Advanced Electric Power Generation
Integrated Gasification Combined-Cycle

Kentucky Pioneer Energy IGCC Demonstration Project

Participant
Kentucky Pioneer Energy, L.L.C.

Additional Team Members
Fuel Cell Energy, Inc. (formerly Energy Research Corporation)—molten carbonate fuel cell designer and supplier; cofunder

Location
Trapp, Clark County, KY (East Kentucky Power Cooperative's Smith site)

Technology
Integrated gasification combined-cycle (IGCC) using a BGL (formerly British Gas/Lurgi) slagging fixed-bed gasification system coupled with Energy Research Corporation's molten carbonate fuel cell (MCFC)

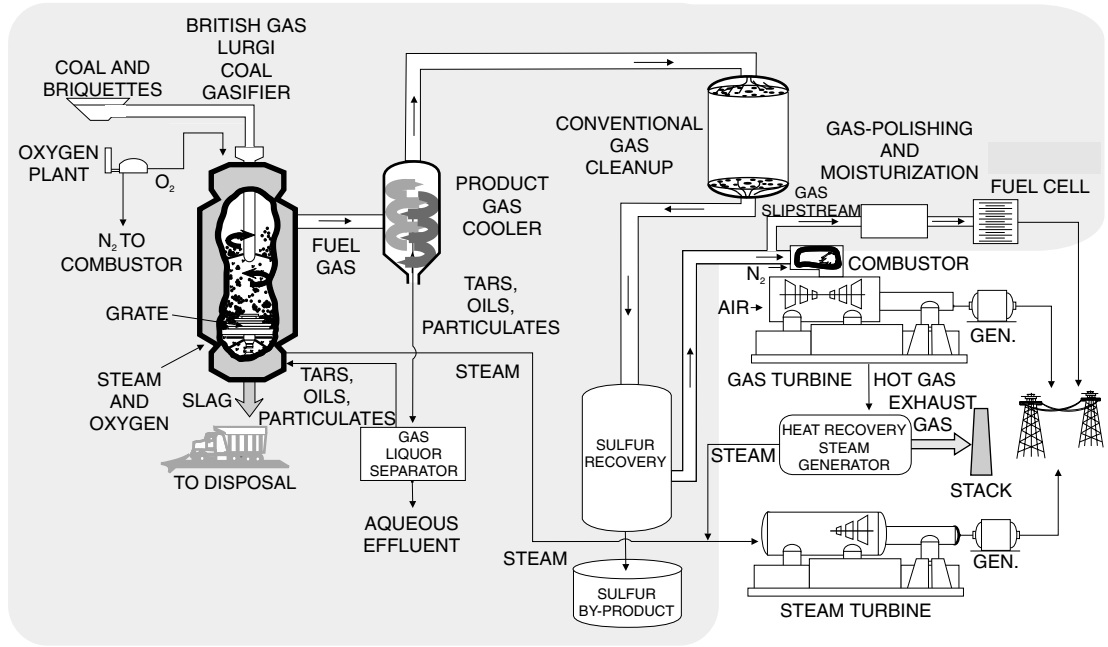
Plant Capacity/Production
400-MWe (net) IGCC; 2.0-MWe MCFC

Coal
High-sulfur Kentucky bituminous coal blended with municipal solid waste

Project Funding

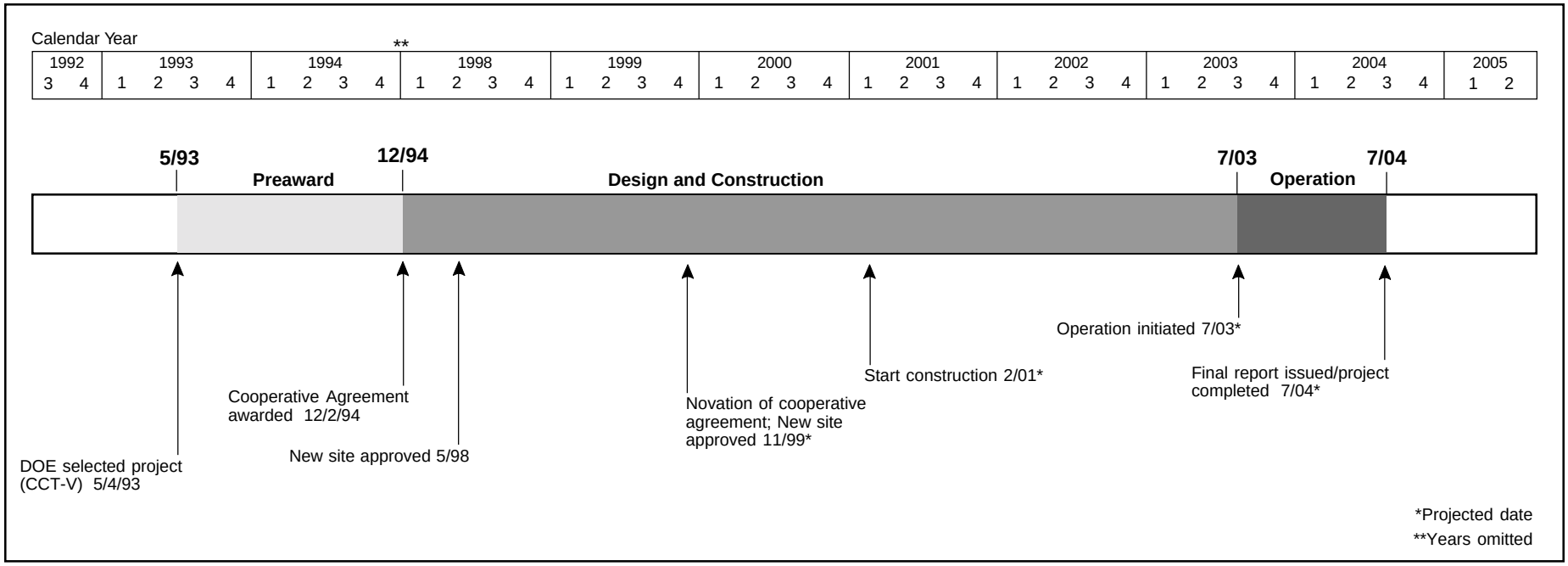
Total project cost	$431,932,714	100%
DOE	78,086,357	18
Participant	353,846,225	82

Project Objective
To demonstrate and assess the reliability, availability, and maintainability of a utility-scale IGCC system using a high-sulfur bituminous coal and municipal solid waste blend in an oxygen-blown, fixed-bed, slagging gasifier and the operability of a molten carbonate fuel cell fueled by coal gas.



Technology/Project Description
The BGL gasifier is supplied with steam, oxygen, limestone flux, and a coal and municipal waste blend. During gasification, the oxygen and steam react with the coal and limestone flux to produce a raw, coal-derived fuel gas rich in hydrogen and carbon monoxide. Raw fuel gas exiting the gasifier is washed and cooled. Hydrogen sulfide and other sulfur compounds are removed. Elemental sulfur is reclaimed and sold as a by-product. Tars, oils, and dust are recycled to the gasifier. The resulting clean, medium-Btu fuel gas fires a gas turbine. A small portion of the clean fuel gas is used for the MCFC.

The MCFC is composed of a molten carbonate electrolyte sandwiched between porous anode and cathode plates. Fuel (desulfurized, heated medium-Btu fuel gas) and steam are fed continuously into the anode; CO_2-enriched air is fed into the cathode. Chemical reactions produce direct electric current, which is converted to alternating power in an inverter.



Project Status/Accomplishments

On May 8, 1998, the DOE conditionally approved Ameren Services Company (merger of Union Electric Co. and Central Illinois Public Service Co.) as an equity partner and host site provider subject to completing specific business and teaming milestones. The new project site to be provided by Ameren was at their Venice Station Plant in Venice, Illinois, or near East St. Louis, Illinois. On April 30, 1999, Ameren Services Company withdrew from the project for economic and business reasons.

In May 1999, Global Energy USA Limited (Global), sole owner of Kentucky Pioneer Energy L.L.C. (KPE), expressed interest in acquiring the project and providing a host site at East Kentucky Power Cooperative's Smith Site in Clark County, Kentucky. Subsequently, Global negotiated all the necessary documents with DOE and Clean Energy Partners, L.P. (CEP) to acquire the project.

Commercial Applications

The IGCC system being demonstrated in this project is suitable for both repowering applications and new power plants. The technology is expected to be adaptable to a wide variety of potential market applications because of several factors. First, the BGL gasification technology has successfully used a wide variety of U.S. coals. Also, the highly modular approach to system design makes the BGL-based IGCC and molten carbonate fuel cell competitive in a wide range of plant sizes. In addition, the high efficiency and excellent environmental performance of the system are competitive with or superior to other fossil-fuel-fired power generation technologies.

The heat rate of the IGCC demonstration facility is projected to be 8,560 Btu/kWh (40% efficiency) and the commercial embodiment of the system has a projected heat rate of 8,035 Btu/kWh (42.5% efficiency). The commercial version of the molten carbonate fuel cell fueled by a BGL gasifier is anticipated to have a heat rate of 7,379 Btu/kWh (46.2% efficiency). These efficiencies represent a greater than 20% reduction in emissions of CO_2 when compared to a conventional pulverized coal plant equipped with a scrubber. SO_2 emissions from the IGCC system are expected to be less than 0.1 lb/10^6 Btu (99% reduction); and NO_x emissions less than 0.15 lb/10^6 Btu (90% reduction).

Also, the slagging characteristic of the gasifier produces a nonleaching, glass-like slag that can be marketed as a usable by-product.

Piñon Pine IGCC Power Project

Participant
Sierra Pacific Power Company

Additional Team Members
Foster Wheeler USA Corporation—architect, engineer, and constructor
The M.W. Kellogg Company—technology supplier
Bechtel Corporation—start-up engineer

Location
Reno, Storey County, NV (Sierra Pacific Power Company's Tracy Station)

Technology
Integrated gasification combined-cycle (IGCC) using the KRW air-blown pressurized fluidized-bed coal gasification system

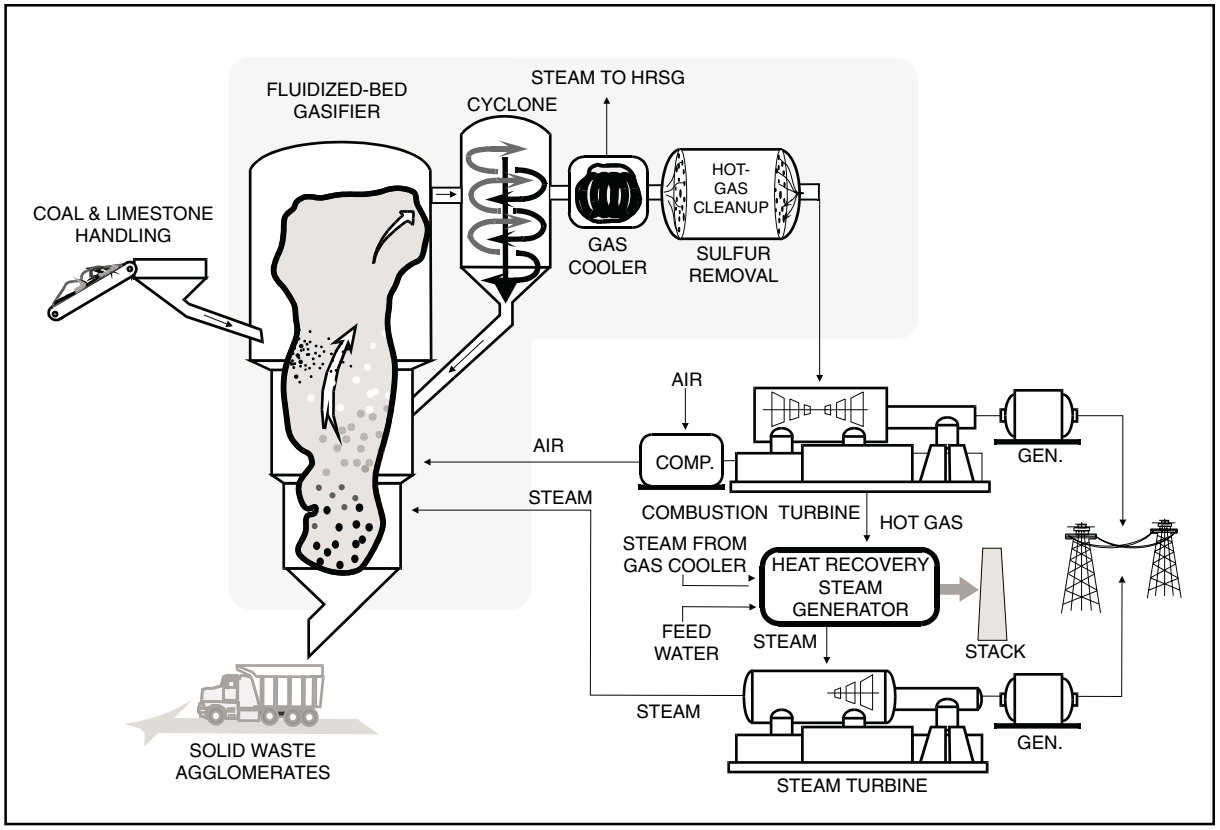
Plant Capacity/Production
107-MWe (gross), 99-MWe (net)

Coal
Southern Utah bituminous, 0.5–0.9% sulfur (design coal); eastern bituminous, 2–3% sulfur (planned test)

Project Funding

Total project cost	$335,913,000	100%
DOE	167,956,500	50
Participant	167,956,500	50

Project Objective
To demonstrate air-blown pressurized fluidized-bed IGCC technology incorporating hot gas cleanup; to evaluate a low-Btu gas combustion turbine; and to assess long-term reliability, availability, maintainability, and environmental performance at a scale sufficient to determine commercial potential.

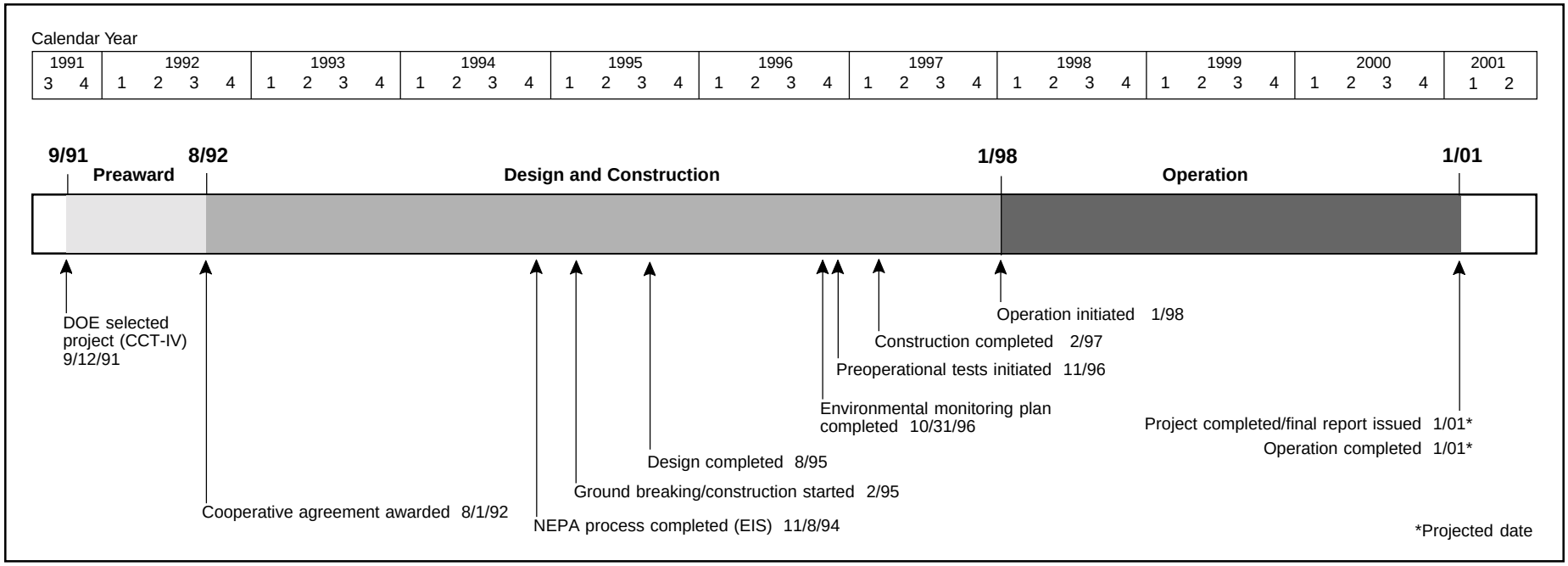


Technology/Project Description
Dried and crushed coal and limestone are introduced into a KRW air-blown pressurized fluidized-bed gasifier. Crushed limestone is used to capture a portion of the sulfur. The sulfur reacts with the limestone to form calcium sulfide which, after oxidation, exits as calcium sulfate along with the coal ash in the form of agglomerated particles suitable for landfill.

Low-Btu coal gas leaving the gasifier passes through cyclones, which return most of the entrained particulate matter to the gasifier. The gas, which leaves the gasifier at about 1,700 ºF, is cooled to about 1,100 ºF before entering the hot gas cleanup system. During cleanup, virtually all of the remaining particulates are removed by ceramic candle filters, and final traces of sulfur are removed by reaction with a metal oxide sorbent in a transport reactor.

The cleaned gas then enters the GE MS6001FA (Frame 6FA) combustion turbine, which is coupled to a 61-MWe (gross) generator. Exhaust gas from the combustion turbine is used to produce steam in an HRSG. Superheated high-pressure steam drives a condensing steam turbine-generator designed to produce about 46 MWe (gross).

The IGCC plant will remove 95+% of the sulfur in the coal. Due to the relatively low operating temperature of the gasifier and the injection of steam into the combustion fuel stream, the NO_x emissions are expected to be 70% less than a conventional coal-fired plant. The IGCC will produce 20% less CO_2 than conventional plants.



Project Status/Accomplishments

The system has initiated test-plan operations but continues to experience operational difficulties. The station began operation on natural gas in November 1996. Preoperational testing and shakedown of the coal gasification combined-cycle system continued through 1997 with syngas produced in January 1998. The plant was dedicated in April 1998.

The project continues to suffer from a number of design issues, many of which have been solved, but others remain. In 1998 and the first three months of 1999, the gasifier had 10 successful runs, which averaged 7 hours each, with the longest being 12 hours. The gasifier has produced syngas for over 33 hours. Problems have been attributed to the high degree of new technology, high scaleup factors on auxiliary components, and some design and engineering deficiencies. Nevertheless, Sierra Pacific is confident that no fatal flaws exist that will preclude successful demonstration and subsequent commercialization of the KRW gasification technology.

Despite the problems with the gasifier, the plant continues to operate on natural gas. The first-of-a-kind GE Frame 6FA CT had an 85 percent availability in 1998 and a 100 percent availability in the first quarter of 1999. Sierra Pacific's 2000 performance goals include: 90 percent combined-cycle availability; achieve stable, sustained production of syngas; demonstrate sustained operation on syngas; and successfully run the gas turbine on syngas.

Commercial Applications

The Piñon Pine IGCC system concept is suitable for new power generation, repowering needs, and cogeneration applications. The net heat rate for a proposed greenfield plant using this technology is projected to be 7,800 Btu/kWh (43.7% efficiency), representing a 20% increase in thermal efficiency compared to a conventional pulverized coal plant with a scrubber and a comparable reduction in CO_2 emissions. The compactness of an IGCC system reduces space requirements per unit of energy generated relative to other coal-based power generation systems. The advantages provided by phased modular construction reduce the financial risk associated with new capacity additions.

The KRW IGCC technology is capable of gasifying all types of coals, including high-sulfur, high-ash, low-rank, and high-swelling coals, as well as bio- or refuse-derived waste, with minimal environmental impact. There are no significant process waste streams that require remediation. The only solid waste from the plant is a mixture of ash and calcium sulfate, a nonhazardous waste.

Tampa Electric Integrated Gasification Combined-Cycle Project

Participant
Tampa Electric Company

Additional Team Members
Texaco Development Corporation—gasification technology supplier
General Electric Corporation—combined-cycle technology supplier
Air Products and Chemicals, Inc.—air separation unit supplier
Monsanto Enviro-Chem Systems, Inc.—sulfuric acid plant supplier
TECO Power Services Corporation—project manager and marketer
Bechtel Power Corporation—architect and engineer

Location
Mulberry, Polk County, FL (Tampa Electric Company's Polk Power Station, Unit No. 1)

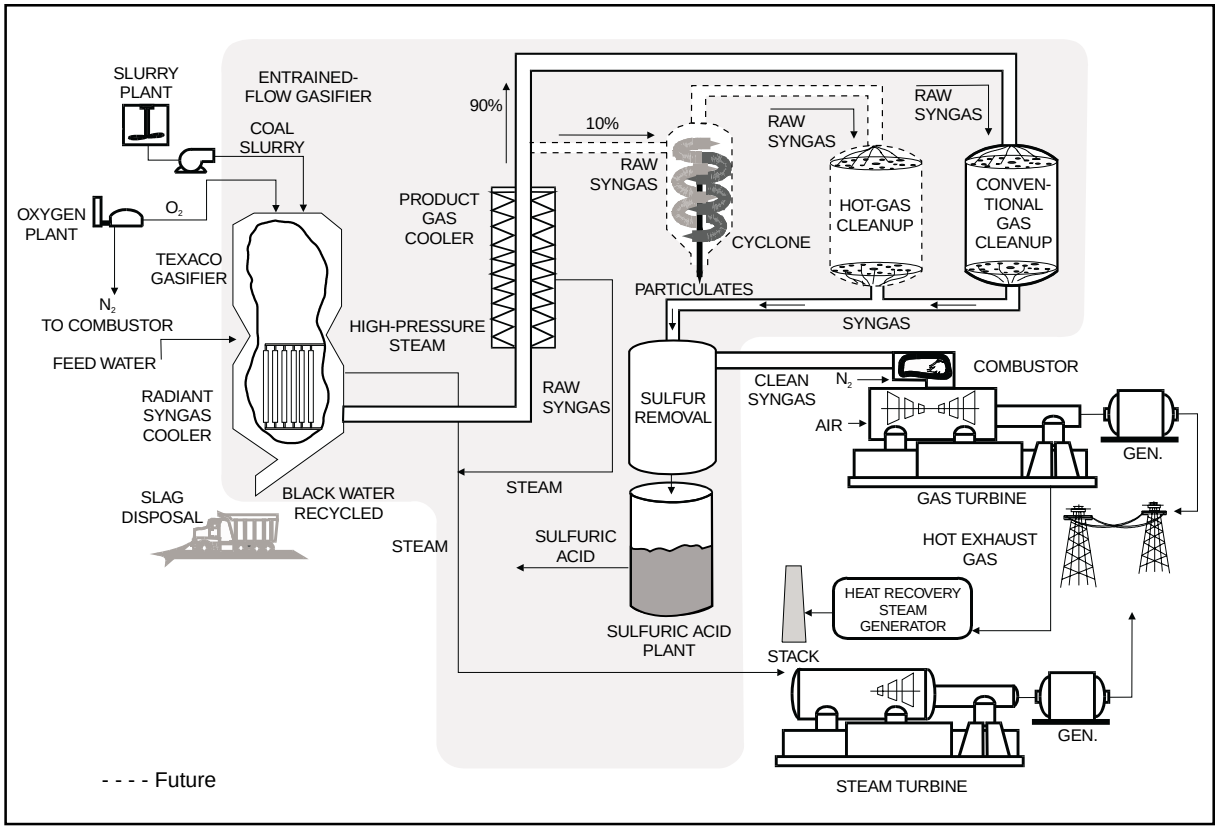
Technology
Advanced integrated gasification combined-cycle (IGCC) system using Texaco's pressurized, oxygen-blown entrained-flow gasifier technology

Plant Capacity/Production
Output: 316 MWe (gross), 250 MWe (net)

Coal
Illinois #6, Pittsburgh #8, Kentucky # 11, and Kentucky #9; 2.5-3.5% sulfur

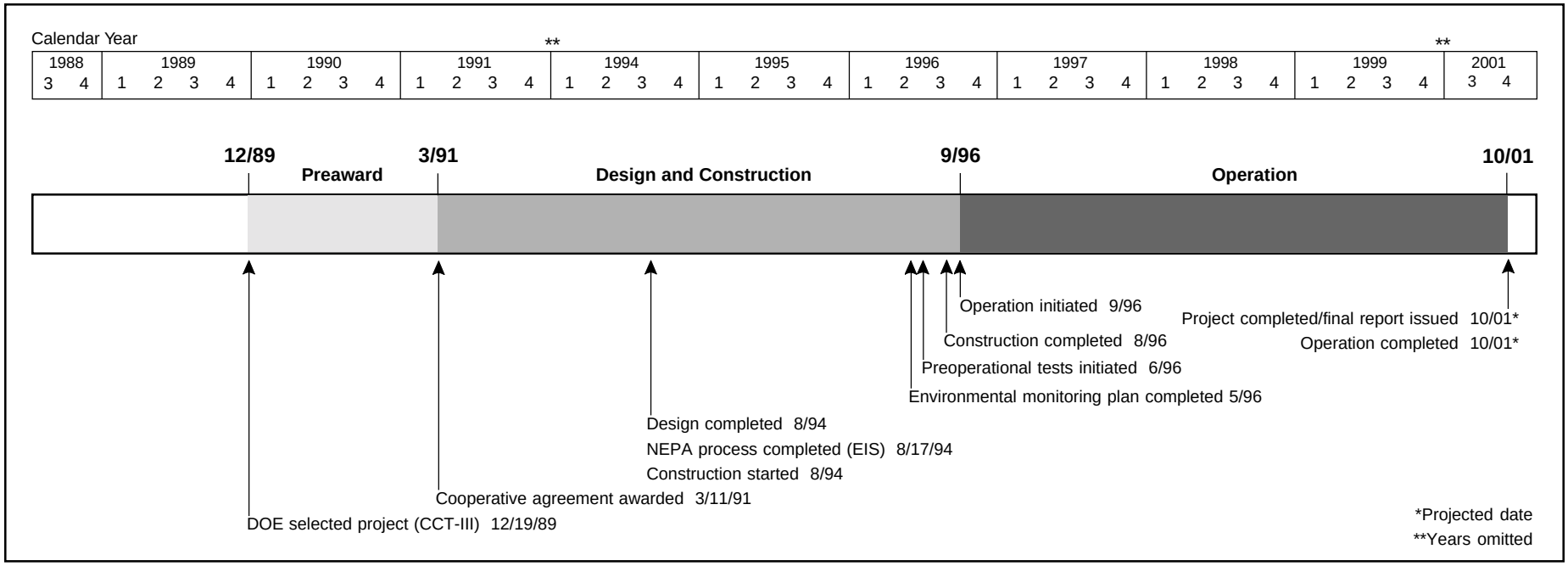
Project Funding

Total project cost	$303,288,446	100%
DOE	150,894,223	49
Participant	152,394,223	51



Project Objective
To demonstrate IGCC technology in a greenfield commercial electric utility application at the 250-MWe size using an entrained flow, oxygen blown, gasifier with full heat recovery, conventional cold-gas cleanup, and an advanced gas turbine with nitrogen injection for power augmentation and NO_x control.

Technology/Project Description
Coal/water slurry and oxygen are reacted at high temperature and pressure to produce a medium BTU syngas in a Texaco gasifier. Molten ash flows out of the bottom of the gasifier into a water-filled sump where it is forms a solid slag. The syngas moves from the gasifier to a high temperature heat-recovery unit, which cools the syngas while generating high pressure steam. The cooled gases flow to a water wash for particulate removal. Next, a COS hydrolysis reactor converts one of the sulfur species in the gas to a form which is more easily removed. The syngas is then further cooled before entering a conventional amine sulfur removal system. The amine system keeps SO_2 emissions below 0.15 lb/10^6 Btu (97% capture). The cleaned gases are then reheated and routed to a combined-cycle system for power generation. (A 10 MWe slipstream for hot syngas cleanup system had been envisioned but has been placed on hold pending resolution of technical problems.) A GE MS 7001FA combustion turbine (CT) generates 192 MWe. Thermal NO_x is controlled to below 0.27 lb/ 10^6 Btu by injecting nitrogen. A steam turbine uses steam produced by cooling the syngas and superheated with the CT exhaust gases in the HRSG to produce an additional 124-MWe. The plant heat rate is 9350 Btu/KWH (HHV), which is an efficiency of 38.4% (LHV).



Project Status/Accomplishments

Since Polk Power Station's first gasifier run in July 1996, the gasifier has operated over 16,000 hours. The station generated more than 4.5 million MWh of electricity from syngas it produced through September 1999. During one six-month period, 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 37 and 51 days, respectively.

Several modifications to the original design and procedures were required to achieve the recent high availability, including: (1) removing or modifying some of the heat exchangers in the high temperature heat recovery system and making compensating adjustments in the balance of the system to resolve ash plugging problems, (2) additional solid particle erosion protection for the combustion turbine to protect the machine from ash, (3) implementing hot restart procedures to reducer gasifier restart time by 18 hours, (4) adding a duplicate fines handling system to deal with increased fines loading resulting from lower than expected carbon conversion, (5) revising operating procedures to deal with high shell temperatures in the dome of the radiant syngas cooler, and (6) making various piping changes to correct for erosion and corrosion in the process and coal/water slurry systems. A COS hydrolysis unit was installed in 1999 to further reduce SO_2 emissions, enabling the station to meet recent more stringent emissions restrictions.

Tampa Electric will face two major challenges in 2000, both of which have efficiency improvement as a major objective. The first will be to commission the slag handling system that separates the slag into its main constituents, a useful by-product for sale and a suitable fuel for recycle. The second will be to upgrade the brine concentration system.

Applications

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 and innovative siting process: 1993 Ecological Society of America Corporate Award and 1993 Timer Powers Conflict Resolution Award from the State of Florida, and the 1991 Florida Audubon Society Corporate Award.

As a result of the Polk Power Station demonstration, Texaco-based IGCC can be considered commercially and environmentally suitable for electric power generation utilizing a wide variety of feedstocks. Sulfur capture for the project is greater than 98%, while NO_x emission reduction are 90% that of a conventional pulverized coal-fired power plant. The integration and control approaches utilized at Polk can also be applied in IGCC projects using different gasification technologies.

TECO Energy is not only actively working with Texaco to commercialize the technology in the United States, but has been contacted by European power producers to discuss possible technical assistance on using the gasifier technology.

Wabash River Coal Gasification Repowering Project

Participant

Wabash River Coal Gasification Repowering Project Joint Venture (a joint venture of Dynegy and PSI Energy, Inc.)

Additional Team Members

PSI Energy, Inc.—host

Dynegy (formerly Destec Energy, Inc., a subsidiary of Natural Gas Clearinghouse)—engineer and gas plant operator

Location

West Terre Haute, Vigo County, IN (PSI Energy's Wabash River Generating Station, Unit No. 1)

Technology

Integrated gasification combined-cycle (IGCC) using Global Energy's two-stage pressurized, oxygen-blown, entrained-flow gasification system

Plant Capacity/Production

296-MWe (gross), 262-MWe (net)

Coal

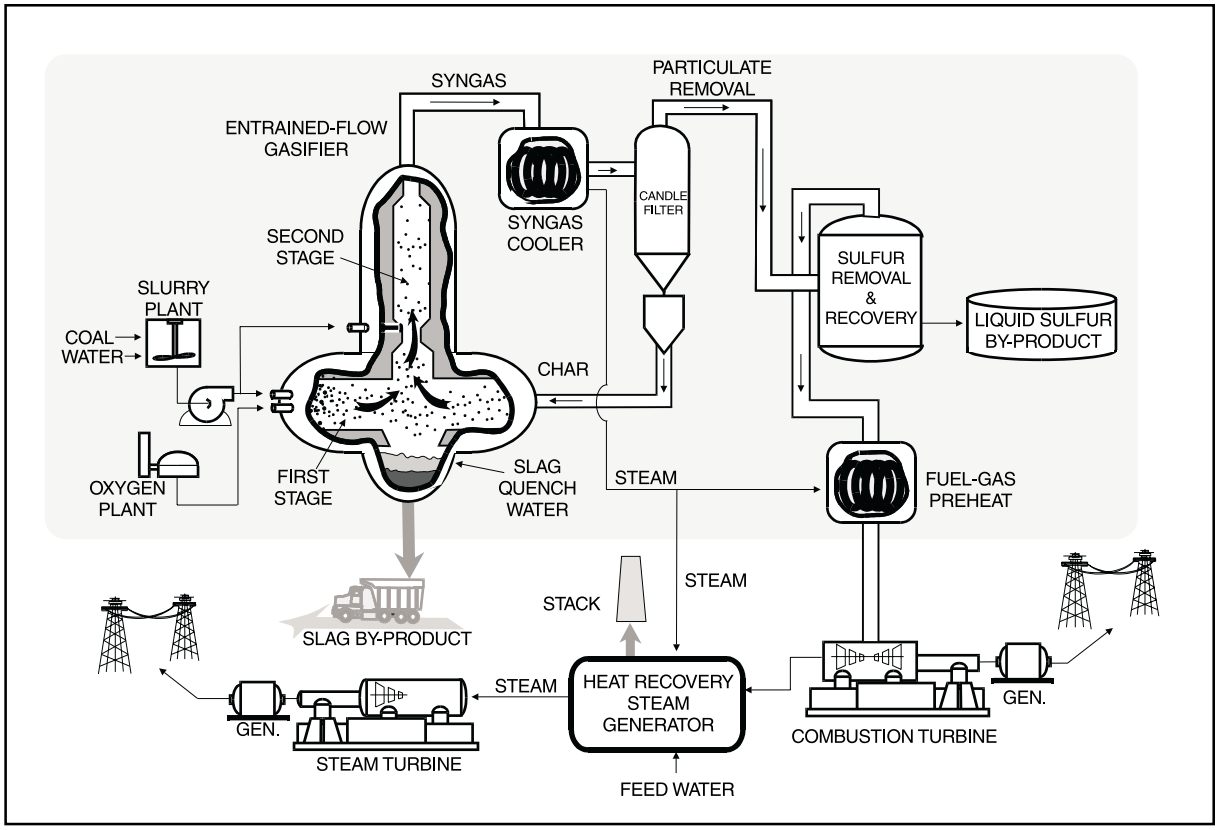
Illinois Basin bituminous

Project Funding

Total project cost	$438,200,000	100%
DOE	219,100,000	50
Participant	219,100,000	50

Project Objective

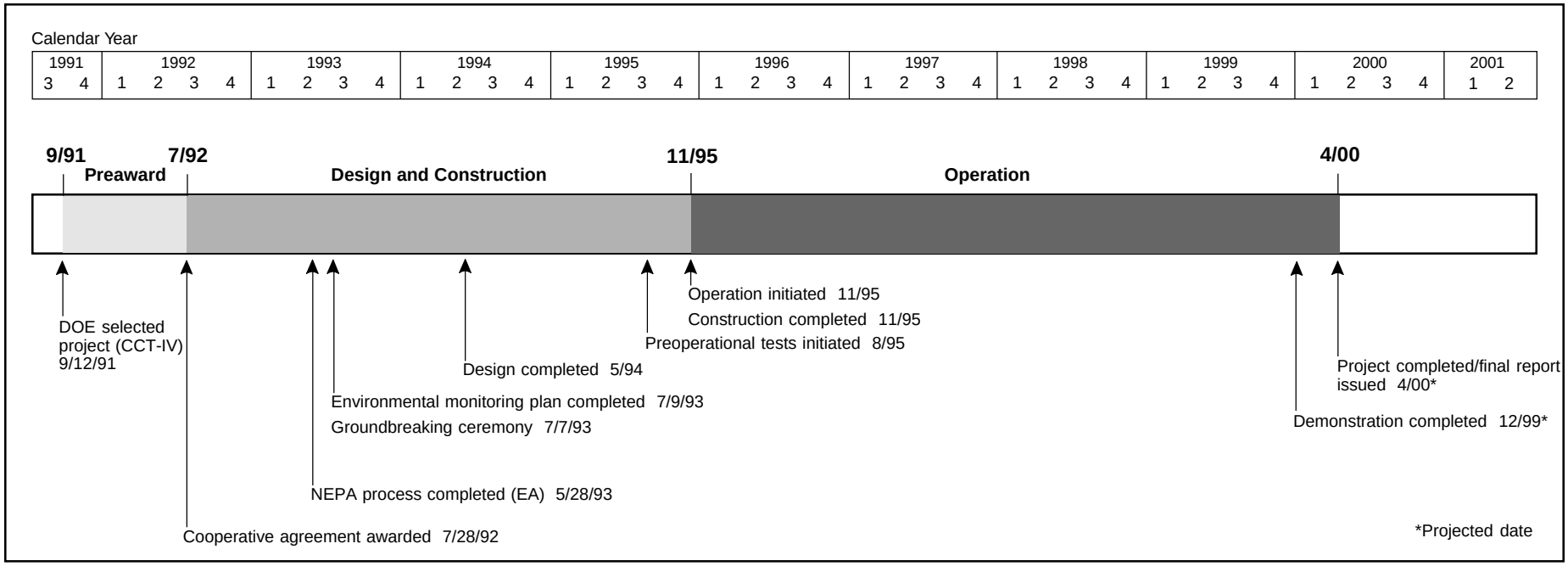
To demonstrate utility repowering with a two-stage pressurized oxygen-blown entrained-flow IGCC system, including advancements in the technology relevant to the use of high-sulfur bituminous coal; and to assess long-term reliability, availability, and maintainability of the system at a fully commercial scale.



Technology/Project Description

The Destec process features an oxygen-blown, continuous-slagging, two-stage entrained flow gasifier. Coal is slurried, combined with 95% pure oxygen, and injected into the first stage of the gasifier, which operates at 2600 °F/400 psig. In the first stage, the coal slurry undergoes a partial oxidation reaction at temperatures high enough to bring the coal's ash above its melting point. The fluid ash falls through a tap hole at the bottom of the first stage into a water quench, forming an inert vitreous slag. The syngas flows to the second stage, where additional coal slurry is injected. This coal is pyrolyzed in an endothermic reaction with the hot syngas to enhance syngas heating value and improve efficiency.

The syngas then flows to the syngas cooler, essentially a firetube steam generator, to produce high-pressure saturated steam. After cooling in the syngas cooler, particulates are removed in a hot/dry filter and recycled to the gasifier. The syngas is further cooled in a series of heat exchangers. The syngas is water-scrubbed to remove chlorides and passed through a catalyst that hydrolyzes carbonyl sulfide into hydrogen sulfide. Hydrogen sulfide is removed in the acid gas removal system using MDEA-based absorber/stripper columns. A Claus unit is used to produce elemental sulfur as a salable by-product. The "sweet" gas is then moisturized, preheated, and piped to the power block. The power block consists of a single 192-MWe GE MS 7001FA (Frame 7 FA) gas turbine, a Foster Wheeler single-drum heat recovery steam generator with reheat, and a 1952 vintage Westinghouse reheat steam turbine.



Project Status/Accomplishments

The Wabash River Coal Gasification Repowering Project, which is the world's largest single train IGCC plant operating commercially, is currently in its fourth year of operation and nearing the end of the planned demonstration. The Dynegy gasification process (formerly known as the Dow gasification process) has demonstrated the ability to operate at full load while meeting environmental requirements for SO_2 and NO_x emissions. The facility is demonstrating a heat rate of 8,910 Btu/kWh (HHV) and SO_2 emissions of 0.1 lb/10^6 Btu. The total NO_x emissions are 0.15 lb/10^6 Btu and particulate emissions are below detectable limits. The facility has operated approximately 15,000 hours and processed approximately 1.5 million tons of coal to produce about 23 x 10^{12} Btu of syngas.

The GE Frame 7 FA gas turbine has performed well on syngas, but not without problems. In addition to cracking in the syngas flow sleeves and in the combustion liners previously reported, compressor rows 4 through 17 of the rotor and stator incurred damage in mid-March 1999, resulting in a three month outage. The outage allowed time to focus on other issues. Efforts are now focused on reducing nuisance trips in the air separation unit, which produces 2,060 tons/day of 95% pure oxygen. The particulate removal system has performed well since a major improvement project in 1997. Downtime associated with the barrier filter system had been reduced by nearly 80% over the first commercial year statistics. An ongoing filter element development program reduced 1998 filter-related downtime by an additional 66 percent over 1997. An extended outage adversely affected the 1999 operating statistics; however, the facility was able to set another quarterly production record of 2.7 x 10^{12} Btu. In 1999, the annual contract capacity was 69.9% and the annual availability was 79.1%. For comparison, the 1998 annual availability was 71.8%.

Destec Energy and CINergy Corp./PSI Energy received the 1996 Powerplant Award from *Power* magazine. Sargent & Lundy, engineer for the combined-cycle facility, won the American Consulting Engineers Council's 1996 Engineering Excellence Award.

On December 31, 1999, the demonstration was completed and Global Energy, Inc. purchased Dynegy's gasification assets and technology. Global Energy plans to market the technology under the name "E-Gas Technology™."

Commercial Applications

Throughout the United States, particularly in the Midwest and East, 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. Repowering these plants with IGCC systems will improve plant efficiencies and reduce SO_2, NO_x, particulate, and CO_2 emissions. The modularity of the gasifier technology will permit a range of units to be considered for repowering, and the relatively short construction schedule for the technology will allow utilities greater flexibility in designing strategies to meet load requirements. Also, the high degree of fuel flexibility inherent in the gasifier design will provide utilities with more choice in selecting fuel supplies to meet increasingly stringent air quality regulations.