DEVELOPMENT OF TECHNOLOGIES AND ANALYTICAL CAPABILITIES FOR VISION 21 ENERGY PLANTS

COOPERATIVE AGREEMENT NO DE-FC26-00NT40954

DISCUSSION ON TEST AND DEMONSTRATION CASE 2

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DISCLAIMER

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ABSTRACT

The goal of this DOE Vision-21 project work scope is to develop an integrated suite of software tools that can be used to simulate and visualize advanced plant concepts. Existing process simulation software does not meet the DOE's objective of "virtual simulation" which is needed to evaluate complex cycles. The overall intent of the DOE is to improve predictive tools for cycle analysis, and to improve the component models that are used in turn to simulate the cycle. Advanced component models are available; however, a generic coupling capability that will link the advanced component models to the cycle simulation software remains to be developed. In the current project, the coupling of the cycle analysis and cycle component simulation software will be based on an existing suite of programs. The challenge is to develop a general-purpose software and communications link between the cycle analysis software Aspen Plus® (marketed by Aspen Technology, Inc.), and specialized component modeling packages, as exemplified by industrial proprietary codes (utilized by ALSTOM Power Inc.) and the FLUENT™ CFD code (provided by Fluent Inc).

ALSTOM Power has a task responsibility to select and run a combined cycle test case (designated as Demonstration Case 2) to demonstrate the feasibility of the linkage concept. This report summarizes and documents the unit selected to represent Case 2, a 250 MW, natural gas-fired, combined cycle power plant. An analogous document for Demonstration Case 1 was previously submitted on April 30, 2001. Sufficient information is available from the plant to adequately benchmark the model. Hence, the proposed unit is deemed to be well suited as a demonstration case. However, as the combined cycle plant selected for this study contains recent technology, sensitivity to the commercial implications of this study prevents the release of the plant name and limits the quantity of operating / design information that can be presented. These limitations will not prevent the goal of this task, demonstration of the feasibility of software integration for "virtual simulation", from being accomplished.

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1.0 BACKGROUND ON VISION 21 PROGRAM

The goal of the overall program work scope is to develop an integrated suite of software tools that can be used to simulate and visualize advanced plant concepts that are being developed as part of DOE's Vision 21 program. Simulation tools will be needed to evaluate new power plant concepts that could minimize costly laboratory and field trials.

Existing process simulation software does not meet the DOE's objective of "virtual simulation" which is needed to evaluate complex cycles. The intent of the DOE is to improve predictive tools for cycle analysis, and to improve the component models that are used in turn to simulate the cycle. At present, the modeled performance of various components, e.g., a boiler, are derived from a simple set of rules and are used by the cycle simulation software primarily as a black box. These simple component models are not sufficient for component design and the evaluation of the impact of the component on cycle performance. To meet DOE's goal of predicting and visualizing the performance of these complex systems, there is a need to upgrade the component models and their interaction protocols with cycle software, providing "hooks" to industrial design methodologies, CFD codes (like FLUENT™), and spreadsheets.

The simulation software will be based on an existing suite of programs being marketed by Aspen Technology, Inc. (AspenTech), Intergraph Corp. and Fluent Inc. AspenTech has developed a number of advanced process simulation tools, like Aspen Plus® and Zyqad® that have many of the characteristics needed to evaluate Vision 21 concepts. Intergraph Corp., in partnership with AspenTech, has developed elements of the visualization software. Fluent Inc. has developed a multi-dimensional flow and combustion code (FLUENT™) used by many parts of the power generation industry. The challenge is to develop a general-purpose software and communications link between Aspen Plus® and other modeling software, such as industrial proprietary codes, CFD codes like FLUENT™, and simpler spreadsheet analyses.

2.0 INTRODUCTION

The feasibility of using various models in concert with a process model like Aspen Plus® will be a focus of the Vision 21 project. The role of ALSTOM Power (AP) will be to assist the project team in helping to develop and demonstrate the capabilities of the advanced Vision 21 simulation and visualization tool. The primary AP responsibilities and tasks include:

- providing its expertise and experience base in the utilization of both CFD and cycle analysis for the power generation industry,
- selecting and running two cases to test and demonstrate the feasibility of the concept,
- providing the data links and executables for any proprietary (AP) industrial codes that will be coupled with the process simulation software,
- forming an advisory board to provide project review and feedback.

One of the tasks (Task 3.2), as specified in the Project Management Plan (Ref. 1), is to select the AP Test and Demonstration Cases. The project team's philosophy of progressing in a step-by-step manner, from the relatively simple to the more complex, was adopted in the plan. Therefore, Case 1 was required to be a conventional and relatively modest power generation cycle, of sufficient simplicity that it could be used to test the initial feasibility of using CFD and other methods in concert with a process model like Aspen Plus®. Case 2 was stipulated to be a more advanced cycle. More specifically, Case 1 was defined to be a conventional steam cycle, containing a wall-fired coal boiler and post combustion cleanup equipment, fuel handling equipment, steam turbine and generator, heat exchange equipment, and pumps. Case 2 was anticipated to be a natural gas combined cycle, consisting of a gas turbine, steam turbine, heat recovery steam generator, etc. Although neither case constituted a Vision 21 concept, a number of the cycle components will exist in a Vision 21 plant. The final selection of an appropriate unit was also to be based on the availability of the cycle conditions and component data.

One of the milestones and deliverables, as stipulated in the Project Management Plan (Ref. 1), is to discuss and document the AP Test and Demonstration Case 2. This report summarizes and documents the unit selected to represent Case 2. Please note, however, that the combined cycle plant selected for this study contains recent technology and sensitivity to commercial concerns will prevent the release of the plant name and limit the quantity of operating / design information that can be presented in this study. These limitations on the presentation of the unit design information will not prevent the demonstration of the feasibility of the linkage concept from being accomplished.

3.0 COMBINED CYCLE POWER PLANT

An aerial view of the combined cycle power plant is shown in Figure 1. The power plant consists of a GT24 advanced gas turbine, steam turbine, generator, and heat recovery steam generator (HRSG) all supplied by ALSTOM Power. Plant construction was completed in the late 1990s and the unit is currently generating power on a merchant basis.

Figure 1: Photograph of the Combined Cycle Power Plant.

3.1 Gas Turbine

The GT24 gas turbine, illustrated in Figure 2, generates approximately 2/3 of the 250 MW of electrical output from the combined cycle power plant. The gas turbine generator has an efficiency of 38.5% when firing natural gas fuel with an ambient air temperature of 15 °C. The exhaust gas exits the gas turbine around 640 °C where it enters an HRSG.

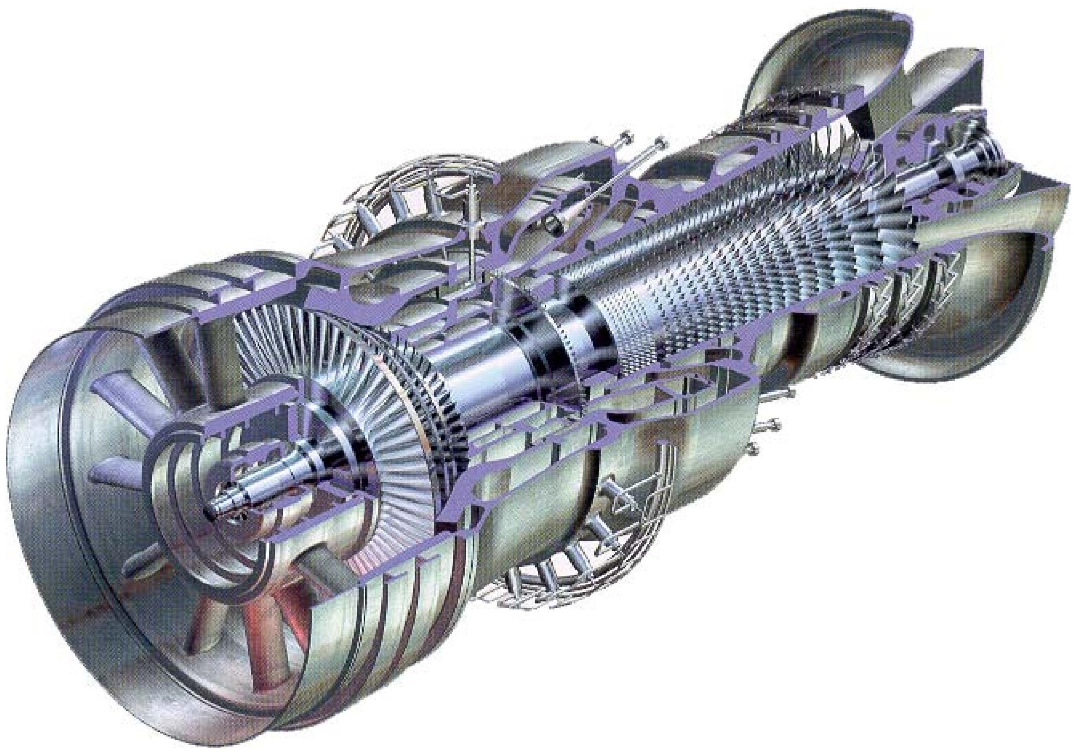

Figure 2: GT24 Gas Turbine.

3.2 Heat Recovery Steam Generator (HRSG)

In combined cycle mode, the power plant operates at a net efficiency of 57.5%. The HRSG is a dual pressure reheat design. The HRSG combines a low pressure, natural circulation steam drum system with a high pressure once-through boiler. Saturated, low-pressure (LP) water from the LP drum is used to feed the once-through high pressure (HP) system. The HP system utilizes a novel steam/water separator to maintain high steam quality while eliminating the need for a thick-walled, thermally sluggish HP steam drum. This allows the power plant to more rapidly cycle to adjust to variations in load.

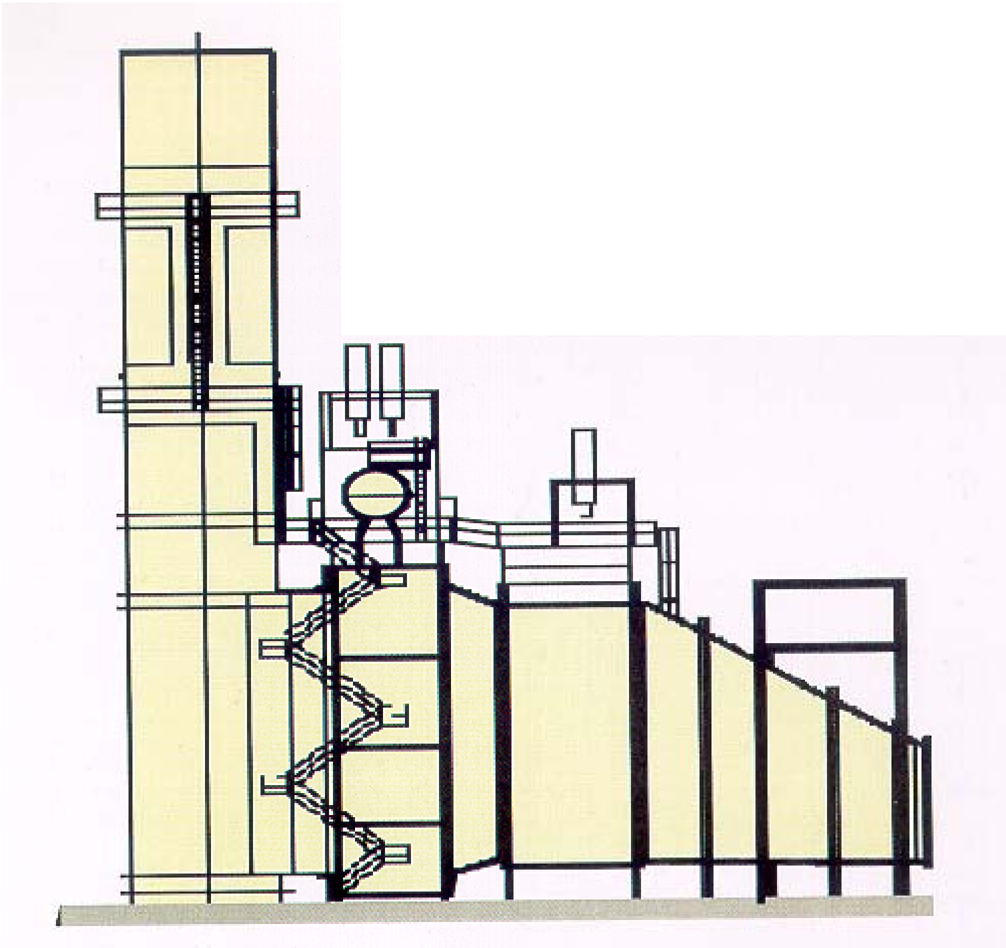

Figure 3: Once-Through Heat Recovery Steam Generator Arrangement.

3.3 Steam Cycle

A schematic of the combined cycle unit is shown in Figure 4. As illustrated in the figure, the gas and steam turbines are both on a single shaft. The HRSG contains both high and low pressure evaporative and superheat surface as well as HP reheat. Condensate from the condenser is mixed with a small quantity of hot water from the feed water economizer (FWECON) to control the water temperature into the FWECON. The main portion of the hot water from the FWECON is fed into the LP drum. Water flows through downcomers into evaporator tubes and the resulting saturated steam/water mixture is returned to the drum through risers by natural circulation. The saturated steam exits the top of the LP drum where it passes through a superheater section before entering the LP section of the steam turbine.

The HP feed pump also takes water from the LP steam drum, a small part of which is sent to the gas turbine cooler. Most of the HP feedwater flows through the HP economizer and then into the once-through evaporator section where it exits as slightly superheated steam. The steam is then sent to the HP separator where it is mixed with superheated steam from the gas turbine (GT) cooler. The steam is then superheated and conditioned in the HP desuperheater and sent to the HP steam turbine. From the steam turbine outlet, the steam passes through a reheat (RH) section and then into the RH desuperheater.

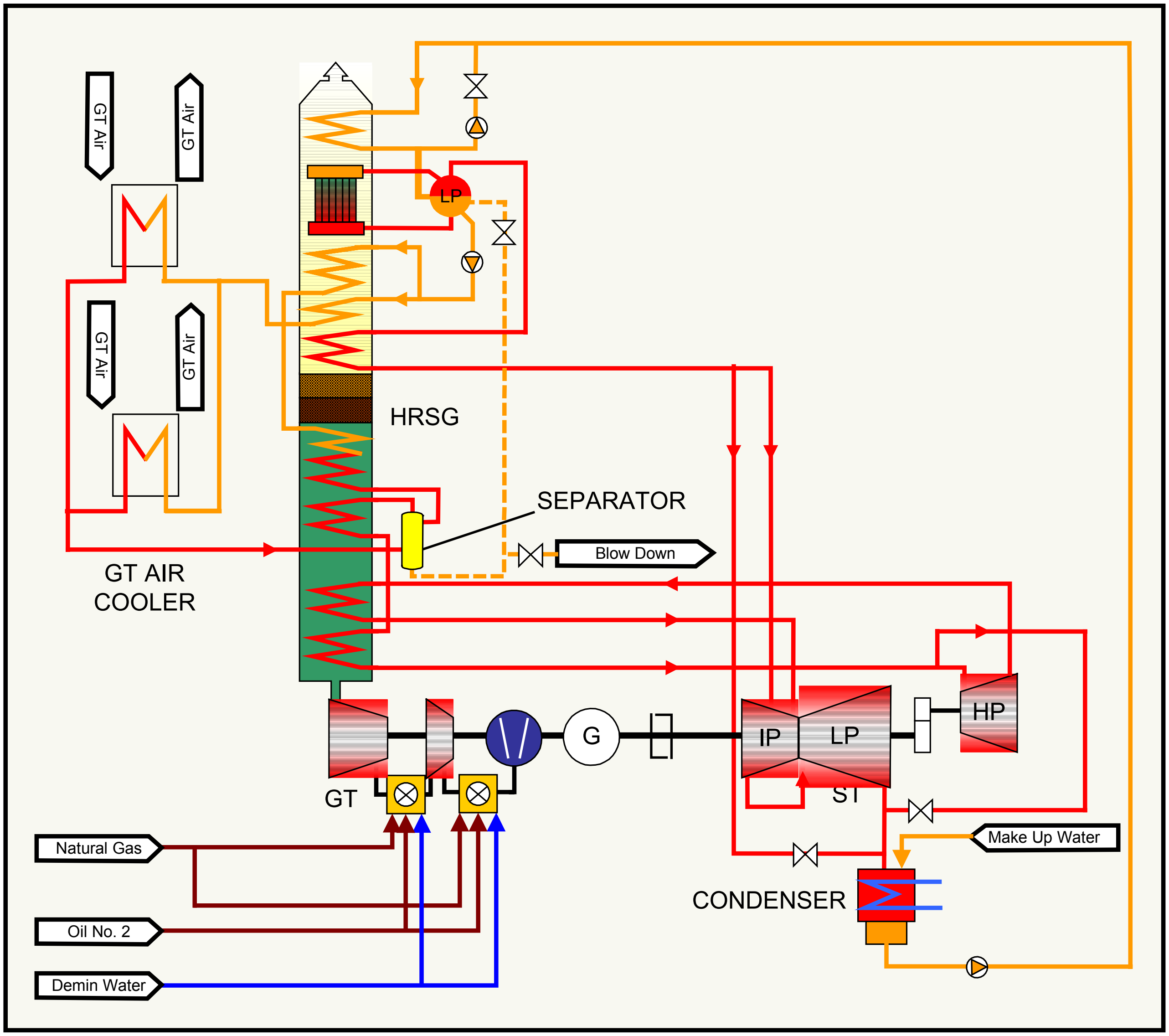

Figure 4: Steam Cycle Schematic for the Combined Cycle Power Plant.

At the maximum continuous rating (MCR), the HRSG is designed to provide a superheat outlet steam flow of approximately 60 kg/s at 565 °C and 165 bar. The design reheat steam flow is approximately 59 kg/s at 563 °C and 36 bar, while the low pressure steam flow is approximately 12 kg/s at 322 °C and 7 bar.

A tentative model of the gas turbine portion of the combined cycle plant, as constructed by AP for use with Aspen Plus® library modules, is shown in Figure 5. A preliminary model of the steam cycle is shown in Figure 6. In actuality, both models are tightly coupled and are combined together to form a single model within Aspen Plus ®; they were separated in Figures 5 and 6 simply for illustrative purposes.

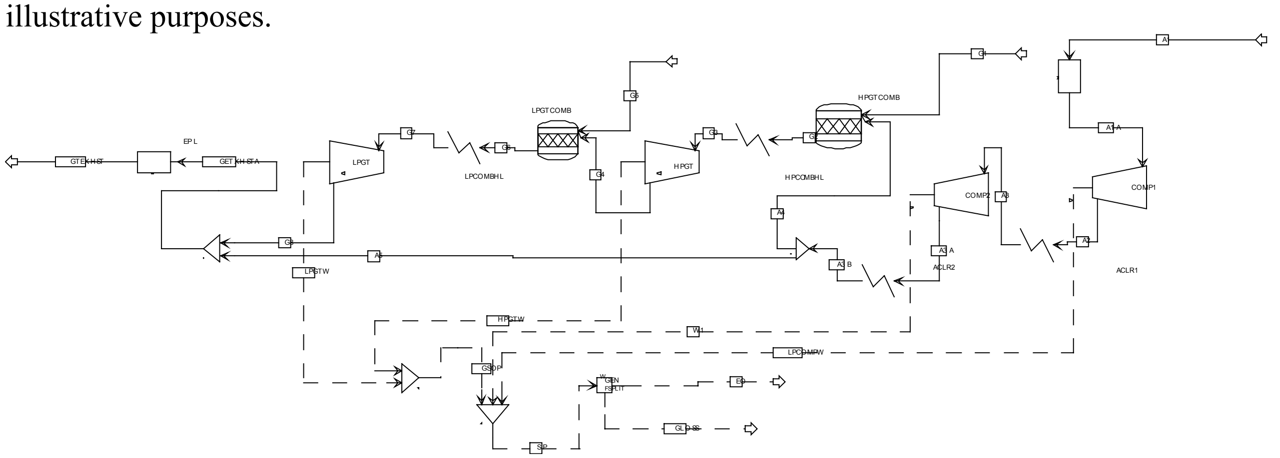

Figure 5: Aspen Plus® Gas Turbine Model for Combined Cycle Plant.

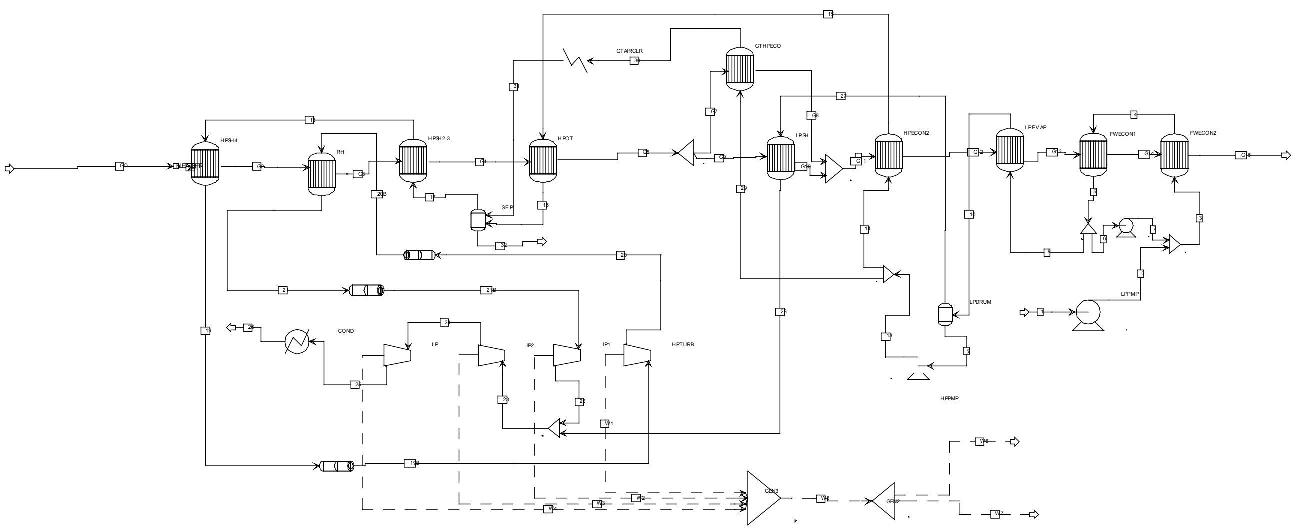

Figure 6: Aspen Plus® Steam Cycle Model for Combined Cycle Plant.

4.0 DISCUSSION ON ADEQUACY OF THE UNIT SELECTED TO BE CASE 2

As stated previously, Demonstration Case 2 was required to be an example of an advanced power generation cycle, of sufficient simplicity that it could be used to test the initial feasibility of using CFD and other methods in concert with a process model like Aspen Plus®. The adequacy of the case and the available experimental data must be judged within the context of the subsequent work scope and on the basis of (a) the quality and quantity of the board data, and (b) the compatibility of the case with the software tools.

The subsequent work scope involving Case 2 envisions various demonstrations of viability. An initial (baseline) run will be completed with the existing component libraries in Aspen Plus® to determine cycle performance and the sensitivity of the components to cycle performance. This effort has been initiated (i.e., a preliminary model was provided in Figures 5 and 6). The library module for the tube bank and HRSG components in the Aspen Plus® cycle will then be replaced by a more sophisticated software package for HRSG design. Software protocols using the Cape Open (CO) interface and wrapper will be developed which will enable this linkage. At a minimum, the HRSG will be modeled using an existing AP proprietary design package code (HRSGSIM), and subsequently modeled using the FLUENT™ CFD code. AP will simulate the steam cycle at various loads (e.g., to simulate power demand changes from 100% to 50%), using plant information for the initial calibration and subsequent predictive comparisons. Predictions will be used to visualize process changes and detailed boiler component performance.

As the combined cycle power plant selected for this study is recent ALSTOM Power technology, the quantity of available plant data is quite large. The plant was well instrumented and the current control and data acquisition systems allow for much of the plant data to be monitored by ALSTOM personnel online at the Windsor site through internet technology. Such data will be accessed as required to calibrate the flowsheet simulation.

The combined cycle power plant selected for Case 2 also has been simulated across the load range using the ALSTOM proprietary HRSGSIM code. The models have been developed and calibrated to provide good agreement between the model predictions and the available plant data. Some work will be required, however, to develop the interface between the Aspen Plus® and the HRSGSIM codes. AP believes that there will not be any "show-stoppers" associated with its HRSGSIM design package and that a demonstration of the linkage between Aspen Plus® and such design packages should be viable.

The selected combined cycle unit is anticipated to be amenable to CFD modeling efforts with the FLUENT™ code, and to efforts to couple a CFD HRSG model with Aspen Plus® in cycle simulations of that same unit. Note that the gas turbine will not be modeled with CFD. Estimated and / or measured changes in gas turbine exhaust conditions as a function of turbine load will be used as input to the CFD model of the HRSG. Since only a qualitative representation of the computational domain is required to demonstrate proof of concept and viability of the "virtual simulation software," a rather coarse (CFD) grid will be used to model the domain.

5.0 CONCLUSIONS

Based on the information provided in the preceding sections, the following conclusions may be drawn:

- The combined cycle unit selected offers significant quantities of relevant data on a high efficiency plant built with the latest in power generation technology.

- The quality of the available data from the selected unit is deemed to be sufficient for constructing a cycle and the component boiler models. Appropriate assumptions and adaptations can be made that will permit the unit to be simulated successfully both with an AP design package and with CFD.

- Overall, the combined cycle plant selected is judged to be an adequate and a reasonable unit with which to demonstrate "virtual simulation" feasibility and it is recommended as Demonstration Case 2.

6.0 REFERENCES

1. "Project Management Plan, Development of Technologies and Analytical Capabilities for Vision 21 Energy Plants, Cooperative Agreement No. DE-FC26-00NT40954", for Diane Madden USDOE-NETL, compiled by M. Syamlal, representing team entities: Fluent Inc., ALSTOM Power, Aspen Technology Inc., Intergraph Corporation, and Concurrent Engineering Research Center (West Virginia University), January 23, 2001