Piñon Pine IGCC Power Project
A DOE Assessment

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Executive Summary

The goal of the U.S. Department of Energy's (DOE) Clean Coal Technology (CCT) program is to furnish the energy marketplace with a number of advanced, more efficient, and environmentally responsible coal utilization technologies through demonstration projects. This document serves as a DOE post-project assessment (PPA) of the Piñon Pine IGCC Power Project, selected in Round IV of the CCT Demonstration program.

In August 1992, Sierra Pacific Power Company (SPPCo) entered into a cooperative agreement with DOE to conduct the project, which was sited at the SPPCo Tracy Station, located near Reno, Nevada. The purpose of this CCT project was to demonstrate air-blown integrated gasification combined cycle (IGCC) technology as commercially viable by installing a Kellogg/Rust/Westinghouse (KRW) gasifier and a General Electric (GE) Frame 6FA combustion turbine. In addition to SPPCo, the project team included Foster Wheeler USA Corporation (FWUSA) for engineering and construction, Bechtel Corporation for startup engineering, and M.W. Kellogg Company as technology supplier. DOE provided $167.9 million, or 50 percent of the total project funding of $335.9 million. DOE participation in the project ended on January 1, 2001, when the cooperative agreement expired.

A protracted effort was made to bring the facility on stream, but a series of equipment problems resulted in aborting all startup attempts. Sustained integrated operation of the gasifier and hot-gas cleanup facilities was never achieved. Although some problems were encountered with the gasifier, startup failures were mostly related to problems with the filter-fines removal system. Attempts to start the IGCC plant were discontinued in 2001, and the gasifier is being mothballed.

The Piñon Pine IGCC project facilities are divided into two main equipment areas (referred to as islands), the Gasifier Island and the Power Island. (See Figure 1.) The Gasifier Island includes: solids receiving, storage, and crushing; oxidant compression and supply; coal gasification; gasifier-exhaust heat recovery; hot-gas desulfurization; gasifier fuel-gas particulate removal; recycle-gas compression; solid-waste handling; and wastewater treatment facilities. The Power Island consists of the combustion turbine/generator, the heat-recovery steam generator (HRSG), and the steam turbine/generator. Although the Gasifier Island never operated continuously for more than 24 hours at a time, the Power Island has successfully generated electric power operating on natural gas.

The project has three solids feed streams: coal; limestone, which acts as a sorbent for sulfur in the coal; and coke breeze (fine coke particles) used during gasifier startup. Air for the Gasifier Island is extracted from the compressor supplying combustion air to the combustion turbine.

The purpose of the gasifier is to convert coal into a fuel gas with a lower heating value (LHV) of approximately 130 Btus per standard cubic foot. The primary gasification reactions occurring in the gasifier are between carbon and oxygen, or steam, to form predominantly carbon monoxide (CO) and hydrogen (H_2). Limestone in the gasifier is calcined to calcium oxide (CaO) that reacts with some of the hydrogen sulfide (H_2S) to form calcium sulfide (CaS).

The KRW fluidized-bed gasifier consists of a vertical vessel with a smaller diameter at the bottom than at the top. It is fitted with a central feed tube through which coal, limestone, and air are introduced. Steam (extracted from the steam turbine) is also added to the gasifier at the grid to aid with fluidization. Solids are fed through a series of bins, which raise the pressure from atmospheric to gasifier operating conditions. Coal and limestone are pneumatically transported to the gasifier central feed tube, where air is added and the streams merged to form a central jet. The coal quickly devolatilizes, and unburned char and limestone enter the gasifier bed. Combustion within the jet provides the heat necessary for the endothermic devolatilization, gasification, and desulfurization reactions.

As the carbon in the coal and char gasifies, the particles become enriched in ash. These ash particles tend to agglomerate and, along with dense calcium sulfide/oxide particles, separate from the bed because of their different density and fluidization characteristics. These solids are cooled in the annulus around the gasifier feed tube by a countercurrent flow of recycle gas, removed through a rotary feeder, and transported to the ash collection system.

Gas exiting the gasifier enters a cyclone for removal of entrained solids (char, ash, and sorbent). Solids collected in the cyclone are returned to the gasifier via the cyclone dip leg, while the gas passes through the product gas cooler, which generates steam. This steam is combined with steam from the HRSG.

The hot-gas cleanup system includes the transport desulfurizer, the transport regenerator, the sulfator, and the hot-gas filter. In the desulfurizer, hydrogen sulfide reacts with a zinc-based sorbent. The desulfurized gas passes through a cyclone and then goes to the hot-gas filter. Part of the solids from the cyclone are sent to the bottom of the transport regenerator, with the rest being recycled to the desulfurizer. In the regenerator, air oxidizes absorbed sulfur to sulfur dioxide (SO_2) and regenerates the sorbent, which is returned to the desulfurizer.

The sulfator is a bubbling bed reactor, which is fluidized by air. In the sulfator, SO_2 in the regenerator off-gas is absorbed by CaO to form calcium sulfite, which is oxidized to calcium sulfate. Solids from the sulfator are cooled and pneumatically transported to the solid-waste silo.

Product gas from the desulfurizer is sent to the hot-gas filter, a steel vessel containing ceramic candles. Product gas exiting the hot-gas filter is sent to the combustion turbine. The fines combustor is a fired burner used to burn any carbon in the particulates that collect in the cone section at the bottom of the filter.

The combustion turbine is coupled to a generator, which has an expected operating output of 61 megawatts electric (MWe), when burning LHV fuel gas. Approximately 20 percent of the air from the compressor providing air to the combustion turbine is extracted for injection into the gasifier and returns as part of the fuel gas. An HRSG is provided to recover combustion turbine exhaust heat as steam, which is sent to the steam turbine. The steam turbine is a condensing-type unit with extraction to provide steam to the gasifier. The steam turbine/generator has an output of 46 MWe.

At the time that DOE participation in this project ended, the gasifier had not been successfully operated for more than 24 hours at a time. Therefore, it is not possible to report on performance of the system under typical operating conditions.

Prior to expiration of the Cooperative Agreement on January 1, 2001, attempts had been made to start the Gasifier Island 24 times. The first attempt took place on January 18, 1998, and the last on August 10, 2000.

Despite considerable effort and much progress, the Gasifier Island was successfully operated for only short periods of time prior to the end of the project. A significant problem with this project was that it incorporated not one, but two new technologies, the KRW gasifier and hot-gas cleanup. For the Gasifier Island to produce fuel gas, both technologies must operate successfully. A great deal of difficulty was encountered with the hot-gas filter-fines removal system. Solids handling is inherently more difficult than handling liquids and gases, and the large number of solids streams contributed to the complexity of operations. Major problems were encountered with the filter-fines removal system, the fines combustor, and the refractory in the gasifier.

The environmental system designed for the plant had great potential. However, the Gasifier Island was not successfully operated for a long enough time to demonstrate the environmental goals for this project; that is, environmental performance at a scale sufficient to establish the commercial viability for this technology was not achieved.

The 1999 World Gasification Survey shows that there has been a significant increase in gasification activity in the past decade. In particular, the majority of the recent increase in installed gasification capacity is fueled by coal or petroleum coke. The impetus for this growth is the increased cost of environmental compliance for conventional units fired with pulverized coal (PC), the drive to improve efficiency, the availability of low-cost alternative feedstocks, such as petroleum coke, and the need to utilize indigenous coal in areas having no access to natural gas. The maturation of coal gasification through successful completion of several large-scale CCT demonstration projects has made this technology a popular and viable alternative to conventional combustion approaches. In addition to generating power by burning the gas in a combustion turbine, the IGCC process can also be modified to produce value-added chemicals or transportation fuels from coal by chemical processing of the CO and H_2 in the fuel gas produced.

The failure of the Piñon Pine project to operate successfully makes it difficult to determine the potential market for the KRW gasifier technology. It appears that most of the Piñon Pine Project problems were associated with the filter-fines removal system, rather than with the gasifier itself. Had a more proven technology for gas cleanup been used, it seems likely that the gasifier startup would have been successful. However, it is doubtful that there will be any other installations of the KRW technology until the Piñon Pine IGCC Power Project is successfully operated. If this should occur, then the KRW gasifier could be in position to capture part of the power market. Although the gasifier is being mothballed, both an independent engineering service group and a consultant are examining the feasibility of restarting the gasifier.

It is not possible to evaluate economics for the Piñon Pine Project technology, because the facility never operated successfully for an extended period. Total project cost was $336 million, including construction, operations, and plant modifications. In December 1994, FWUSA prepared a construction cost estimate of $222 million. Combustion-turbine capacity is 61 MWe and steam-turbine capacity is 46 MWe, for a total generation of 107 MWe. Assuming that the FWUSA cost estimate is reasonably correct, capital cost was approximately $2,000/kW of capacity. This figure appears to be reasonable considering the first of a kind nature of the project. Because the facility never operated in steady state, it is not possible to estimate operating cost or to perform a cost-of-electricity calculation.

From the beginning, this project was plagued with problems; some were the result of design deficiencies, and some were a result of defective equipment. Much progress was made during this project in overcoming these problems through design changes and by repairing or replacing faulty equipment. Nevertheless, this project cannot be considered a success, because the gasifier and hot-gas cleanup system never functioned fully for more than 24 hours at a time. Thus, the objective of this project to demonstrate the KRW air-blown gasifier was not achieved. This is unfortunate, as most of the aborted startups were caused by problems with the filter-fines removal system, rather than with the gasifier. It seems probable that if proven technology had been used for the fuel-gas cleanup system, successful operation of the KRW gasifier would have been achieved. With the increasing interest in IGCC, an air-blown gasifier capable of operating on a wide range of feeds would be a desirable addition to the suite of gasifiers available to power providers.

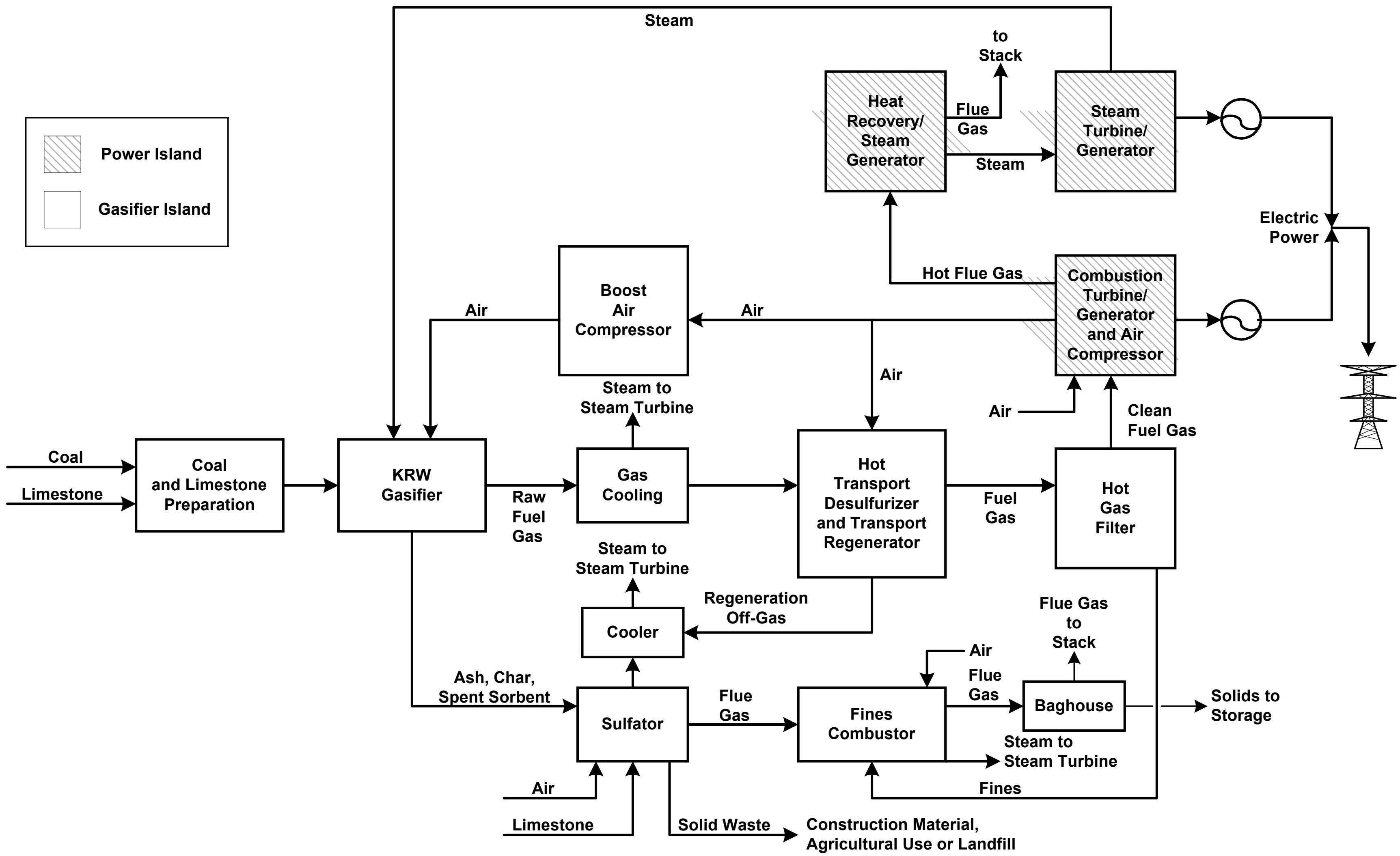

Figure 1. Block Flow Diagram of Piñon Pine IGCC Project

I Introduction

The goal of the U.S. Department of Energy's (DOE) Clean Coal Technology (CCT) program is to furnish the energy marketplace with a number of advanced, more efficient, and environmentally responsible coal utilization technologies through demonstration projects. These projects are conducted to establish the commercial feasibility of the most promising advanced coal technologies that have developed beyond the proof-of-concept stage.

This document serves as a DOE post-project assessment (PPA) of a project selected in CCT Round IV, the Piñon Pine IGCC Power Project, as described in a Report to Congress (U.S. Department of Energy 1992). The desire to demonstrate a promising new Integrated Gasification Combined Cycle (IGCC) technology incorporating hot-gas cleanup and a low heating value (LHV) gas combustion turbine prompted Sierra Pacific Power Company (SPPCo) to submit the proposal for this project. In addition to demonstrating new technology with great potential, this project would increase SPPCo's fuel flexibility, while providing needed additional power for SPPCo customers in an efficient and environmentally friendly way. In August 1992, SPPCo entered into a cooperative agreement with DOE to conduct the project. The facility was sited at SPPCo's Tracy Station, located near Reno, Nevada. The purpose of this CCT project was to demonstrate air-blown pressurized fluidized-bed IGCC as a commercially viable technology by installing a KRW (Kellogg/Rust/Westinghouse) gasifier and a General Electric (GE) Frame 6FA combustion turbine. DOE provided $167.9 million, or 50 percent of the total project funding of $335.9 million.

Before addition of the IGCC facility, the Tracy Station consisted of three gas/oil-fired units with a total generating capacity of 244 megawatts electric (MWe). The CCT demonstration project, which added 107 MWe, was installed as Unit 4, a stand-alone plant, not integrated with any of the three existing units, except for a shared control room with Unit 3. Construction for the demonstration project was started in February 1995 and completed in February 1997. Operations were initiated in January 1998. DOE's participation in the project ended on January 1, 2001, when the cooperative agreement expired. In 1999, Sierra Pacific Resources merged with Nevada Power Company. This merger required the merged company to sell its power-generating assets and retain only power transmission and distribution.

A protracted effort was made to bring the facility on stream, but a series of equipment problems resulted in aborting all startup attempts. Thus, sustained integrated operation of the gasifier and hot-gas cleanup facilities was never achieved. Although some problems were encountered with the gasifier, for the most part, startup failures were related to problems with the filter-fines removal system. The pending sale of the Piñon Pine facility tended to defer the problem of making the unit operational to the new owners. Only minimal operators were retained at the Tracy site. Later, because of power-shortage problems, the requirement to sell generating assets was withdrawn, and the PUC allowed for the maintenance of the power-generating assets.

Attempts to start the IGCC plant were discontinued in 2001, and the plant is currently being mothballed because of the uncertainty of the operating status of the Tracy facility and the need to keep costs low. The independent evaluation contained herein is based primarily on information from the Sierra Pacific Resources Final Report (Sierra Pacific Resources 2001), as well as other references cited.

II Project/Process Description

II.A Potential of the Technology

The goal of this project was to demonstrate air-blown, pressurized, fluidized-bed IGCC technology incorporating hot-gas cleanup integrated with a combustion turbine fueled with a low heating value gas. IGCC has an inherent advantage for controlling sulfur emissions, since sulfur is produced as hydrogen sulfide (H_2S) rather than as sulfur dioxide (SO_2). It is much easier to remove H_2S from fuel gas than it is to remove SO_2 from flue gas. Air-blown coal gasification avoids the need for an expensive oxygen plant. In addition to fewer pollutant emissions, IGCC with hot-gas cleanup promises increased efficiency compared to a standard pulverized coal (PC)-fired power station.

II.B Project Description

The Piñon Pine IGCC Project was sited at SPPCo's Tracy Station, located about 17 miles east of Reno, Nevada. The project involved construction of a new facility at the site, including a KRW air-blown gasifier for the production of fuel gas, a hot-gas cleanup system for removal of sulfur compounds and particulates, a combustion turbine/generator, a heat-recovery steam generator (HRSG), and a steam turbine/generator. The gasifier was a scaled up version of the KRW gasifier tested at Waltz Mill, Pennsylvania. The Waltz Mill pilot unit, with a capacity of 12-18 tons of coal per hour, was operated for a total of 12,000 hours between 1975 and 1988. The M.W. Kellogg Company (MWK) owns the rights to the KRW gasifier technology.

Design, procurement, and construction of the entire project were the responsibility of the Foster Wheeler USA Corporation (FWUSA). MWK, under subcontract to FWUSA, was responsible for the design and procurement of the major components for the Gasifier Island, including the hot-gas cleanup system. Foster Wheeler Constructors Incorporated (FWC), under subcontract to FWUSA, was responsible for construction management of the entire project. General Electric coordinated design and installation of the combustion turbine and steam turbine. Startup engineering was done initially by Foster Wheeler (from 1996 to mid 1997) and then Bechtel Corporation (beginning in September 1997). Expected plant performance, on both higher heating value (HHV) and lower heating value (LHV) bases, is listed in Table 1.

The gasifier was designed to operate with low-sulfur Western coal with a range of properties, as shown in Table 2 (U.S. Department of Energy 1996). Coal used during the demonstration was provided by the Southern Utah Fuel Company (SUFCO). Planned tests with higher-sulfur (one to two percent) eastern bituminous coal were not completed because of the problems encountered in bringing the gasifier on line.

Table 1. Expected Project Performance

Performance Criteria	Value
Coal Feed, tons/day	880.6
Gas Turbine Power, MWe	61.0
Steam Turbine Power, MWe	46.2
Gross Power, MWe	107.2
Auxiliary Power Use, MWe	7.5
Net Power, MWe	99.7
Thermal Efficiency, % (HHV)	40.6
Thermal Efficiency, % (LHV)	42.1
Net Heat Rate, Btu/kWh (HHV)	8390
Net Heat Rate, Btu/kWh (LHV)	8096

Table 2. Expected Range of Coal Properties

Property	Range
Higher heating value (as received), Btu/lb	11,250-11,750
Sulfur, wt % (dry)	0.5-0.9
Ash, wt % (dry)	7-11
Moisture, wt %	7-14

Training of the operations staff, which was assisted by Foster Wheeler Power Systems Inc. and MWK, commenced on January 1, 1996. Because of the many novel aspects of the project, a long lead-time was provided for training. Startup of the Gasifier Island portion of the project on natural gas was initiated in August 1996, and operation became commercial in December 1996. The first attempt to start up the Gasifier Island was made in January 1998. (See Section II.C. for a description of the equipment included in the gasifier and Power Islands.) Twenty-four attempts were made to start up the Gasifier Island, but all attempts failed because of design or equipment flaws. The Cooperative Agreement expired on January 1, 2001, terminating DOE's participation in the Piñon Pine CCT project before the Gasifier Island was successfully operated for more than 24 hours at a time.

II.C Project Goals

The goals of the Piñon Pine IGCC project were the following:

- To utilize advanced technologies to produce clean, low-cost power from coal.
- To demonstrate air-blown, pressurized fluidized bed IGCC technology coupled with hot-gas cleanup.
- To evaluate performance of a gas turbine fueled by low heating value gas.
- To assess long-term reliability, maintainability, and environmental performance of the technology at a scale sufficient to demonstrate commercial viability.

II.D Technology Description

Figure 2 presents a block flow diagram of the Piñon Pine IGCC Project facilities. This is a simplified drawing with only major equipment areas and streams being shown. Project facilities are divided into two main equipment areas, referred to as islands: the Gasifier Island and the Power Island. The Gasifier Island includes the following facilities:

- Solids receiving, storage, and crushing – This area handles preparation of coal before it is sent to the gasifier. (Limestone and startup coke breeze are pre-sized offsite and received via closed trucks for conveying into storage bins.)
- Oxidant compression and supply – These facilities provide the compressed air needed by various parts of the plant, including the gasifier and sorbent regenerator.
- Coal gasification – The gasifier converts coal into LHV fuel gas that is burned in the combustion turbine.
- Gasifier-exhaust heat recovery – This unit cools the gasifier fuel gas by generating steam that is used elsewhere in the plant.
- Hot-gas desulfurization – This system removes sulfur from the raw fuel gas and converts it to calcium sulfate for use or disposal.
- Gasifier fuel-gas particulate removal (hot-gas filter) – This unit removes any remaining particulates from the fuel gas before it is burned in the combustion turbine. Carbonaceous fines are removed from the fuel gas and combusted for additional steam generation.
- Recycle gas compression – This compressor provides recycle gas required by the gasifier, the desulfurizer, and the hot-particulate filter.

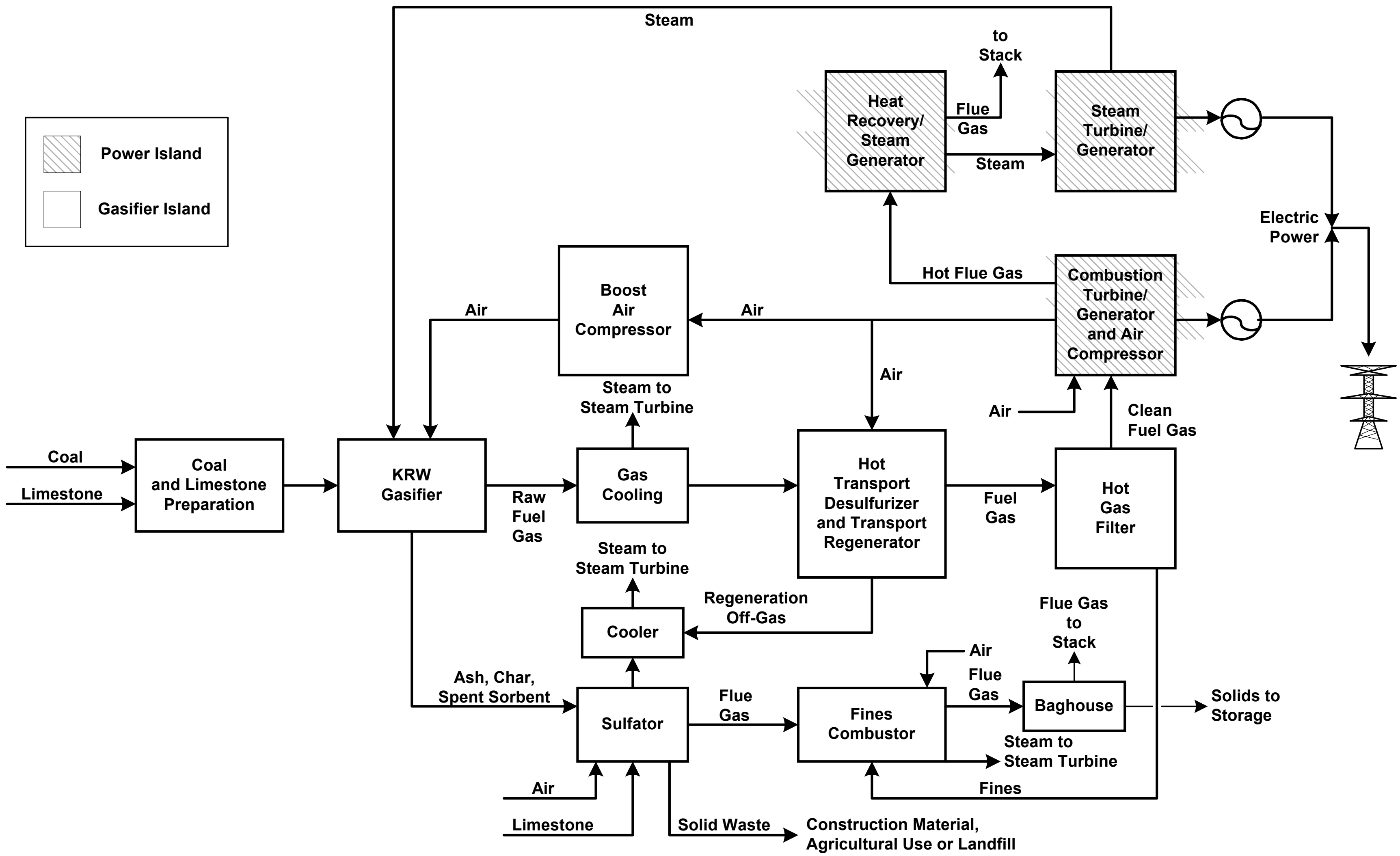

Figure 2. Block Flow Diagram of Piñon Pine IGCC Project

- Solid-waste handling – These facilities handle the solid waste from the plant.

- Wastewater treatment – These facilities treat the small amount of plant wastewater.

The Power Island consists of the following:

- Combustion turbine/generator – This unit burns the fuel gas produced in the gasifier and generates electric power.

- Heat-recovery steam generator – This HRSG recovers waste heat from the gas turbine exhaust and generates steam for use by the steam turbine.

- Steam turbine/generator – This unit generates additional electric power using steam generated from waste heat produced by the Gasifier Island and gas turbine.

II.D.1 Gasifier Island

The Gasifier Island includes all the facilities involved with fuel-gas production and cleanup and the handling of waste by-products.

Solids Receiving, Storage, and Crushing. Three solid streams are feeds to the project: coal; limestone, which acts as a sorbent for sulfur; and coke breeze (fine coke particles) that is used during gasifier startup. Raw coal, crushed to minus 2 inches, is received by the train. An automatic system has the capacity to unload an 84-car train (a one-week supply at design gasifier capacity) in 4 hours. The coal is stored in a dome with a capacity of 16,400 tons, approximately a 20-day supply. The raw coal is stockpiled and reclaimed by an automated stacker/reclaimer. Reclaimed coal is fed to the coal crusher, where it is reduced to a size range of 1/4 inch or smaller. The crushed and screened coal is conveyed to the coal storage silo, which holds a 1-day supply. Some problems were encountered with spontaneous combustion of coal in the dome. This was a result of the low consumption of coal because of startup problems. The solution was to store the coal outside.

Dried coke breeze is delivered to the plant by truck. The truck's blower pneumatically transfers the breeze to an 800-ton capacity storage silo. In a similar fashion, sized limestone with a nominal particle diameter of 650 microns (about the size of sand) is received by truck and pneumatically unloaded into the limestone silo. Individual weigh belt feeders supply materials from the three silos (coal, coke breeze, and limestone) to the common-feed elevating conveyor that transports them to the gasifier.

Oxidant Compression and Supply. Air for the Gasifier Island is extracted from the compressor supplying combustion air to the Power Island combustion turbine. Air for the gasifier is first cooled in a series of three exchangers and then compressed in the booster compressor to about 325 psig. A portion of the compressed air is again cooled, used to transport coal and limestone (or coke breeze) to the gasifier, and fed to the suction of the pressurization air compressor for coal- and limestone-feed pressurization. A small portion of the compressed air is sent to the transport regenerator to regenerate the desulfurization sorbent, but the bulk of the air is heated and sent to the gasifier air tube.

Coal Gasification. Figure 3 is a schematic drawing of the KRW gasifier. The gasifier consists of three sections. In the bottom, ash and spent sorbent separate; in the middle is a fluidized bed of char, ash, and sorbent; and at the top, gas/solids separation occurs. Solids fed to the gasifier are coal and limestone that act as a sorbent to capture sulfur compounds generated during gasification. A single conveyor transports coal and limestone, as well as coke breeze used during startup. The feed system consists of a series of bins, which are designed to raise the pressure from atmospheric to gasifier operating conditions. This system provides a continuous flow of coal and limestone to the gasifier. Coal or coke and limestone are pneumatically transported to the gasifier's central feed tube, where air is added and the streams merged to form a central jet. The coal quickly devolatilizes, and unburned char and limestone enter the gasifier bed. Combustion of char and gas occurs within the jet to provide the heat necessary for the endothermic devolatilization, gasification, and desulfurization reactions. Steam extracted from the steam turbine is also injected into the gasifier at the grid to aid in fluidization of the bed.

As the carbon in the coal and char gasifies, the particles become enriched in ash. These ash particles tend to agglomerate and, along with dense calcium sulfide/oxide particles, separate from the char bed because of a difference in density and fluidization characteristics. This separation occurs primarily in the region surrounding the central feed tube at the bottom of the gasifier. These solids are cooled in the annulus around the gasifier feed tube by a countercurrent stream of recycle gas. The spent solids leaving the gasifier are unconverted calcined limestone, sulfided limestone, and ash (referred to as LASH). They pass through the ash grinder and the ash feeder and are transported to the ash collection system, consisting of a series of bins designed to reduce the pressure from gasifier conditions to sulfator operating pressure.

Gas exiting the gasifier enters a cyclone for removal of entrained solids (char, ash, and sorbent). The gas passes from the cyclone through the product-gas cooler and the product-gas trim cooler. Solids collected in the cyclone are returned to the gasifier via the cyclone dip leg. Recycle gas from the recycle-gas compressor is used to fluff the dip leg to facilitate flow of solids back to the gasifier.

Gasifier-Exhaust Heat Recovery. Product gas from the cyclone is cooled to 1,000^{o}F by the product-gas cooler and the product-gas trim cooler that generate high-pressure steam. This steam is combined with steam from the HRSG, superheated to 600^{o}F in the HRSG, and sent to the steam turbine for electric power production.

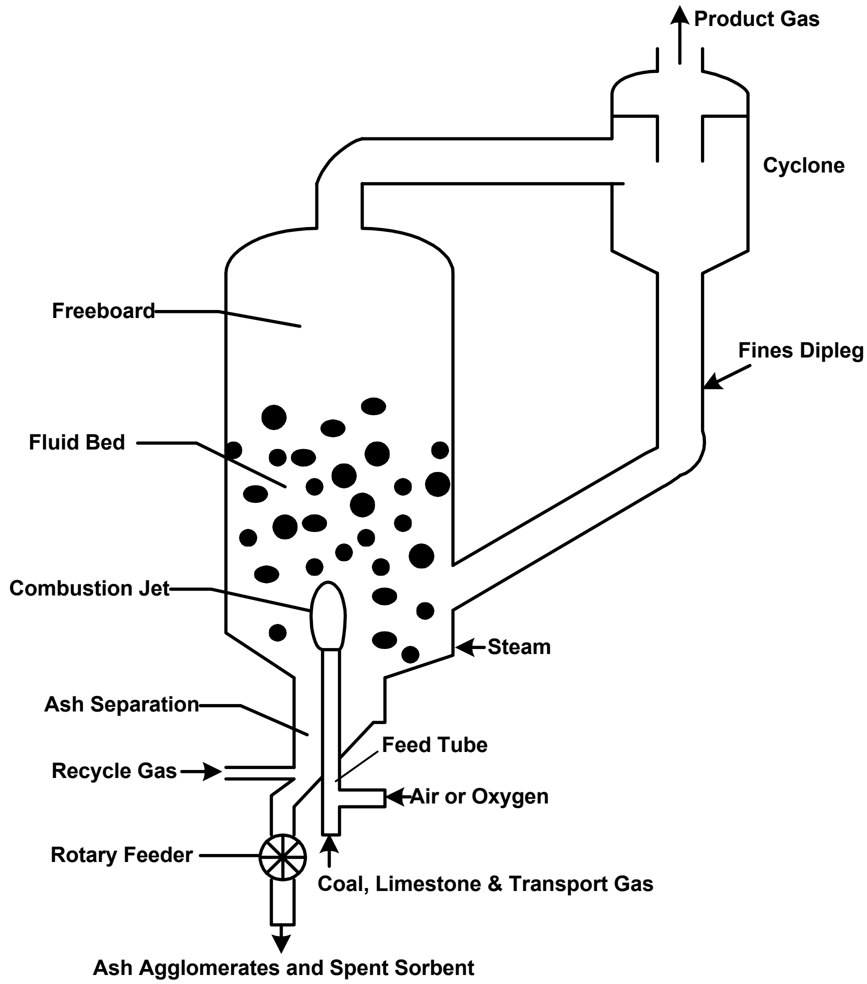

Figure 3. Schematic of KRW Gasifier

Hot-Gas Desulfurization. The hot-gas desulfurization system includes the transport desulfurizer, the transport regenerator, and the sulfator. Figure 4 is a schematic drawing of the transport desulfurizer and regenerator. The 1000^{o}F gas from the gasifier gas cooler passes through the desulfurizer feed cyclone to remove particulates. The fines collected in the cyclone are pneumatically transported to the hot-gas filter, where they are combined with the fines removed by the filter. The gas exiting the cyclone is sent to the mixing zone at the bottom of the desulfurizer riser. In the riser, hydrogen sulfide reacts with the zinc-based sorbent.

Separation of cleaned product gas from sorbent occurs in the desulfurizer cyclone. The cleaned gas is sent to the hot-gas filter. Part of the recovered solids is sent to the mixing zone at the bottom of the transport regenerator, and the rest is recycled to the desulfurizer. Regeneration air is preheated in the sorbent regeneration air heater before being fed to the mixing zone at the bottom of the transport regenerator. In the regenerator, sorbent is regenerated and SO_2 is produced.

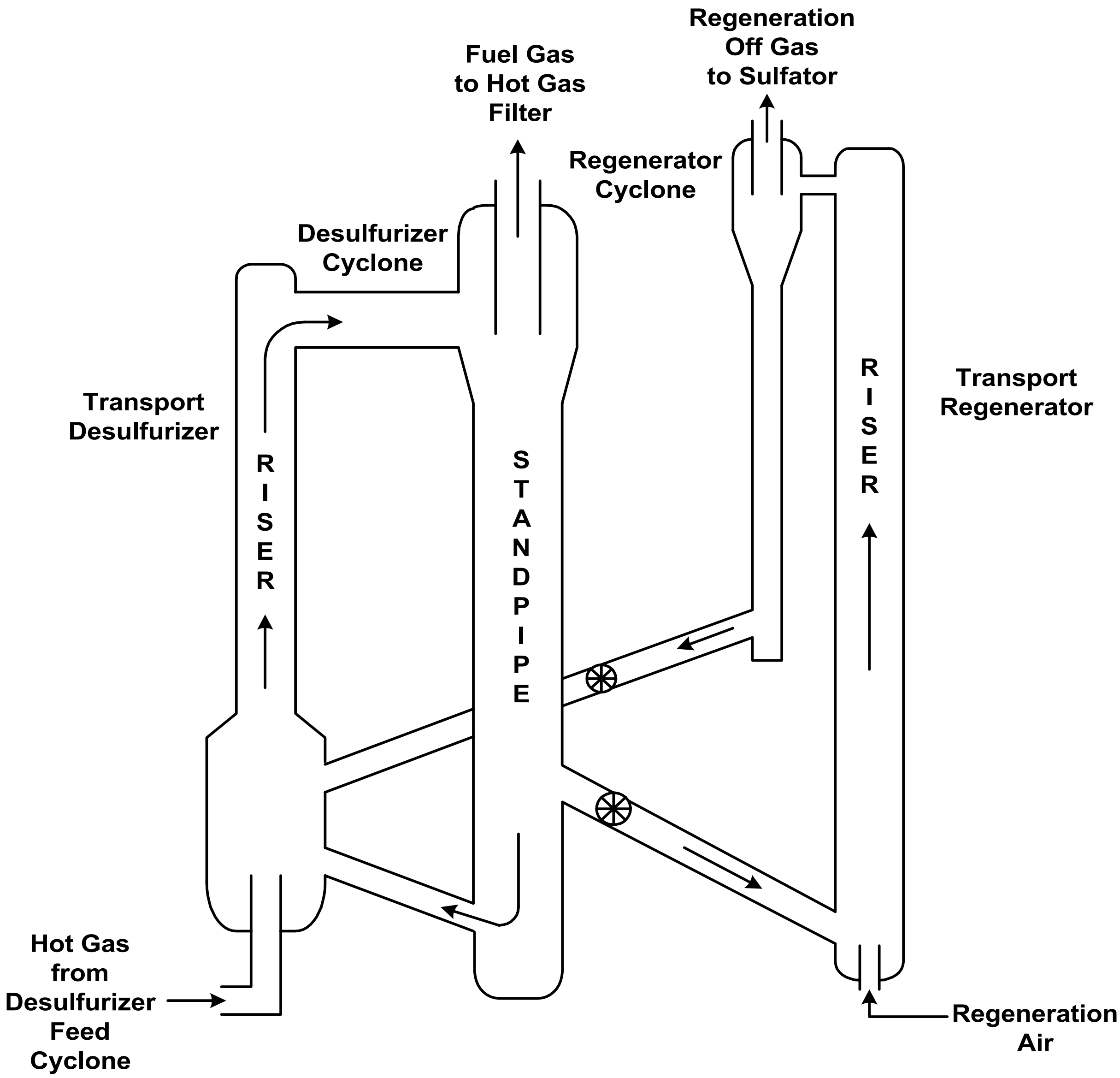

Figure 4. Schematic of Transport Desulfurizer and Transport Regenerator

The regeneration reactions are very exothermic, and the gas leaving the regenerator riser has a temperature of approximately 1,200°F. This gas flows to the regenerator cyclone, where solids are removed. The regenerated sorbent is recycled to the desulfurizer standpipe. The regenerator off-gas is cooled in the regenerator effluent cooler and sent to the sulfator for SO_2 removal.

The sulfator is a bubbling bed reactor, which is fluidized by air supplied from the sulfator air compressor. LASH exiting the gasifier annulus, containing unconverted CaO, is conveyed from the ash-feed hopper to the sulfator by cooled recycle gas. Small recycle gas streams from the a regenerator off-gas is converted to calcium sulfate. If there is insufficient CaO in the feed solids to react with all the SO_2, limestone can be added to the sulfator.

The sulfator is operated at essentially atmospheric pressure and about 1,600^oF. Temperature is maintained by generating steam in the primary solids cooler. The steam is sent to the gasifier steam drum. Flue gas from the sulfator flows through the sulfator cyclone to remove entrained particles and then mixes with flue gas from the fines combustor prior to passing through the heat- recovery steam generator. Solids from the sulfator are cooled in the sulfator-solids screw cooler. The cooled solids are pneumatically transported to the solid-waste silo.

Gasifier Exhaust-Gas Particulate Removal. Product gas from the desulfurizer, containing a small quantity of particulates, is sent to the hot-gas filter, which removes essentially all the remaining particles. Figure 5 is a schematic drawing of the hot-gas filter system. The hot-gas filter is a steel vessel containing ceramic candles. Particulate-free gas from the filter is sent to the combustion turbine. Fines from the filter are pneumatically transported to either the fines combustor or the LASH silo.

Recycle-Gas Compression. Most of the product gas exiting the hot-gas filter is sent to the combustion turbine. However, a small part is diverted through the recycle gas cooler. Most of this then goes to the recycle gas compressor that raises the pressure of the fuel gas so that it can be used for fluidizing purposes in the gasifier. Some of the cooled gas is further cooled in the trim cooler and then sent to the recycle gas booster compressor to supply back-pulse gas for the hot-gas filter. A small percentage of the recycle gas is used as low-pressure transport gas to convey filter fines to the fines combustor.

Solid-Waste Handling. The fines combustor is a fired burner that is used to combust residual particulates produced during gasification. These particulates consist of carbon, LASH, and a very small amount of desulfurizer sorbent. Fines that collect in the cone section at the bottom of the filter are removed by a screw conveyor/cooler and dumped into the fines collection bin. From there, they move to a depressurization bin and finally to a feed bin. The fines feeder then dumps them into the transport line, which uses recycle gas to transport them to the combustor for incineration. Hot flue gas produced in the combustor is used to produce steam. Particulates resulting from the combustion are removed in a baghouse and conveyed to the waste silo. The flue gas is sent to a stack.

The other source of solid waste is the sulfator. This solid waste is conveyed pneumatically with air to the solid-waste silo. The silo is periodically emptied into trucks, and the material is hauled to a local permitted landfill. However, this waste can be used in agriculture or construction.

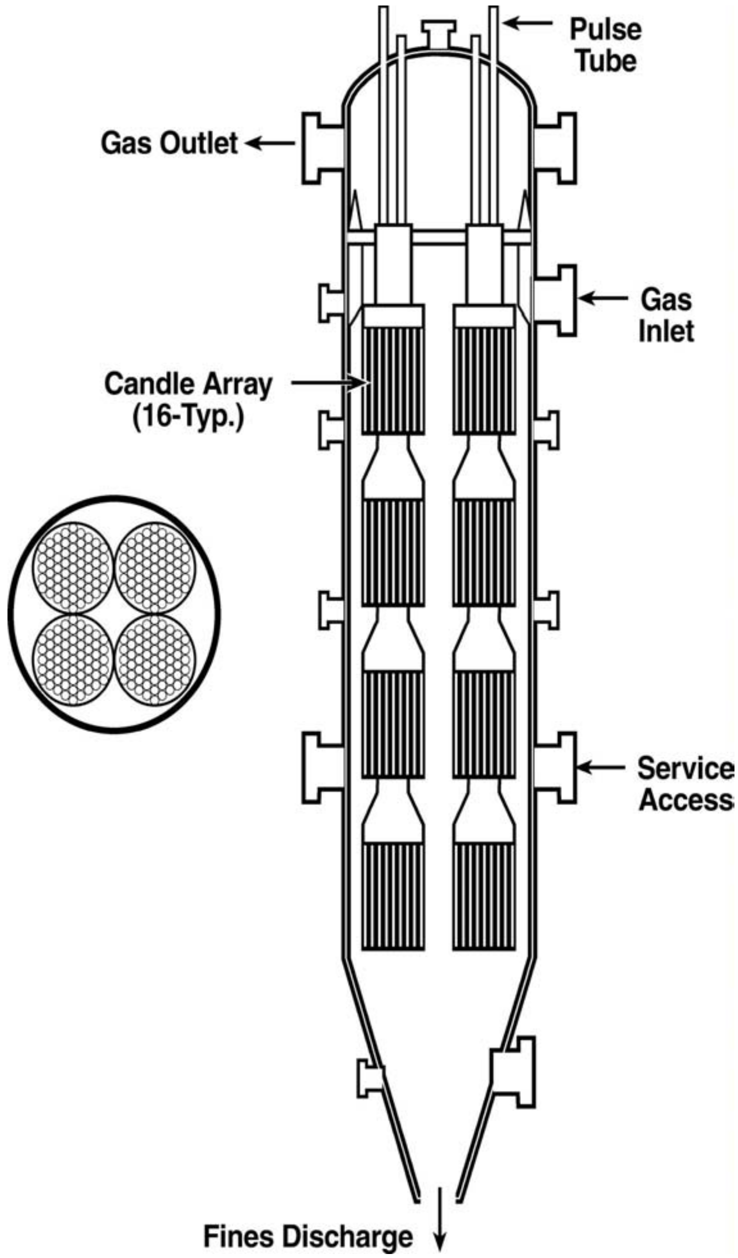

Figure 5. Schematic of Hot Particle Removal System

Wastewater Treatment. A slipstream of circulating cooling water, along with regeneration wastewater, is sent to the equalization tank. Water from this tank is pumped to a clarifier, where caustic is added for pH adjustment. Magnesium sulfate ($MgSO_4$) and sodium carbonate (Na_2CO_3) are added to reduce silica content, and polymers are added to promote the settling of calcium and magnesium salts and silica. This stream is then filtered, and the filtrate returned to the cooling tower. Cooling tower blowdown is discharged to a double-lined evaporation pond.

II.D.2 Power Island

The Power Island includes all the facilities involved with the production of electric power.

Combustion Turbine/Generator. The combustion turbine, a General Electric Model MS6001FA (70.1 MWe ISO rating), is coupled to a once-through air-cooled synchronous generator. The expected operating output when burning fuel gas with a LHV of about 130 Btu per standard cubic foot (scf), at annual average ambient air conditions (50^{o}F, 12.56 psia, 20-percent relative humidity), is 61 MWe with 1.422 million lb/hr of exhaust gas at 1,103^{o}F. The combustion turbine has an 18-stage axial flow compressor with modulated inlet guide vanes. Approximately 20 percent of the total compressor discharge air is extracted for the air-blown gasifier and returns as part of the fuel gas.

Heat-Recovery Steam Generator. A HRSG is provided to recover heat from the combustion-turbine exhaust. Two levels of steam are generated: 1006.7 psia and 59.1 psia. The 1006.7 psia steam is combined with the high-pressure steam generated in the gasifier and sent to the steam turbine at 950 psia and 950^{o}F. The 59.1 psia steam is superheated and sent at 55 psia and 360^{o}F to the de-aerator with the excess sent to the steam turbine.

Steam Turbine/Generator. The steam turbine is a condensing type unit with extraction at nominally 485 psia to provide steam, after pressure control and desuperheating, to the gasifier at 420 psia and 700^{o}F. (This steam can be used for injection at the gas-turbine inlet for nitrogen oxides (NOx) control when operating on natural gas.) The steam turbine exhausts into a surface condenser at 2 inches of mercury when operating at normal gasifier load and an ambient temperature of 50^{o}F. The steam turbine/generator has an output of 46.2 MWe.

II.E Process Chemistry

The chemistry of the reactions occurring in the gasifier and transport regenerator is complex, and the following discussion is intended only to cover typical reactions and not to provide a comprehensive analysis.

II.E.1 Gasifier Chemistry

The purpose of the gasifier is to convert coal into a low-heating-value fuel gas (approximately 130 Btu/scf LHV). The primary gasification reactions occurring in the gasifier are between carbon and oxygen or steam, as illustrated below:

$$C + O_2 \rightarrow CO_2$$
$$C + \tfrac{1}{2}O_2 \rightarrow CO$$
$$C + H_2O \rightarrow CO + H_2$$
$$C + CO_2 \rightarrow 2CO$$
$$CO + H_2O \rightarrow CO_2 + H_2$$

Carbon monoxide (CO) and hydrogen (H_2) are the major combustible constituents of the product gas. Methane and other hydrocarbons are produced in small quantities during devolatilization of the coal, but gasifier temperature is high enough to crack the tars and oils produced. Therefore, essentially no hydrocarbons heavier than methane are produced. Other major constituents are CO_2 from combustion and N_2 from the air used as the oxidizing agent.

Because of the reducing atmosphere present during gasification, sulfur in the coal is released predominantly as H_2S, and some of the coal nitrogen forms NH_3. At operating conditions in the gasifier, limestone is rapidly calcined (heated and decomposed) to form lime that reacts with the H_2S. These reactions are illustrated below:

$$S(coal) + H_2 \rightarrow H_2S$$
$$S(coal) + CO \rightarrow COS$$
$$CaCO_3 \rightarrow CaO + CO_2$$
$$CaO + H_2S \rightarrow CaS + H_2O$$
$$N(coal) + 3/2H_2 \rightarrow NH_3$$

Chemical equilibrium limits sulfur capture. With low-sulfur SUFCO coal, approximately 50 percent of the sulfur is removed by reaction with CaO. H_2S in the product gas is captured in the transport desulfurizer. (See Section II.D.1.) A typical fuel-gas composition is shown in Table 3 (U.S Department of Energy 1996).

Table 3. Typical Gasifier Fuel-Gas Composition After Hot-Gas Cleanup

Component	Composition, vol. %
CO	23.9
CO_2	5.5
CH_4	1.4
H_2	14.5
N_2	48.6
H_2O	5.5
Ar	0.6
H_2S	20 ppmv
NH_3	200 ppmv
Total	100
Heat of Combustion	
Higher Heating Value	138 Btu/scf
Lower Heating Value	129 Btu/scf

II.E.2 Transport Desulfurizer Chemistry

The purpose of the transport desulfurizer is to remove sulfur compounds from the fuel gas. This is accomplished by reacting hydrogen sulfide with a zinc oxide/nickel oxide sorbent, as shown below:

$$ZnO + H_2S \rightarrow ZnS + H_2O$$
$$ZnO + COS \rightarrow ZnS + CO_2$$
$$NiO + H_2S \rightarrow NiS + H_2O$$
$$NiO + COS \rightarrow NiS + CO_2$$

Before the sorbent can absorb more H_2S, the oxides must be reconstituted. This occurs in the transport regenerator, where oxygen reacts with the sorbent to reform zinc and nickel oxides and liberate SO_2, as shown:

$$ZnS + 3/2O_2 \rightarrow ZnO + SO_2$$
$$NiS + 3/2O_2 \rightarrow NiO + SO_2$$

These reactions are very exothermic, and the gas leaving the regenerator riser is approximately 1,200^{o}F.

II.E.3 Sulfator Chemistry

The purpose of the sulfator is to remove SO_2 from the transport regenerator tail gas so that the tail gas can be vented to the atmosphere. The SO_2 is removed as calcium sulfate, according to the following reaction:

$$CaO + SO_2 + \frac{1}{2}O_2 \rightarrow CaSO_4$$

At the same time that the SO_2 is being absorbed, CaS in the LASH fed to the sulfator is oxidized to calcium sulfate, as shown below:

$$CaS + 2O_2 \rightarrow CaSO_4$$

If insufficient CaO is present in the LASH to react with all the SO_2, limestone, which undergoes the following reactions, can be fed to the sulfator.

$$CaCO_3 + SO_2 \rightarrow CaSO_3 + CO_2$$
$$CaSO_3 + \frac{1}{2}O_2 \rightarrow CaSO_4$$

The calcium sulfate, along with the rest of the LASH, can be marketed for agricultural and industrial uses.

III Technical And Environmental Assessment

DOE involvement with this project ended on January 1, 2001, with the expiration of the cooperative agreement. At that time, the gasifier had not been successfully operated for more than a few hours at a time. Therefore, it is not possible to report on performance of the system under typical operating conditions. Rather, the following discussion covers the more important problems that were encountered, what actions were taken to overcome these problems, the lessons learned, and project achievements.

III.A Technical Results

III.A.1 Gasifier Island

Prior to expiration of the Cooperative Agreement, 24 attempts had been made to start up the Gasifier Island, as listed in Tables 4 and 5. The first attempt was made on January 18, 1998 and the last on August 10, 2000. On July 1, 1998, the position of Gasifier Process Specialist was created. Following this, each startup was given a number. There were six startup attempts prior to the creation of the Specialist position and 18 startups following it. In general, after a startup, the next startup was not attempted until all the problems identified from the previous startup had been corrected. In some cases, considerable time elapsed between attempted startups.

To start the gasifier, it is first loaded with a mixture of approximately 50-percent coke breeze and 50-percent limestone. Preheated extraction air from the compressor is introduced, and heat up is started. Coke breeze combustion typically begins at a temperature of approximately 400^{o}F. When the temperature reaches approximately 1,200^{o}F, steam is introduced, and feeding of coal is begun. Fuel gas produced is sent to the hot-gas cleanup system, and the clean gas is burned in the combustion turbine.

Despite considerable effort and much progress, the Gasifier Island was successfully operated for only short periods of time prior to the end of the project. A significant problem with this project was that it incorporated not one, but two new technologies, the KRW gasifier and hot-gas cleanup, and for the Gasifier Island to produce fuel gas, both technologies needed to operate successfully. Initially, consideration was given to providing both hot and cold-gas cleanup systems, but the added cost was felt to be prohibitive. From Table 4, it is seen that a great deal of difficulty was encountered with the hot-gas filter-fines removal system. Some of the problems encountered in the Gasifier Island are discussed next.

Table 4. Summary of Startup Attempts

Start-up Number	Date of Startup	Reason for Shutdown
*	1-18-98	Poor circulation in the gasifier.
*	3-20-98	Solids removal problems.
*	6- 2-98	High differential pressure in the hot-gas filter.
*	6- 5-98	Fines emissions from the flare, and high vibrations in the recycle-gas compressor.
*	6-17-98	Failure of filter-fines removal system.
*	6-30-98	High level in the filter-fines hoppers.
1	9-22-98	Failure of the filter-fines depressurization hopper to depressurize.
2	12-17-98	Plug in the vent filter of the filter-fines depressurization hopper.
3	1- 4-99	Failure of the expansion joint in the fines combustor.
4	1-27-99	Excessive emissions from flare stack.
5	3-31-99	Failure of desulfurizer cyclone fines filter seal and failure of valve on filter-fines depressurization bin.
6	4- 7-99	High level in hot-gas filter.
7	7-12-99	Air leak into combustion air line caused hot spot in line.
8	7-22-99	Problems with the filter-fines removal package.
9	9- 2-99	High level in the hot-gas filter.
10	9- 9-99	Failure of the booster air compressor.
11	1-28-00	Failure of seals on LASH feeder.
12	2 -4-00	LASH feeder transport line plugged.
13	2- 5-00	High level in hot-gas filter.
14	2- 7-00	Lack of fuel in coal-feed package as result of valve failure.
15	2-12-00	High level in hot-gas filter.
16	2-13-00	High level in hot-gas filter.
17	2-26-00	High level in hot-gas filter; later determined to be false.
18	8-10-00	Fire in hot-gas filter.

* On July 1, 1998, the Position of Gasifier Process Specialist was created. Following this appointment, each startup was given a number.

Table 5. Results of Startup Attempts

Startup Number	Time on Stream, hr	Time Producing Fuel Gas, hr	Fuel-Gas Quality, Btu/ft^3	Coal Properties, dry basis		
				Sulfur, wt %	Ash, wt %	Higher Heating Value, Btu/lb
1	5	2	129	0.35	8.41	12,722
2	24	0	---	0.42	9.08	12,628
3	24	9	135	0.31	8.41	12,699
4	120	25	120	0.69	9.92	13,235
5	72	20	145	0.61	12.02	12,516
6	72	18	145	0.62	11.45	12,568
7	144	5	---	0.54	11.77	12,468
8	72	5	128	0.37	8.83	12,628
9	24	8	145	0.37	8.90	12,665
10	48	4	---	0.38	9.19	12,627
11	48	0	---	0.39	9.54	12,552
12	48	0	---	0.75	12.23	12,900
13	24	10	---	0.45	10.85	12,317
14	24	6	---	0.48	10.99	12,381
15	24	5.5	---	0.55	10.94	12,485
16	24	4	---	0.53	9.92	12,577
17	24	6	110	0.53	13.74	12,373
18	120	0	---	0.53	15.50	11,991

Filter-Fines Removal System. The purpose of the filter-fines removal system is to remove fines from the hot-gas filter and feed them to the fines combustor. This system consists of three lock hoppers (filter-fines collection bin, filter-fines depressurization bin, and filter-fines feed bin separated by valves, a depressurization filter, and a filter-fines screw feeder. As initially designed, this system exhibited many problems and caused many startups to be aborted. The mode of operation is as follows:

1. The filter-fines collection bin, which operates at the same pressure as the hot-gas filter, receives a continuous flow of fines from the filter-fines screw cooler. The valve to the filter-fines depressurization bin is open, allowing fines to pass through.

2. When the depressurization bin is full the inlet valve is closed, and the bin is depressurized by venting through the depressurization filter. The outlet valve is then opened, and the fines flow into the filter-fines feed bin.

3. The outlet valve is then closed, and the depressurization bin is repressurized by backflow of recycle gas through the depressurization filter, and the inlet valve is reopened, ready for another cycle.

4. The filter-fines feed bin is emptied by means of a screw feeder, and the fines are pneumatically transported to the fines combustor.

A major problem with this system was that, after a short period of operation, the depressurization bin would fail to depressurize. The cause of the failure was traced to the depressurization filter, which consisted of eight sintered metal filter elements in a housing. The filter elements tended to become blinded by fines and failed to release the pressure. Increasing the filter capacity by an order of magnitude and providing a high-pressure back pulse to keep the filter elements clean overcame this problem.

Another problem with the filter-fines removal system was caused by inaccurate level indications in the bins. This problem was overcome by replacing capacitance probes with nuclear and vibration-based level detectors. Problems were also encountered with bridging of fines in the bins. This was overcome by adding skimmer valves to the bins.

A further problem was the accumulation of fines in the bottom of the hot-gas filter. Two systems were installed to provide an indication of the fines level. One was a vertical thermocouple array, which provided a level indication by means of the temperature differential between the solids and gas; the other system consisted of two nuclear switches. As the fines level rose, the lower switch would set off an alarm; then, if the level increased, the higher switch would automatically shut down the gasifier. Although these devices solved the problem of fines level detection in the hot-gas filter, they did not solve the problem of fines accumulation, and a high fines level in the hot-gas filter resulted in aborting a number of startups.

The last attempted startup (August 10, 2000) ended with a fire in the hot-gas filter. This fire was apparently caused by material from the desulfurizer being transported to the hot-gas filter and igniting. The fire caused considerable damage to the filter assemblies and candle filters. As of the end of DOE involvement, the hot-gas filter had not been repaired. There should be no problem in developing an inert gas startup scheme to avoid this type of problem.

Fines Combustor. The purpose of the fines combustor is to recover the energy in the fines by burning them and recovering the heat released in a downstream HRSG. A major problem with this system was that the feed rate was erratic, resulting in unstable operation. To avoid this problem for startups after April 1999, the fines combustor was removed from service, and the fines from the filter-fines feed bin were diverted to the waste silo.

Gasifier Refractory. The refractory initially installed in the gasifier consisted of an inner six-inch layer of thermal refractory and an outer 6-inch layer of wear-resistant refractory. Thermal cycling of the gasifier caused the outer layer of this refactory to spall off the walls and nozzles. Replacing the double layer of insulation with a single layer of thermal insulation solved this problem. Also, the startup procedure was modified to include a slower heat up of the gasifier.

Other Problems. There were a variety of other mechanical problems, such as failure of the fines-combustor expansion joint, erosion of the recycle-gas compressor impeller, a leak in the sulfator- solids screw cooler, leaks in the HRSG recovering heat from the fines-combustor flue gas, and failure of the baghouse. For the most part these problems were corrected by replacing the failed part, along with design and/or operating changes to obviate future problems.

Changes to the project after the contract was awarded resulted in insufficient funds being available to successfully complete the project as modified. Two circumstances contributed to this. First, after DOE funding had been capped, the size of the project was increased from 64 to 100 MWe (net). This followed the decision to use a new GE Frame 6FA combustion turbine, with the overall size of the project being increased to be consistent with the turbine's capacity. This capacity change increased the capital cost of the project. Also, approximately $12 million dollars of DOE funding was spent on natural gas purchases to run the gas turbine and generate power, while attempts were made to get the gasifier on line. The effect of these added costs was to make the operating funds account insufficient to accomplish the project goals (U.S. Department of Energy 2001).

III.A.2 Power Island

Although the Gasifier Island operated successfully for only a few hours, the combined cycle portion of the plant has operated successfully on natural gas with a high availability. The first-of-a-kind GE Frame 6FA combustion turbine had an 85-percent availability in 1998 and a 100-percent availability in the first quarter of 1999. Thus, although the Gasifier Island has not yet produced fuel gas on a sustained basis, the project facilities can still generate electric power.

III.B Environmental Assessment

SPPCo's primary objective for the Piñon Pine Power Project was to utilize advanced technology to generate low-cost, base-load power, while burning coal in a clean and environmentally acceptable manner. The environmental system designed for the plant had great potential. However, the Gasifier Island was not successfully operated for a long enough time to demonstrate the environmental goals for this project; that is, environmental performance at a scale sufficient to establish the commercial viability for this technology was not achieved. As a consequence, the following discussion only covers expected performance, not actual results.

The Piñon Pine Power Project was designed to achieve low air-pollutant emissions levels through use of an advanced hot-gas cleanup system. The hot fuel gas is partially cooled and then cleaned of sulfur and particulates by emerging technologies. In general, all air or flue-gas streams in the Gasifier Island were filtered before being exhausted to the atmosphere. Pollutant emission rates were expected to be well below requirements of the 1990 Clean Air Act Amendments.

IGCC plants use a gasifier to convert various carbon-based feedstocks to low or medium heating value fuel gas. The fuel gas is burned in a high efficiency combustion turbine/generator. Heat is extracted from the exhaust gas to produce steam to drive a steam turbine. Because IGCC plants operate at higher efficiencies, these systems have the potential to emit less pollution per unit of energy than conventional fossil-fueled plants providing the same amount of electric power. In this project, inefficiencies associated with cold-gas cleanup are avoided by cleaning the product gas at high temperature.

In IGCC systems, sulfur in the coal is converted to H_2S during gasification. For several reasons, it is easier to remove H_2S from the fuel gas than it is to remove SO_2 from the flue gas: the chemistry involved is simpler, the pressure is higher, and the volume of the gas to be treated is smaller. Fuel gas is treated at production pressure, rather than at atmospheric pressure as is flue gas. A much lower gas volume, resulting from the higher pressure and the fact that the gas is not diluted with nitrogen from the combustion air, reduces equipment costs.

Through use of a calcium-based sorbent in the gasifier and use of an external regenerable desulfurizing sorbent, high sulfur removal is possible. The hot-gas cleanup system was expected to achieve 91- to 98-percent removal, depending on the sulfur content of the coal fed to the gasifier. The type of equipment used and the general flow of solids in the desulfurizer/regenerator are an outgrowth of processing common to the refining industry, such as fluid catalytic cracking.

NO_x emissions, inherently low because of the tempering effect that low heating value fuel gas has on combustion temperature, was expected to be well below permit requirements for the project. Low particulate emissions were also anticipated, since the hot ceramic filter system was designed to operate more efficiently than an electrostatic precipitator. In addition, the coal unloading station was enclosed, and a dust collection system was installed to prevent fugitive coal-dust emissions.

Because of increased efficiency, the use of natural resources (coal, limestone and water) was expected to be less than that of a comparably sized conventional power plant. Water conservation is especially important in arid regions. Because the hot-gas sorbents operate dry, there is no wastewater treatment from the desulfurization. Wastewater from the demineralization system and blowdown from the cooling tower were clarified and softened in a wastewater treatment system and reused as makeup water for the cooling tower. Sludge generated in the clarifier was thickened, dewatered, and the supernatant recycled. Therefore, water usage for this technology was expected to be 20-percent less than conventional PC-fired power generation, because of reduced evaporation losses from lower heat rejection requirements and reuse.

The facility was expected to produce less solid waste than a conventional coal-fired power plant with a wet scrubber. The waste, a mixture of calcium sulfate and ash, could be marketed for agricultural and industrial uses. Another environmental benefit of this technology includes lower generation of carbon dioxide per unit of electricity produced, because of improved efficiency.

III.C Overall Evaluation

Although, as indicated above, sustained, integrated operation of the gasifier was not achieved, there were a number of project successes that deserve to be mentioned.

- When the original sulfur sorbent for the transport reactor was found to have an excessively high attrition rate, a new sorbent was quickly developed through a supporting NETL program initiative. The new sorbent did not experience any attrition during extended circulation tests under heat up conditions.

- Siemens-Westinghouse designed and constructed a commercial-scale hot-gas filter system, capable of undergoing routine maintenance. Siemens-Westinghouse provided this system with a commercial guarantee; and, during operation, the system successfully removed particles from the dirty gas. Removal of particles from the filter was limited by problems in the lockhopper system that was not supplied by Siemens.

- Engineering, procurement, and construction of the combined cycle portion of the plant went smoothly and efficiently. (Only 18 months were required for construction.) The gasifier was completed in an additional 6 months.

- The combined-cycle portion of the plant performed extremely well throughout the project. The gas turbine was the second unit of the design built by GE and operated very reliably, including the extraction of air to supply the gasifier. The control system also worked well.

- The final report contains “as built” piping and instrumentation drawings (P&IDs). This is the only IGCC project on which DOE will have such detailed information.

- Although never operated at steady state, the gasifier produced a syngas representative of that which could be burned in a gas turbine.

IV Market Analysis

IV.A Market Size/Commercialization

The total of all gasification projects, including those projected to start up by 2004, is a little over 40,000 equivalent megawatts, according to the 1999 World Gasification Survey. This survey is a database of all the gasification projects in the world operating on all fuels (natural gas, coal, petroleum coke, and biomass) and producing all products (power, hydrogen, heat, and chemicals). Of the installed capacity, a little more than half (approximately 54 percent) is coal or petroleum-coke based. The survey shows that there has been a significant increase in gasification activity in the past decade. In particular, the majority of the recent increase in installed gasification capacity is fueled by coal or petroleum coke. Of the 16,500 MW of solid-fueled capacity, nearly half (43 percent) has started up, or is scheduled to start up by 2004.

The impetus for this growth is the increased cost of environmental compliance with conventional PC-fired units, the drive to improve efficiency, the availability of low-cost alternative feedstocks, and the need to utilize indigenous coal in areas without access to natural gas. The maturation of coal gasification through completion of several large-scale CCT demonstration projects has made this technology a popular and viable alternative to conventional combustion approaches.

In addition to generating power, IGCC Plants can be modified to produce value-added chemicals or transportation fuels from coal by chemical processing of the fuel gas produced, as opposed to using the gas to drive a combustion turbine. It may be that the near-term market niche for IGCC lies not only in the production of electricity, but also in the generation of multiple products, where electricity, steam, and fuels/chemicals are economically bundled as products from a fully integrated complex.

General Electric (GE) has recently reported (Todd 1998) that there are about 5,000 MW of gasification projects for power generation that have proceeded to the point of placing orders for combustion turbines. Many of these projects include coproduction facilities for production of hydrogen or chemicals. The GE report also states that it is in discussions with various refiners, developers, and others about projects totaling another 50,000 MW. This indicates a significant market for gasification technology in the near future, bolstered by trends of rising energy prices and tightening environmental controls. Air-blown gasifiers are suitable for plants smaller than 500 MWe, where conventional oxygen plants are too expensive.

The failure of Piñon Pine project to operate successfully makes it difficult to determine the potential market for the KRW gasifier technology. It appears that most of the problems with the Piñon Pine Project were with the filter-fines removal system, rather than with the gasifier itself. Had a more proven gas cleanup technology been used in the project, it appears likely that the gasifier would have been successfully started up. It is doubtful that there will be any other installations of the KRW technology unless the Piñon Pine IGCC Power Project is successfully operated. If this should occur, then the KRW gasifier could be in position to capture part of the power market. Although the gasifier is being mothballed, an independent utility engineering service group and consultant are examining the feasibility of restarting the gasifier.

IV.B Economics

It is not possible to present economics for the technology used in the Piñon Pine Project, because the facility never operated successfully. The total project costs were $336 million, including both construction and operation expenditures, as well as plant modifications. In December 1994, FWUSA prepared a construction cost estimate of $222 million. Gas-turbine capacity is 61 MWe and steam-turbine capacity is 46.2 MWe, for a total generation of 107.2 MWe. Assuming that the FWUSA cost estimate is reasonably correct, capital cost was approximately $2,000/kW of capacity. This figure appears to be reasonable, considering the first of a kind nature of the project. Based on available information, it is not possible to estimate how much capital costs might decrease for a new plant incorporating lessons learned from this project.

Because the facility never operated in steady state, it is not possible to estimate operating cost or to perform a cost-of-electricity calculation.

V Conclusions

From the beginning, this project was plagued with problems; some were the result of design deficiencies, and some were a result of defective equipment. Much progress was made during this project in overcoming these problems through design changes and by repairing, or replacing, faulty equipment. Nevertheless, this project cannot be considered a success, because the gasifier and hot-gas cleanup system never functioned fully for more than 24 hours at a time. Thus, the demonstration of the KRW air-blown gasifier that was the objective of this project was not achieved. This is unfortunate, as most of the startup difficulties were caused by problems with the filter-fines removal system, rather than with the gasifier. It seems possible that if proven technology had been used for the fuel-gas cleanup system, successful operation of the KRW gasifier would have been achieved. With the increasing interest in IGCC, an air-blown gasifier capable of operating on a wide range of feeds would be a desirable addition to the suite of gasifiers available to power providers.

Whether this facility will ever be successfully operated is in doubt, as Sierra Pacific management has rejected a proposal for capital expenditures to achieve operating status for the plant. Therefore, the plant is being mothballed and probably will be maintained in that state unless a new buyer for the plant decides to attempt to restart the unit.

Abbreviations

CCT	Clean Coal Technology
IGCC	Integrated Gasification Combined Cycle
DOE	Department of Energy
FWC	Foster Wheeler Constructors Incorporated
FWUSA	Foster Wheeler USA Corporation
GE	General Electric
HRSG	heat-recovery steam generator
HHV	higher heating value
KRW	Kellogg/Rust/Westinghouse
LASH	unconverted calcined limestone, sulfided limestone, and ash
LHV	lower heating value
PC	pulverized coal
P&IDs	piping and instrumentation drawings
PPA	post-project assessment
SPPCo	Sierra Pacific Power Company
SUFCO	Southern Utah Fuel Company

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