Coal Integrated Gasification Fuel Cell System Study

Pre-Baseline Topical Report

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ABSTRACT

The pre-baseline configuration for an Integrated Gasification Fuel Cell (IGFC) system has been developed. This case uses current gasification, clean-up, gas turbine, and bottoming cycle technologies together with projected large planar Solid Oxide Fuel Cell (SOFC) technology. This pre-baseline case will be used as a basis for identifying the critical factors impacting system performance and the major technical challenges in implementing such systems.

Top-level system requirements were used as the criteria to evaluate and down select alternative sub-systems. The top choice subsystems were subsequently integrated to form the pre-baseline case. The down-selected pre-baseline case includes a British Gas Lurgi (BGL) gasification and cleanup sub-system integrated with a GE Power Systems 6FA+e gas turbine and the Hybrid Power Generation Systems planar Solid Oxide Fuel Cell (SOFC) sub-system.

The overall efficiency of this system is estimated to be 43.0%. The system efficiency of the pre-baseline system provides a benchmark level for further optimization efforts in this program.

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EXPERIMENTAL

No experimental work will be performed as part of this coal-based system study.

RESULTS AND DISCUSSION

1 TASK OBJECTIVES

The objective of this task is to identify an initial system configuration that is based on current gasification, clean-up and bottoming cycle technologies integrated with projected large planar Solid Oxide Fuel Cell (SOFC) technology. Further, the performance of the selected pre-baseline system configuration is estimated and used as a benchmark for further optimization, leading to the baseline system configuration.

The results from this effort will be used in future efforts to identify the technological opportunities available for Integrated Gasification Fuel Cell (IGFC) systems, the critical factors impacting performance of such systems, and the technical challenges present in realizing such systems.

2 TECHNICAL APPROACH

The sub-systems comprising the pre-baseline system were selected using a structured approach. This approach, called Quality Function Deployment (QFD), starts by flowing down the top-level plant requirements to each sub-system. The sub-system requirements are then used to rank the available sub-system technology choices and select the optimal technology for the pre-baseline system. The highest ranked sub-systems were integrated to produce the pre-baseline IGFC design.

The starting point for the QFD is the expected customer requirements for the IGFC system, as communicated in the request for proposal and subsequently defined in the agreement issued by the Department of Energy (DOE). The elements of these top-level requirements are listed outlined in this report.

The pre-baseline system concept is determined by integrating the elements of a commercially feasible Integrated Gasification Combined Cycle (IGCC) system with a syngas treatment sub-system and the SOFC modules. The sub-systems considered in the QFD include the gasification sub-system, the syngas cooling and cleaning sub-system (including optional CO_2 removal), the air separation unit, the bottoming cycle, the fuel integration and fuel cell sub-systems.

The performance of the pre-baseline system was estimated using a performance model, which includes a heat and mass balance and other key flow parameters. This estimate assume a GE 6FA+e gas turbine and Hybrid Power Generation Systems planar SOFC modules.

3 SYSTEM DESCRIPTION

The IGFC system is a hybrid system that combines the current advantages of IGCC for the conversion of coal energy into electric power with the highly efficient SOFC technology. For the pre-baseline case a conventional IGCC gasifier, gas cooling and cleanup system, with two 6FA+e gas turbines and bottoming cycle configuration was modified such that one of the gas turbines was replaced by a SOFC system. This IGFC system includes the following subsystems:

- Gasifier
- Bottoming cycle
- Gas cooling and cleanup
- Air separation
- Fuel Integration and pretreatment
- Gas turbine
- SOFC stack
- Balance of Plant

4 ASSUMPTIONS

The selection of the IGFC sub-systems and the subsequent system performance analysis are based on a number of assumptions. The two major assumptions are summarized in this section.

As described above, the sub-system technologies are selected based on a requirements flow-down method that starts with the customer expectations and requirements. The mechanics of this process relies on the identification of key sub-system choice parameters and their importance rating. The assumptions around this process are described in Section 4.1.

The second set of major assumptions is regarding the site conditions and process specifications that are used in the performance analysis of the pre-baseline configuration. These are summarized in Section 4.2.

4.1 IMPORTANCE WEIGHTINGS FOR SUB-SYSTEM SELECTION

The requirements for selecting the suitable IGFC sub-system technologies for the pre-baseline system were determined using a QFD that starts with the expected customer requirements. The top-level attributes that are critical to the quality of the system concept and that represent customer expectations were identified to be:

- Plant efficiency (with a target of 60% HHV)
- Low cost of electricity
- Plant capacity
- Technology applicable for integration with SOFC
- “Near zero” emissions of traditional pollutants
- Carbon dioxide reduction or capture capability

- Minimum hazardous waste
- Technology feasibility in the 2010-2030 time frame
- Co-product capability (transportation fuels, Hydrogen, etc.)
- Coal flexibility with other optional fuels
- Minimum water usage

These attributes were cross-correlated in matrix form with the IGFC system performance requirements to yield the relative importance of each requirement in achieving the plant attributes listed above. The weighted list of performance requirements, called the system choice parameters, is used in determining the suitability of sub-system choices. The system performance requirements or system choice parameters that were determined sufficient for this study include:

- Plant Cost
- System Power Output
- System Efficiency
- System Availability
- NO_x Emissions
- CO Emissions
- CO_2 Emissions
- SO_x Emissions
- Maintainability
- Water Usage
- Subsystem R&D Required
- Sub-System Technology Choice

The importance weights determined for these choice parameters is shown in Figure 1. These system choice parameters and importance weights are used to select the sub-systems.

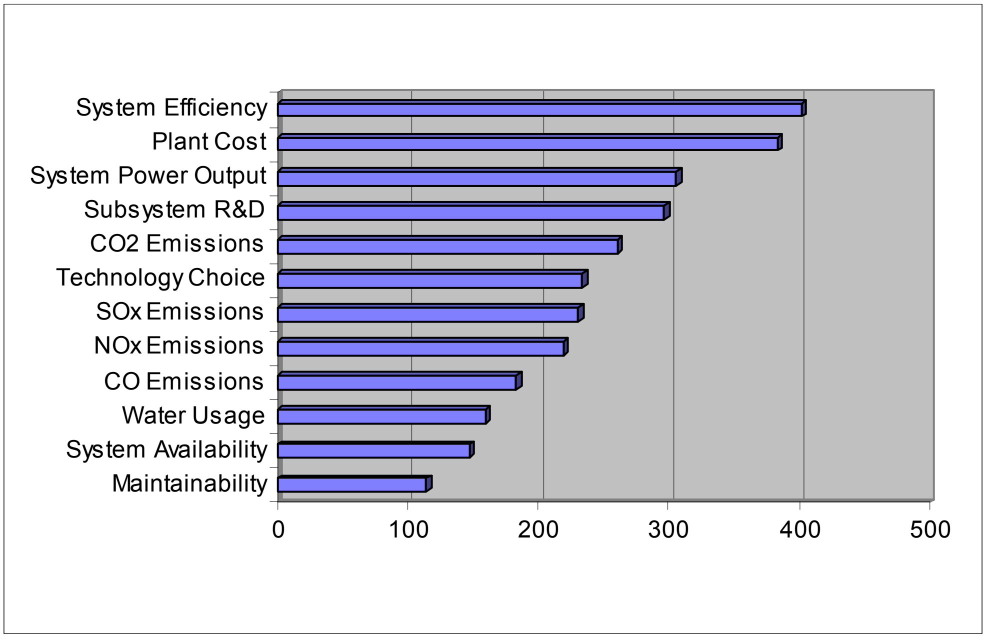

Figure 1 Importance Weighting for System Choice Parameters

4.2 SITE CONDITIONS AND PROCESS SPECIFICATIONS

The performance analysis of the pre-baseline system relies on a variety of assumptions regarding the site conditions and processes. These assumptions are summarized here.

Site Conditions:	Temperature	-	59 ^{o}F
	Humidity	-	60 % RH
	Elevation	-	30 Feet
	River Water	-	60 ^{o}F Nominal

Gasification Process Conditions:

Coal Specifications:	Type	-	Pittsburgh No. 8
	Mode	-	Briquette
	Binder	-	Bitumen (Binds 55% Fines Coal)
	Flux	-	Limestone
Gasifier Specifications:	Type	-	Oxygen-Blown, Commercially Proven Technology
	Oxygen	-	Provided by Air Separation Plant (Stand Alone Compressors)
	Waste	-	Slag Disposed On-Site Less Soluble Salts

	Output Gas	-	Pressure of 400 psia Temperature of 300 ^oF
Gas Cooling:	Final Cooling by Cooling Water to Nominal 80 ^oF		
Acid Gas Removal:	Process	-	Chemical Solvent Based, Acid Gas treated by Claus Plant

Power Island Basis:

Gas Turbine:	General Electric 6FA+e Gas Turbine Startup and Backup Fuel - Natural Gas NO_x Abated through Syngas Saturation
Steam Cycle:	2 Pressure, Reheat Boiler with Steam Turbine (Gas Turbine Exhaust and Fuel Cell Stack Vitiated Air Combined as Boiler Feed) Once Through Cooling System

Fuel Cell Integration Performance Parameters:

Syngas Shift:	Adiabatic, High-Temperature WGS Reactor (60% Shift of Syngas CO)
Pressure Drops: (for each piece of equipment)	Nominal Pressure Drop - 1.0 % (> 200 psia) 2.5 % (< 50 psia)
Heat Losses:	1.0 % of Syngas LHV Content (Heat Exchangers and Piping)
Heat Exchangers:	LMTD Range - 110. to 280. ^oF (Not Optimized - Constrained by Heatup/ Cooldown Requirements)
Compressor/Expander:	Polytropic Efficiencies (Nominal HYSYS Values) Compressors - 78. to 80. % Expanders: - 71. to 73. %

Fuel Cell Stack Performance Parameters:

Configuration:	4 modules in Series		
Module Pressure Drops:	2.0% for modules 1 and 4, 1.0% for modules 2 and 3		
Stack Module Temp:	Inlet Air - 1280 ^oF, Inlet Fuel - 1300 ^oF		
	Outlet Air - 1450 ^oF, Outlet Fuel - 1450 ^oF		
Operating Conditions:	Fuel Utilization	-	80 Percent of Input Fuel
	Cell Inlet Loss	-	1 Percent of Flow
	Cell Output Loss	-	2 Percent of Flow
	Cell Voltage	-	0.7 Volts
	Cell Power Loss	-	2 Percent of Cell Power
	Maximum CO	-	15 Volume Percent
	DC to AC Conversion	-	97 Percent Efficiency

5 SELECTION OF GASIFICATION SUB-SYSTEM

The selection of the pertinent sub-system technologies was accomplished by first identifying the major performance requirements for each sub-system and then ranking these requirements against the weighted sub-system choice parameters shown in Figure 1. Subsequently, the major sub-system technology choices were identified and ranked against the weighted sub-system requirements to determine the optimal sub-system configuration for the pre-baseline system concept.

The choice of the pre-baseline sub-systems were limited, wherever possible, to presently commercially available offerings. The sub-system technologies selected for the pre-baseline system includes a

- British Gas Lurgi (BGL) gasifier
- Reheat bottoming cycle
- Selexol based syngas cooling and cleaning sub-system, and
- Elevated pressure air separation unit

6 ANALYSIS OF PRE-BASELINE SYSTEMS.

Sub-system optimizations were considered within the framework of existing studies for production of syngas for IGCC systems. Previous IGCC studies provide the best examples of syngas sources and are used as a starting point for integration with SOFC stacks. In particular, the original British Gas Lurgi (BGL) IGCC reference system, shown in Figure 2, was selected as the starting point for the pre-baseline configuration. This reference IGCC system best matches the sub-system choices selected in this program and provides a high-efficiency syngas source.

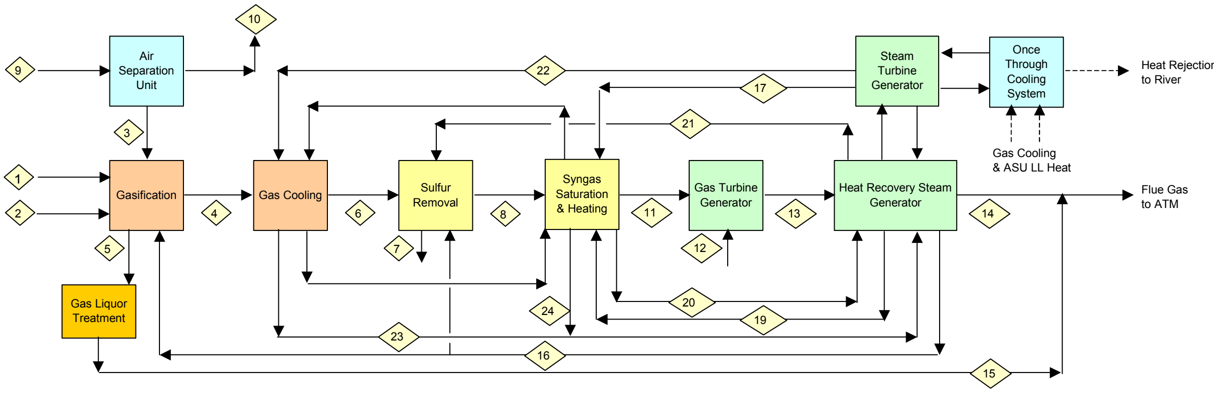

Figure 2 -Original BGL Reference System Configuration

The reference IGCC system was minimally modified to produce the IGFC pre-baseline system. One of the two gas turbines from the reference IGCC system was replaced by a SOFC stack module and conditioning system. In addition, extraction air from the one remaining gas turbines was used to partially fulfill the oxidant flow requirements of the fuel cell stack. Subsequently, the depleted air from the stack is combined with the gas turbine exhaust as input to the Heat Recovery Steam Generator (HRSG).

Syngas from the BGL system is sent to the fuel cell module after a Water-Gas Shift (WGS) of the syngas to a fuel more suitable for the SOFC Fuel Cell Stack. Also, a sulfur and particulate removal unit is included prior to the fuel cell. Pressure integration is accomplished in this system by means of compressors and expanders.

Modifications to the reference system are depicted by the red lines in the pre-baseline system configuration drawing, shown in Figure 3. The fuel cell stack is integrated into the pre-baseline IGFC system via flow streams 25, 26, 27, and 28, representing the fuel flow entering the fuel cell, the fuel flow exiting the fuel cell, the air flow exiting the fuel cell, and the air flow entering the fuel cell, respectively.

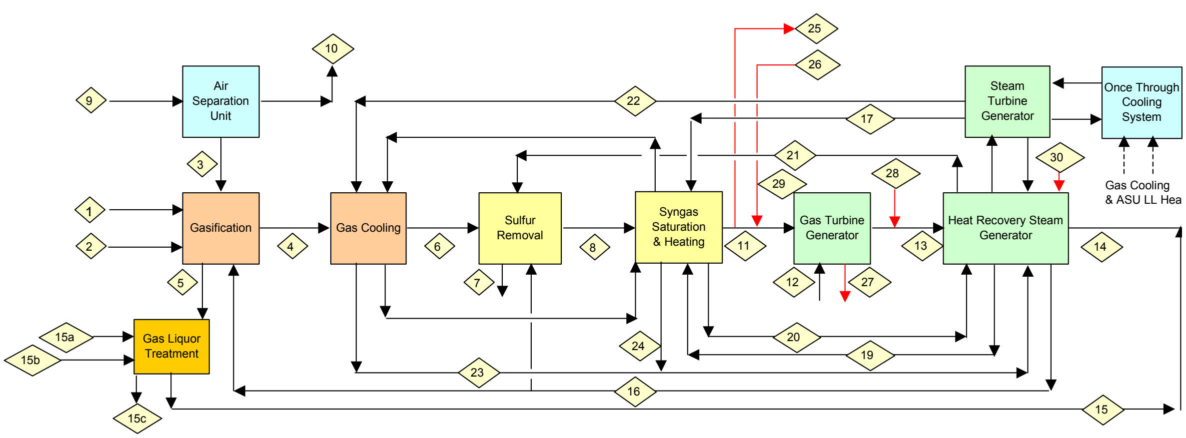

Figure 3 The Pre-Baseline IGFC System

The flow stream compositions and flow parameters for the pre-baseline system were estimated at each location identified in Figure 3 and 4. Analysis of the complete heat and mass balances indicates that mass balances for the complete IGFC System are within 0.002 % and energy balances are found to be within 0.03 %.

Fuel from the fuel cell integration section is sent to the fuel cell stack sub-system, where it reacts with air supplied by the gas turbine (stream 27) to produce electricity. The fuel cell stack sub-system consists of one or more fuel cell stack modules arranged to enable efficient stack thermal management. The fuel cell exhaust is sent to the gas turbine, where the fuel cell by-product heat is converted into electrical power.

Results of the overall net power output and system efficiency for the Reference IGCC System and the Pre-Baseline System are provided in Table 1. It can be noted that the integration of the fuel cell into the reference IGCC system is expected to yield an increase in net system efficiency of 2.2% HHV.

Reference System

Gross Power Gen.		
- Gas Turbines	- kW	180000
- Steam Turbine	- kW	65200
Sub-Total:	- kW	245200
In-Plant Power Cons.		
- Gasification	- kW	3211
- Air Separation	- kW	15034
- Combined Cycle	- kW	2190
- Cooling Water CC	- kW	340
- Cooling Water PP	- kW	894
- BOP+Misc	- kW	1379
Sub-Total:	- kW	23047
Net Power To Grid	**- kW**	**222153**
Heat Input, HHV	- MMBtu/h	1856.9
Net Heat Rate, HHV	- Btu/kWh	8358.6
Net Efficiency, HHV	**- %**	**40.8**

Pre-Baseline System

Gross Power Gen.		
- Gas Turbines	- kW	70217
- Net Fuel Cell System	- kW	90034
- Steam Turbine	- kW	65207
Sub-Total:	- kW	225458
In-Plant Power Cons.		
- Gasification	- kW	2810
- Air Separation	- kW	13158
- Combined Cycle	- kW	2149
- Cooling Water CC	- kW	365
- Cooling Water PP	- kW	782
- BOP+Misc	- kW	1283
Sub-Total:	- kW	20548
Net Power To Grid	**- kW**	**204910**
Heat Input, HHV	- MMBtu/h	1625.2
Net Heat Rate, HHV	- Btu/kWh	7931.4
Net Efficiency, HHV	**- %**	**43.0**

Table 1 - Performance Summaries

Most of the performance efforts involved the integration of the fuel cell stack with the gasifier system and the initial conceptual design of the fuel cell integration sub-system. Within the bounds of the available gasifier information and the HYSYS simulation of the fuel integration sub-system, the pre-baseline performance results provide a realistic benchmark case for further optimization.

The carbon monoxide level in the fuel going to the fuel cell stack could be kept within the recommended 15 % maximum CO level (with a nominal 12 % CO level) by using a single WGS reactor. A simple, single-reactor shift sub-system was possible since the syngas from the gasification system was highly saturated with steam. Optimization of the shift level for the syngas from the gasifier would be the subject of post-baseline studies.

The findings from the pre-baseline analysis indicates the adverse impact of excess air required for stack cooling and high stack pressure losses on the performance potential of the system. Significant effort was spent on minimizing this air flow. This effort will continue into the baseline system conceptual studies.

It is important to understand that if both the gas turbines in the referenced IGCC system were replaced by the fuel cells the resulting system is potentially capable of 45 to 46% thermal efficiency.

In the baseline study specific attention must be paid to the size of the individual cells and their arrangement in the stack module. This has an impact on the pressure losses and stack cooling air requirements, both of which have an impact on the system performance. Optimization of the stack cell size and configuration has the potential to improve the plant performance while minimizing the plant capital equipment cost.

Also, the thermal integration of the fuel cell heat with the gasifier has not been fully optimized in the pre-baseline case. More extensive optimization is possible in future work.

The presence of the Rankine cycle in addition to the Brayton cycle offers significant flexibility to the fuel cell system, such that the overall plant performance can be further improved by recovering the waste heat in either of the two bottoming cycles.

CONCLUSION

This pre-baseline IGFC system has been conceived by integrating a SOFC stack module with a reference IGCC system. The pre-baseline IGFC sub-systems were chosen based on a philosophy of selecting commercially available technology wherever possible. An estimated overall efficiency of 43.0% for the pre-baseline IGFC system presents a 2.2% improvement in system efficiency over the equivalent IGCC system. Although this does not constitute a significant increase, the IGFC concept continues to hold promise for further significant efficiency improvements in subsequent configurations, to be studied. These efficiency improvements are anticipated through increased integration of the fuel cells with the syngas system and the bottoming cycle.

REFERENCES

None