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CLEAN COAL TECHNOLOGY

Tampa Electric Integrated Gasification Combined-Cycle Project

An Update

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An Update

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.

CLEAN COAL TECHNOLOGY

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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 "showcase" facilities built across the country. These projects are carried out on a sufficiently large scale to prove technical feasibility and provide the information required for additional commercial 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 use of coal.

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 Tampa Electric Integrated Gasification Combined-Cycle Project. In this project, the Texaco coal gasification process is used to fuel a gas combustion turbine generator, whose exhaust is integrated with a heat recovery steam generator and a steam turbine generator. Over 98% of sulfur contaminants are removed. Sulfur is recovered as sulfuric acid which is sold, as is the slag byproduct of gasification.

The project was conducted at Polk Power Station, a greenfield site located near Mulberry, Polk County, Florida.

The Tampa Electric CCT project has successfully demonstrated the commercial application of Texaco coal gasification in conjunction with electric power generation. Over 18,000 hours of operation have been accumulated. Net power production meets the target goal of 250 MWe at a high stream factor and plant availability. Carbon burnout exceeds 95%, and emissions of SO_2, NOx and particulates are well below the regulatory limits set for the Polk plant site. The Polk 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 Tampa Electric Integrated Gasification Combined-Cycle 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 emissions targets for nitrogen oxide (NOx) emissions from coal-fired boilers subject to compliance under the 1990 Clean Air Act Amendments (CAAA).

Aerial view of Polk Power Station

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, low 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. 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, 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

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

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 permits 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 coal reserves, and use of coal helps to reduce dependence on foreign oil.

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.

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

Project Description

The Tampa Electric Integrated Gasification Combined-Cycle Project was selected by DOE in December 1989 as a CCT Program Round III demonstration project. Construction was started in October 1994 and operation began in September 1996.

The project demonstrates use of the Texaco coal gasification process to fuel a gas combustion turbine generator, whose exhaust is integrated with a heat recovery steam generator (HRSG) and steam turbine generator. Over 98% of sulfur contaminants are removed. Sulfur is recovered as sulfuric acid which is sold, as is the slag byproduct of gasification. The greenfield site is located near Lakeland, Polk County, Florida.

The combustion turbine is an advanced General Electric gas turbine unit that produces 192 MWe (gross). The steam turbine produces an additional 121 MWe (gross). With parasitic power consuming 63 MWe, total net power output is 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 other process needs.

Project Participant

The Participant is Tampa Electric Company (TEC), headquartered in Tampa, Florida. Its service territory includes the city of Tampa and a 2000-square mile area in west-central Florida, primarily in and around Tampa. TEC, an investor-owned electric utility serving over 500,000 customers, has about 3650 MWe of generating capacity, of which about 97% is coal-fired. TEC is the principal wholly-owned subsidiary of TECO Energy, Inc., an energy related holding company heavily involved in coal mining, transportation, and power generation.

TECO Power Services Corporation (TPS), another subsidiary of TECO Energy, operates two power plants firing natural gas: a 295-MWe combined-cycle plant in Hardee County, Florida and a 78-MWe plant in Guatemala. In addition, TPS has several other projects at various stages of development.

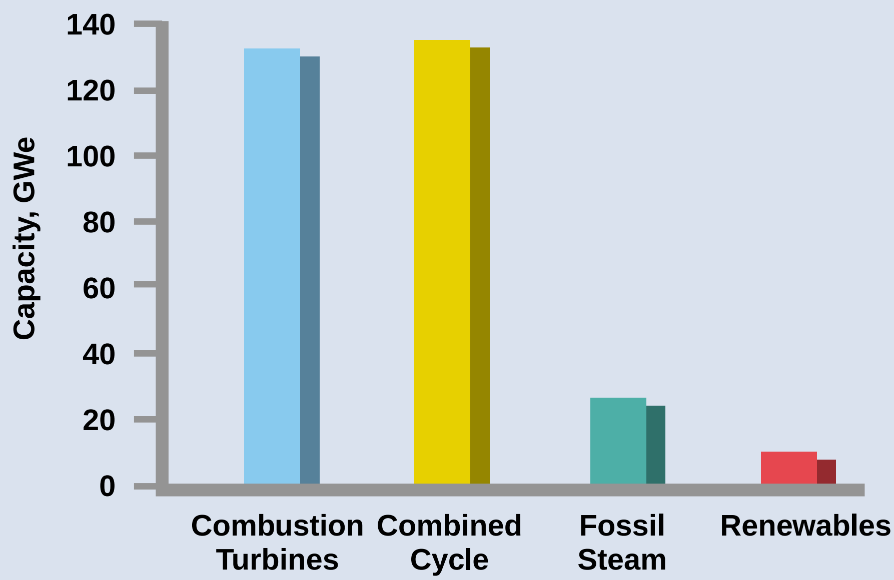
Major Participants

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
Bechtel Power Corporation	Detailed engineering/construction management services, procurement, and startup
MAN Gutehoffnüngshutte AG	Supplier of radiant syngas cooling system
L. & C. Steinmüller 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

Project Subcontractors

Other participants in the CCT project are major technology suppliers, including Texaco Development Company, the licensor of the coal gasification process; General Electric Corporation, the supplier of the combined-cycle technology; Air Products and Chemicals, Inc., supplier of the air separation unit; Monsanto Enviro-Chem Systems, Inc., supplier of the sulfuric acid plant; TPS, project manager and marketer; and Bechtel Power Corporation, who provided detailed engineering and construction management services.

New U.S. Generating Capacity Forecast 1998–2020



Includes non-utility generators and cogenerators

Source: U.S. Energy Information Administration, 1999

Site Description

The demonstration unit is Unit 1 of the Polk Power Plant, a new facility built in 1996 and located near Mulberry in south central Polk County, Florida. The 4300-acre site is 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 had been previously mined for phosphate rock, and has been redeveloped and revegetated by TEC for this project.

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

About one-third of the site is used for power generation facilities. Another third, about 1500 acres, is used to enhance the environment by creation of public fishing lakes for the Florida Fish and Game Commission. This area was converted from phosphate mining spoils to wetlands and uplands, thereby providing habitat for native plants and animals, and was transferred to the Commission in 1997. The final third of the site is used primarily for access and to provide 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.

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

Coal Supply

Coal is delivered to the site by truck from a transloading facility at TEC's Big Bend Station in Apollo Beach, Florida. Coals tested include Illinois No. 6, Pittsburgh No. 8, Kentucky No. 9, and Kentucky No. 11, all bituminous coals having a sulfur content ranging from 2.5-3.5%.

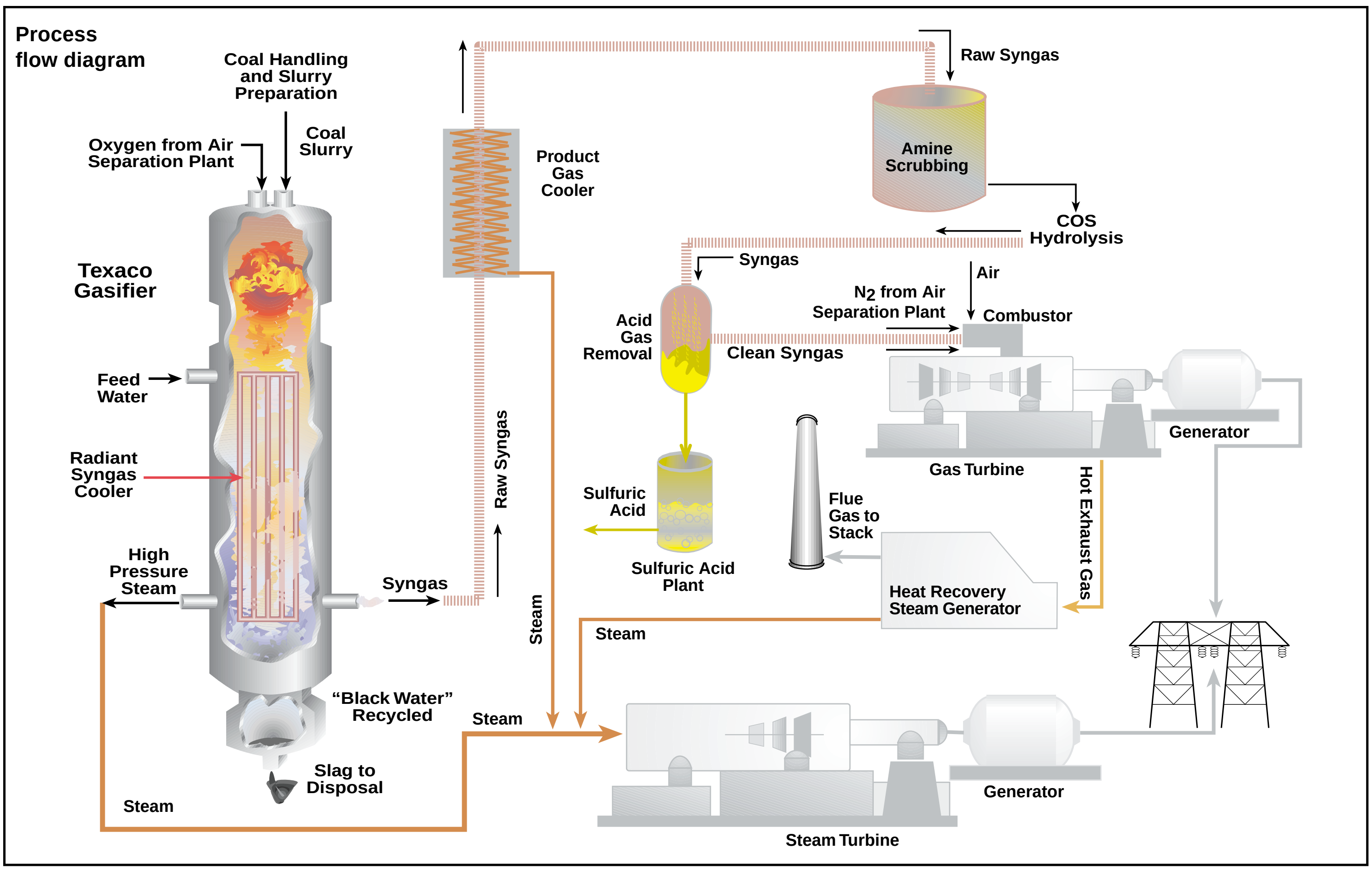
Power Plant Description

The Tampa CCT project demonstrates advanced IGCC technology using Texaco's commercially available oxygen-blown, entrained-flow gasifier, integrated with a combined-cycle turbine system for power generation.

The facility processes approximately 2,200 tons/day of coal in a single Texaco gasifier. Once on site, the coal is ground and slurried using recycled process water and makeup water. The slurry contains 60-70% solids.

Coal is partially oxidized in the gasifier with 95% pure oxygen from the air separation unit to produce a high temperature, high pressure, medium-Btu synthesis gas (syngas) with a heat content of about 267 Btu per standard cubic foot. The gasifier achieves about 95% carbon conversion per pass. Molten ash flows from the bottom of the gasifier into a water-filled sump, where it solidifies into a marketable slag byproduct. The slag, which is nonleachable, is sold for use in blasting grit, roofing tiles, and construction products.

The syngas is cooled in a high-temperature radiant heat exchanger, generating high pressure steam. The cooled gas is washed with water for particulate removal, followed by a hydrolysis reactor where carbonyl sulfide (COS) is converted to hydrogen sulfide (H_2S). After additional cooling, the raw syngas is sent to a conventional acid gas removal unit, where H_2S is absorbed by scrubbing with an amine solvent. H_2S is removed from



Process flow diagram

IGCC Inputs and Outputs

Inputs	*Quantity, tons/day*
Coal	2,200
Oxygen	2,171
Slurry water (recycled)	972
Nitrogen to gas turbine	5,600
Solids Output	
Slag/fines from dewatering pit	342
Dry solids from brine concentrator	3.1
98% Sulfuric Acid	240
Net Electrical Output	250 MWe

Selected Milestones

- Initial roll of the steam turbine: June 1996
- Sulfuric acid plant and gasifier completion: June 1996
- Start of operational test program: October 1996
- First continuous run > 50 days for combustion turbine: September 1998
- Produced > 1.2 million MWh in 1998
- 94% availability for the combined-cycle system achieved by end of 1999
- > 18,000 hrs. of operation by the end of 1999
- First petroleum coke burned: 1st quarter 2000

the amine by steam stripping and sent to the sulfuric acid plant.

As originally envisioned, the overall process scheme was to have incorporated hot gas cleanup on a portion of the raw syngas stream. After some initial test work, support for this option was discontinued.

The cleaned syngas is sent to the General Electric model MS 7001FA gas combustion turbine. Nitrogen from the air separation unit (at 98% purity) is mixed with the syngas at the combustor inlet. Nitrogen addition has important benefits to the power plant: (1) the increased mass flow through the gas turbine produces more power than without the nitrogen; (2) the overall efficiency of the system is enhanced; (3) NOx emissions are reduced; and (4) nitrogen injection is a viable alternative to steam. The use of nitrogen that would otherwise be vented represents a novel approach in oxygen-blown gasification technology.

Hot exhaust from the gas turbine passes through the 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 the reheat steam turbine generator.

A 220-kV, five-mile transmission line connects the Polk Power Station to the TEC grid.

The sulfuric acid plant uses oxygen and a catalytic reactor to convert the H_2S from the gas cleanup system to sulfuric acid (H_2SO_4), which is sold to the local phosphate mining industry. H_2SO_4 production is about 240 tons/day.

A brine concentration unit processes “grey” water discharged from the gas cleanup systems, recovering a reusable water stream for slurry preparation and a land-fillable solid waste stream. There is no liquid effluent.

Gaseous emissions are controlled to very low levels. SO_2 emissions are below 0.15 lb/million Btu and NOx emissions are below 0.27 lb/million Btu. The target emissions for the Tampa Electric project are 0.21 lb/million Btu for SO_2 and 0.27 lb/million Btu for NOx. Emissions of particulates are consistently below 17 lb/hr, the permit limit. Thus, the plant performance exceeds project goals.

Environmental Considerations

As indicated above, the Tampa IGCC Project has very low pollution impacts. Environmental considerations have been a major driving force from the inception of the project. The site was selected by an independent Community Siting Task Force, commissioned by TEC. Members included environmentalists, educators, economists, and community leaders. Economic factors were also considered. The Task Force evaluated 35 sites in six counties and recommended three in south-western Polk County that had previously been mined for phosphate.

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, the U.S. Army Corps of Engineers, and DOE. Some of the inputs for this comprehensive document were provided by TEC and its environmental consultants.

All federal, state, and local environmental permits were obtained. An Environmental Monitoring Plan was developed by TEC that gives details of the performance monitoring of environmental control equipment, stack emissions, and the surrounding area.

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

Process Description

Coal Gasification

Texaco coal gasification technology uses a single-stage, downward-firing, entrained-flow coal reactor fed with a coal/water slurry (60-70% water) and 95% pure oxygen. The coal reacts with steam and oxygen at a temperature of 2400-2600 ˚F to produce raw fuel gas and molten ash. The hot gas flows downward into a radiant gas cooler, where high pressure steam is produced. The syngas passes over the surface of a pool of water at the bottom of the syngas cooler and exits the vessel. The slag drops into the water pool and is fed to the lockhopper from the syngas cooler sump.

The radiant gas cooler is about 16 feet in diameter and 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.

The raw syngas exiting the radiant syngas cooler is sent to parallel convective coolers, where it is cooled to below 800°F and additional high pressure steam is produced.

Gas Cleanup

Particulate matter and hydrogen chloride (HCl) are removed from the syngas by scrubbing with water. 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 that is shipped off-site either for reuse or for disposal in a permitted landfill. The separated water is recycled for slurrying coal feed.

COS Hydrolysis

One compound produced in the gasification reactor is carbonyl sulfide (COS), which cannot be removed in the downstream amine scrubbing unit. If not removed from the syngas stream, COS is converted to SO_2, which must be minimized in the plant stack gas. The COS problem is accentuated when higher sulfur coals are fed to the gasifier.

To avoid this problem, Polk plant staff designed and installed a hydrolysis unit, a cylindrical vessel in which COS is reacted with water in the presence of a catalyst to form CO_2 and H_2S. Polk personnel selected the catalyst based on testing performed on the plant syngas. Six catalysts were tested, of which two proved satisfactory and one was chosen for this service. Preliminary operating results indicate negligible catalyst degradation. Long-term operation will be required to fully evaluate the COS hydrolysis step.

Acid Gas Removal

The COS-free syngas flows to the amine absorber, where the H_2S and some of the CO_2 is 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.

Sulfuric Acid Plant

In the sulfuric acid plant, the sulfur-containing gases from the gas cleanup system are converted to 98% H_2SO_4 for sale to the local Florida fertilizer industry. The H_2S is converted to SO_2 by combustion with air. Medium pressure steam is generated from the combustion products. The SO_2 is oxidized over a vanadium pentoxide catalyst, forming SO_3. The SO_3 is scrubbed with weak sulfuric acid to make 98% H_2SO_4. The concentration of SO_2 and SO_3 remaining in the gas stream is low enough to permit direct discharge to the atmosphere through a 200-ft stack.

Simplified Gasification Chemistry

C (coal)	***+***	***O_2***	***--->***	***CO_2***	***+***	***Heat***
C (coal)	***+***	***H_2O (steam)***	***--->***	***CO***	***+***	***H_2***

Power Block

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

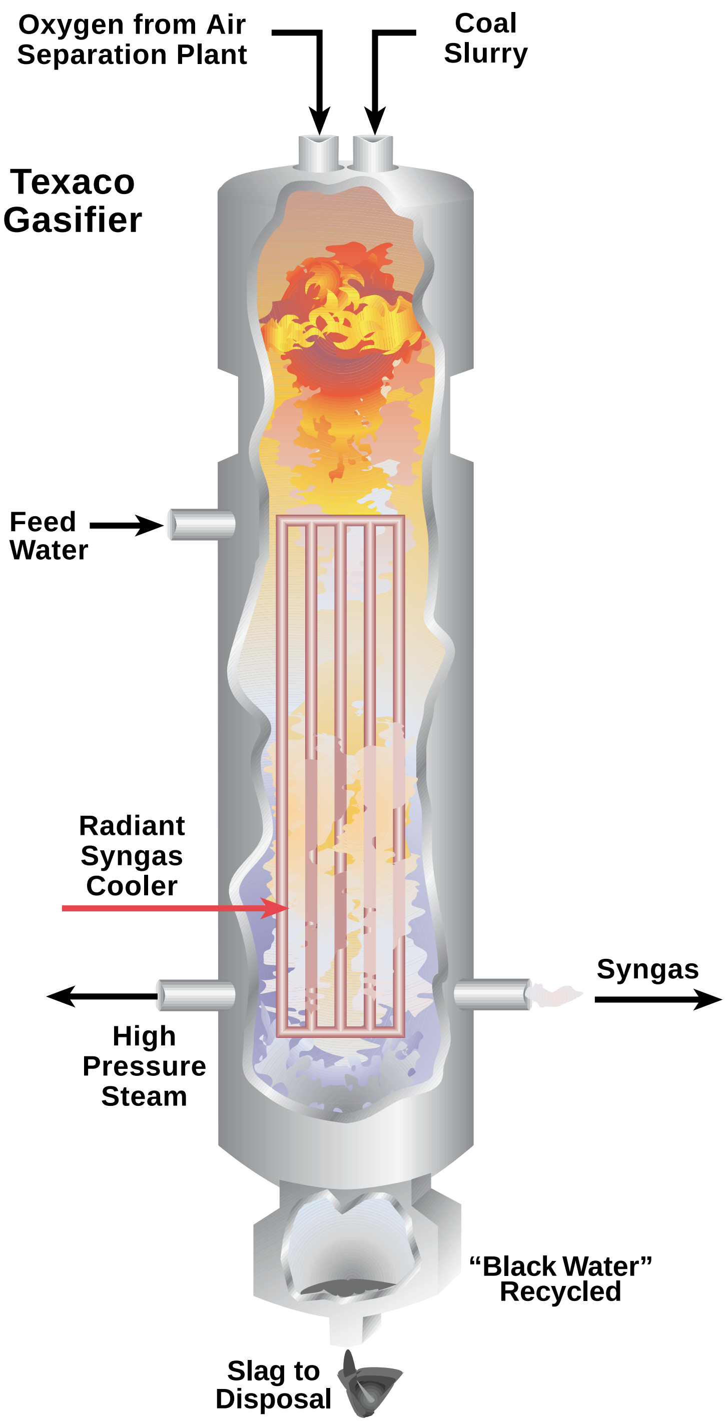
Nitrogen is used as a syngas diluent to reduce NOx formation and to increase mass flow, resulting in higher power output from the gas turbine.

The heat recovery steam generator (HRSG) is a three-pressure design with natural circulation and reheat. The exhaust gas leaving the HRSG is vented to the atmosphere via a 150-ft stack. The steam from the HRSG flows to a steam turbine, which 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. Generator output during normal operation is 121 MWe.

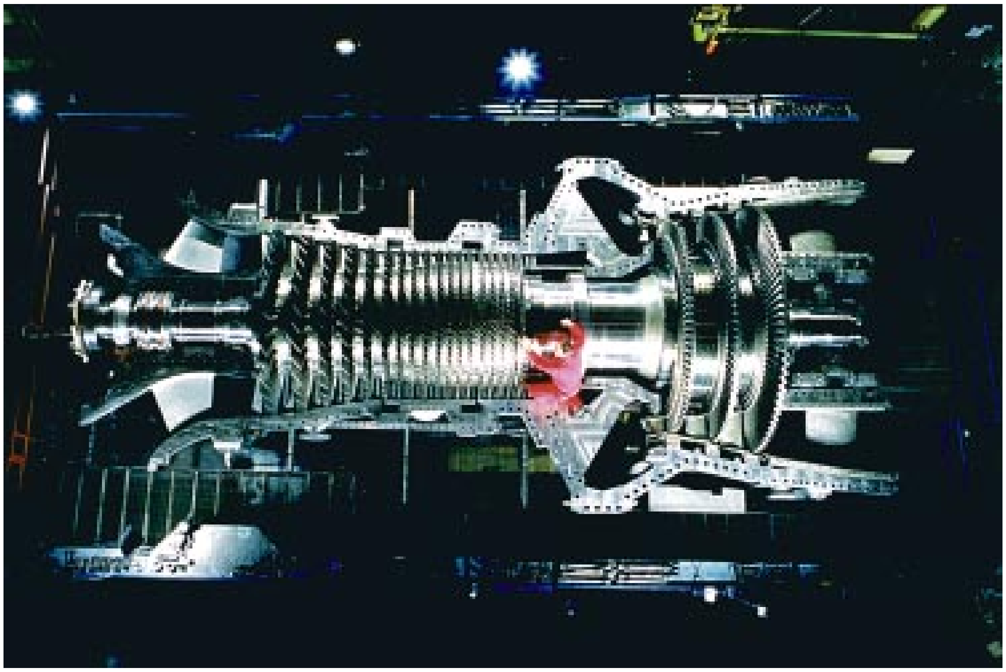
Total power production is 192 MWe from the gas turbine and 121 MWe from the steam turbine, giving a total of 313 MWe. With parasitic power of 63 MWe, total net power output is 250 MWe.

Air Separation Unit

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



A single Texaco gasifier processes 2,200 tons per day of coal 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.



Gas turbine, model MS 7001F, during manufacture

Allowed Stack Emissions

Pollutant	Allowed Emissions, lb/hr
SO_2	357
NO_x	223
CO	98
VOC	3
PM/PM-10	17

Cost/Schedule

The total cost of the Tampa Electric IGCC Project is $303 million, of which the Participant has provided $152 million (51%) and DOE has provided $151 million (49%). The cooperative agreement between TEC and DOE was signed in March 1991. Construction started in August 1994, and operation began in September 1996. A four-year demonstration program is in progress, with completion expected by October 2000.

The total project cost includes the cost of operating the unit throughout the demonstration peroid as well as experimental work on hot gas cleanup. The investment for a commercial unit would be significantly lower than that of the Tampa project.

Project Objective

The project objective is to demonstrate IGCC technology in a greenfield commercial electric utility application at the 250-MWe scale using a Texaco gasifier with full heat recovery, conventional cold-gas cleanup, and an advanced gas turbine with nitrogen injection for power augmentation and NOx control.

Plant Modifications/ Improvements

Several modifications to the original design and procedures were required to achieve the high availability that has been demonstrated. Soon after initial startup, ash plugging caused failure of some exchangers in the high-temperature heat recovery system. This led to serious damage to the combustion turbine. The exchangers were removed in 1997, and compensating adjustments were made in the rest of the heat recovery system. Additional particulate removal was provided to protect the turbine.

Pluggage in another bank of exchangers in the high-temperature heat recovery system was arrested by a design modification in 1999.

In late 1997, hot restart procedures were implemented. These eliminated the need to change burners and reheat the gasifier every time it shut down, reducing gasifier restart time by over 18 hours.

Initially, there were problems with the gasifier which is 50% larger than any previous Texaco gasifier. Carbon conversion in this larger gasifier was lower than expected, and refractory life has been identified as a significant issue. Liner replacement is expensive and requires considerable down time. To achieve the target life of two years, the gasifier is being operated at a lower temperature than design, which in turn results in a further decrease in carbon conversion efficiency. This caused load restrictions due to capacity limitations in the fines handling system. A slag crusher and a duplicate fines handling system installed in 1998 solved this problem.

Thermocouple replacement in the gasifier also presents a problem. Replacement is relatively expensive. Thermocouple failure by shearing is attributed to expansion of dissimilar materials.

In early 1998, revised operating procedures were developed to handle high shell temperatures in the dome of the radiant syngas cooler. This problem had caused two extended outages.

Numerous short forced outages occurred in 1997 and 1998 due to erosion and corrosion in the process water and coal/water slurry piping systems, pumps, and valves. Various changes have virtually eliminated these problems, and no such outages occurred in 1999. Some of the corrective actions taken to solve operating and maintenance problems in this project have resulted in patent applications.

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.

Power Output

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

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

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
1/97	First continuous 30-day run

Results

Polk Power Station has operated over 18,000 hours, generating more than 4.8 million MWh of electricity through 1999. For the last six months of 1999, the gasifier had an 83.5% on-stream factor, and the combined-cycle availability was 94%. The gasifier and combustion turbine continuous operation records are 46 and 52 days, respectively.

Environmental performance has been excellent. The overall heat rate is 9350 Btu/kWh (36.5% efficiency, higher heating value basis). The efficiency is somewhat lower than design because of removal of the high temperature exchangers and lower than excepted carbon conversion discussed above, and a compressor failure in the brine concentration unit which necessitates its operation as a single effect evaporator. In the second half of 2000, a slag recovery system will be commissioned to recover and utilize the unconverted carbon, and the brine concentration unit will be restored to its original more efficient vapor compression cycle. Ways are being evaluated to utilize the heat available as a result of removing the high temperature exchangers. Together, these projects are expected to increase the efficiency to 38% (9000 Btu/kWh), consistent with the original design value.

Ten coals and blends were tested in the 3 years of operation to date to determine the impact of feedstock properties on system performance. These coals included Kentucky No. 9, Kentucky No. 11, two Illinois No. 6 coals, and three Pittsburgh No. 8 coals. The performance criteria were: (1) feasibility of processing into a high concentration slurry, (2) carbon conversion, (3) aggressiveness of the slag to the gasifier's refractory liner, and (4) tendency toward fouling of the syngas coolers. All of the coals were found to be suitable with some design modifications.

The unit is currently running Kentucky No. 9 coal. Testing of lower cost petroleum coke blends is in progress.

Awards

The project was presented the 1997 Powerplant Award by *Power* magazine. In 1996, the project received the Association of Builders and Contractors Award for construction quality. Several awards were presented for using an innovative siting process, including the 1993 Ecological Society of America Corporate Award and the 1991 Florida Audubon Society Corporate Award.

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 very well 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.

As a result of the Tampa demonstration project, Texaco-based IGCC can be considered commercially and environmentally suitable for electric power generation utilizing a wide range of feedstocks. Sulfur capture for the project is

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

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

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 40-60 times greater 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.

greater than 98%, while NOx emissions are reduced by over 90% compared with those of a conventional pulverized coal-fired power plant.

The integration and control approaches utilized at Polk and many of the other lessons learned can also be applied in IGCC Projects using different gasification technologies.

TECO Energy is actively working with Texaco to commercialize the technology in the U.S. and overseas as well.

Future Developments

Work is in progress on two equipment modifications, both of which have efficiency improvement as a major objective. The first is to commission the slag handling system that separates the slag into its main constituents, a by-product for sale and a fuel for recycle. The second is to upgrade the brine concentration system by converting it to a more efficient vapor compression cycle.

The achievements and knowledge gained from the Tampa Electric IGCC 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 offerings of the technology are anticipated to have lower cost and exhibit improved performance.

DOE believes that future IGCC power plants, based on mature and improved technology, will cost in the range of $900-1250/kW (1999 basis) depending on the degree to which existing equipment and infrastructure can be utilized. Heat rate ultimately is expected to be in the range of 7000-7500 Btu/kWh (46-49% efficiency, higher heating value basis).

Polk Power Station control room

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

Higher Heating Value 13,290 Btu/lb

Composition of Cleaned Syngas

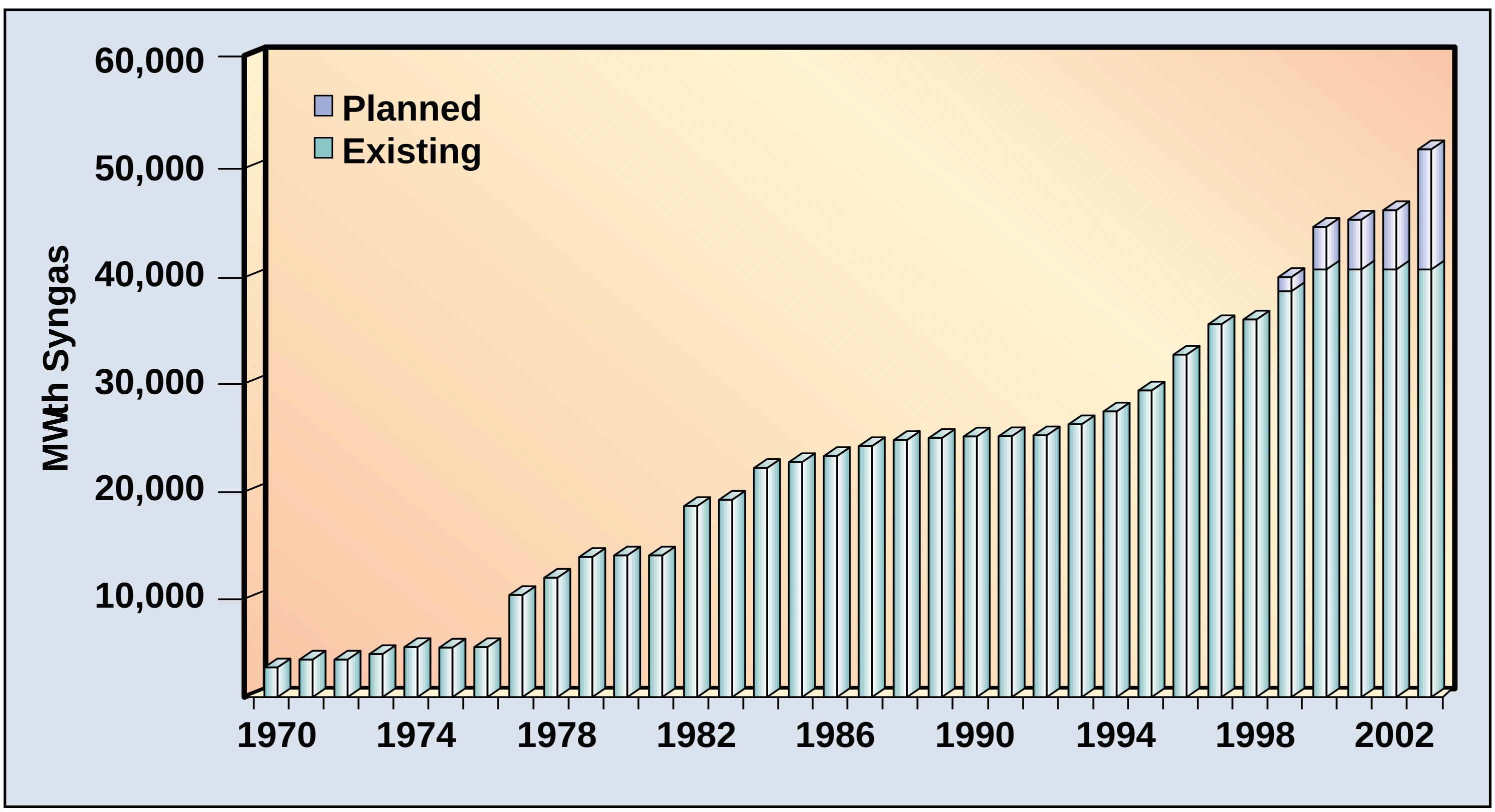
Constituent	Volume %
Carbon monoxide	42.7
Hydrogen	38.3
Carbon dioxide	14.4
Methane	0.1
Water	0.3
Nitrogen	3.3
Argon	0.9
Hydrogen sulfide	200 ppmv
Carbonyl sulfide	10 ppmv
Ammonia	0.0 ppmv

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.



Cumulative worldwide gasification capacity and growth

GE frame 7FA combustion turbine (left background) and its generator (right center) and clean gas filter (lower left foreground). The clean syngas filter prevents pipe scale and any coal ash from damaging the combustion turbine. The filter was installed in response to two turbine failures from coal ash and pipe scale in 1997, and has proven its worth.

Throughout the United States there are more than 95,000 MWe of existing coal-fired utility boilers over 30 years old. Many of these plants are without air pollution controls, and are candidates for repowering with IGCC technology. IGCC technology is projected to be a major candidate for both repowering and new power generating capacity. The Tampa Electric CCT Project is an example of a new power plant using IGCC technology.

IGCCs offer the advantages of modularity, rapid and staged on-line generation capability, high efficiency, flexibility, environmental controllability, and reduced land and natural resource needs. For these reasons, IGCCs are a strong contender for new electric power generation. Commercial offerings of IGCC technology will be based on a nominal 300-MWe train, which is ideally suited to utility-scale power production.

Conclusions

The Tampa Electric IGCC project conducted at Polk Power Station has successfully demonstrated the commercial application of Texaco coal gasification in conjunction with electric power generation. Power production meets the target goal of 250 MWe at a high stream factor and plant availability. Carbon burnout exceeds 95%, and emissions of SO_2, NOx and particulates are well below the regulatory limits set for the Polk plant site.

Along with other IGCC demonstrations in the CCT Program, the Polk Plant is one of the cleanest coal-based power generation facilities in the world.

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Aerial view of Tampa skyline

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Installation of radiant syngas cooler

The Clean Coal Technology Program

The Clean Coal Technology (CCT) Program of the U.S. Department of Energy (DOE), a model of government and industry cooperation, supports DOE's mission to foster a secure and reliable energy supply system in the United States that is environmentally and economically sustainable. The CCT Program represents an investment of over $5 billion in advanced coal-based technology, with industry and state governments providing a significant share —66% —of the funding. With 26 of the 38 projects having completed operations, the CCT Program has resulted in clean coal technologies that are capable of meeting existing and emerging environmental regulations and competing in a deregulated electric power marketplace.

The CCT Program provides a portfolio of process options that will enable continued use of the United States' huge economically recoverable coal reserves (over 270 years at current consumption rates) to meet the nation's energy needs economically and in an environmentally sound manner.

As the new millennium begins, many of the clean coal technologies have reached commercial status. Industry stands ready to employ them both domestically and internationally to respond to the energy and environmental demands of the 21st century. For existing power plants, there are cost-effective environmental control devices to minimize emissions of sulfur dioxide (SO_2), nitrogen oxides (NOx), and particulate matter (PM). The CCT Program has taken a pollution prevention approach as well, providing technologies that remove pollutants or their precursors from coal before combustion.

Also ready is a new generation of technologies that can produce electricity and other commodities, such as steam and synthesis gas, at high efficiencies consistent with concerns about global climate change.

Additionally, new technologies have been introduced into major coal-using industries, such as steel production, to enhance environmental performance. Thanks in part to the CCT Program, coal—abundant, secure, and economical throughout much of the world—can continue in its role as a key component in supplying U.S. and world energy needs.

The CCT Program also has global importance in providing clean and efficient coal-based technologies to a burgeoning energy market in developing countries. World energy consumption is expected to increase 63% by 2020, and coal, the predominant indigenous fuel in much of the world, will be the fuel of choice for electricity production. CCT processes offer a cost-effective means to mitigate potential environmental problems associated with this unprecedented energy growth.

Most of the CCT demonstrations have been conducted at commercial scale, in actual user environments, and under circumstances typical of commercial operations. Each project addresses one of the following four market sectors:

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

The project described in this Topical Report was developed under the category of Advanced Electric Power Generation.

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

Participant Contact

Mark Hornick
General Manager - Polk Power Station
Tampa Electric Company
P.O. Box 111
Tampa FL 33601-0111
(813) 228-1111 x 39988
(863) 428-5927 fax
mjhornick@tecoenergy.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

James U. Watts
Project Manager
National Energy Technology Laboratory
P.O. Box 10940
Pittsburgh PA 15236-0940
(412) 386-5991
(412) 386-4775 fax
jim.watts@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
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
CO	carbon monoxide
CO_2	carbon dioxide
COS	carbonyl sulfide
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
HCl	hydrogen chloride
HRSG	heat recovery steam generator
H_2S	hydrogen sulfide
H_2SO_4	sulfuric acid
IGCC	integrated gasification combined-cycle
kV	kilovolt
kWh	kilowatt hour
MWe	megawatts of electric power
MWth	megawatts of thermal power (1 MWth = 3.413×10^6 Btu/hr)
NETL	National Energy Technology Laboratory
NOx	nitrogen oxides
O_2	oxygen
PM	particulate matter
ppmv	parts per million by volume
psig	pressure, pounds per square inch (gauge)
SO_2	sulfur dioxide
SO_3	sulfur trioxide
syngas	synthesis gas
TEC	Tampa Electric Company
TPS	TECO Power Services Corporation
VOC	volatile organic compounds
wt %	percent by weight