ENGINEERING DEVELOPMENT OF A HIGH-PERFORMANCE POWER SYSTEM

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INTRODUCTION

A High-performance Power System (HIPPS) is being developed. This system is a coal-fired, combined cycle plant that will have an efficiency of at least 47 percent, based on the higher heating value of the fuel. The cost of energy (COE) for this plant must be at least 10 percent less than a conventional PC plant and the emissions one-tenth of current New Source Performance Standards (NSPS). Foster Wheeler Development Corporation is leading a team of companies in the development of this system. The team members are AlliedSignal, Bechtel, Foster Wheeler Energy Corporation, The University of Tennessee Space Institute and Westinghouse.

A conceptual commercial plant design was developed in Phase 1 of the project. A simplified process flow diagram of the plant is shown in Figure 1. This type of HIPPS plant will achieve the program goals without requiring natural gas as a portion of the plant heat input. This system uses a pyrolyzation process to convert coal into fuel gas and char. The char is fired in a High Temperature Advanced Furnace (HITAF) where it heats air for the gas turbine cycle and steam for the steam turbine cycle. The gas turbine air is heated to 760 C (1400 F) in the HITAF. It then goes to the topping combustor which is fired with the fuel gas from the pyrolyzation process. Some of the gas turbine exhaust is used as combustion air in the HITAF, and the rest goes through a Heat Recovery Steam Generator (HRSG). Both the gas turbine exhaust stream and the HITAF exhaust stream need back end DeNOx and DeSOx systems to meet the very low emissions goals of the project.

Our High Performance Power System has very high efficiency and other benefits relative to alternate coal-fired combined cycle systems. By using a process that requires only partial gasification of coal, the conversion process is made simpler and less critical than Integrated Gasification Combined Cycles (IGCC). Also, the HITAF is an atmospheric boiler/air heater which is closer to conventional boiler design than systems that require combustion to be done at pressure. The environmental benefits of HIPPS derive from the high efficiency of the cycle which lowers emissions globally by virtue of the lower amount of fuel being burned, and by the use of back end pollution control systems. The need for back end emissions systems could be looked at as a negative relative to other systems, but it also has positive aspects. Since any emissions control systems can be applied to HIPPS, it can take advantage of future developments in that area. Systems with inherent emissions control run the risk of becoming obsolete if advances in emissions control go beyond their capabilities.
In Phase 1 a design study of a repowering version of HIPPS was also done. It is one of the few

repowering concepts that utilizes the existing boiler. It is similar to "Hot Windbox" repowering where gas turbine exhaust is used as combustion air for the boiler. Current hot windbox concepts use natural gas fired gas turbines and usually natural gas fired boilers. The HIPPS repowering is totally coal-fired. It will increase the unit output by around 24% and the cycle efficiency by over 5 percentage points.

Phase 2, which involves pilot plant testing of the key HIPPS plant systems, is now in progress. Separate pilot plant tests of the pyrolyzer and char combustion system will be run, and then an integrated test of these systems will be done at the University of Tennessee Space Institute. Key results of the Phase 1 R&D and the plan and status of the Phase 2 R&D are discussed in this paper.

COMMERCIAL PLANT PERFORMANCE AND ECONOMICS

A conceptual design study of a 310 MW commercial HIPPS plant was done in Phase 1. Table 1 lists some of the operating and performance parameters of that plant. This arrangement of the HIPPS cycle has an efficiency of 47%.

Table 1
310 MW Commercial Plant Performance

Coal Flow to Pyrolyzer, 10^3 lb/h	164.4
Coal Flow to Boiler, 10^3 lb/h	16.5
Coal HHV, 10^3 Btu/h	12.5
Fuel Gas Flow, 10^3 lb/hr	583.5
Char Flow, 10^3 lb/h	71.7
Gas Turbine Gross Power, MW	153.2
Steam Turbine Gross Power, MW	169.3
Total Net Power, MW	310.4
Efficiency (HHV), Percent	47.1

Part of the Phase 2 effort is to revise the commercial plant design. The additional parametric studies in Phase 2 indicate that the cycle has potential for efficiencies of over 50 percent with optimized pyrolyzer/HITAF conditions and the higher gas turbine inlet temperatures that are currently under development.

A cost estimate was made of the Commercial Plant, and the Cost of Electricity (COE) is 14 percent less than an equivalent size PC plant. This lower COE is a result of both the increased efficiency and lower capital cost of the HIPPS plant. At first glance it may seem unusual that the HIPPS plant, with its extra systems, would have lower capital costs. The reason for this situation is that the steam cycle part of HIPPS is only about half the size of the PC plant. The rest of the output of the HIPPS plant is from the gas turbine cycle. Gas turbine systems have much lower capital cost than steam turbine systems.

REPOWERING PERFORMANCE AND ECONOMICS

As part of the Phase 1 R&D, a study was done on the application of HIPPS repowering to a specific utility boiler. Working with actual plant performance data, equipment designs and site conditions, a repowered system was designed and cost estimates were made. Table 2 summarizes the key plant performance and operation parameters for the existing unit and what would result from repowering with HIPPS. For this plant, the cycle efficiency will increase by 5.6 percentage points and the net power output by 24 percent.

Table 2
Repowering Case Study Performance

	Existing Plant	HIPPS Repowering
Coal Flow to Pyrolyzer, 10^3 lb/h	0	61.25
Coal Flow to Boiler, 10^3 lb/h	73.02	16.40
Char Flow to Boiler, 10^3 lb/h	0	32.6
Fuel Gas to Gas Turbine, 10^3 lb/h	0	130.8
Gas Turbine Gross Power, MW	0	32.6
Steam Turbine Gross Power, MW	98.9	90.2
Total Net Power, MW	93.7	116.4
Efficiency (HHV), Percent	33.6	39.2

In the design of the HIPPS repowering system, emphasis was placed on making the system as compatible with existing equipment as possible. It was also designed to be simpler and more near term than the “greenfields” HIPPS plant. As with the “greenfields” plant, a pyrolyzer is used to generate fuel gas and char. The fuel gas is used as fuel for the gas turbine, and the char is fired in the boiler along with raw coal. The pyrolyzer and gas turbine are sized such that all the gas turbine exhaust will be used as combustion air in the boiler. With this design, the flue gas stream from the boiler is the only exhaust stream to the stack.

The modifications required for the plant include the removal of some tube surface in the boiler and complete removal of the existing air heater. A pyrolyzer system is added including modifications to the feed systems for pyrolyzer operation. Economizer tube banks and some new ducting are also added along with the gas turbine. For this study, new pulverizers, low NOx burners, SCR, baghouse and FGD were also included, but these items are not integral to the HIPPS repowering concept and may not be needed in all applications.

A Net Present Value (NPV) analysis was used for the economic evaluation because this type of analysis accounts for the income streams that will be generated by the increased capacity of the plant. Figure 2 compares the NPV of several repowering options that are available to the utility. Since capital costs can vary depending on what is included in the various systems, the NPV’s are plotted as a function of capital cost. It can be seen that with no real natural gas price escalation HIPPS repowering and natural gas hot windbox repowering are essentially equal; however, with even a 1 percent real escalation in the price of natural gas HIPPS will have superior NPV. Table 3 shows the breakdown of the repowering capital costs by system.

Table 3
HIPPS Repowering Study
Distribution of Capital Costs by System

System	Percent
Solids Feeding	6.2
Steam Generator Island	10.4
Pyrolyzer	20.4
Gas Turbine	35.7
Emissions Systems	20.9
Balance of Plant	6.4

DEVELOPMENT PLAN FOR PHASE 2

The major areas of R&D in Phase 2 are the pyrolyzer subsystem, the char combustion subsystem and the integration of these systems. Other important issues are being addressed, but these three areas are the major emphasis of Phase 2.

<u>Pyrolyzer/Char Transport Test (PCTT)</u>. The pyrolyzer R&D will investigate both the chemical and hydrodynamic characteristics of the system. The particular pyrolyzer operating and design parameters required to achieve the proper carbon conversion and acceptable char particle size distribution (PSD) must be determined. These factors are important to the operation and efficiency of the system. Pyrolyzer pilot plant tests will be run at the FWDC Livingston facility to establish these parameters. A pilot plant originally used for second-generation PFB testing is being modified to operate under the HIPPS conditions.

These tests will be run at 500 lb/h coal input. The pilot plant is being designed to allow pyrolyzer velocity variation during each run. All the tests will be with the base case Pittsburgh #8 coal, but feedstock PSD's will be varied during the test campaign. The system has also been designed such that the cyclone can be modified between runs.

The pyrolyzer pilot plant design is complete. A few tests will be run in the current bubbling bed configuration of the pyrolyzer, and then the system will be modified for circulating bed operation. The bubbling bed tests are scheduled to start in September of this year. The pyrolyzer test program will be completed by the third quarter of 1997.

<u>Char Combustion System</u>. The original HIPPS plant used TRW slagging combustors. The TRW combustors have been replaced with a Foster Wheeler arch-fired combustion system. Foster Wheeler is a world leader in the supply of combustion systems for low volatile fuels, and our technology is a good fit for the HIPPS char combustion. Tests of the char combustion system will be run at our Dansville, NY combustion test facility. This facility includes coal preparation equipment, a water cooled furnace and downstream tube banks. The facility is being modified for HIPPS testing. The furnace wall is being modified for arch-firing and auxiliary systems are being designed to simulate the transport conditions of the char and the chemical composition and temperature of the HIPPS combustion air. The Dansville tests, in conjunction with design analysis, computer modeling and physical modeling will determine the combustion system design and the required char PSD and char/air temperature.

<u>Integrated System Test</u>. The Integrated System Test (IST) will be run at the University of Tennessee Space Institute (UTSI). In this test, the pyrolyzer subsystem will be run together with the char combustion system and simulated HITAF. The UTSI facility is also an existing facility that will be modified for the HIPPS testing. The pyrolyzer coal flow will be about 6,000 lb/h for the IST. The char will be depressurized and transported to the simulated HITAF where it will be burned. The IST testing will not involve a lot of parametric testing. It will mainly be a demonstration of the integrated operation of the system. Testing of this system will start in mid-

1998.