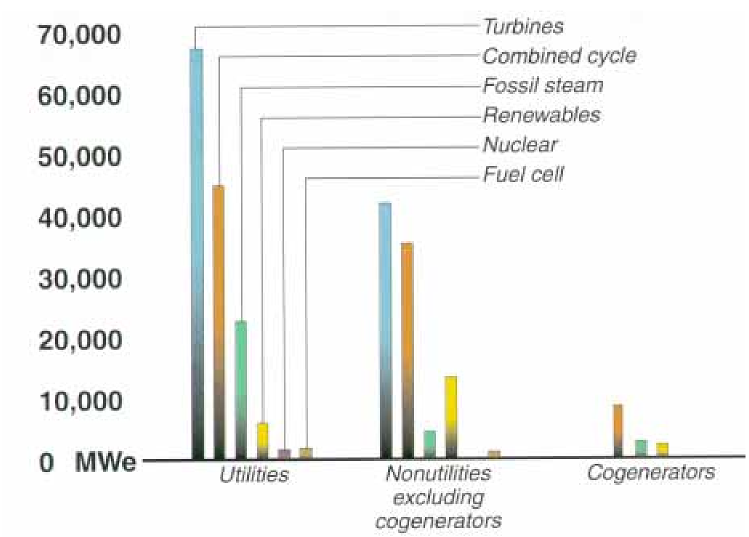
A successful demonstration will help to provide the impetus for future use of IGCC technology throughout the U.S. The Project participants will benefit through sales and licensing of their products.

The Project will also benefit the local area. Approximately 1500 acres of the plant site have been converted by TEC from phosphate mining spoils to wetlands and uplands. The restoration provides habitat for native plants and animals.

A peak total of 1400 construction jobs were created, and 75 full-time new jobs were created for operation and maintenance of the IGCC power plant. Contract labor is utilized as required for additional maintenance.

There are new jobs for coal truck drivers, and other secondary employment related to plant operation. The economy will benefit through payment of as much as $7.0 million per year in additional taxes by TEC.

New Generating Capacity Forecast 1994-2015



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Source: U.S. Energy Information Administration, 1996

Project Description

Project Participant

TEC is an investor owned electric utility headquartered in Tampa, Florida. It is the principal wholly owned subsidiary of TECO Energy, Inc., an energy related holding company heavily involved in coal transportation and power generation.

TEC presently has about 3400 MWe of generating capacity, about 99 percent from coal-fired units. TEC serves an area of about 2000 square miles in west central Florida. TECO Power Services (TPS), another subsidiary of TECO Energy, operates a 295 MWe natural gas fired combined cycle power plant in Florida, with the electric power being sold under long-term power sales agreements.

TPS developed the Project and has been performing project management throughout. Under terms of the Cooperative Agreement TPS plans to commercialize the Project IGCC

Major Participants

TEC has selected major technology suppliers for this project that are experienced and successful in their respective industries. They include Texaco Development Corporation, as the licensor of the coal gasification technology and related services; Bechtel Power Corporation, for detailed engineering, procurement, start-up and construction management; General Electric, as the supplier of combined cycle equipment; and GE Environmental Services, Inc., designer of the hot-gas cleanup system.

Site Description

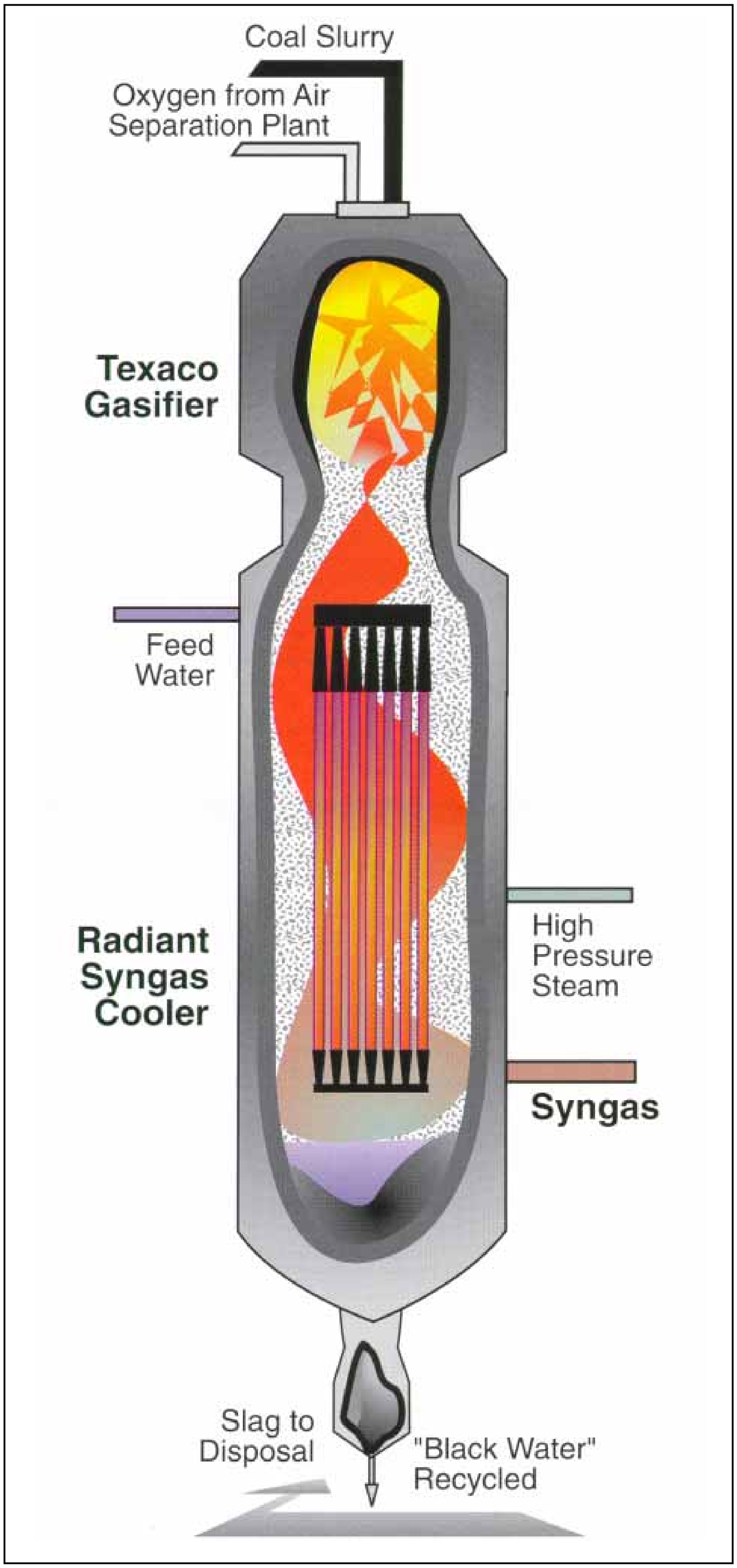
The Project is Unit I of the new Polk Power Plant, located in south central Polk

IGCC Inputs and Outputs

Inputs	Quantity, tons/day
Coal	2000
Oxygen	1974
Slurry water (recycled)	884
Nitrogen to gas turbine	6024
Solids Output	
Slag/fines from dewatering pit	311
Dry solids from brine concentrator	2.8
98% Sulfuric Acid	218
Net Electrical Output	250 MWe

Major Participants

Tampa Electric Company	Owner/operator
TECO Power Services Corporation	Project management and commercialization
Texaco Development Corporation	Licensor of gasification technology
General Electric Corporation	Supplier of gas turbine/combined cycle equipment
GE Environmental Services, Inc.	Designer of hot-gas cleanup system
Bechtel Power Corporation	Detailed engineering/construction management services, procurement, and startup
MAN Gutehoffnüngshutte AG	Supplier of radiant syngas cooling system
L. & C. Steinmbller Gmbh	Supplier of convective syngas cooling system
Air Products & Chemicals, Inc.	Turnkey supplier for air separation unit
Monsanto Enviro-Chem Systems, Inc.	Turnkey supplier for sulfuric acid plant
H.B. Zachry Company	Power block construction
The Industrial Company	Gasification area construction
Johnson Brothers Corporation	Site development and civil contractor
Aqua-Chem, Inc.	Supplier of brine concentration plant
Davenport Mammoet Heavy Transport	Transportation/erection of radiant syngas cooler



A single Texaco gasifier processes 2000 tons per day of coal at about 2500-2700°F (1371°-1482°C) to produce a raw syngas and molten slag. The gas flows downward into the radiant syngas cooler where it is partly cooled and high pressure steam for power generation is produced. Slag is collected in a water pool at the bottom of the radiant syngas cooler and removed.

County, central Florida. The 4348 acre site is located about 45 miles southeast of Tampa and 17 miles south of Lakeland in the heart of central Florida's phosphate mining region.

The Polk site is on a tract of land that was previously mined for phosphate rock and has been redeveloped and revegetated by TEC for this project.

The site area is predominantly rural. Polk County is an important citrus-raising and phosphate mining center, each being important Florida industries.

About a third of the site is used for power generation facilites. Another third is used to enhance the environment by creation of public fishing lakes for the Florida Fish and Game Commission. Transfer of these 1511 acres is expected to take place before April 1997. The final third of the site is primarily for access and providing a visual buffer.

The site contains an 850 acre cooling reservoir. State Highway 37 crosses the site about one mile from the IGCC power plant.

Power Plant Description

The Project is demonstrating advanced IGCC technology for production of 250 MWe in a commercial, electric utility environment on a greenfield site. It is demonstrating the integrated performance of a Texaco gasifier, metal oxide hot-gas cleanup system, conventional cold-gas cleanup, and an advanced gas turbine with nitrogen injection (from the air separation plant) for power augmentation and NO_X control.

Makeup water for the power plant is provided from on-site wells. All process water is recycled.

Texaco gasifier

Coal is delivered to the site by truck from a transloading facility at TEC's Big Bend Station in Apollo Beach, Florida. Once on site, the coal is conveyed from coal silos and fed to the grinding mill with recycled process water and makeup water from on-site wells.

The project gasifies about 2000 tons per day of coal in a single gasifier. The Texaco gasifier has been commercially proven in several applications and the scaleup, of less than a factor of two, to this throughput is not considered to pose a high level of risk.

Coal is slurried in water, and reacted in the gasifier with 95 percent pure oxygen (from the air separation unit) to produce a high temperature, high pressure, medium-Btu synthesis gas, also known as syngas.

The raw syngas is partly cooled by a high temperature radiant heat recovery unit prior to subsequent cooling stages. Molten coal ash flows from the bottom of the radiant syngas cooler into a water-filled quench chamber where it solidifies into a marketable slag by-product. The slag has been found by the U.S. Environmental Protection Agency (EPA) to be non-leaching.

After additional cooling of the raw syngas stream in parallel convective heat exchangers the stream is split into streams for both hot- and cold-gas cleanup to remove sulfur compounds and other contaminants.

Cold-gas cleanup

Cold-gas clean-up is the primary method because the specific technologies utilized are proven effective, reliable and commercially available.

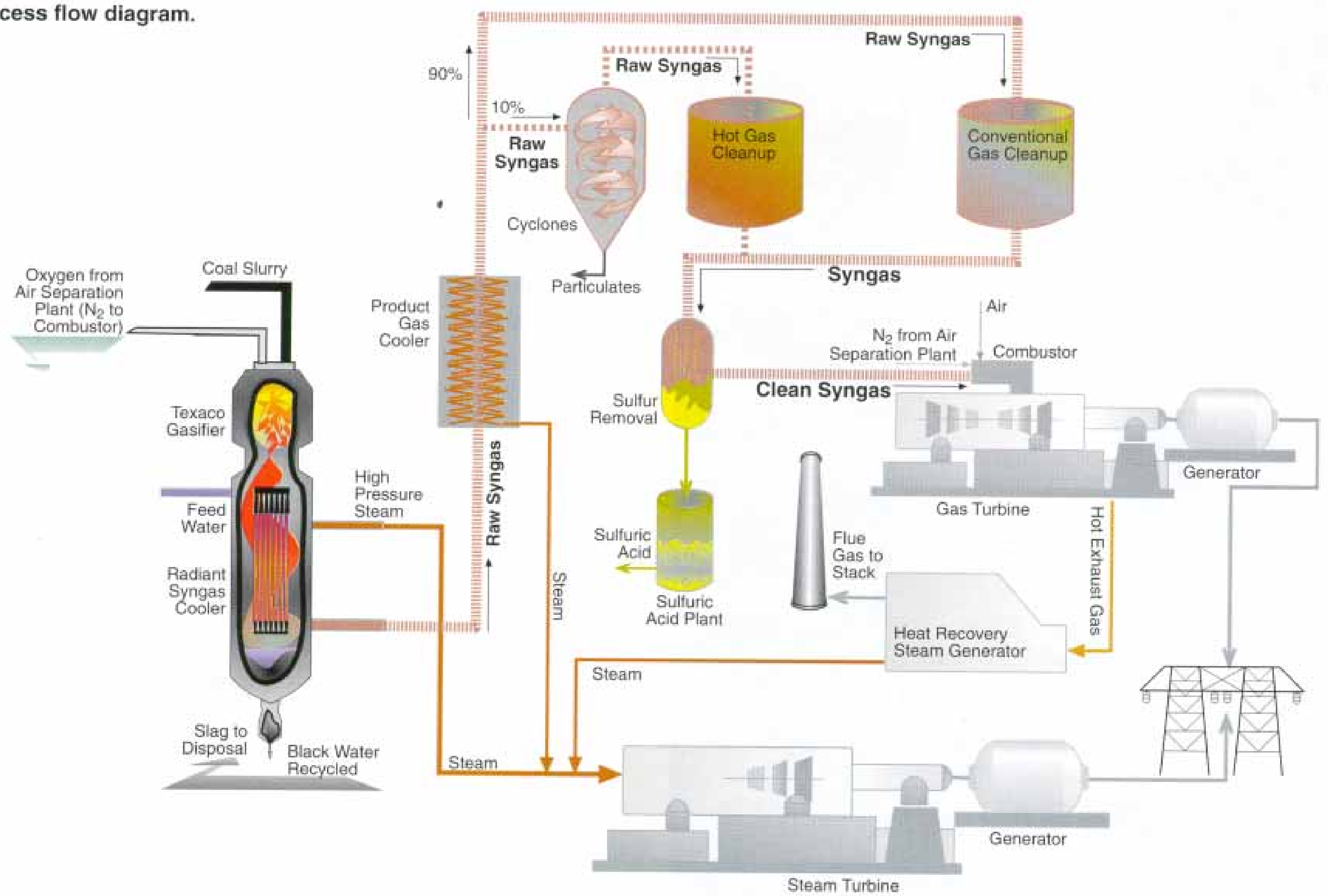
Ninety percent of the syngas is cleaned by the cold-gas cleanup, but the system is designed to accommodate the full production of syngas if performance of the hot-gas cleanup system is unacceptable.

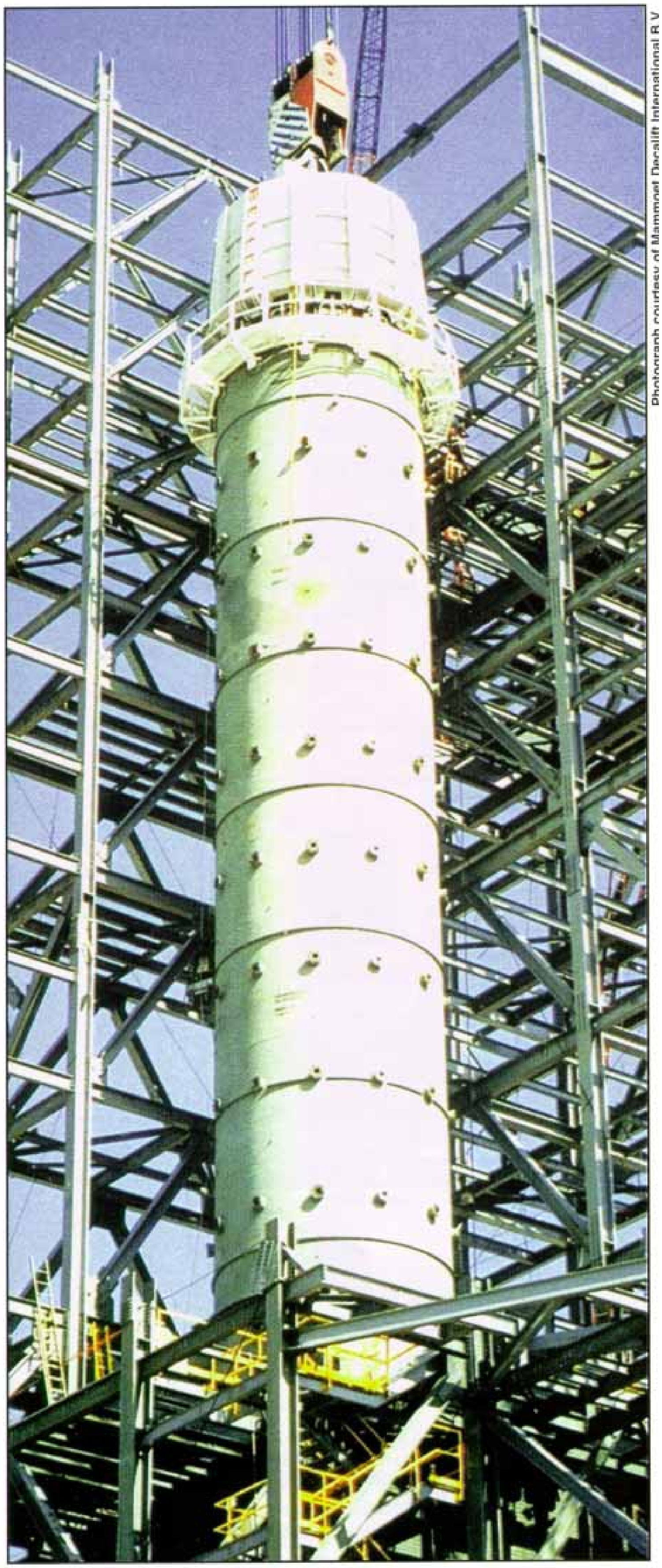
Typical Coal Analysis (Pittsburgh No. 8 Seam)

Ultimate Analysis As-Received, wt%	
Moisture	4.74
Carbon	73.76
Hydrogen	4.72
Nitrogen	1.39
Chlorine	0.10
Sulfur	2.45
Ash	7.88
Oxygen	4.96
Total	**100.0**

As-Received Higher Heating Value, Btu/lb 13,290

Process flow diagram.





Installation of radiant syngas cooler.

The raw hot syngas is cooled to 100°F for cold-gas cleanup by conventional acid gas removal technology. This portion of the plant is based upon absorption of H_2S by a liquid amine compound and is capable of processing 100 percent of the syngas produced by the gasifier. Steam stripping removes the absorbed H_2S which then flows to the sulfuric acid plant.

Hot-gas cleanup

The potential advantage of hot-gas cleanup is that it increases overall power plant thermal efficiency because energy losses in cooling the syngas to near ambient temperature (used for cold-gas cleanup) are eliminated. Costs are reduced compared to cold-gas cleanup because less gas cooling and other process equipment is needed.

To evaluate these potential benefits, TEC included hot-gas cleanup to clean 10 percent of the syngas. GE Environmental Services' advanced intermittently moving bed hot-gas cleanup system is utilized. This technology and the sorbents used show important promise but are not yet proven in commercial operation.

In the hot-gas cleanup system, the syngas first passes through two cyclones to remove entrained dust. Sodium bicarbonate ($NaHCO_3$) is added before the second cyclone to capture trace amounts of chlorides and fluorides in the syngas for protection of gas turbine components.

The hot-gas desulfurization unit operates at 900°F (482°C). It is an intermittently moving bed of a metal oxide based sorbent that removes sulfur-containing compounds (mainly hydrogen sulfide [H_2S]) and residual dust in the syngas.

Regeneration of the metal sulfides produced by syngas desulfurization takes place in a separate vessel utilizing oxygen and nitrogen. The original metal oxide is restored and the product sulfur dioxide ($S0_2$) flows to the sulfuric acid plant.

This is the first unit to demonstrate advanced moving bed metal oxide hot-gas desulfurization technology on a commercial scale.

Power island

Combined, the cleaned syngas streams have a heating value of about 265 Btu per standard cubic foot (higher heating value basis). It is sent to the advanced General Electric model MS 7001F gas turbine of the combined cycle power island where it is burned. About 192 MWe of electric power is produced. The pressure of the gasifier was selected to match the inlet pressure requirement of the gas turbine.

Nitrogen from the air separation unit (at 98 percent purity) is mixed with the syngas at the gas turbine combustor to give the following benefits to the power plant: (1) the enhanced mass flow through the gas turbine produces more power than without the nitrogen; (2) the overall efficiency of the system is enhanced; and (3) low levels of NO_X emissions are obtained.

Hot exhaust from the gas turbine unit passes through a heat recovery steam generator (HRSG) where three pressure levels of steam are produced. The majority of the steam is at high pressure and, with high pressure steam produced in the gasification stage, drives a reheat steam turbine-generator to produce about 121 MWe. Flue gas exits through a 150 foot stack. A flare is provided to dispose of syngas produced during startup, shutdown, and during transient operations.

Power consumption within the facility is 63 MWe, resulting in a net power output of 250 MWe.

The net power plant heat rate is an impressive 8600 Btu/kWh (about 40 percent efficiency), higher heating value basis. A 230 kV, five-mile transmission line connects the power plant to the TEC grid.

Simplified Chemistry

TEXACO GASIFIER

$$C\ (coal) + O_2 \xrightarrow{2700°F} CO_2 + Heat$$

$$C\ (coal) + H_2O\ (steam) \xrightarrow{2700°F} CO + H_2$$

HOT GAS CLEANUP

Desulfurization

$$\underset{(metal\ oxide)}{MO} + H_2S \xrightarrow{900°F} \underset{(metal\ sulfide)}{MS} + H_2O$$

$$MO + COS \xrightarrow{900°F} MS + CO_2$$

Regeneration

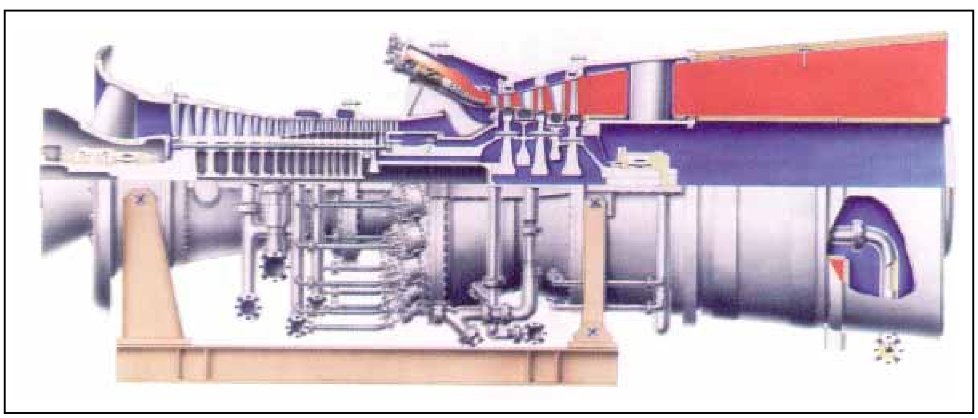
$$MS + 1.5\ O_2 \xrightarrow{1200°F} MO + SO_2$$

Other operations

The sulfuric acid plant converts the SO_2 and H_2S from the hot- and cold-gas cleanup systems to sulfuric acid which is sold in the sulfuric acid trading market. Production is about 200 tons per day.

A brine concentration unit processes a blowdown stream discharged from the process water systems and discharges a reusable water stream for slurry preparation and salts which will be marketed or disposed of in a permitted landfill.

General Electric model MS 7001F gas turbine



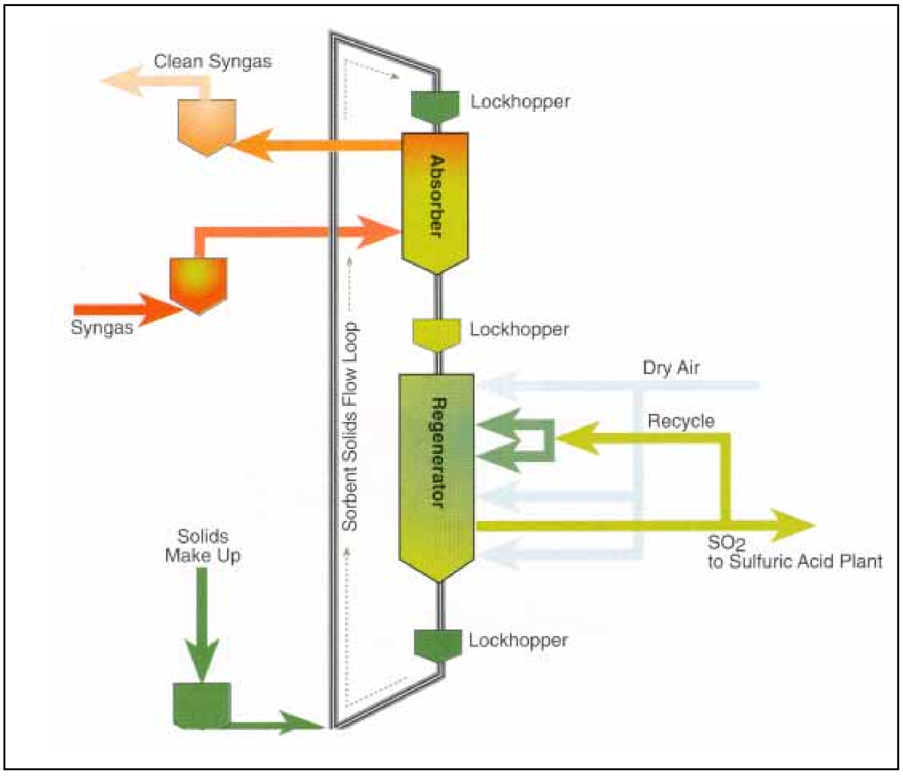
Cleaned Syngas Composition

Delivered to Gas Turbine, Volume %

Constituent	*Hot-Gas Cleanup*	*Cold-Gas Cleanup*
Carbon monoxide	35.6	48.3
Hydrogen	27.0	33.8
Carbon dioxide	12.6	10.0
Methane	0.1	0.2
Water	18.6	0.5
Nitrogen	5.8	6.1
Argon	0.0	1.1
Hydrogen sulfide	94.0 ppmv	8.4 ppmv
Carbonyl sulfide	0.0	127.0 ppmv
Ammonia	0.1 ppmv	0.0 ppmv

About 10 percent of the syngas is cleaned by hot-gas cleanup and up to 100 percent by cold-gas cleanup.

General Electric Intermittent Moving Bed Hot Gas Desulfurization System.



Process Description

Texaco Gasification

Texaco coal gasification technology uses a single-stage, downward-firing, entrained-flow coal gasifier in which a coal/water slurry (60-70 percent coal) and 95 percent pure oxygen are fed to a hot gasifier. At a temperature of about 2700°F (1482°C), the coal reacts with oxygen to produce raw fuel gas (syngas) and molten ash.

The hot gas flows downward into a radiant syngas cooler where high pressure steam is produced. The syngas passes over the surface of a pool of water at the bottom of the radiant syngas cooler and exits the vessel. The slag drops into the water pool and is fed from the radiant syngas cooler sump to a lockhopper.The radiant syngas cooler is about 17 feet in diameter, 100 feet long, and weighs about 900 tons. The "black" water flowing out with the slag is separated and recycled after processing in the dewatering system.

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 contaminants are removed from the pressurized fuel gas before combustion. In contrast, the volume of flue gas from a coal-steam power plant is 40–60 times greater because the flue gas is cleaned at atmospheric pressure.

Cold-Gas Cleanup

The raw syngas exiting the radiant syngas cooler is first sent to parallel convective syngas coolers. Ninety percent of the syngas flows to the cold-gas cleanup system where it is first treated in water scrubbers for removal of entrained solids and the gas then flows to the low temperature syngas cooling system. The scrubber bottoms are routed to the "black" water handling system where the solids are separated. The effluent is concentrated and crystallized as a solid form that is shipped off-site either for reuse or disposal in a permitted landfill. The separated water is recycled for slurry coal feed.

The particulate-free gas is water-washed to remove contaminants that would degrade the sorbent in the absorber. The wash water is sent to the ammonia stripper. The washed syngas flows to the amine absorber where the H_2S and some of the CO_2 (acid gases) are absorbed. The "rich" amine is stripped of acid gas in the stripper. The amine is recycled and the separated acid gas is routed to the sulfuric acid plant.

The cold-gas cleanup system is designed to accept 100 percent of the raw syngas.

Hot-Gas Cleanup

This unit is designed to handle 10 percent of the hot, raw syngas. Entrained fine particles in the hot syngas are removed in the primary cyclone and sent to the "black" water handling system. The exiting gas is injected with sodium bicarbonate and then enters a secondary cyclone where halogen compounds (primarily chlorides and fluorides) in the gas are chemically absorbed. Halogens are removed to minimize corrosion of the gas turbine. Solids collected from the second cyclone are sent off-site for disposal in a permitted landfill and the gas flows to the absorber.

A large fraction of any remaining particulate matter entering the absorber is captured by the bed of mixed metal oxide sorbent.

The absorber is an intermittently moving bed reactor. Syngas, containing H_2S and carbonyl sulfide (COS), enters the bottom of the absorber and flows countercurrent to the moving bed of sorbent pellets. The sulfur compounds react with sorbent to form metal sulfides. Syngas exiting the absorber is expected to contain a maximum of 30 parts per million of H_2S and COS.

Regeneration of the spent sorbent is important to avoid excessive sorbent replacement costs. In this part of the hot gas cleanup process the sulfide is converted back to the oxide.

Sulfided sorbent is fed from the absorber lockhopper to the top of the regenerator where oxidation occurs. The sorbent moves down the regenerator in concurrent flow with the regeneration gas.

Temperature control is important to prevent damage to the sorbent structure at temperatures that are too high. Conversion of metal sulfide to the inactive sulfate occurs at temperatures that are too low.

The final regeneration step occurs at the lower stage of the regenerator where nitrogen flows countercurrent to the sorbent. This stream cools the sorbent, purges the SO_2-rich off gas and ensures complete regeneration without sulfate formation

Recycled regenerator effluent gas is used as a diluent for air to control the temperature by means of a heat exchanger in the loop. Steam is generated and utilized in the combined cycle unit. A small amount of sorbent fines is entrained in the gas stream and collected in a high efficiency barrier filter that removes fines larger than five microns (99.5 percent removal of particulates). Collected solids are sent offsite for disposal.

Larger sorbent particles entrained in the gas stream are collected on screens at the regenerator sorbent outlet; fugitive fines from the screens are collected in a small baghouse.

Combined Cycle Power Generation

The gas turbine is a General Electric model MS 7001F, designed for low-NO_X emissions when firing sygnas and with low sulfur fuel oil that is used for startup and backup. Rated output from the hydrogen cooled generator on syngas is 192 MWe. The gas turbine is an advanced turbine that has been proven in a utility environment.

Nitrogen is used as a syngas diluent to reduce NO_X formation and also to increase mass flow, resulting in a higher gas turbine power output.

The HRSG is a three-pressure design with natural circulation and reheat. The steam turbine is a double flow reheat unit with low pressure extraction. Nominal steam inlet conditions are 1450 psig and 1000°F with 1000°F reheat temperature. Expected generator output during normal operation is 121 MWe.

Air Separation Unit

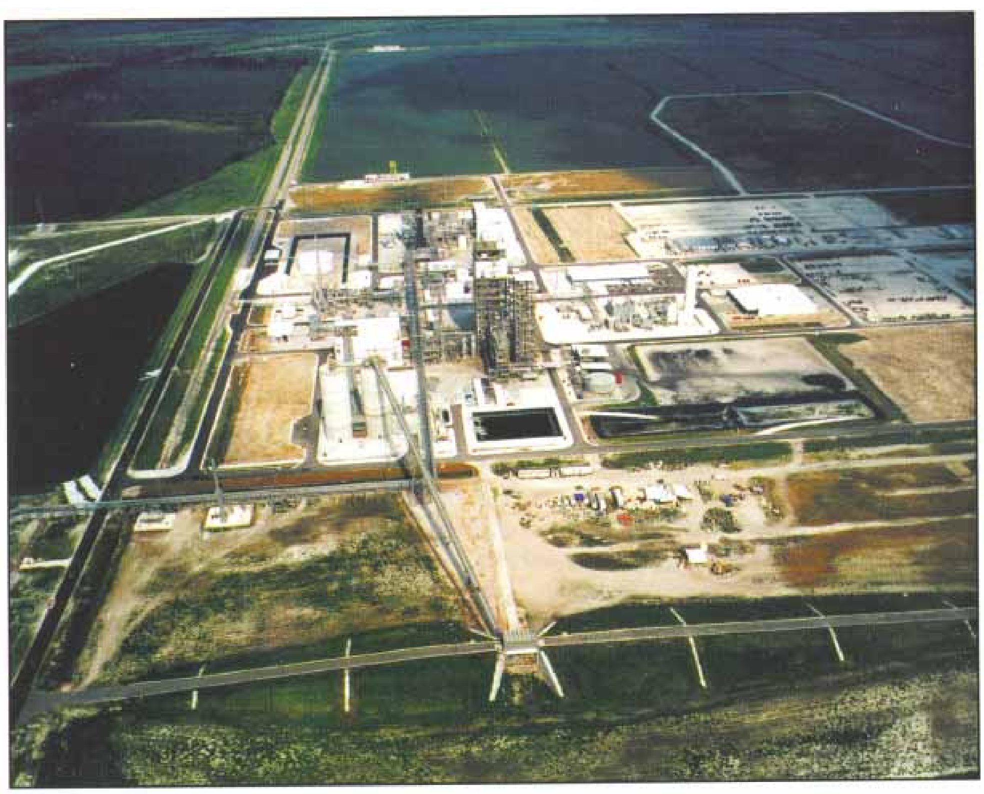
The air separation unit provides 95 percent pure oxygen for the gasifier operation, and warmed compressed nitrogen for the gas turbine. Low pressure 95 percent oxygen is also supplied to the sulfuric acid plant.

Sulfuric Acid Plant

In the sulfuric acid plant, the sulfur containing gases from the hot- and cold-gas cleanup systems are converted to 98 percent sulfuric acid for sale to the local Florida fertilizer industry. The H_2S from the cold-gas cleanup unit is combusted to SO_2 and mixed with hot gases containing SO_2 from the hot-gas cleanup unit. The combustion product gas stream, which also contains sulfur trioxide ($S0_3$) and sulfuric acid (H_2SO_4), is cooled.

The gas is converted to 98 percent H_2SO_4 (about 200 tons per day are produced) after passing through three catalyst beds charged with vanadium pentoxide catalyst. Oxygen is utilized for conversion of SO_2 to SO_3 in the process. After separation of H_2SO_4, the concentration of SO_2 remaining in the gas stream is low enough to permit direct discharge to the atmosphere through a 200 foot stack.

Polk Site before (above) and after (below) construction.



Environmental Considerations

The Tampa Electric Integrated Gasification Combined-Cycle Project is designed to have low environmental impacts. Emissions to the atmosphere are low because they are controlled by technologies that are very effective.

The site was selected by an independent Community Siting Task Force, commissioned by TEC. Members included environmentalists, educators, economists, and community leaders. Environmental impact was a primary driver in the choice of acceptable sites for the plant. Economic factors were also considered. The Task Force considered 35 sites in six counties and recommended three in southwestern Polk County that had previously been mined for phosphate.

The U.S. Environmental Protection Agency (EPA), the lead federal agency, issued the final Environmental Impact Statement for this project in June, 1994. Favorable records of decision were issued by EPA, U.S. Army Corps of Engineers, and DOE by August, 1994. Some of the inputs for this comprehensive document were provided by TEC and its environmental consultants .

All federal, state, and local environmental permits have been obtained. An Environmental Monitoring Plan developed by TEC gives details of the performance monitoring of environmental control equipment, stack emissions, and also for the site and surrounding area.

Costs/Schedule/ Demonstration Milestones

The estimated cost of the Tampa Electric Integrated Gasification Combined-Cycle Project including the operation and testing phase is approximately $506 million. DOE is providing about $142 million.

Work on the project was initiated with the completion of an agreement between TEC and DOE in July 1992. Site, environmental and permitting, engineering, procurement and construction activities were completed since then. Groundbreaking took place in November, 1994, and the facility was released to operations in October 1996.

The four-year demonstration program began in October, 1996. Data are being gathered on power plant performance, including environmental performance. Operation will be on four Eastern U.S. bituminous coals. Data will be collected involving systems performance and operating and maintenance costs. Information on startup, shut down and ramp rates will be gathered and evaluated. Behavior of the gas cleanup systems will be established and emissions monitored.

Selected Startup Milestones Achieved

- Initial roll of the steam turbine: June,1996
- Sulfuric acid plant and gasifier completion: June, 1996
- Completion of the hot-gas cleanup system: July, 1996
- Start demonstration program: October, 1996

Allowed Stack Emissions

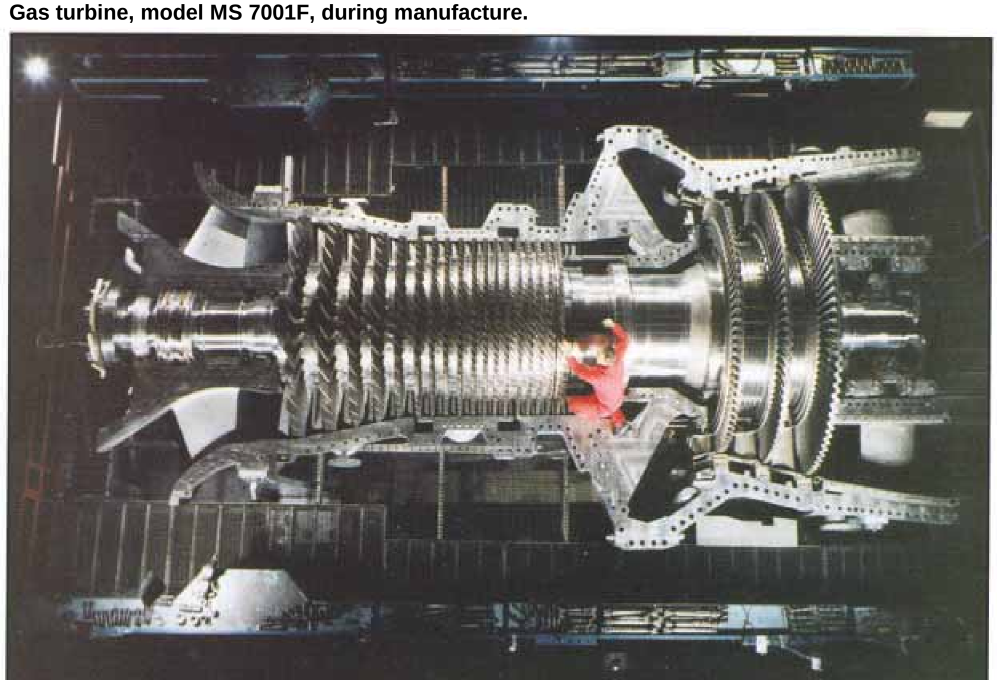
(at 15 percent excess oxygen)

Pollutant	Allowed Emissions, pounds/hour: During First Two Years of Demonstration	Allowed Emissions, pounds/hour: After First Two Years of Demonstration
SO_2	518	357
NO_X	664	223
CO	99	98
VOC	3	3
PIVI/PM-10	17	17

Power Output

Gas Turbine	192 MWe
Steam Turbine	121 MWe
Gross	***313 MWe***
Auxiliaries Power Use	63 MWe
Net Power Output	***250 MWe***

Gas turbine, model MS 7001F, during manufacture.



Photograph courtesy of: General Electric Company

Gasifier Run Summary

Start Date	Major Accomplishments
7/96	First production of syngas
8/96	Achieved steady state in process water system
8/96	First utilization of low temperature gas cooling system
9/96	Achieved 100% gasifier load, first syngas to gas turbine, and first production of brine crystals
9/96	First integration of steam drums
10/96	First run >100 hours, full load gas turbine and combined cycle operation on syngas, and first production of sulfuric acid.

Preliminary Results

All construction activities at the Polk Power Plant have been completed. TEC also completed the reclamation of wetlands on both sides of State Highway 37 that crosses the site.

The Project power plant entered the demonstration phase in October 1996. Operating on a Pittsburgh No. 8 bituminous coal, results achieved have been positive and encouraging.

A 101.6 hour run of the lGCC system was conducted in mid-October. Long term stable operation and full capacity were achieved. These are critical elements of the demonstration since they are necessary precursors to the conduct of acceptance tests for the coal-gas cleanup and sulfuric acid plant systems downstream of the gasifier.

Operating on syngas as well as distillate fuel, the unit has achieved full load on the combustion turbine and steam turbine. As planned, the combustion turbine achieved the design values of 192 MWe on syngas, and 121 MWe from the steam turbine, for a total output of 313 MWe. The nitrogen injection system operated as expected.

As of the end of October, 1996 the unit was operated only in the cold-gas cleanup mode. Work continues on check-out of the hot-gas cleanup systems and equipment; as of the publication date sorbent was loaded and attrition testing underway.

The sulfuric acid plant is in the foreground and the combined-cycle unit is in the background. The large black object (left center) is the heat recovery steam generator.

Controls tuning continues and when completed, performance testing of the IGCC system and equipment will be conducted.

As a result of its solid operating experience in the test program, the combined cycle unit has been made available for operation on distillate fuel to help meet TEC's load on an as-needed basis.

By-product evaluation is in progress. The brine concentration system has produced chloride crystals which will be evaluated by potential purchasers for reuse. The sulfuric acid plant has produced sulfuric acid which will be sold through the sulfuric acid trading market in Florida. The slag is being evaluated by the purchaser to determine how it will be utilized.

Testing of the IGCC system is planned to optimize operation, improve overall cycle efficiency and achieve emission targets. TEC will begin with parametric testing of key subsystems, including the hot-gas cleanup system. Four types of coals will be used in accordance with the demonstration test plan.

Future Developments

The achievements and knowledge gained from the Tampa Electric Integrated Gasification Combined-Cycle Project demonstration are expected to benefit future users of this technology. Evaluation of advanced features of the Project will determine their viability for future commercial applications. Future commercial offerings of the technology would be expected to be lower in cost and improved in performance.

DOE believes that future IGCC greenfield power plants, based upon mature and improved technology, will cost in the range of $1000-1350/kW (1995 basis). Heat rate is expected to be 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.

Dawn arrives over the reclaimed wetlands surrounding the Tampa Electric Integrated Gasification Combined-Cycle Project

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
at www.lanl.gov/projects/cctc

Bibliography

Black, C.R., "Polk Status Update," *Twelfth EPRI Conference on Coal Gasification Power Plants* (San Francisco CA), October 1993.

Black, C.R., "Tampa Electric Company's Polk Power Station Construction Update," *EPRI Conference on New Power Generation Technology* (San Francisco CA), October 1995.

Energy Information Administration, Office of Integrated Analysis and Forecasting, *"Annual Energy Outlook 1996 with Projections to* 2015," pp. 29, 38, DOE/FE-0346, January 1996.

"IGCC Takes a Bold Leap Forward," *Power, pp.* 81-84, April 1996.

Jenkins, S., "Tampa Electric Company Polk Power Station IGCC Project," *Twelfth Annual International Pittsburgh Coal Conference* (Pittsburgh PA), September 1995.

Jenkins S.D., "Polk Power Station Syngas Cooling System," *Eleventh Worldwide Texaco Gasification Licensee Symposium* (White Plains NY), October 1994.

Jenkins, S.D., "Polk Status Update," *Economics of Emerging Clean Coal Technologies III*, February 1994.

Pless, D.E., "Polk Status Update," U.S. *DOE Third Annual Clean Coal Technology Conference* (Chicago IL), September 1994

Pless, D.E., "Status Update, Polk Power Station" U.S. *DOE Fourth Annual Clean Coal Technology Conference* (Denver CO), September 1995.

Pritchard, P.A. and Starheim, G.J., "Turbine Developments for IGCC Applications, Status Update," *Thirteenth EPRI Conference on Coal Gasification Power Plants* (San Francisco CA), October 1994.

Stambler, I., "Progress in IGCC and Advanced Cycles Outlined at EPRI Meeting," *Gas Turbine World*, pp. 16-23, January-February 1996.

Swanekamp, R., "Startup of Large-Scale Projects Casts Spotlight on IGCC," *Power*, pp. 59-68, June 1996.

Tampa Electric Company, "Integrated Gasification Combined Cycle (IGCC) Demonstration Project, Polk Power Station Unit No. 1," Annual Report, October 1993-September 1994, May 1995.

Tampa Electric Company, "Tampa Electric Company Polk Power Station Unit No. 1," Annual Report, January-December 1992, October 1992.

Tampa Electric Company, "Tampa Electric Company Polk Power Station Unit No. 1," Annual Report, January-December 1993. August 1993.

Tampa Electric Company, "Tampa Electric Company Polk Power Station Unit No. 1," Preliminary Public Design Report, June 1994.

Tampa Electric Company, "Volume of Environmental Information, Tampa Electric Company Polk Power Station," (Submitted to) U.S. Department of Energy, 1992.

U.S. Department of Energy, "Clean Coal Technology Demonstration Program—Program Update 1995:" pp. 6-3, 7-26, 7-27; DOE/EIA-0383(96), April 1996.

U.S. Department of Energy, "Integrated Gasification Combined Cycle," Brochure, Morgantown Energy Technology Center, 1993.

U.S. Environmental Protection Agency, "Final Environmental Impact Statement, Tampa Electric Company-Polk Power Station," EPA 904/9-94-002(b), June 1994.

List of Acronyms and Abbreviations

Btu ....British thermal unit
CCT ....Clean Coal Technology
DOE .... U.S. Department of Energy
EPA .... U.S. Environmental Protection Agency
HRSG ....heat recovery steam generator
IGCC ....integrated gasification combined cycle
kV ....kilovolt
kWh ....kilowatt hour
MWe ....megawatt electric
ppmvd .... parts per million by volume, dry
TEC ....Tampa Electric Company
TPS .... TECO Power Services Corporation
PM ....particulate matter
PM-10 ....particulate matter less than 10 micrometers in diameter
VOC ....volatile organic compounds