Tampa Electric Company
Polk Power Station IGCC Project
Project Status

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INTRODUCTION

Over the last nine years, Tampa Electric Company (TEC) has taken the Polk Power Station from a concept to a reality. In previous papers at this conference, we reported on site selection, permitting, engineering, construction, contracting, capital costs, and staffing of the project. Our paper at last year's Gasification Technologies Conference discussed the plant's performance (heat rate and output) as well as some of the challenges we encountered through the first year of commercial operation. In this year's paper, we would like to focus on the plant's reliability growth in the second year of commercial operation and results of the alternate fuel tests we have conducted to date.

BACKGROUND

TEC's original objective for the project was to build a coal-based generating unit providing reliable, low-cost electric power. IGCC technology will meet those requirements. Demonstration of the oxygen-blown entrained-flow IGCC technology is expected to show that such a plant can achieve significant reductions of SO_2 and NO_x emissions when compared to existing and future conventional coal-fired power plants. In addition, this project is expected to demonstrate the technical feasibility of commercial scale IGCC technology. Only commercially available equipment has been used for this project. The integrated arrangement of these commercially available pieces of hardware and systems is intended to optimize cycle performance, costs, and marketability at a commercially acceptable size of nominally 250 MW (net).

TEC is an investor-owned electric utility, headquartered in Tampa, Florida. It is the principal, wholly-owned subsidiary of TECO Energy, Inc., an energy related holding company heavily involved in coal mining, transportation, and utilization. TEC has about 3,650 MW of generating capacity. Over 97 percent of TEC's power is produced from coal. TEC serves over 500,000 customers in an area of about 2,000 square miles in west-central Florida, primarily in and around Tampa, Florida. Polk Power Station is an integral part of TEC's generation expansion plan.

Polk Power Station was partially funded by the U.S. Department of Energy (DOE) under Round III of its Clean Coal Technology Program. TECO Power Services (TPS), a subsidiary of TECO Energy, Inc., and an affiliate of TEC, is responsible for the overall project management for the DOE portion of the project. TPS is also concentrating on commercialization of this IGCC technology as part of the Cooperative Agreement with DOE. TPS was formed in the late 1980's to take advantage of the opportunities in the non-regulated utility generation market. TPS currently owns and operates a 295 MW natural gas-fired combined cycle power plant in Hardee County, Florida. Seminole Electric Cooperative and TEC are purchasing the output of this plant under a twenty-year power sales agreement. In addition, TPS owns and operates a 78 MW plant in Guatemala.

TECHNICAL DESCRIPTION

A general flow diagram of the entire process is shown in Figure 1.

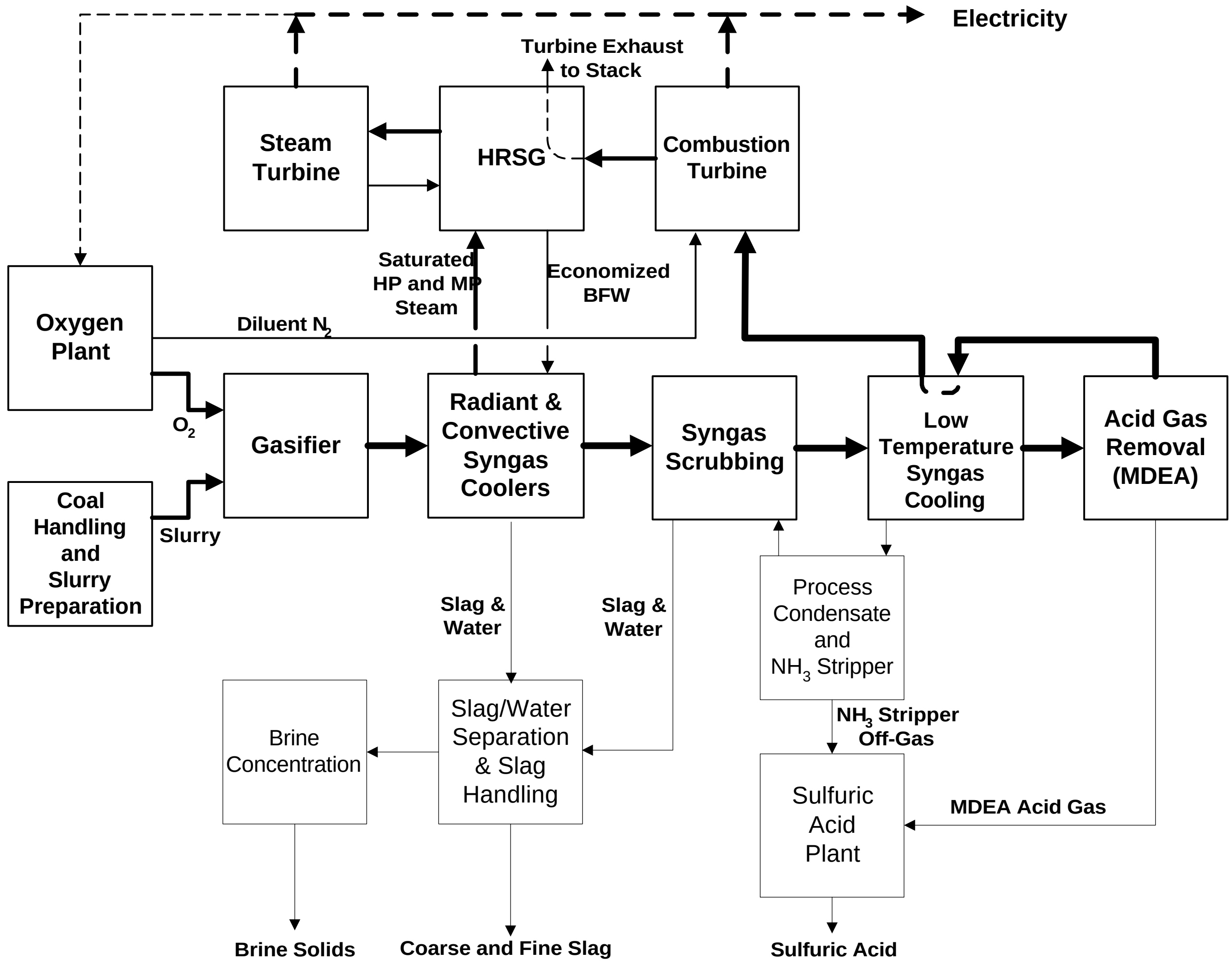

FIGURE 1
Polk Unit #1 IGCC Block Flow Diagram

This IGCC utilizes commercially available oxygen-blown entrained-flow coal gasification technology licensed by Texaco Development Corporation (Texaco). In this arrangement, coal is ground with water to the desired concentration (60-70 percent solids) in rod mills. The unit is designed to utilize about 2200 tons per day of coal (dry basis). An air separation unit (ASU) separates ambient air into 95% pure oxygen for use in the gasification system and sulfuric acid plant, and nitrogen which is sent to the advanced combustion turbine (CT). The ASU is sized to produce about 2100 tons per day of oxygen and 6300 tons per day of nitrogen. The ASU was provided by Air Products and Chemicals, Inc.

This coal/water slurry and the oxygen are then mixed in the gasifier process feed injector. This produces syngas with a heat content of about 250 BTU/SCF (LHV). The gasifier is designed to achieve greater than 95 percent carbon conversion in a single pass. The gasifier is a single vessel feeding into one radiant syngas cooler (RSC) which was designed to reduce the gas temperature to

1400°F while producing 1650 psig saturated steam.

After the RSC, the gas is split into two (2) parallel convective syngas cooler boilers (CSC), where the temperature is further reduced to less than 800°F and additional high pressure steam is produced. Next, the particulates and hydrogen chloride are removed from the syngas by intimate contact with water in the syngas scrubbers. Most of the remaining sensible heat of the syngas is then recovered in low temperature gas cooling by preheating clean syngas and heating steam turbine condensate. A final small trim cooler reduces the syngas temperature to about 100°F for the cold gas clean-up (CGCU) system.

The CGCU system is a traditional amine scrubber type which removes most of the sulfur from the syngas. Sulfur is recovered in the form of sulfuric acid. The sulfuric acid plant was provided by Monsanto. Sulfuric acid has a ready market in the phosphate industry in the central Florida area.

Most of the ungasified material in the coal exits the bottom of the RSC into the slag lockhopper where it is mixed with water. These solids generally consist of slag and uncombusted coal products. As they exit the slag lockhopper, these non-leachable products are saleable for blasting grit, roofing tiles, and construction building products. TEC has been marketing slag from its existing units for such uses for over 25 years.

All of the water from the gasification process is cleaned and recycled, thereby creating no requirement for discharging process water from the gasification system. To prevent the build-up of chlorides in the process water system, a brine concentration unit removes them in the form of marketable salts.

The key components of the combined cycle are the advanced combustion turbine (CT), heat recovery steam generator (HRSG), steam turbine (ST), and electric generators. The combined cycle power block is provided by General Electric.

The CT is an advanced GE 7F machine adapted for syngas and distillate fuel firing. The initial startup of the power plant is carried out on low sulfur No. 2 fuel oil. Transfer to syngas occurs upon establishment of fuel production from the gasification plant. The exhaust gas from the CT passes through the HRSG for heat recovery, and leaves the system via the HRSG stack.

The HRSG is installed in the CT exhaust in a traditional combined cycle arrangement to provide superheated steam to the 130 MW ST. No auxiliary firing is done in the HRSG system. The HRSG high and medium pressure steam production is augmented by steam produced from the coal gasification plant's syngas coolers (HP and MP steam) and sulfuric acid plant (MP steam). All steam superheating and reheating is performed in the HRSG before the steam is delivered to the ST.

The ST is a double-flow reheat turbine with low pressure crossover extraction. The ST and associated generator are designed specifically for highly efficient combined cycle operation with nominal turbine inlet throttle steam conditions of approximately 1450 psig and 1000°F with 1000°F reheat inlet temperature.

The heart of the overall project is the integration of the various pieces of hardware and systems to increase overall cycle effectiveness and efficiency. In our arrangement, benefits are derived from using the experience of other IGCC projects, such as the Cool Water Coal Gasification Program, to optimize the flows from different subsystems. For example, low pressure steam from the HRSG and extraction steam from the ST supply heat to the gasification facilities for process use. The HRSG also receives steam energy from the syngas coolers and sulfuric acid plant to supplement the steam cycle power output. This steam is generated using boiler feedwater which had been economized in the HRSG. Additional low energy integration occurs between the HRSG and the gasification plant. Condensate from the ST condenser is returned to the HRSG/integral deaerator by way of the gasification area, where condensate preheating occurs by recovering low level heat. Probably the most novel integration concept in this project is our use of the ASU. This system provides oxygen to the gasifier in the traditional arrangement, while simultaneously using what is normally excess or wasted nitrogen to increase power output and improve cycle efficiency and also lower NO_x formation.

Emissions from the HRSG stack are primarily SO_2 and NO_x with lesser quantities of CO, VOC, and particulate matter (PM). SO_2 emissions are from sulfur species in the syngas which are not removed in the CGCU system. The CT uses nitrogen addition to control NO_x emissions during syngas firing. Nitrogen acts as a diluent to lower peak flame temperatures and reduce NO_x formation without the water consumption and treatment/disposal requirements associated with water or steam injection NO_x control methods. Maximum nitrogen diluent is injected to minimize NO_x exhaust concentrations consistent with safe and stable operation of the CT. Water injection is employed to control NO_x emissions when backup distillate fuel oil is used.

Part of our cooperative agreement with DOE is a four-year demonstration phase. During the first two years of this period, it is planned that four different types of coals will be tested in the operating IGCC power plant. The results of these tests will compare this unit's efficiency, operability and costs, and report on each of these test coals against the design basis coal, a Pittsburgh #8. These results should provide a menu of operating parameters and costs which can be used by utilities in the future as they make their selection on methods for satisfying their generation needs, in compliance with environmental regulations.

RELIABILITY GROWTH AND LOST PRODUCTION CAUSES

Table 1 on the next page identifies some of the major accomplishments (☺) and setbacks (☹) in the operational history of Polk Power Station in chronological order. Table 2 later in this section summarizes the causes for all lost gasifier production during Polk Power Station's second year of commercial operation from October, 1997, through September, 1998. The gasifier outage causes prior to this were identified and discussed in our paper at last year's conference.

All major setbacks in the gasification area to date have been overcome and the less severe problems are being systematically addressed. This has led to an average gasifier on-stream factor of 68.5% for the second year of commercial operation. This factor and combined cycle availability are shown below in Figure 2 for each quarter since initial operation. Figure 2 also shows that the combined cycle has demonstrated strong availability and availability growth throughout this period. Together, these pave the way to meeting our ultimate commercial IGCC availability targets.

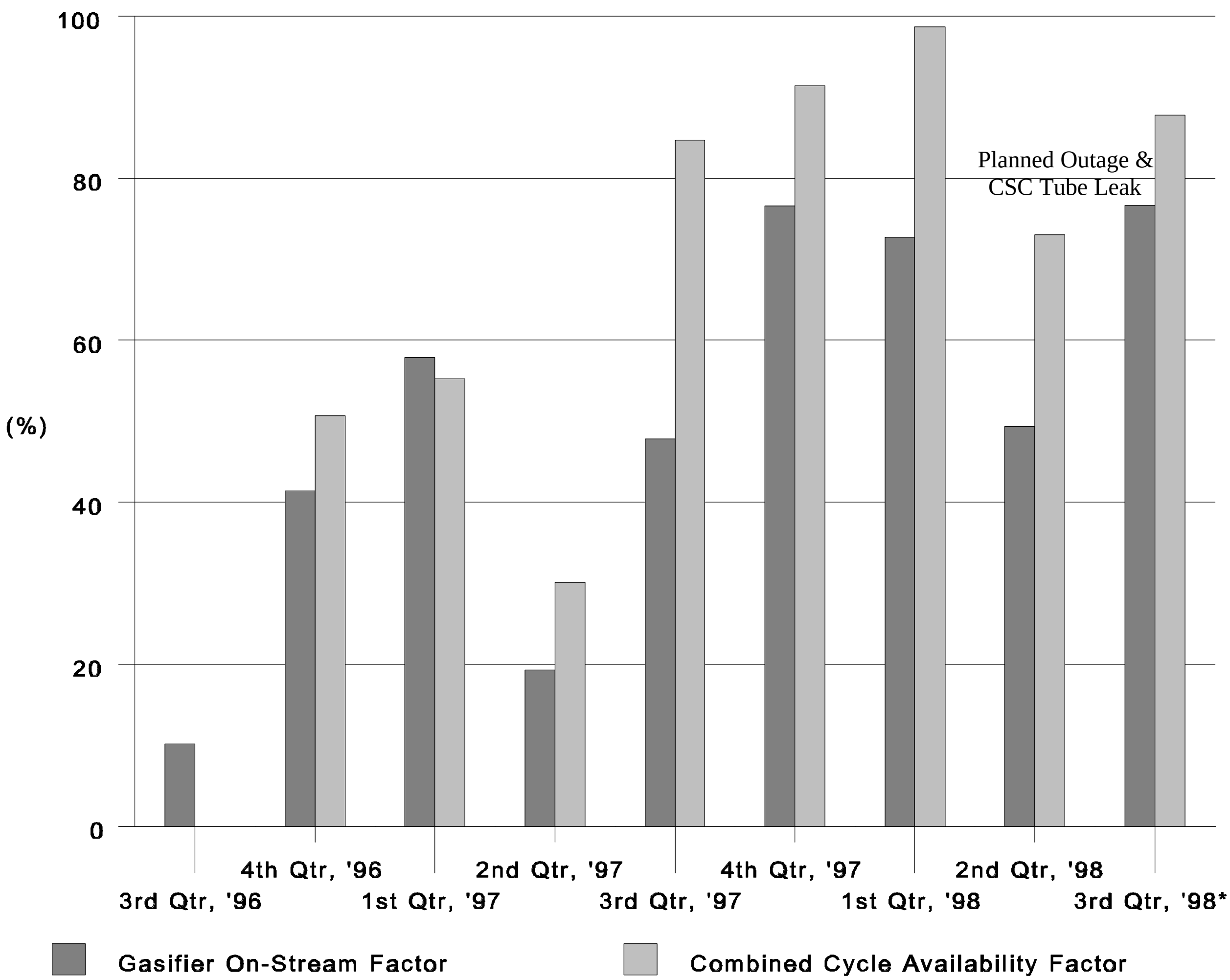

FIGURE 2
Polk Unit #1 Gasifier On-Stream Factor and Combined Cycle Availability Factor

TABLE 1 SIGNIFICANT EVENTS AND DATES IN POLK'S OPERATING HISTORY	
COMMISSIONING PHASE	
☺ First Syngas Production -Record First Run (21.5 Hr) for Texaco Coal Gasifier	July 19, 1996
☹ First of Four Forced Outages Due to Raw/Clean Gas Exchanger Plugging	Sept 1, 1996
☺ First Syngas to Combustion Turbine	Sept 12, 1996
☺ All Systems Commissioned, Commercial Operation Initiated	Sept 30, 1996
COMMERCIAL OPERATION - YEAR 1	
☺ Procedures Developed to Mitigate Raw/Clean Gas Exchanger Plugging	Oct 21, 1996
☺ Record Gasifier Run Completed (28.9 Days)	Jan 22, 1997
☹ Cracks Observed In Clean Syngas Line Strainer - Strainer Removed	Feb 13, 1997
☹ First Forced Outage and CT Damage Due to Raw/Clean Gas Exchanger Leak	Mar 16, 1997
☺ Raw/Clean Gas Exchangers Removed, Clean Syngas Strainer Reinstalled	July 2, 1997
☺ O&M Procedures for Clean Syngas Line and Strainer Cleaning Implemented	July 17, 1997
☹ First of Two Forced Outages Due to RSC Dome Seal Leak	Aug 26, 1997
COMMERCIAL OPERATION - YEAR 2	
☺ First Hot Restart Attempt Was Successful	Oct 15, 1997
☺ Record Gasifier Run Completed (35.5 Days)	Jan 3, 1998
☺ Operating Procedures Developed to Correct Dome Seal Leaks On-Line	Mar 11, 1998
☹ CSC Boiler Tube Damage from Ash Deposits	Apr 24, 1998
☺ Filter Installed on Syngas to CT	May 20, 1998
☺ 30% of Contract Crews Transferred, Remainder Focus on Capital Projects	Sep 1, 1998
☺ Record Gasifier Burner Life (49.3 Operating Days with Significant Life Left)	Sep 10, 1998
☺ Record Continuous CT Run (52.1 Days with 16 Fuel Transfers)	Sep 10, 1998

Early Successes First syngas was produced on July 19, 1996. The first gasifier run lasted 21.5 hours which set the longevity record for first run of a solid fuel Texaco gasifier. Syngas was first fired in the combustion turbine on September 12, 1996. All plant systems had been successfully commissioned by the end of the third quarter of 1996, so Polk Power Station Unit #1 was placed in commercial operation on September 30, 1996.

Raw Gas/Clean Gas Exchanger Plugging One notable setback in Polk Power's early operating history was plugging of the raw gas/clean gas convective syngas coolers (CSC) with flyash. The first of three forced gasifier outages due to this plugging occurred on September 1, 1996, and this negatively impacted gasifier on-stream time for the next two months. However, by late October, 1996, operating procedures were developed to significantly reduce the rate of plugging. This was discussed at last year's conference.

Reliability Improvement In Late 1996 and Early 1997 Solving the raw gas/clean gas CSC plugging problem in October, 1996, led to healthy reliability growth in the fourth quarter of 1996 and the first quarter of 1997. One significant accomplishment during this period was a record gasifier run of almost one month duration. This record run ended on January 22, 1997.

Particulates to Combustion Turbine Polk's most serious cause of lost production was particulate contamination of the "clean" syngas to the combustion turbine. It caused 110 days of lost gasifier production, mostly in the second quarter of 1997, and led to 4 forced gasifier outages and significant combustion turbine damage on two occasions. The root causes were raw gas / clean gas CSC leaks and pipe scale from the syngas line to the turbine. The interim solutions were removing the raw gas / clean gas CSCs, bypassing another raw gas / clean gas exchanger, and reinstalling a syngas strainer immediately upstream of the combustion turbine. This was described in detail in last year's paper.
The permanent solution to this problem, an appropriate filter on the syngas to the turbine, was installed during the May, 1998, outage. The filter is performing as intended, and should provided at least one year of service between cleanings, which was its design basis. The one remaining raw gas/clean gas exchanger, the clean gas preheater, warms the clean syngas to the turbine with relatively particulate-free raw syngas from the syngas scrubbers. It did not experience any corrosion like the raw gas / clean gas CSCs which failed since it was constructed of more suitable materials. Nevertheless, it had been bypassed when the raw gas / clean gas CSCs were removed in 1997 as insurance against any further turbine damage. It was returned to its original service when the filter was installed in May, 1998.

Radiant Syngas Cooler Dome Seal Leaks Polk's second most serious cause of lost production was syngas leakage through seals in the dome area of the radiant syngas cooler. Severe leaks would result in hot syngas impinging on the vessel shell, and could cause shell failure if they were allowed to persist. The first incident of seal leakage causing lost production occurred on August 26, 1997, and resulted in a 29 day outage. This severely impacted gasifier availability for the third quarter of 1997. The seal was modified during the outage.

The only other incident of lost production due to a seal leak in the RSC dome occurred in November, 1997, and led to a 14 day outage. This second failure was in a different, more accessible seal. This seal design was also modified, but some leakage is still observed following each gasifier startup.

Finally, a severe seal leak began on March 11, 1998. This time, however, we developed operating procedures to stop the leak without having to shut down the gasifier and enter the vessel. Design modifications are clearly indicated for the seals, but until then, these new operating procedures have eliminated further lost production from this source.

Another Record Run The gasifier run following the second outage for an RSC dome seal leak established a new run length record: 35½ days. This run ended on January 3, 1998. One particularly encouraging factor from this run is that none of the gasification system components which were expected to ultimately be run limiting showed excessive wear. This opens the door to even longer continuous gasifier runs.

Hot Restarts The conventional method of starting a Texaco gasifier consists of first preheating the refractory liner with a "Preheat Burner", then changing to the "Process Feed Injector" just prior to startup. This preheating and changing burners is costly and time consuming, especially when the gasifier has experienced a nuisance shutdown whose cause can be easily identified and corrected. The average duration of such outages was 30.5 hours at Polk. To shorten this time by eliminating the preheating and burner changes, the Polk staff had been developing the controls and procedures to execute "hot restarts" since early operation. The first attempt at a hot restart on October 15, 1997, was successful. Since then, we have conducted 22 successful hot restarts with an average gasifier outage duration of only 5 hours. We have shown it is even possible to perform some preventative maintenance during these outages which cannot be performed when the gasifier is on line. The development of the hot restart procedure is estimated to have saved 550 hours of lost gasifier production in the last twelve months. This equates to over a 6% boost in gasifier on-stream factor. Development of the procedure contributed significantly to the gasifier reliability growth in the second year of commercial operation.

CSC Boiler Pluggage - Tube Damage During early operation, we experienced severe deposits in the raw gas / clean gas CSCs which led to a number of gasifier outages and finally prompted the removal of these exchangers. At the same time, we sometimes observed some deposits in the tubes of the CSC boilers, another set of CSCs located immediately upstream of the raw gas / clean gas CSCs . These deposits were quickly and easily removed, and caused no operational problems at that time. However, recently, with longer runs, more frequent fuel changes, and higher gasifier on-stream factors, these deposits have become an issue.

The first problem caused by CSC boiler tube deposits occurred in April, 1998. Differential pressure across the CSC boilers had been increasing for some time, indicating deposit growth. Finally, on April 24, just a few days prior to a planned 30 day outage, we detected a tube leak in one of the CSC boilers and promptly shut down the gasifier. The tube leak was caused by erosion due to local high gas/particulate velocities induced by the deposits. The damage was repaired during the planned outage and the exchangers were returned to service. On two subsequent occasions, when differential pressures indicated that we were close to initiating damage, we shut down the gasifier for relatively short 4 day outages to clean the tubes. No damage occurred in these cases.

Until design changes can be made to eliminate or reduce the plugging, it appears that it will be necessary to shut down the gasifier to clean the CSC boilers every 1½ to 2 months with our current base coal. This is not now a major problem since outages of that approximate duration and frequency are needed to perform preventative maintenance work.

Change of Focus to Long Term Projects Ever since initial operation, Polk has maintained contract engineering staff and contract maintenance crews on site. Through the first year of commercial operation, these personnel were intensely involved in designing and implementing repairs to keep the plant on line or return it to service from forced outages. Throughout the second year of commercial operation, their numbers have been reduced, and there has been a consistent shift in focus of the efforts of those remaining away from the day-to-day problems. Instead, their efforts have been directed toward longer term capital projects to improve Polk Power Station's general operability, fuel flexibility, and profitability. This trend has been so gradual that it has barely been noticeable. However, we passed an important milestone on September 1, 1998, when 30% of our contract maintenance personnel were transferred to another of TEC's plants. Those remaining are now almost exclusively dedicated to long term projects. This change in focus, though sometimes subtle, is critical in lowering the cost of electricity to demonstrate the commercial viability of IGCC technology.

July 21-September 10, 1998 Operation During this 51 day period ending on September 10, 1998, Polk Power had eight gasifier runs punctuated only by hot restarts. The same gasifier process feed injector (burner) was in service for the entire 49 days of gasifier operation during this period. Subsequent inspection indicated that it had significant life remaining. The combustion turbine was on-line continually throughout, and it successfully transferred to and from syngas fuel with each shutdown and restart of the gasifier. Most of the gasifier shutdowns were planned and executed at night or over week-ends so the plant would be available at full load during periods of peak demand. Although we obviously would have preferred a continuous gasifier run of this duration, this period demonstrated several very important technical and commercial attributes of the Polk Power IGCC:

- High On-Peak Gasifier Availability
- High Fuel Transfer Reliability
- High Gasifier Hot Restart Reliability
- Record Continuous Combustion Turbine Operation
- Acceptable Process Feed Injector (Burner) Life

Other Causes of Forced Outages and Lost Gasifier Production

Table 2 on the next page summarizes all causes of lost production in Polk Power's second year of commercial operation. The two individual leading causes of lost production, CSC boiler tube plugging/leaks and RSC dome seal leaks, were discussed previously. The remaining causes are discussed briefly on the subsequent pages of this section.

TABLE 2
LOST PRODUCTION SUMMARY - GASIFIER RUNS 33-71
Year 2 of Commercial Operation: October, 1997 through September, 1998

EVENT / CAUSE	FORCED GASIFIER OUTAGES	RESULTING GASIFIER OUTAGE DAYS	REMEDIAL ACTION
CONVECTIVE SYNGAS COOLER - BOILER PLUGGAGE / TUBE LEAKS	2	35	Predictive Maintenance Procedures Proven Operating Procedures Modified
RADIANT SYNGAS COOLER DOME SEAL LEAK	1	14	Improved Seal Designs Operating Procedures Developed
BLACK WATER PIPING EROSION Specific Locations	7	14	Harder Materials Piping System Configuration Changes On-Line Replacement
FUEL CHARACTERISTIC CHANGES	2	10	Fines System Upgrade Equipment Internal Modifications Experience
SLURRY AGITATOR EROSION	2	5	Blade Coating
SYNGAS PIPING EROSION Specific Location	4	3	Hardware Addition Revised Operating Procedure
SLAG CRUSHER SEAL	4	1	Complete Seal Redesign
SGC MP STEAM DRUM LEVEL UPSETS	4	1	Modify Drum Internals Instrumentation Maintenance Procedures
MISCELLANEOUS FORCED OUTAGES, OUTAGE EXTENSIONS, AND MAINTENANCE OUTAGES	13	26	Various Mechanical Improvements, Controls Modifications, and Procedural Changes

Black Water Piping Erosion Black water is the particulate laden water associated primarily with the syngas scrubbers. Since last year's conference, leaks in black water piping caused by localized erosion have been responsible for 7 forced gasifier outages and 14 days of lost gasifier production. These leaks have been at six specific sites. A combination of tactics has been used with considerable success in the last six months to reduce the frequency and impact of these leaks at four of these locations. These tactics involve modifying the piping systems, including making dimensional changes and often incorporating special hard surfaced fittings, and altering the operating conditions. For the two remaining particularly troublesome sites, flanged fittings have been installed which can be replaced on-line or during brief hot restart outages until longer term solutions can be found. Fortunately, the general erosion of the black water piping systems is at an acceptable rate. Unfortunately, there will always be localized problem areas. In our second year of commercial operation, the Polk Power staff has developed a set of very effective tools and techniques to deal with them.

Fuel Characteristic Changes Six different fuels have been gasified at Polk Power Station to date in an attempt to identify an economically optimum feedstock. Specific results of the alternate fuel tests will be discussed in the next section of this paper. Unfortunately, changes in fuels often result in some unpleasant surprises. Changes in fuel reactivity and ash characteristics have led to two gasifier forced outages and 10 days of lost gasifier production in the last 12 months. We are making some minor internal modifications to some of our equipment and expanding our capability to handle fine slag to enable us to better accommodate a wider range of fuel properties. Equally important, with each new fuel, TEC is broadening its experience base to reduce the frequency and impact of upsets brought on by expected as well as unexpected changes in feedstock properties.

Slurry Agitator Erosion Erosive failure of the agitator blades in the two large slurry storage tanks caused two gasifier outages when blade parts partially plugged the suction line to the slurry feed pump. Coating the blades with erosion resistant materials seems to have solved this problem.

Syngas Piping Erosion Erosion leading to pin-hole leaks in the main syngas piping have forced four gasifier shutdowns. This problem occurs at a specific location and can be repaired during brief hot-restart outages. The cause has been positively identified, and this problem will be corrected. Unfortunately, some long-delivery hardware will be needed to fix the problem, so we will have to continue to deal with it until some time next year.

Slag Crusher Seal Slag from the gasifier falls into the RSC sump and is removed in a lockhopper system. Most slag particles are "M & M" size or smaller, but a slag crusher at the bottom of the RSC sump handles the occasional larger slag masses. The slag crusher is a shaft driven device, and failures of its shaft seal have caused four brief forced gasifier outages. This is an extremely hostile environment. The seal has recently been completely redesigned, consistent with successful configurations in other Texaco solid fuel gasification plants. The new seal design has not yet failed, and we expect only minimal future problems.

SGC MP Steam Drum Level Upsets The syngas cooler system (RSC and CSCs) generates a small amount of steam at 425 psig by cooling a few specific components. The associated steam drum is very small, and its level controls are rather unstable. This has led to four nuisance trips of the gasifier. Fortunately, we have been able to recover with hot restarts in each case so far. We have already made some changes to operating procedures for this subsystem, and plan some modifications to the drum internals to improve stability in an attempt to eliminate this source of forced outages.

Most, if not all, of the heat recovered by this MP system could be recovered in the much larger and more stable high pressure 1650 psig steam system. Future plants should avoid installing this very expensive and troublesome MP steam system if at all possible.

Miscellaneous Forced Outages, Forced Outage Extensions, and Maintenance Outage Extensions A total of 13 miscellaneous one-of-a-kind forced gasifier outages, forced outage extensions, and maintenance outages occurred in Polk's second year of commercial operation. All together, these have resulted in 26 days of lost production. We have taken appropriate corrective action wherever practical, so we expect improvement in this category. For example, in the first year of commercial operation, we experienced four forced gasifier outages due to transmission system voltage swings. The trip circuitry was modified, consistent with providing appropriate protection for the equipment, and, as a result, only one outage occurred from this cause in the last 12 months. However, such sources of lost production can never be entirely eliminated.

ALTERNATE FUEL TESTS

Polk Power Station's design coal is a Pittsburgh #8, and the unit operated exclusively on this coal for the first 10 months. However, beginning in May, 1997, we conducted test campaigns on five alternate fuels in an attempt to find the lowest overall cost feedstock and to satisfy DOE requirements. Results from these tests are compared in this section.

Several key properties of gasifier feedstocks which have a known impact on Polk's IGCC performance are identified in the following Table 3.

TABLE 3
Important Texaco Gasifier Feedstock Properties

Available From Lab Tests	**Requires Plant Test**
Sulfur	**Slurryability**
Ash	**Reactivity**
Heating Value	**Slag Aggression**
Ash Fusion Temperature	**Slag Physical Properties**
Chloride	**Syngas Cooler Fouling**

The properties listed in the first column are easily determined by standard laboratory tests. The importance of these properties and their values for the Polk test coals is discussed immediately below.

The properties listed in the second column can be estimated from some laboratory tests, but they can only be accurately determined by plant test. The alternate fuel test campaigns at Polk attempted to at least semi-quantitatively determine each of these properties. They are discussed later in this section.

IMPORTANT STANDARD COAL PROPERTIES
The following Table 4 shows the standard properties of the coals tested to date at Polk Power IGCC.

TABLE 4
Polk Coal Properties

Coal Seam	Pittsburgh 8 #1 (First Base)	Pittsburgh 8 #2	Pittsburgh 8 #3	Kentucky 11 (Current Base)	Illinois 6 #1	Illinois 6 #2
Days of Operation	183	15	25	160	25	5
ASTM ASH FUSION (Fluid/Reducing,Deg F)	2400	2200	2230	2250	2240	2325
Wt % Sulfur (Dry)	2.5	2.8	2.0	3.2	3.4	2.8
Wt % Ash (Dry Basis)	9.0	11.3	9.6	7.0	11.0	9.1
HHV (Dry BTU/Lb)	13500	13350	13500	13500	12700	13,700
Wt % Cl (Dry Basis)	.10	.08	.10	.11	.10	.19

Sulfur Content Polk's acid gas removal system and sulfuric acid plant are designed to accommodate syngas produced from feedstocks containing up to 3½% sulfur. The tests have shown that operation on feedstocks with significantly higher sulfur content would require expensive modifications.

Ash Content Polk's slag removal system limits us to feedstocks with about 12% ash content. High ash content fuels also have an adverse impact on heat rate.

Heating Value The size of Polk's oxygen supply and slurry delivery systems preclude the plant from producing enough syngas to fully load the combustion turbine if the gasifier feedstock has a higher heating value less than approximately 12,500 BTU/Lb. The first Illinois #6 coal tested at Polk was very close to this limit. Its combination of low heating value and relatively poor slurry characteristics (discussed later) precluded our achieving full load operation on the combustion turbine with this coal.

Ash Fusion Temperature Polk's Texaco gasifier is a slagging gasifier, which means that operation must occur at a temperature high enough for the coal's mineral matter to melt and flow freely. The ASTM ash fusion temperature measured under reducing conditions correlates reasonably well with the minimum viable gasifier operating temperature for successful slagging operation. All coals tested to date have reasonable ash fusion characteristics.

Chlorine Content Most of the chlorine in the gasifier's feedstock finds it way into the process water system, and Polk's metallurgy in this area imposes a limit on its allowable chloride content. To keep the process water system below this limit, a continuous blowdown stream is withdrawn to the brine concentration unit. Hence, the capacity of the brine concentration unit ultimately limits the chlorine content of Polk's feedstocks, and this limit is about 0.15%. Table 4 shows that the second Illinois #6 coal tested significantly exceeds this limit with 0.19% Cl. This coal did indeed prove corrosive to Polk's metallurgy. Process or materials changes will be required for Polk to process this coal.

COAL PROPERTIES BEST DETERMINED BY PLANT TEST

The following five coal properties are important to the technical and economic aspects of Texaco based IGCC plant operation. Unfortunately, they can only be accurately determined through plant testing. Quantifying these properties is an important part of Polk's alternate fuel testing program.

"Slurryability" How well does it slurry? The ability of a fuel to be processed into a high concentration slurry improves efficiency and assures that the plant will be able to operate at full load, unconstrained by slurry feed pump or oxygen supply limits. If additive is required, it increases costs, which must be balanced against the efficiency or output gains it provides.

"Reactivity" (Carbon Conversion) How reactive is it? Highly reactive coals provide high carbon conversion at moderate gasifier temperatures. This improves overall system efficiency and reduces the amount of slag to process or handle without sacrificing refractory liner life.

"Slag Aggression" How aggressive is the slag toward the refractory liner? Aggressive slags produce high refractory wear rates, even at moderate gasifier temperatures, and the wear rate increases at higher temperatures. Given the high cost of refractory replacement, there is a very strong economic incentive to select coals with non-aggressive slags and to operate the gasifier at low temperatures to minimize refractory wear rate.

"Slag Characteristics" What are the relative quantities of the three major types of slag produced from the coal? Texaco gasifiers produce three major types of slag: a carbon rich fraction well suited for recycle to the gasifier, a carbon deficient fraction well suited for sale, and an intermediate fraction. Various fuels and operating conditions produce different distributions of these slag products. Knowledge of this distribution is necessary to help select economic optimum operating conditions since slag byproduct credits, recycle value, and/or disposal costs have a noticeable impact on the cost of electricity from an IGCC facility.

"SGC Fouling" How badly does it foul the Syngas Coolers? Severe fouling would inhibit heat transfer, reducing efficiency and causing problems in the syngas scrubbers and low temperature gas cooling.

Slurryability

Polk's slurry preparation system consists of 2 rod mills, each of which has demonstrated the capacity to process up to 120,000 lb/hr of as-received coal (1440 short tons/day each or 2880 tons/day total) under ideal conditions. The slurry is discharged from the mills through trommel screens into relatively small mill discharge tanks. From the mill discharge tanks, it is pumped across vibrating screens into one of the two slurry run tanks. A single slurry feed pump delivers the slurry from a slurry run tank to the gasifier.

The following discussion and Table 5 summarize our slurry preparation experiences on the various coals. Virtually all operation to date has been between 59% and 63% slurry concentration. The main requirement is that the slurry concentration must be high enough that the slurry feed pump can deliver sufficient slurry and the air separation plant can deliver sufficient oxygen to produce enough syngas fuel to fully load the combustion turbine.

TABLE 5
Slurry Concentrations

Coal	Concentration Needed for Full Load	Concentration Achieved	Comments
Pittsburgh 8 #1	59.6	>62.5	Fines Limit
Pittsburgh 8 #2	61.7	>62.5	
Pittsburgh 8 #3	60.4	61.5 (+)	Unstable Slurry
Kentucky 11	62.8	63.5(+)	
Illinois 6 #1	63.0	62.1 (+)	
Illinois 6 #2	63.0	>65	Corrosive

In above table, " (+)" indicates that additive was needed to produce the slurry concentrations shown.

For the **base Pittsburgh 8 coal**, we typically targeted 61% to 62% concentration, although up to

63% slurries were produced on this coal without the use of slurry additive. We intentionally operated at low concentrations since this coal's reactivity is relatively low. Lower concentration slurry permitted reactor operation at the higher oxygen to fuel ratios needed for 95% carbon conversion (our fines handling system cannot accommodate lower conversion at full load) and also at moderate temperatures for reasonable liner life.

The **second Pittsburgh 8** coal we tested had similar slurry characteristics to the base coal. However, it had significantly lower reactivity than the base coal and its slag was much more aggressive toward the gasifier refractory. Consequently, it was an unacceptable feedstock for our unit.

The **third Pittsburgh 8** tested could not be made to yield a slurry over 61.5% concentration, even with the use of slurry additive. The slurry appeared unstable. This feed coal was finer than usual, so our grind size was finer (the rod mills are fixed speed). This may have contributed to the problem. This coal was from a mine which is geographically very close to the mine which produced our base Pittsburgh #8 coal, so it was very surprising that the slurryability was so different.

A **Kentucky 11** was the first alternate coal tested. A 61.5% concentration slurry can be produced without slurry additive, which was not quite sufficient to achieve full load. Higher concentrations require the use of slurry additive. Since this coal has other excellent properties, we have recently converted to it as our new base feedstock. We are now producing 63.5% concentration slurries with slurry additive which does enable us to fully load the combustion turbine.

With the help of slurry additive, we could produce slightly over 62% concentration slurries of the **first Illinois 6** coal we tested, which was not adequate to achieve full load. This coal has other excellent properties, and is one of TECO's long term contract coals. We are exploring future opportunities to work with it to achieve the 63.0% slurry concentration needed for full load operation.

The **second Illinois 6** yielded very high slurry concentrations with minimal effort. Its slurry had one significant drawback: it was highly corrosive. This is probably due to the coal's relatively high chloride content, which also led to high corrosion rates in the black water system.

Reactivity (Carbon Conversion) and Slag Aggression

These two very important dimensions of a coal's performance are discussed together in this section of the paper since they are both intimately related to the key controlled variable for gasifier operation - the temperature. The gasifier temperature must be low enough to provide a reasonable liner life, yet high enough to yield acceptable carbon conversion and a fluid slag.

In Figure 3, gasifier's refractory liner life projected from measurements made during the tests is plotted versus the difference between gasifier operating temperature and the ASTM ash fluid temperature (reducing conditions). This parameter was chosen for the abscissa since the ASTM test is inexpensive, standardized, the results are consistent, and the difference between it and the gasifier operating temperature facilitates the comparison between fuels of differing ash composition. It also provides a quick visual indication of how much cooler we could operate the gasifier without encountering problems with insufficient slag fluidity.

In Figure 4, carbon conversion is plotted directly against gasifier operating temperature. The temperature (instead of oxygen to fuel ratio) was chosen as the abscissa for this figure since in practice temperature is the parameter which we attempt to measure and control in real time operation.

The points connected by lines on the figures are results from sequential tests, or, at least tests where we were quite sure that we were processing the same feedstock. These points show the expected trends: lower liner life and higher conversion at higher temperatures. The fuels are discussed below generally in the order of “best” to “worst” in the remainder of this section.

Illinois 6 #1 This coal was run well above its ash fusion temperature. At this temperature, we expected high refractory losses, but that was not the case. Conversion was also very high (97.5%), indicating that optimal operation would be at significantly lower temperature, where we should achieve well over 3 year liner life while still maintaining very acceptable carbon conversion.

Kentucky 11 (Current Base Coal): This coal demonstrated relatively long liner life and reasonable conversion over a wide temperature range. The higher conversion trend line reflects performance observed during the 5 day pretest in 1997, and the lower trend line reflects recent performance. This combination of properties, along with the ability to produce a sufficiently high slurry concentrations to fully load the combustion turbine and several other technical and commercial factors led us to select this coal as the Polk’s base fuel for 1998.

Illinois 6 #2 Conversion was similar to that of the Kentucky 11, but liner life projections were not quite as good. However, it does seem that a commercially acceptable 2 year liner life should be achievable with Illinois 6 #2 at reasonable carbon conversion rates, so this appears to be a viable fuel.

Pittsburgh 8 #3: This coal is mined on property adjacent to that of Pittsburgh 8 #1, Polk’s first base fuel. Therefore, as we might have expected, it had comparable reactivity to that of the base Pittsburgh #8. However, its ash composition appears to be different, leading to a longer projected liner life. Therefore, Pittsburgh 8 #3 appears to be an attractive feedstock from this perspective.

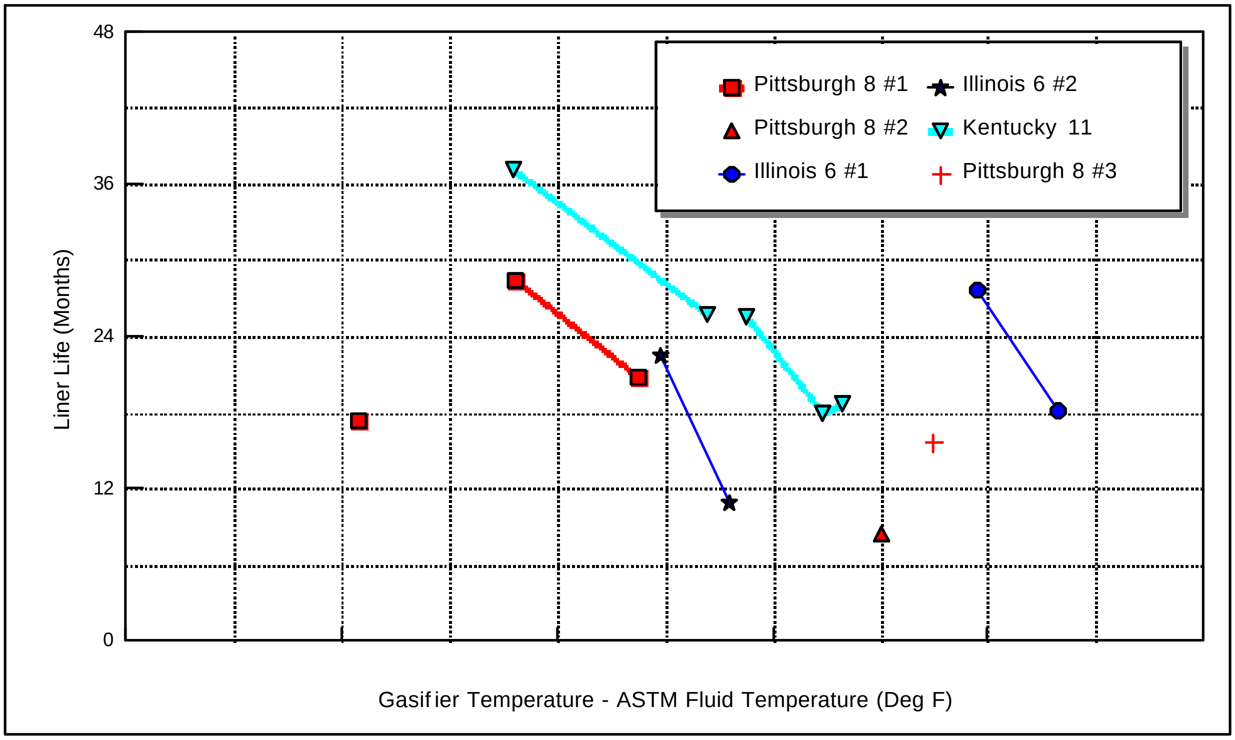

FIGURE 3
Refractory Wear Rate

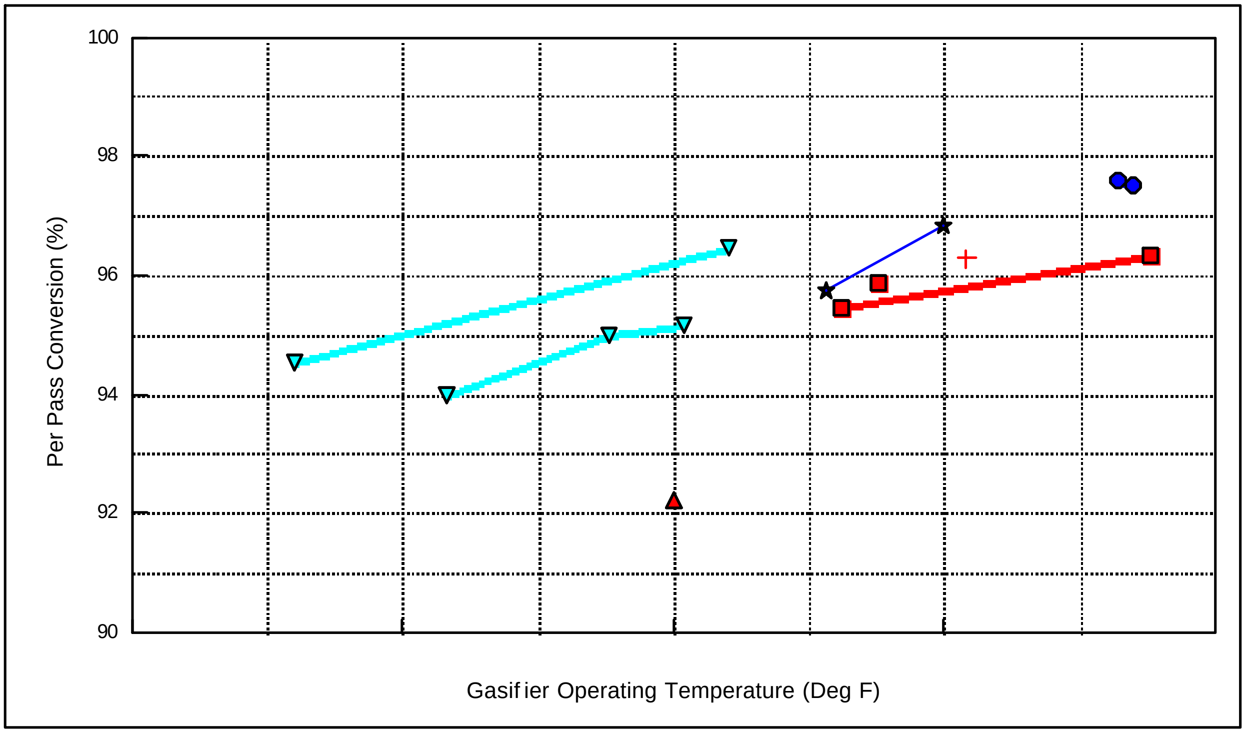

FIGURE 4
Carbon Conversion

Pittsburgh 8 #1 (First Base Coal): The two connected points (sequential runs) show marginally acceptable liner life, while the one other point shows unacceptably low liner life. This coal was supplied from a processing plant which handles coals from more than one local mine, so it is very possible that the mineral matter was indeed different for the outlying point. Carbon conversion values were consistent, but only marginally acceptable for all three points. This Pittsburgh 8 appeared to be rather inconsistent with a very small commercially viable gasifier operating range. Furthermore, its availability was limited and commercial terms were not very attractive. All these factors prompted us to change to the Kentucky 11 as our new base fuel.

Pittsburgh 8 #2: This coal demonstrated low liner life, but this was consistent with its operation well above its fusion temperature. Lower temperature operation would probably have provided an acceptable liner life, but it could not be operated at lower temperature because carbon conversion was unacceptably low, even at the higher temperature. This is by far the worst performer of the three Pittsburgh 8 coals tested, and there are no pricing or other commercial incentives to utilize it. Consequently, Pittsburgh 8 #2 coal appears to have has no commercially viable operating range (or even point) in Polk's gasifier, so it is considered to be an unacceptable feedstock.

Slag Properties

All coals tested produced three types of slag, and the slag fractions could be separated with the same unit operations. The three slag types are:

- Low Carbon (<2% Carbon) This slag is well suited for several commercial applications and represents an excellent byproduct for sales.

- High Carbon (generally >50% Carbon) This slag typically has a heating value between 5,000 and 10,000 BTU/Lb, so is well suited for recycle to the gasifier or possibly sales into some markets.

- Intermediate Carbon (generally 15% to 30% Carbon) This is the least desirable fraction of the slag, but it does have some applications. Generally, operations would strive to minimize the production of this material.

Polk Power Station's current slag handling system is labor intensive and does not provide optimum separation of the slag into the fractions identified above. The data from the alternate fuel test program did provide the basis for design of a much less labor intensive slag handling system which would also provide this separation. We hope to install this system at Polk in 1999.

SGC Fouling

The radiant syngas cooler (RSC) and convective syngas cooler (CSC) design fouling factors were based on extensive analysis of data from other Texaco coal gasification plants. The following Figure 5 shows the RSC and CSC fouling factors as a fraction of their design values.

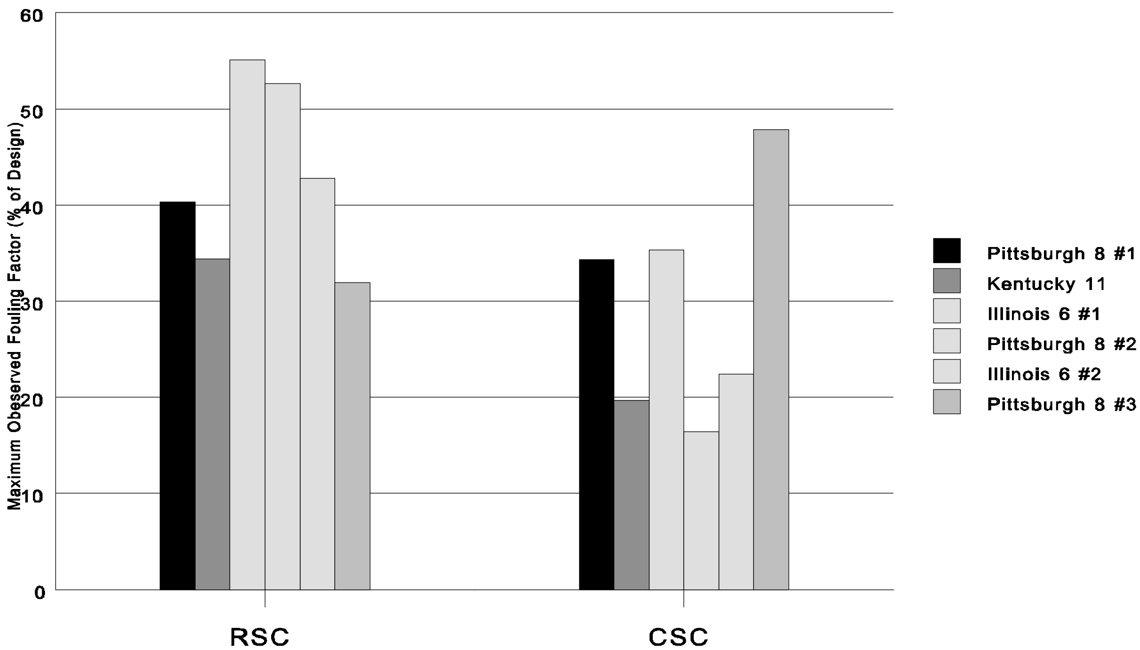

FIGURE 5
Syngas Cooler Fouling Factors

All fouling factors were significantly lower than design. This is particularly remarkable in the case of the RSC since the RSC design data was taken from units which always utilized soot blowing, but no soot blowing has been practiced at Polk. This difference is possibly due to Polk's different metallurgy, geometry, and/or fluid dynamics.

PLANS FOR 1999

The following are some of the significant activities planned for Polk Power Station for 1999.

1) Test operation on a wider range of feedstocks over a wider range of conditions with the revised **fines handling system**. The alternate fuel tests conducted to date provided the basis for the revised design, and the improved system should be commissioned by the end of 1998.

2) Upgrade the **slag handling system** to reduce O&M costs, to produce a more valuable byproduct slag, and to enable selective recycling of some fractions of the current slag product to reduce heat rate The design for the revised system was based on the alternate fuel test results to date.

4) **Reduce HRSG stack SO_2 emissions** from their present levels. Hardware in the existing acid gas removal system has already been upgraded and the system optimized so hydrogen sulfide (H_2S) now consistently represents only a small fraction of the HRSG stack SO_2 emissions. The remaining sulfur compound in the syngas is carbonyl sulfide (COS). Some development work has already resulted in a 30% reduction of carbonyl sulfide (COS) in the syngas. However, this will not be sufficient to meet future SO_2 emission limits, so a more conventional COS hydrolysis unit is being planned.

5) Upgrade the **brine concentration system** to improve its reliability and lower overall plant heat rate. A comprehensive assessment of the problems in this area and their potential solutions has been completed, and the recommendations are currently being evaluated.

6) Continue **testing of alternate fuels** to lower Polk Power Station's overall busbar cost. The revised fines and slag handling systems will provide much more flexibility than we have had in the past to optimize operation on conventional coals, and it will also provide an opportunity to evaluate performance on less conventional fuels such as petroleum coke blends.

CONCLUSIONS

Polk Power Station's second year of commercial operation has been highly successful. The unit achieved nearly a 70% gasifier on-stream factor for the twelve month period. Many major and minor problems have been resolved. The greatest cause of lost production to date, CT damage from contaminated syngas, has been eliminated. Outages due to radiant syngas cooler dome seal leaks have been mitigated through development of operating procedures to solve the problem on-line. The frequency of other outage causes such as black water piping leaks and electrical trips has been dramatically reduced, and the impact of those which persist is largely mitigated through hot restart capability for the gasifier.

The alternate fuel test program has been highly successful. As a result of this program, we changed base coals to a lower cost and better performing fuel. The data from the tests is the basis for designs to correct Polk's weaknesses in the fines and slag handling systems. This data base can serve other plants well. Finally, the testing methodology is proven to provide consistent reliable results.

Focus in 1999 will be on projects which will benefit the long-term profitability and reliability of the Polk Power Station IGCC and on further fuel optimization.