Proceedings of the ASME Turbo Expo 2009: Power for Land, Sea and Air
GT2009
June 8-12, 2009, Orlando, Florida, USA

GT2009-59105

ADVANCED HYDROGEN TURBINE DEVELOPMENT UPDATE

Tim Bradley
Siemens Energy
Orlando, FL, USA

Joseph Fadok
Siemens Energy
Orlando, FL, USA

ABSTRACT

Siemens Energy, Inc. was awarded a contract by the U.S. Department of Energy for the first two phases of the Advanced Hydrogen Turbine Development Program. The 3-phase, multi-year program goals are to develop an advanced syngas, hydrogen and natural gas fired gas turbine fully integrated into coal-based Integrated Gasification Combined Cycle (IGCC) plants. The program goal is to demonstrate by 2010 a 2-3% point improvement in combined cycle efficiency above the baseline, 20-30% reduction in combined cycle capital cost and emissions of 2 ppm NOx @ 15% O2. The 2012 goal is for IGCC-based power with carbon capture. Furthermore, by 2015, the goal is to demonstrate a 3-5% point improvement in combined cycle efficiency above the baseline, and 2 ppm NOx @ 15% O2.

Recent activities have focused on the initiation of Phase 2. This included developing component level technologies and systems required to meet the 2010 and 2015 project objectives, developing validation test plans for systems and components, performing validation testing of component technologies, and demonstrating through system studies the ability to attain the 2010 and 2015 Turbine Program performance goals. The development effort was focused on engine cycles, combustion technology development and testing, turbine aerodynamics/cooling, modular component technology, materials/coatings technologies and engine system integration/flexibility considerations. The first series of oxidation and coating compatibility testing of modified superalloys was completed. High pressure combustion testing was performed with syngas fuels on a modified premixed combustor. High pressure testing of a second premixed combustion system was also performed. Novel turbine airfoil concept testing continued. Conceptual design reviews and risk analyses were carried out on new gas turbine components. Studies were conducted on gas turbine/IGCC plant integration, fuel dilution effects, varying air integration, plant performance and plant emissions. The results of these studies and developments provide a firm platform for completing the advanced Hydrogen Turbine technologies development in Phase 2.

INTRODUCTION

In October, 2005, Siemens Energy, Inc. was awarded a contract by the Department of Energy (DOE) office of Fossil Energy for the Advanced Hydrogen Turbine Development Program Phases 1 and 2. The Siemens program is part of a multi project, $130 million investment of government money in turbine related technology to promote IGCC power systems that capture CO_2 and minimize emissions [1]. Phase 1 was successfully completed in September 2007 and Siemens is now focusing on the Phase 2 deliverables.

The DOE Advanced Power Systems overall program goal is to demonstrate by 2010 a 2-3% point improvement in combined cycle efficiency above the baseline, 20-30% reduction in combined cycle capital cost and emissions of 2 ppm NOx @ 15% O_2. The 2012 goal is for IGCC-based power with carbon capture. Furthermore, by 2015, the goal is to demonstrate a 3-5% point improvement in combined cycle efficiency above the baseline, and 2 ppm NOx @ 15% O2. The two phase, multi year, program will develop an advanced Hydrogen Turbine building from the successful SGT6-6000G technology [2][3][4]. Phase 1 was completed in September 2007, activities focused on identifying the required technologies, preparing technology development plans, carrying out cycle optimization

This paper was written with the support of the U.S. Department of Energy under Contract No. DE-FC26-05NT42644. The Government reserves for itself and others acting on its behalf a royalty-free nonexclusive, irrevocable, worldwide license for Governmental purposes to publish, distribute, translate, duplicate, exhibit and perform this copyrighted paper.

© Copyright 2008 by Siemens Energy, Inc
All Rights Reserved.

studies, risk assessment, estimating plant cost and developing component conceptual designs. Phase 2 started in October 2007 and includes developing component level technologies and systems required to meet the 2010 and 2015 project objectives, developing validation test plans for systems and components, performing validation testing of component technologies, and demonstrating through system studies the ability to attain the 2010 and 2015 Turbine Program performance goals. The development effort thus far has focused on engine cycles, combustion technology development and testing, turbine aerodynamics/cooling, modular component technology, materials/coatings technologies and engine system integration/flexibility considerations. In Phase 3, if awarded, the advanced gas turbine will be manufactured and installed in an IGCC plant for validation and testing to demonstrate the project's commercial viability and that the DOE program goals have been achieved [8].

Because of the aggressive nature of the goals set forth from the DOE, Siemens has proposed a two step approach to meeting the DOE intermediate and long term performance goals (see Figure 1). The baseline for the development is the SGT6-5000F engine in a 2x1 configuration with an estimated performance of 39.5% HHV on syngas [8]. To implement this program plan and bring it to a successful conclusion, a team of Siemens engineers, outside partners and multiple Universities has been formed. Additionally, two needs assessment surveys were conducted to ensure that top customer, DOE and Siemens priorities are integrated into the Hydrogen Turbine Development and to provide accurate industry driven direction [5].

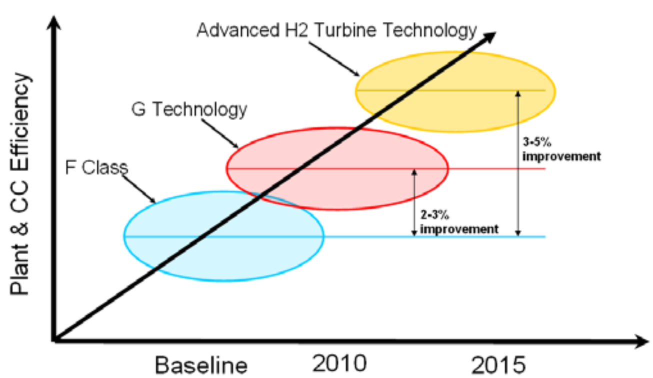

Figure 1 Proposed 2 Step Approach to Meeting the DOE Efficiency Goals

ADVANCED TECHNOLOGIES DEVELOPMENT

Compressor

Starting from today's advanced compressor design, stages were added to the rear of the compressor to reach the targeted pressure ratio determined from Phase 1 studies [6]. Preliminary airfoils have been designed and these airfoils were analyzed using 3D Computational Fluid Dynamics (CFD) to give an estimate of the compressor efficiency of the high pressure ratio compressor using today's design philosophy. The preliminary airfoil designs created for a high pressure ratio compressor with the targeted mass flow have been analyzed in a whole compressor 3D CFD analysis. For the initial analysis, the tip clearances of the rear stage airfoils were assumed to be unchanged from the baseline. The results from the analysis showed that the higher pressure ratio compressor, at the same technology level, would have a lower efficiency. The tip clearance of the airfoils was then adjusted and further analyses were carried out to assess the impact of tip clearance changes on compressor efficiency see Figure 2. The resulting analysis sets aggressive goals for compressor clearances in addition to the planned aerodynamic improvements.

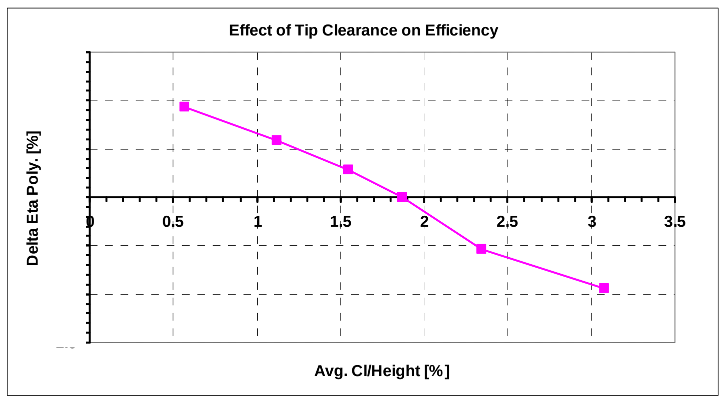

Figure 2 Effect of Tip Clearances on Efficiency

Additional modeling studies included determining the effect of varying integration level (air bled from the compressor for plant use). To simulate changing integration levels during operation, the compressor mass flow was varied while maintaining a constant pressure ratio. This resulted in a significant change to the compressor operating line and hence the available surge margin (see Figure 3). Going from low flow to high flow increases the surge margin, but the lower operating line results in a less efficient compressor. Going from high flow to low flow causes a decrease in surge margin. The model used in the calculations also assumed the tip clearances from the baseline compressor. Again, tip clearances

This paper was written with the support of the U.S. Department of Energy under Contract No. DE-FC26-05NT42644. The Government reserves for itself and others acting on its behalf a royalty-free nonexclusive, irrevocable, worldwide license for Governmental purposes to publish, distribute, translate, duplicate, exhibit and perform this copyrighted paper.

© Copyright 2008 by Siemens Energy, Inc
All Rights Reserved.

were varied and it was found that an increase in clearances resulted in reduced surge margin, which if too severe, would require an additional stage.

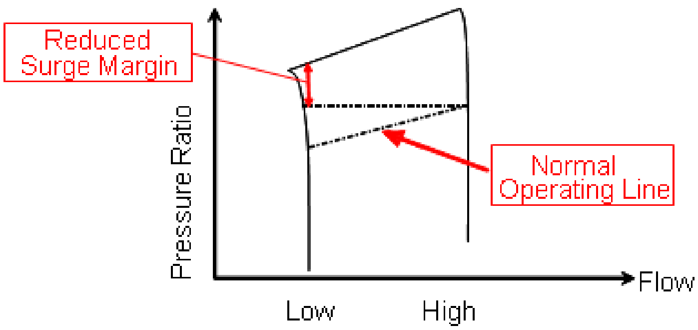

Figure 3 Surge Margin Variation with Compressor Design Mass Flow

Combustor

Four combustion system concepts were investigated during Phase 1, and several configurations were explored to further develop the most promising concepts and help in down selection at the end of Phase 1.

Figure 4 shows the photograph of the high pressure combustion test rig and two of the combustor nozzle configurations tested. The diffusion flame combustor was tested up to G-Class firing temperature (over 1500°C [2732°F] Turbine Inlet Temperature) on syngas and hydrogen fuels. These tests showed that this concept could operate on high hydrogen content fuels with dilution and produce <15ppm NOx [7]. However, to achieve the ultra low NOx target required by this program, while reducing dilution, other approaches were pursued. The first iteration premix combustor tested on syngas and hydrogen fuels at elevated temperatures also showed good potential with H_2 content up to approximately 60%. Data analysis from the premix test resulted in an improved premix nozzle to reach higher H_2 content and also improve operability.

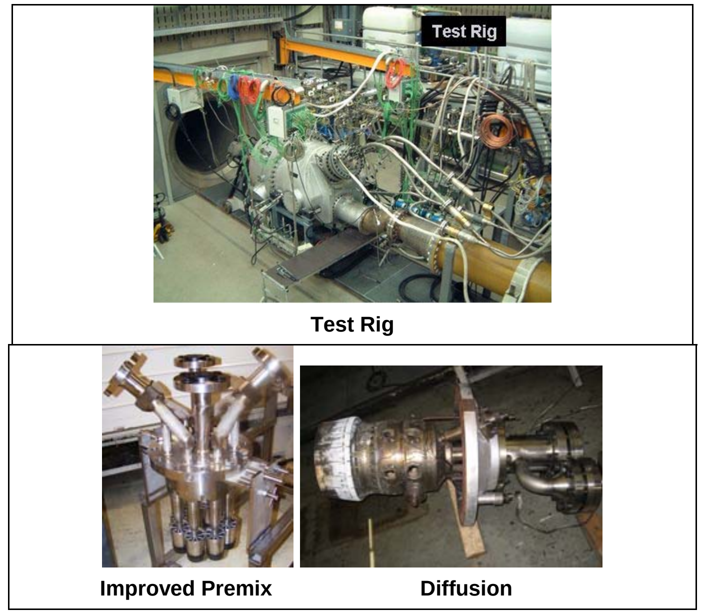

Figure 4 Photograph of High Pressure Test Rig and Combustion Nozzle Configurations

Initial CFD calculations of an advanced combustion system concept showed that low NOx emissions could be achieved at flame temperature above the capabilities of state of the art premix designs. As proof of the concept, a prototype full scale high pressure test was conducted. The concept, which was tested on methane and hydrogen fuels at elevated temperatures achieved promising results (see Figure 5). These results were used to enhance the system design for further testing in support of a down selection of two combustors and the end of Phase 1. A final down selection resulted in two premix concepts for further development in Phase 2.

This paper was written with the support of the U.S. Department of Energy under Contract No. DE-FC26-05NT42644. The Government reserves for itself and others acting on its behalf a royalty-free nonexclusive, irrevocable, worldwide license for Governmental purposes to publish, distribute, translate, duplicate, exhibit and perform this copyrighted paper.

© Copyright 2008 by Siemens Energy, Inc
All Rights Reserved.

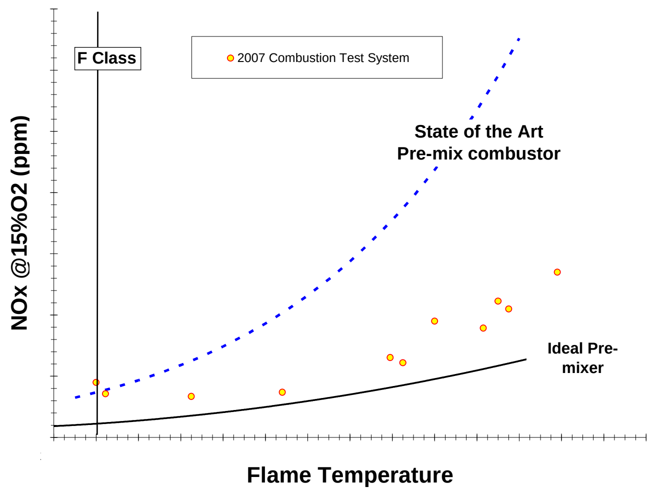

Figure 5 Results for Advanced Combustion System Concept

Preliminary design work and prototype testing were performed on each to evaluate the potential of meeting the program goals when operating on syngas and hydrogen fuels. Verification testing on simulated syngas fuel on the improved premix syngas design was performed at the Siemens high pressure combustion test facility. Fuel transfer strategy from natural gas to syngas was successfully demonstrated, and stable operation was achieved with 100% syngas in all stages above F-Class firing temperatures.

Testing continued at collaborating universities on flame speed and syngas kinetics. Georgia Institute of Technology performed initial turbulent flame speed tests at atmospheric pressure, for mixtures of CO and hydrogen at up to 50% hydrogen, to check out the measurement system. These results showed an impact of fuel composition on the turbulent flame speed even at very high levels of turbulence intensity. Georgia Tech has developed a rig for measurement of turbulent flame speed of syngas mixtures at elevated pressures and future testing will focus on elevated conditions. The laminar flame speed and ignition delay test data obtained from Princeton University, in Phase 1, are being used to develop improved chemical kinetic models for use in combustor design. The latest data are being incorporated into the detailed kinetic mechanism for methane, hydrogen and syngas and reduced kinetic mechanisms have been received for two different syngas mixtures. These data are being used to develop a simplified global mechanism for syngas and hydrogen for use in CFD calculations.

Turbine

Aerodynamics

A major study, recently completed by Siemens, addressed the increased turbine mass flow resulting from low heat content syngas combustion and possible low air integrated levels. The increased mass flow results in elevated Mach numbers in the flow path and reduced efficiency. Increasing the turbine annulus height overcomes this challenge, but increases loads exerted on the turbine discs. This is especially critical on the last stage blade which is already near its limiting height from both disc load and flutter considerations [6]. Several different annulus height increases (see Figure 6) were considered and their impact on aerodynamic performance, cooling design, stresses and manufacturability was assessed. The four different outer annulus configurations included the baseline (black line on Figure 6), minor height increase in rear stages (red line), small height increase in the first three stages and a large increase in the fourth stage (green line) and finally a significant height increase over the whole turbine annulus (blue line). The last configuration showed a significant improvement in turbine efficiency compared to the baseline. Extensive studies carried out on the variant concluded that a large increase in annulus height, especially in the last row blade, was feasible from mechanical integrity, vibration, manufacturing and life cycle cost basis. The influence of increased mass flow and annulus height on turbine efficiency is shown in Figure 7. The red line shows the change in turbine efficiency with increase in turbine exit flow for the baseline configuration and the green line represents the variation for the increased annulus design (blue line on Figure 6).

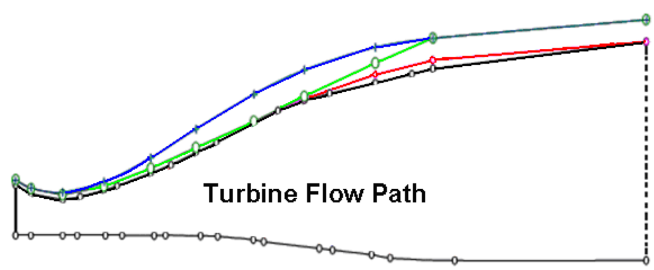

Figure 6 Increased Height Turbine Annulus

This paper was written with the support of the U.S. Department of Energy under Contract No. DE-FC26-05NT42644. The Government reserves for itself and others acting on its behalf a royalty-free nonexclusive, irrevocable, worldwide license for Governmental purposes to publish, distribute, translate, duplicate, exhibit and perform this copyrighted paper.

© Copyright 2008 by Siemens Energy, Inc
All Rights Reserved.

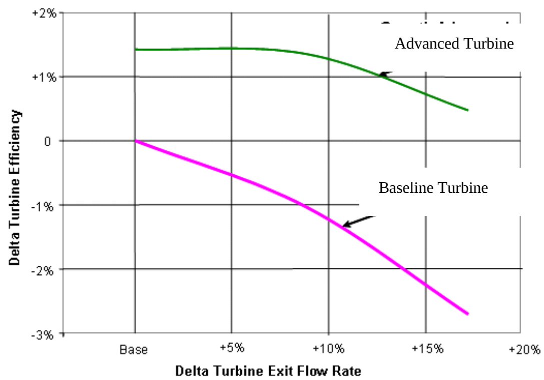

Figure 7 Impact of Turbine Flow Rate on Efficiency

The turbine throughflow model was updated based on the latest flow path geometry and boundary flow conditions. The potential variations in airfoil and platform gas temperatures were evaluated by iterating on the throughflow model with various inlet radial temperature profiles. In Phase 1, the conceptual turbine design concluded that highly loaded turbine airfoils are desirable for optimal overall turbine efficiency. An aerodynamic cascade test is required to verify the performance of these airfoil shapes. In preparation for these tests, facility requirements were specified and various airfoil geometries were selected.

Novel Cooling Concepts Development

In order to maximize efficiency, very aggressive cooling airflow targets have been established for the Hydrogen Turbine. Novel high effectiveness cooling concepts are being developed to ensure that these targets are met in the final design. A number of potential advanced cooling schemes have been proposed, but in many cases correlations do not exist that would enable design with these concepts. In order to develop correlations for advanced internal cooling features, the most promising concepts were identified and test programs were initiated in collaboration with major Universities. These universities have state-of-the–art test facilities and the ability to conduct rotational blade heat transfer tests. The overall test program objective is to study heat transfer and pressure losses in representative leading edge and trailing edge flow passages in the internal cores and tip geometry of an advanced first stage blade. Models of selected cooling concepts have been fabricated, instrumented and installed. Heat transfer tests are in progress and test results are being extensively analyzed to produce enhanced heat transfer correlations which will be used in the advanced airfoil designs. These development efforts will result in designs with minimized cooling airflows, maximized efficiencies, while maintaining and mechanical integrity.

Sealing

At high temperature and pressure ratio, increased leakage can become a serious performance penalty, especially in the turbine section. In addition, adverse hot gas mixing in the turbine disc cavities will severely impact the life and performance of the hot end parts. A sealing program was set up to address these major challenges. CFD and other modeling predictions of base line geometry were first performed to identify main parameters and features which influence sealing effectiveness. Then, numerous concepts were generated to improve the sealing efficiency. Through the use of quality functional deployment tools and in-house assessment techniques, a catalogue of concepts was created and ranked for further development. Feasibility studies of candidate geometries were conducted and concepts were selected for sub-scale testing. In addition, collaborative programs are in place with Universities to obtain performance information for sealing configurations and develop advanced sealing elements for potential implementation into the hydrogen turbine.

Materials and Coatings

High Temperature TBC (Thermal Barrier Coating) Development

Prime reliant, high temperature, low conductivity Thermal Barrier Coating (TBC) is mandatory for the Advanced Hydrogen Turbine. Figure 8 shows graphically the advancements required for TBC. The primary TBC function is to provide a low thermal conductivity barrier to impede heat transfer from the hot gas to the engine components. Two potential new ceramic compositions are being evaluated which have met the room temperature and elevated temperature thermal conductivity targets. Phase stability testing up to 1850°C, well above the targeted temperature, showed no phase transformation. Specimens are being tested under various thermal transients in the laser rig at NASA Glenn to determine the TBC failure mechanisms. The test conditions were selected using a Design of Experiments (DoE) approach. The experimental efforts have focused on two primary aspects: (1) an evaluation of the repeatability of the rig and (2) an assessment of the manufacturing process sensitivity of the TBC's using multiple specimens tested under similar conditions. The samples were tested to failure and the degradation mechanism associated with each test was identified.

This paper was written with the support of the U.S. Department of Energy under Contract No. DE-FC26-05NT42644. The Government reserves for itself and others acting on its behalf a royalty-free nonexclusive, irrevocable, worldwide license for Governmental purposes to publish, distribute, translate, duplicate, exhibit and perform this copyrighted paper.

© Copyright 2008 by Siemens Energy, Inc
All Rights Reserved.

Modified Superalloys

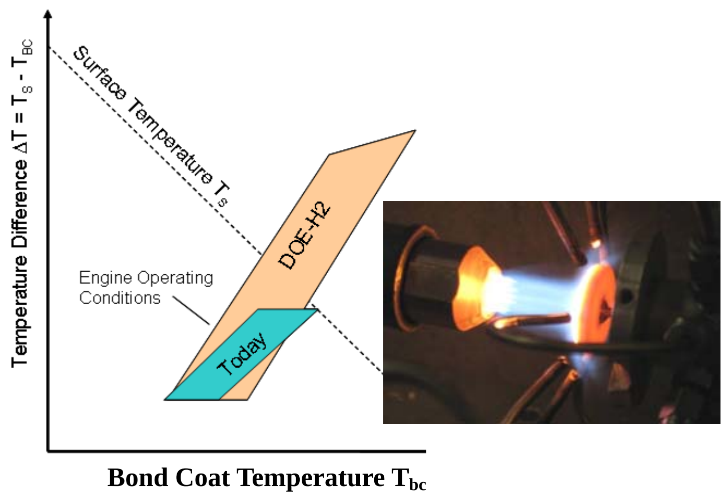

Figure 8 Increased TBC Temperature Capability

Advanced Bondcoat Development

The advanced bondcoat research and development effort has focused on increasing the bondcoat temperature limit. The methodology during FY2007 introduced multiple individual elemental additions for reducing oxidation kinetics. In FY2008, the focus continued these efforts with concentration on elemental additions with respect to interaction and combined benefit. Taking the best performing individual elemental additions and combining them in Design of Experiment (DoE) matrices to evaluate the beneficial effect of each element, both mechanism and concentration may be determined. Multiple alloys were used in both oxidation and TBC spallation studies to determine alloy contribution to changes in results. Testing is conducted at three prescribed temperatures to obtain short term, medium term, and long term results. At high temperature, one modified bondcoat demonstrated a 40% improvement in TBC spallation life, reference Figure 9.

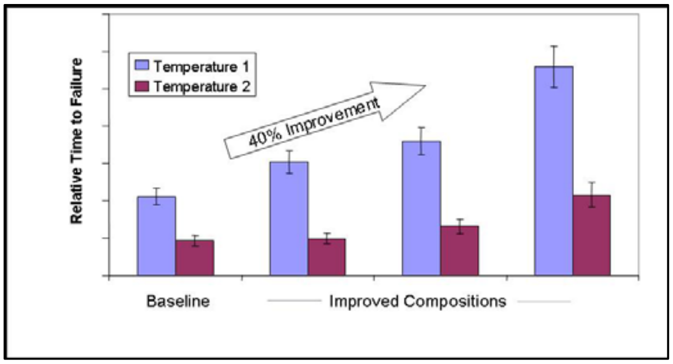

Figure 9 Modified Bondcoat Spallation Life

This project focuses on the additions of varying levels of elements to superalloys to increase the oxidation resistance and coating capabilities without degrading mechanical properties. The first phase of this project focused on rare earth additions to the baseline Alloy in fifteen varying compositions. Cyclic oxidation tests on each of the fifteen modified alloys plus an unmodified base alloy at three different temperatures have been completed. The trend developed through the testing showed that the base alloy oxidized more rapidly than the modified alloys. Six alloys have been down selected for further analysis with one of these modified alloys showing a 30% improvement in thermal barrier coating life compared to the baseline, see Figure 10. Samples of each alloy have been coated using standard production bond coats and TBC, and these samples are currently being cyclically exposed at three temperatures.

The down-selected alloys were also manufactured into creep and tensile specimens for mechanical testing. Tensile testing results showed no degradation of properties with the modified alloys. Creep and Low Cycle Fatigue (LCF) testing will be performed on specimens manufactured from the new alloys to complete the mechanical verification process.

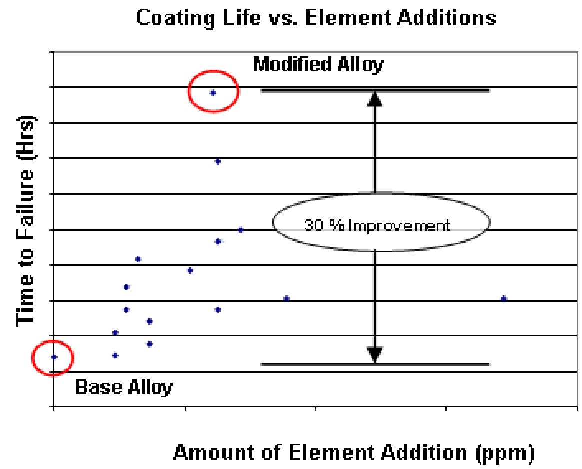

Figure 10 Improved Superalloy Thermal Bond Coat Life

Modular Airfoils

Initial manufacturing trials are underway for the most promising concepts which were selected from Phase 1 development activities. Modular airfoil design concepts which resolve the challenges of utilizing the next generation

This paper was written with the support of the U.S. Department of Energy under Contract No. DE-FC26-05NT42644. The Government reserves for itself and others acting on its behalf a royalty-free nonexclusive, irrevocable, worldwide license for Governmental purposes to publish, distribute, translate, duplicate, exhibit and perform this copyrighted paper.

© Copyright 2008 by Siemens Energy, Inc
All Rights Reserved.

superalloys, particularly low casting yields associated with large parts, are being manufactured with current geometries to determine feasibility and optimize joining technologies. In addition, fabrication methods are being explored on sub-scale level to develop components with a significant improvement over monolithic airfoil castings. Specifically, this concept will produce material systems that can operate at increased temperatures, while using less cooling air, reducing use of expensive alloys, thus reducing manufacturing and life cycle cost. Using this process, turbine vanes could be fabricated with different alloys for the airfoil and the end walls, or superalloy inserts can be employed in airfoil regions subjected to the highest gas temperatures. In another potential variation of the concept, intricate internal cooling features could be machined into the cast airfoil spar and then the outer skin, which could be made of a single crystal alloy, could be joined with the spar. Considerable progress has been made in this project though bonding trials and application of other advanced joining methods. The most promising concepts were subjected to further mechanical testing to ensure tensile, creep, and LCF capability were not compromised.

PLANT INTEGRATION

In the interest of evaluating future gas turbine developments as well as the impact of multiple variables in the overall plant performance, a high hydrogen baseline plant model was completed. The technology of all plant auxiliary systems such as the gasifier, water/gas shift, CO_2 compression, Low Temperature Gas Cooling (LTGC) and Air Separation Unit (ASU) have been fixed in order to isolate the effects of gas turbine and power block improvements for the 2010 and 2015 technologies. As instructed by DOE, the hydrogen baseline assumes a 90% capture, and thereby utilized a 2-stage CO shift and CO_2 compression to 152 Bar. The efficiency of the IGCC Plant was calculated for the baseline SGT6-5000F and the 2010 cases and showed that the DOE goals of 2-3 % points could be achieved. This major increase in overall plant efficiency is mainly due to increased GT efficiency as well as the higher exhaust temperatures that enable a more efficient bottoming cycle.

POWER BLOCK BASELINE COST ESTIMATE

Capital cost is in an important factor in determining the viability of IGCC application in the power industry and a major DOE project goal is to reduce the $/kW by 20-30%. Additionally, establishing the power block reference cost provides a basis for sensitivity studies for other major components of the gas turbine, auxiliaries, and balance of plant. A preliminary cost evaluation of the power block for the baseline syngas case has been performed.

The first step in determining the cost was to outline the scope of the estimate. The intent of the cost estimate for the baseline case is to provide a basis for comparison with the future 2010, and 2015 cases. The scope ensures that the cost estimates can be compared on a consistent basis. Once the scope was ascertained the cost information was gathered from in-house sources. The power block was divided into several sections as shown in Figure 11.

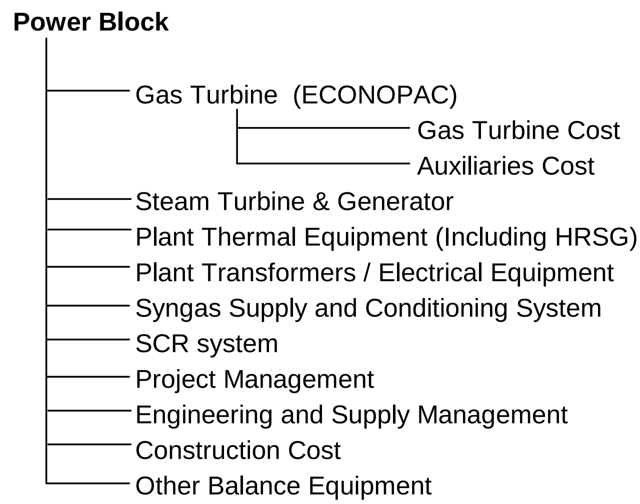

Figure 11 Overall Power Block Cost Breakdown

The estimating philosophy was to obtain current costs for major balance of plant components such as HRSG, Steam turbine and generator, thermal equipment auxiliaries, syngas conditioning and supply systems, plant electrical systems and the Selective Catalytic Reduction (SCR) system, and build up of components within the GT ECONOPAC®. A cost stack up for the GT ECONOPAC® systems was obtained from a detailed build up of Gas Turbine component costs and associated auxiliary cost. Current efforts include establishing an optimum design for the syngas system based on which auxiliary costs may vary marginally. Detailed cost data was gathered from established models to quantify cost trends in the gas turbine.

A preliminary baseline cost breakdown for an IGCC plant is presented in Figure 12. This figure shows the system/component cost as a percentage of the total cost. The power block is approximately 30-40% of the total IGCC cost and the gas turbine, which is the main focus of this development, represents only 5-10% of the total IGCC cost.

This paper was written with the support of the U.S. Department of Energy under Contract No. DE-FC26-05NT42644. The Government reserves for itself and others acting on its behalf a royalty-free nonexclusive, irrevocable, worldwide license for Governmental purposes to publish, distribute, translate, duplicate, exhibit and perform this copyrighted paper.

© Copyright 2008 by Siemens Energy, Inc
All Rights Reserved.

Although the turbine is only a small percentage of the total plant cost it has the greatest impact on capital cost. By increasing the output of the turbine the $/kW is reduced having an important direct effect on capital cost.

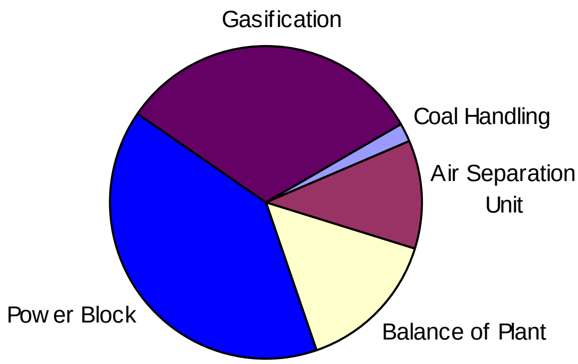

Figure 12 Power Plant Cost Breakdown

SUMMARY

Under the sponsorship of the US Department of Energy National Energy Technology Laboratories, Siemens Energy, Inc. is working on the Advanced Hydrogen Turbine Development Program to develop an advanced gas turbine for incorporation into future coal-based IGCC plants. Phase 1 of the project has been completed and significant progress has been made towards achieving DOE program goals. Combustion tests on four promising concepts produced encouraging results and allowed downselection to only two concepts for further development. Novel cooling concept tests gave a strong indication that the initially set cooling airflow targets are achievable. Coatings/materials development progressed sufficiently and showed good potential to produce advanced coatings, enhanced superalloy and modular airfoils in time for the Hydrogen Turbine manufacture. Conceptual component, gas turbine and plant designs were completed.

Although availability and efficiency are key attributes, the advanced Hydrogen Turbine must also be highly flexible in order to be adaptable to emerging IGCC technologies and fuels. The design is being optimized with built-in flexibility to accommodate different gasification and air separation technologies, gas turbine integration levels, carbon sequestration approaches, fuel types, diluent types and quantities, and operation duty cycles. This program is expected to provide significant benefits, such as the utilization of a secure and abundant energy source, reduced emissions and high technology infusion into current Siemens gas turbines.

ACKNOWLEDGMENTS

This material is based upon work supported by the Department of Energy, National Energy Technology Laboratory (NETL), under Award Number DE-FC26-ONT42644. This program is administered under the guidance of NETL Project Manager, Mr. Rondle Harp and NETL Turbine Technology Manager Mr. Rich Dennis.

The authors with to express their gratitude to the Team Leaders and Members for their dedicated work on this program and for preparing the Quarterly Progress Reports which provided information for this paper.

PERMISSION FOR USE

The content of this paper is copyrighted by Siemens Energy, Inc. and is licensed to ASME for publication and distribution only. Any inquiries regarding permission to use the content of this paper, in whole or in part, for any purpose must be addressed to Siemens Energy, Inc. directly.

REFERENCES

[1] National Energy Technical Publications News Release, September 8, 2005, "Tech Line: Enabling Technologies for Hydrogen Fuels, Turbine Program Advances Ultra-Clean, Coal-Based Systems".

[2] Southall, L. McQuiggan, G., 1995, "New 200 MW Class 501G Combustion Turbine", ASME Paper 95-GT-215.

[3] Banacalari, E., Diakunchak, I. S., McQuiggan, G., 2003, "A Review of W501G Engine Design, Development and Field Operating Experience", ASME Paper GT 2003-38843.

[4] Bancalari, E., Chan, P., 2005, "Adaptation of the SGT6-6000G to a Dynamic Power Generation Market", POWER-GEN International 2005.

[5] Bancalari, E., Chan, P., Diakunchak, I. S., 2006, "Advanced Hydrogen Turbine Development", 23rd International Pittsburgh Coal Conference, Pittsburgh, Pennsylvania.

[6] Bancalari, E. Chan, P., Diakunchak, I. S., 2007, "Advanced Hydrogen Turbine Development Program," AMSE Turbo Expo, Montreal, Canada.

[7] Wu, J., Brown, P., Diakunchak, I. S., Gulati, A., Lenze, M., Koestlin, B., 2007, "Advanced Gas Turbine Combustion System Development for High Hydrogen Syngas Fuels", ASME Paper GT2007-28337.

[8] Diakunchak, I. S., Fadok, J., 2008, "Advanced Hydrogen Turbine Development Update," Pittsburg Coal Conference.

This paper was written with the support of the U.S. Department of Energy under Contract No. DE-FC26-05NT42644. The Government reserves for itself and others acting on its behalf a royalty-free nonexclusive, irrevocable, worldwide license for Governmental purposes to publish, distribute, translate, duplicate, exhibit and perform this copyrighted paper.

© Copyright 2008 by Siemens Energy, Inc
All Rights Reserved.

ANNEX A

PUT ANNEX TITLE HERE

Put text of Annex here

This paper was written with the support of the U.S. Department of Energy under Contract No. DE-FC26-05NT42644. The Government reserves for itself and others acting on its behalf a royalty-free nonexclusive, irrevocable, worldwide license for Governmental purposes to publish, distribute, translate, duplicate, exhibit and perform this copyrighted paper.

© Copyright 2008 by Siemens Energy, Inc
All Rights Reserved.