ADVANCED HYDROGEN TURBINE DEVELOPMENT

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ABSTRACT

The Advanced Hydrogen Turbine Development Project objective is to design and develop a fuel flexible (coal derived hydrogen or syngas) advanced gas turbine for Integrated Gasification Combined Cycle (IGCC) and FutureGen type applications that meets the U.S. Department of Energy (DOE) turbine performance goals. The overall DOE Advanced Power System goal is to conduct the Research and Development necessary to produce CO_2 sequestration ready coal-based IGCC power systems with high efficiency (45-50% [HHV]), near zero emissions (< 2 ppm NOx @ 15% O_2) and competitive plant capital cost (< $1000/kW).

DOE has awarded Siemens Power Generation a contract for Phases 1 and 2 development work. Phase 1 activities will include identification of advanced technologies required to achieve the Project goals, detailed Research & Development Implementation Plan preparation and conceptual designs for the new gas turbine components. In Phase 2, the identified concepts/technologies will be down selected and a detailed design of the gas turbine will be completed. Phase 3, which has not yet been awarded, will involve the advanced gas turbine and IGCC plant construction and validation/demonstration testing. The end objective is to validate the advanced gas turbine technology by 2015. The starting point for this development effort is the SGT6-6000G gas turbine. This gas turbine will be adapted for operation on coal and biomass derived hydrogen and syngas fuels, as well as natural gas, while achieving high performance levels and reduced capital costs. This paper describes Phase 1 activities and accomplishments in the first 9 months since the program was initiated.

INTRODUCTION

In October, 2005, the U.S. Department of Energy (DOE) awarded Siemens Power Generation a multi-million dollar contract for Phases 1 and 2 of the Advanced Hydrogen Turbine Development Project. This work is the result of the solicitation from DOE's Office of Fossil Energy and addresses the long term energy development plans outlined in the FutureGen Report to Congress (see References 1 and 2). The DOE Advanced Power Systems goal is to conduct research and development necessary to produce CO_2 sequestration ready coal-based Integrated Gasification Combined Cycle (IGCC) power systems with high efficiency, near zero emissions and competitive capital cost (see Figure 1). These are very challenging goals when compared to the current IGCC plant performance, emissions and cost.

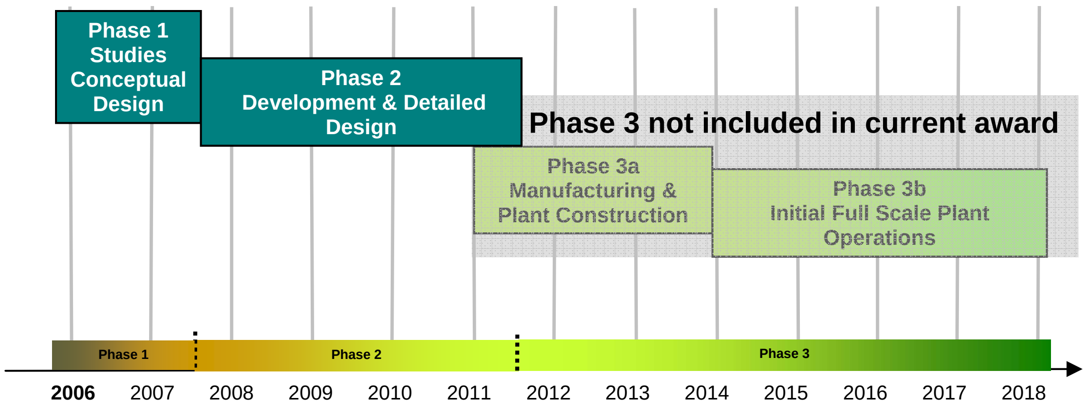

Figure 1. DOE Advanced Hydrogen Turbine Development Timeline

The main program thrust will be developing an advanced gas turbine that will operate in an IGCC plant on hydrogen and syngas fuels. In the current context of high natural gas and oil prices and concerns about availability, there is an urgent need for the United States to embark on an alternative fuels program to reduce dependence on imported oil and harmful emissions. Since the U.S. has more than a 250-year coal supply, this provides a great opportunity for achieving energy self-sufficiency. However, burning coal produces CO_2, which is exacerbating global warming. The solution is to convert coal into syngas, which can be processed to produce hydrogen fuel, which when burned in a gas turbine produces water as the primary emission. The underlying driver behind this DOE program is the urgent need for energy self-sufficiency and security, as well as the economic incentive to employ the abundant coal reserves in an efficient, environmentally safe and commercially viable way.

The two Phase, 6-year (with future extension to three Phase, 10-year) program will develop a Hydrogen Turbine based on the SGT6-6000G gas turbine. This gas turbine was selected as the starting point due to its high firing temperature, output power and efficiency, as well as its advanced secondary air and steam cooling systems (see References 3 to 7). Phase 1 activities focus on developing conceptual designs for the gas turbine components and plant, conducting cycle optimization studies, preparing technology development plans, producing preliminary cost estimates and initializing R&D activities. A major deliverable was the Research & Development Implementation Plan describing in detail the Siemens approach to developing the Advanced Hydrogen Turbine for integration in a coal-based IGCC plant. This Plan was submitted to DOE in March, 2006. Phase 2 will include validating and down selecting advanced technologies critical to the Research & Development Implementation Plan through component and system testing, detailed engineering and design studies, engine component detailed designs, cycle and plant performance estimations, gas turbine and plant cost estimations and IGCC plant economic evaluations. Phase 3, if awarded, would entail the advanced gas turbine manufacture, its installation in FutureGen type IGCC plant and validation testing to demonstrate that all DOE program goals have been achieved.

To ensure that the very challenging program goals are achieved, a structured technology roadmap was produced to focus effort on GT-IGCC plant optimization and new or enhanced technologies development. In order to provide applicational and operational flexibility, the gas turbine will be designed to operate with various gasifier and ASU systems, while achieving the efficiency goal. Auxiliaries cost optimization and plant integration studies will be carried out to reach the capital cost target.

Siemens has considerable experience with its small and large frame gas turbines operating on syngas and high hydrogen fuels, as well as large frames operating on syngas in IGCC plants in both the U.S. and Europe (see References 8 to 12). The lessons learned from large gas turbines operation in prior and current IGCC plants will provide a solid foundation for developing an advanced gas turbine for incorporation into future IGCC plants. To take advantage of the abundant, low cost and secure U.S. coal supply, the SGT6-5000F has been adapted for incorporation into an IGCC plant and is now being offered commercially (see References 13 and 14). Also, Siemens has previous successful experience in conducting other large programs, both internal and DOE co-funded (see References 15 and 16). To ensure that the project plan is implemented and brought to a successful conclusion in the shortest time and within budget, a team of Siemens engineers and outside partners has been formed, see table 1.

Participants	**Participant Function**
Siemens Power Generation	Overall Program Execution
Florida Turbine Technology	Support Turbine Component Design Plant Performance Calculations
ConocoPhillips	Gasification Technology
Air Products & Chemicals	Air Separation Technology
Nooter Eriksen	HRSG Technology
Combustion Science & Engineering	Support Combustion Modeling
ENEL or DLR	Combustion Testing
Parker Hannifin	Combustion Hardware for Testing
MECO	Combustion Hardware for Testing
Texas A&M University	Support for Advanced Heat Transfer Technology
University of Central Florida	Advanced Cooling / Coatings Technology Testing
University of Florida	Support for Material Development/Testing
Princeton University	Combustion Modeling
Georgia Tech University	Combustion Modeling
Honeywell International	Hydrogen Embrittlement Material Testing
Engelhard	Coating Deposition Trials

Table 1. Project Participants and Major Functions.

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HYDROGEN TURBINE DEVELOPMENT ROADMAP

Utilizing the abundant coal reserve available in the United States is a necessity to secure energy independence and provide a low cost energy source that is secure from supply interruptions. IGCC is expected to play an important role in utilizing this vast coal resource in an efficient and environmentally safe manner. Today's industrial gas turbines are optimized for operation on natural gas. The largest gas turbine engines with highest efficiency, lowest emissions and lowest operating cost, such as the SGT6-6000G, are not currently designed to operate on either syngas or hydrogen fuels. The advanced G-class gas turbine will, however, be necessary to achieve the full potential of advanced gasification technology. The advanced gas turbine will be developed to operate on syngas and hydrogen fuels. Hydrogen is the preferred fuel from an emissions point of view since it produces only water and nitrogen. Siemens, in cooperation with the US Department of Energy, is undertaking the Advanced Hydrogen Turbine Development Project to develop an advanced fuel flexible gas turbine which when integrated with the advanced gasifier/air separation unit in an IGCC plant will achieve high efficiency, near zero NOx emissions and a commercially competitive capital cost.

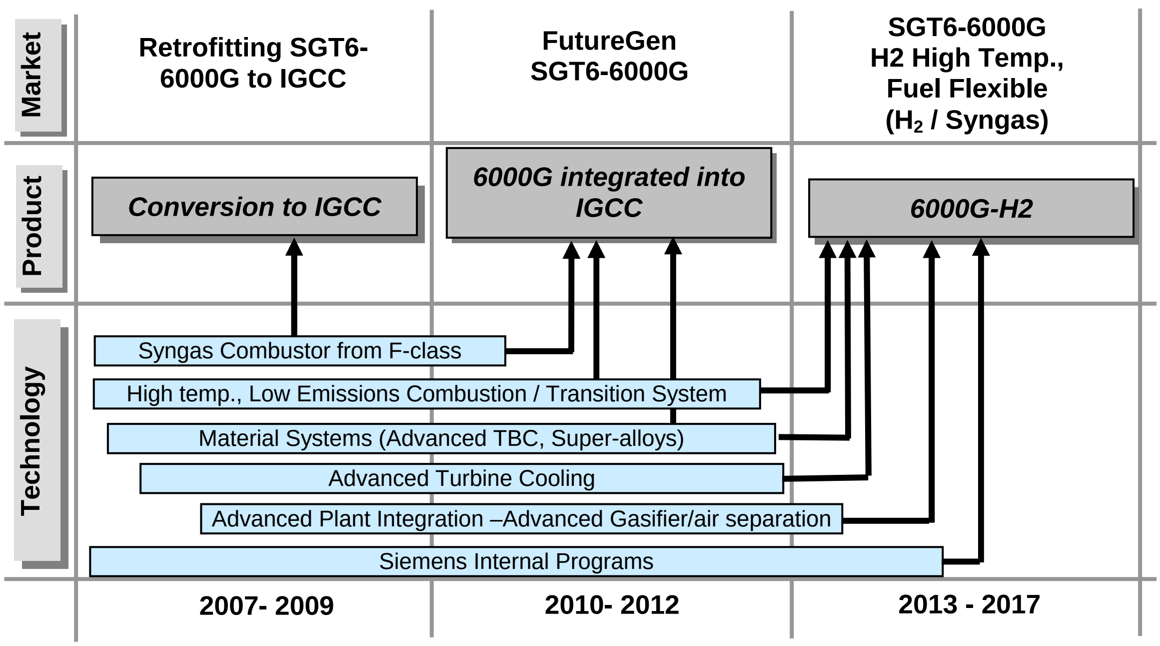

Figure 2. Hydrogen Turbine Potential Development Roadmap

Siemens has developed an overall program strategy and approach that supports the DOE Program goals and future commercialization. Figure 2 outlines the technology development roadmap and shows how the various plan aspects integrate in achieving the final goal. The path forward outlined in the roadmap shows three Scenarios that represent three time frames. Shown are the target markets, what Siemens turbine products are needed to support these markets and the key technology developments expected to occur over this time frame. The gas turbine technology evolves from current F-Class engines that are modified to operate in current IGCC application. In Scenario 1 (2007/2009 time frame), the F-Class syngas combustor will be adapted to the current G-

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Class engine, possibly in a retrofit application. Partial integration with the gasifier and air separation systems is expected. This engine technology is expected to serve the near term emerging IGCC market with minimal risk and provide valuable operating experience that will also benefit ongoing developments.

In the roadmap interim step (2010/2012), technology developments are inserted to improve gas turbine performance that will be necessary to meet market demands. These technologies will evolve from ongoing Siemens R&D programs, the Siemens/DOE Advanced Hydrogen Turbine project and other synergistic technology programs. These interim technology upgrades will result in improved gas turbine engine performance, enhanced operational/integration flexibility, reduced capital cost on a $/KW basis and the ability to operate on hydrogen fuel.

In Step 3 (2013/2017 time frame), the Siemens/DOE Hydrogen Turbine technology program will have been completed (through Phase 2, 2011) resulting in a detailed engine design that meet the ambitious performance and economic DOE targets. The objective is to achieve a fuel flexible (hydrogen/syngas), high performance gas turbine engine (SGT6-6000G-H2) that can be integrated with an advanced gasification system and achieve the program performance and emission goals. The Siemens/DOE Advanced Hydrogen Turbine Development project is focused on developing and validating the technology needed to achieve this goal.

The Siemens Hydrogen Turbine Development Project is closely integrated with the DOE FutureGen program. The DOE FutureGen Plant (being developed through a consortium involving countries such as US, Australia, China, India and South Korea) is scheduled for start-up in the 2011/2012 time frame. The technologies being developed in the Siemens/DOE Advanced Hydrogen Turbine Development project in the Phase 2 time frame will be evaluated for application in the DOE FutureGen plant. Several opportunities for technology insertion will develop based on final schedules and technology progress. In this way technology developed in the Hydrogen Turbine Program will directly benefit the FutureGen project.

IGCC PLANT DEVELOPMENT

Current conventional IGCC plants have high capital costs (>$1800 $/kW) and relatively low plant efficiencies (around 40%, fueled by syngas and without CO_2 sequestration penalty). The gasifier island equipment drives plant capital cost while the gas turbine combined cycle will drive plant efficiency. Gas turbines used in today's IGCCs are de-rated which results in a diminished efficiency. A significant interplay exists between the gas turbine and IGCC plant equipment. The IGCC plant size is based on the gas turbine fuel flow requirements. The higher the gas turbine fuel flow, the larger the IGCC plant (more fuel flow, larger gasifier and ASU equipment). Although efficiency plays a greater role, GT size (G-class vs F-class) brings in economy of scale. Thus for the same efficiency level, the larger the GT the better from capital cost considerations. Gas Turbine efficiency is the key parameter in minimizing the cost of electricity and developing the most commercially competitive IGCC plant when compared with currently available technology, since it reduces fuel consumption for a given power output, thus minimizing plant size and cost.

Design of Experiments process (described below) was employed to determine the engine parameters to be investigated in order to achieve the optimum advanced gas turbine integration into the IGCC plant. The starting point for this development was the state-of-the-art (SOTA) IGCC plant utilizing a 2x1 combined cycle power plant incorporating two syngas capable SGT6-5000F (formerly W501F) gas turbines and generator packages, each coupled to a non-duct fired heat recovery steam generator (HRSG). Steam generated in the HRSGs powers the two-case reheat steam turbine with double flow low pressure turbine and high efficiency blading design. The two gas turbines are integrated with an ASU, which supplies 95% pure oxygen and the oxygen-blown, Partial Slurry Quench, 2-stage entrained flow gasifier.

Starting with the SOTA plant, a baseline model with IGCC plant thermal performance on syngas fuel was generated. The baseline SCC6-6000G 2x1 LCG (Low Calorific Gas) model consists of multiple train entrained flow 2-stage gasifier operating in Partial Slurry Quench mode, conventional cold gas clean-up systems, cryogenic ASU equipment, 2 syngas fired SGT6-6000G (W501G) engines equipped with inlet air evaporative cooling and compressed air extraction for ASU supply, 2 triple-pressure reheat HRSGs with kettle boilers for GT cooling air heat recovery, an HP/IP – LP (KN) steam turbine and wet condenser and cooling tower heat rejection system.

Although the high efficiency, high output power of the SGT6-6000G engine will result in significant improvement in IGCC plant efficiency and net power, initial thermal cycle studies indicated that increased GT firing temperature and pressure ratio will be required to meet the DOE program performance and cost goals. Based on these studies, a preliminary design point was selected for the GT conceptual design and technology development.

In the preliminary studies, both cryogenic and ion transport membrane (ITM) ASU technologies were investigated. ITM ASU technology has the potential for increased IGCC plant efficiency and reduced capital cost. However, ITM-GT integration poses some concerns and challenges. An investigation was conducted to identify these concerns and to formulate their resolution plans. The GT casing will require additional attachments and high temperature piping. The piping will require high temperature capable materials. High temperature return air will cause difficulties in cooling the combustor and transitions, as will as increase flashback and auto-ignition risks. The plant design and sizing will be significantly impacted by the ASU technology choice.

Figure 3 shows the process block diagram for the advanced Hydrogen Turbine integrated into an IGCC plant.

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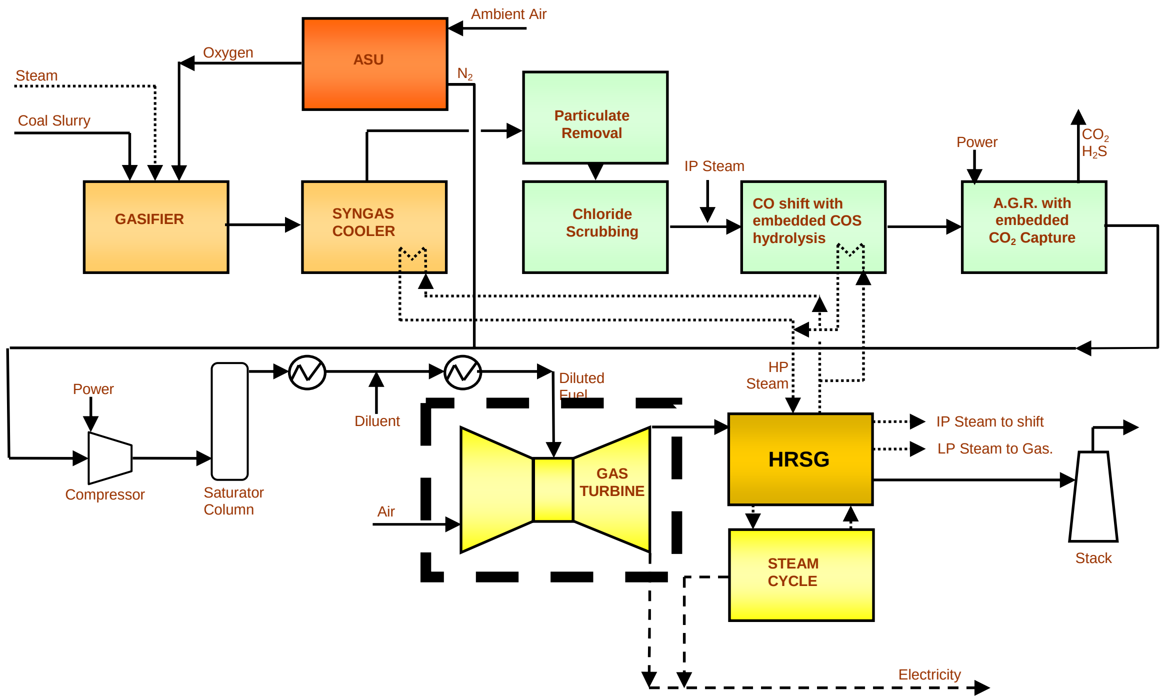

Figure 3. IGCC Plant Process Block Diagram

GT INTEGRATION

To determine the optimization direction for major GT design parameters, the Design of Experiments tool was employed. This process was used to identify which are the most critical engine design parameters to ensure that the key project requirements are achieved. The following parameters were thus selected: firing temperature, exhaust temperature (pressure ratio), ASU type and dilution level. A 4-parameter, fractional-factorial Design of Experiments was then carried out to identify the optimum GT firing temperature and pressure ratio and IGCC plant configuration.

An evaluation of different concepts to accommodate various ASU types and a range of air integration levels were completed.

In developing and commercializing gas turbine engines today, Siemens utilizes a Platform Approach. This approach designs component parts that can be interchanged between engine frames. For example, common compressor parts can be utilized between different frames. Likewise, some turbine and combustor basket components can be interchanged. This harmonization of engine components also extends through both 50 and 60Hz product lines resulting in reduced capital and maintenance costs. In addition, the Platform Approach allows focusing of resources to maximize end product results. This same Platform Approach is being utilized in the development of the Hydrogen Turbine. This should maximize development synergies with the application of components and technologies from F/G frame engines while minimizing development costs, thus greatly benefiting the Hydrogen Turbine development.

To achieve high quality design and minimize risks for the Hydrogen Turbine, the following Six-Sigma quality tools are being employed: (1) Quality, Function and Deployment (QFD), (2) Failure Mode and Effects Analysis (FMEA), (3) Design for Six-Sigma (DFSS), (4) Design of Experiments, and (5) Probabilistic Design. The QFD methodology is a systematic, step-based approach to translate requirements into solutions. These solutions are prioritized in accordance with the importance of the given requirements and with respect to potential influences among certain solutions. QFD therefore allows for prioritizing properties, functions, processes, or instructions to achieve specified requirements. This QFD tool is planned to be employed in the beginning of Phase 2 to prioritize the Product Design Specification obtained from the end of Phase 1. The FMEA tool is used to predict and prevent potential failures, risks and malfunctions. Different types of FMEAs will be applied during Phase 2 to identify weak points of overall engine concepts as well as design aspects and critical characteristics of different components. Design For Six Sigma (DFSS) means fundamental design or re-design of a process (transactional) or a product. This structured approach places a strong emphasis on customer needs and expectations. Unique tools and process modeling techniques are used to assist in delivering the final output - a robust and measurable process or product.

Design of Experiments techniques, provide an efficient and structured approach to change multiple factor settings concurrently within a process and observe the outputs collectively for improvements and degradations. Probabilistic Design provides methods and tools to perform engineering calculations using probability distributions of design parameters instead of just nominal or mean values. The probabilistic approach enables targeting specific levels of reliability, durability or performance conformance to improve safety, quality and cost. Applications include quantifying uncertainty in the prediction of a product's performance (probabilistic risk assessment) and reducing sensitivity in the presence of operating condition or manufacturing variability (probabilistic robust design).

ADVANCED TECHOLOGIES DEVELOPMENT

To achieve higher engine efficiencies and meet DOE program goals, engine operating conditions must be up-graded, component technologies must be improved or developed and new or improved material systems implemented. A cross-section of the SGT6-6000G engine is shown in Figure 4, identifying what new or improved technologies are being developed and where they are incorporated.

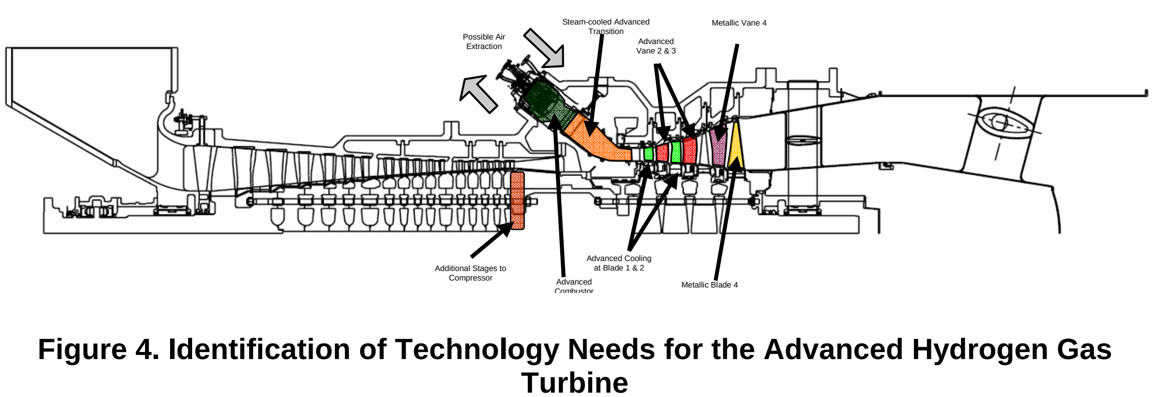

Figure 4. Identification of Technology Needs for the Advanced Hydrogen Gas Turbine

Compressor

Based on the selected engine design point, preliminary studies were carried out on an advanced compressor design to provide the required stage number and flow path geometry. The conceptual design utilized the existing advanced compressor design, with additional stages added to the rear to reach the target pressure ratio. A range of pressure ratios was also investigated and the implication on stage count was assessed.

Combustion System

A key component in successfully developing a fuel flexible Hydrogen Turbine is the combustion system (combustor and transition) development. To achieve the very challenging program emission goal at the increased firing temperature and pressure ratio, several competing combustion concepts, such as diffusion flame, premixed and catalytic, are being investigated. The candidate combustion systems will be developed through component modeling studies specifically for syngas and hydrogen application; through subscale test programs to evaluate critical combustion and operating issues; and through validation testing that will include module testing and both reduced and full pressure basket testing using syngas, hydrogen and natural gas fuels. Conceptual and detailed designs will be prepared.

A QFD exercise was carried out using program requirements, combustion system characteristics and the combustion concepts being considered in order to translate the customer requirements into design or system requirements. For each combustor configuration being evaluated a high-level summary was prepared to identify risks, benefits and interdependencies. Chemical reactor modeling (CRM) was performed on diffusion and catalytic systems. The approach being taken is to calibrate these models using existing combustion rig data on natural gas, syngas and hydrogen. The hydrogen and syngas mechanism for use in CRM and CFD are being evaluated. Hydrogen fuel mixing studies were performed using CFD on a premixed swirler fuel injection design. The goal was to compare the hydrogen fuel mixing characteristics with existing natural gas results to determine if design changes are required prior to performing a rig test on hydrogen fuel. Catalytic module test was performed on syngas fuel at the Siemens Lincoln facility. The diffusion flame and premixed system combustors will be tested in the summer of 2006 at elevated firing temperatures and pressures on diluted syngas and hydrogen. Hydrogen is deemed the most challenging fuel being considered for this project, due to its high flame speed, propensity for flashback and higher dilution requirement for NOx emissions, flame speed and flashback abatement.

Turbine

In order to ensure that the Hydrogen Turbine and IGCC plant attain the desired performance, advanced turbine aerodynamic concepts and cooling schemes are being evaluated and developed. To achieve this, high effectiveness cooling schemes, advanced alloy castings and high temperature thermal barrier coatings (TBC) will be required.

The increased firing temperature and pressure ratio selected for the advanced GT, as well as increased mass flow resulting from syngas and hydrogen fuel operation, introduce considerable challenges to the turbine aerodynamic, thermal and mechanical designs. The increased pressure ratio increases stage aerodynamic loadings and, in order not to suffer an efficiency penalty, may result in increase in number of stages. This in turn will result in additional cooled airfoil rows, increased part count and increased cost. Thus a study must be conducted to achieve a balance between efficiency and cost. Unless improved sealing designs are incorporated, the higher pressures in the turbine will result in increased leakage and a performance loss. The higher firing temperature throughout the turbine flow path, as well as increased moisture content when operating on syngas or hydrogen fuels, will increase the thermal load on the turbine airfoils. This will pose a challenge, since in order to maintain adequate hot parts lives, the metal temperatures must be kept at acceptable levels. This will require advance in cooling technology, TBC / bond coat performance, alloy strength or use of novel concepts, such as CMCs or fabricated airfoils. The increased mass flow will result in elevated Mach numbers throughout the flow path and may penalize efficiency. This challenge may be solved by increasing the turbine annulus area. But this will increase loads exerted on the turbine discs. This will be especially critical on the last stage blade which is already near its limiting height from both disc load and flutter considerations. Based on the preliminary engine design point, optimization studies were carried out to resolve all of the above challenges and to produce a preliminary turbine definition.

Rotor

Several rotor enhancements were identified that would satisfy the rotor requirements at the elevated design point pressure ratio and increased shaft output power. These configurations may use higher temperature materials and alternative cooling schemes. An initial rotor configuration has been established.

Casings

The casing design must be integrated with the boundary conditions from all other engine components and accommodate requirements for the IGCC plant air extraction needs, as well as the higher operating temperatures and pressures. The effect of the different engine design options on casing configurations has been identified. The required high temperature materials for the exhaust, bolting and fasteners were also identified.

Materials Systems

Advanced or novel materials systems are critical to supporting the advanced engine components and systems. A broad range of materials development activities are planned to address the requirements arising from the advanced operating conditions anticipated for the Hydrogen Turbine. Driving these requirements are higher firing temperature, higher operating pressure level, minimized component cooling for higher efficiency and increased steam content in the turbine gas flow. To achieve target component lives in hostile gas environments that result from the hydrogen and syngas fuels, novel material systems are being developed for the combustion system and turbine components.

The material property requirements for each Hydrogen Turbine component and potential materials technologies that could meet these requirements were identified. The components that needed advanced materials were: (1) Combustion system: diffusion, catalytic, premixed, transition, (2) Turbine: increased firing and exhaust temperatures,

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increased pressure level, reduced cooling air consumption and leakage, lower first time costs/life cycle costs, (3) Compressor: increased exit temperature, (4) Rotor: increased temperature, and (5) Casing and Auxiliaries: increased temperatures/pressures and hydrogen environment. To support these requirements the following materials technologies will be enhanced or novel ones developed: (1) catalytic coatings, (2) high temperature bond coats, (3) high temperature capable TBC, (4) rare earth alloy modifications, (5) hydrogen embrittlement resistance, and (6) fabricated airfoils. Materials development and validation will follow the Six-Sigma approach.

A new thermal stress resistant and robust catalytic system for advanced combustors is being developed. Three new noble metals have been selected as modifying elements for new high temperature bond coat. New ceramic compositions have been identified for advanced TBC development, test matrix has been defined and substrates have been defined for spray trials. Four rare earth elements have been selected as alloying additions to enhance the CM247LC superalloy. A literature survey on hydrogen Embrittlement issues has been completed, test facility selected and Hydrogen Turbines subjected to hydrogen environment have been identified for testing. Hybrid component design and fabrication offer significant advantages over casting monolithic components. This airfoil construction concept allows the use of materials with selected desirable properties in critical locations and geometry that could not be cast in a monolithic fashion. An extensive open literature review has been completed on fabricated airfoil processes and architectures for increased airfoil cooling efficiencies.

PLANT PERFORMANCE

Plant thermal cycle performance studies started with the S0TA IGCC plant estimation and continued throughout Phase 1. The 2x1 SGT6-5000F IGCC plant HHV thermal efficiency on syngas was estimated at 39.5%. The 2x1 SGT6-6000G IGCC plant performance on syngas showed a substantial improvement. The Design of Experiments exercise played a significant role in narrowing down the major cycle parameters, such as firing temperature, exhaust temperature (pressure ratio), ASU type and dilution level. This is illustrated graphically in Figure 5. A total of 10 cases were run on hydrogen fuel with the 4 major parameters. The results helped to define the design point parameters.

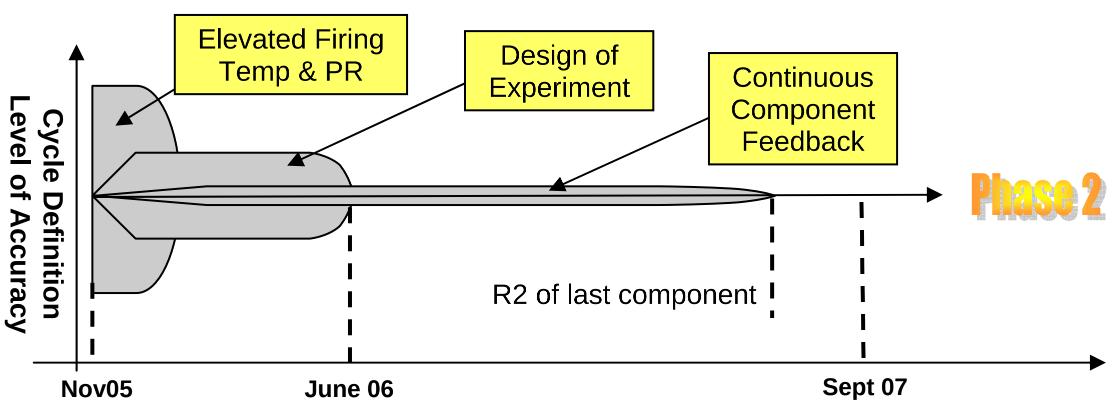

Figure 5. Evolution Process for Cycle Definition

A study was carried out to determine the IGCC plant efficiency penalty versus carbon capture rate. At 75% carbon capture, the HHV efficiency penalty was estimated to be quite small. However, this penalty increased to about five times at 90% carbon capture, (see Figure 6). The initial FutureGen Program carbon capture target is in the 85-90% range. To achieve this target will incur a significant efficiency penalty.

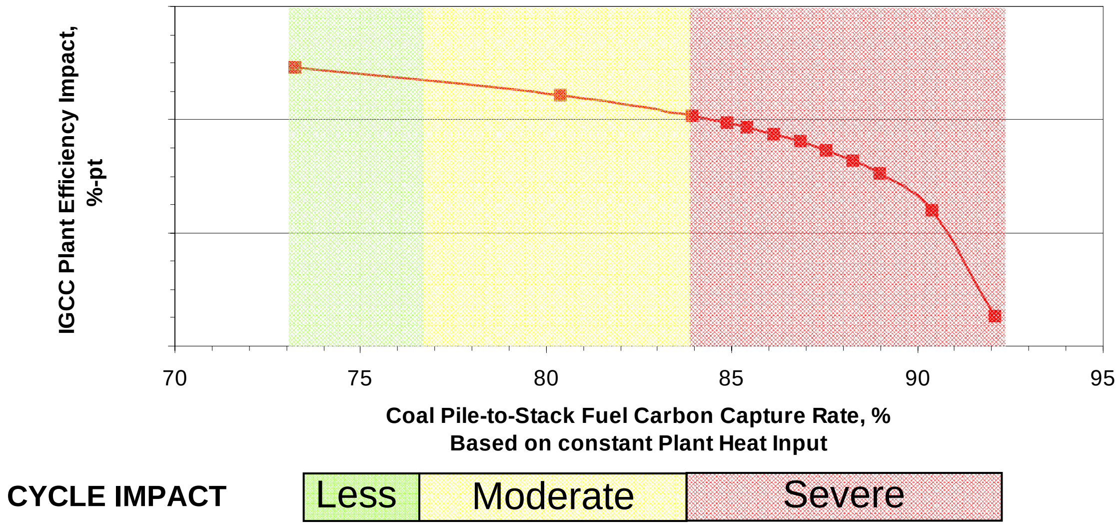

Figure 6. IGCC Efficiency Penalty versus Fuel Carbon Removal

PLANT CAPITAL COST ESTIMATION

The first iteration on the Hydrogen Turbine-IGCC plant capital cost was based on the SGT6-5000F IGCC plant cost and the preliminary GT and plant configurations. Cost deltas were estimated for the new equipment compared to current designs for the power block and the gasification island. The final plant price estimate was scaled from 2006 dollars to 2002 dollars to give a better comparison with the $/kW target value as per DOE's instruction. The estimate included the following:

1. Power Block (Equipment + Construction): 2 Hydrogen-fueled GT's, 2 HRSGs, 1 Steam Turbine, 3 Generators and all associated Auxiliaries/Controls/BOP Equipment.

2. Gasifier and ASU (Equipment + Construction): Full Slurry Quench Gasifier (with initial charge of chemicals and catalysts, syngas cooling and particulate removal), Coal Handling, Slurry Preparation, Slag Handling, Acid Gas Removal with CO_2 Compressor, Sulfur Recovery, Sour Water System, Tail Gas Treating, CO Shift Sour, ITM ASU with Oxidant Feed and General Facilities.

The estimate did not include interest during construction, prepaid royalties, preproduction costs or land.

The estimated $/kW value was considerably below the current estimates for a syngas-fueled IGCC plant but above the $1,000/kW target. It should be pointed out that the GT,

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which is the object of this development effort, itself represents a small percentage of the total price. Even the power block (GTs, ST, HRSGs, BOP) represents only about 30% of the total capital cost. The gasifier island represents the major part of the costs. Therefore, the GT impact is small, except that with its improved efficiency and output the overall plant $/kW can be significantly lowered. A significant reduction in gasifier/ASU costs will be required to achieve the $/kW target. It should be pointed out that the above estimate was done for hydrogen-fueled plant. Since the performance penalty for H_2 separation and carbon capture is quite severe, the syngas fueled IGCC plant $/KW will be significantly lower. This calculation will be carried out in the near future.

ECONOMIC ADVANTAGE EVALUATION

In down selecting plant configurations, concepts, technologies, etc., the process used will be based on levelized electricity cost (LEC) and plant net present value (NPV) or benefit/cost analyses, as deemed appropriate. An additional important element in this process will be risk analysis carried out on the concepts being considered. The main focus will be to establish how each concept/component/technology under consideration will benefit the coal-derived, hydrogen-fired advanced gas turbine integrated into the IGCC plant. LEC will be used mainly in down selecting the plant configurations, different ASU and gasifier technologies and BOP configurations. LEC is defined as the sum of the following five levelized elements: carrying charges (a function of capital cost), fixed operating and maintenance expense, variable operating and maintenance expense, cost of consumables and fuel costs. Based on preliminary plant performance and capital cost estimates, plant LEC and/or NPV will be estimated.

PROGRAM BENEFITS

Technologies developed in this program have the potential to accelerate the adoption of advanced coal-based IGCC plants in the United States and around the world, thereby reducing emissions, water use (up to 40% less than today's equivalent conventional coal plants), solid waste production (up to 50% less) and dependence on foreign energy supplies. The new/enhanced technologies will down flow into current Siemens production GTs, thus enhancing their competitiveness and value to their customers. Finally, the commercialization of these technologies will create and maintain high quality U.S. jobs over a broad range of engineering disciplines and manufacturing industries, as well as reduce U.S. trade imbalance.

CUSTOMER ADVISORY BOARD

To ensure that customer's, DOE and Siemens' needs will be integrated into the Advanced Hydrogen Turbine Development, a customer Advisory Board was constituted. The Board members include FutureGen Consortium members, current IGCC plant operators, prospective IGCC plant customers and DOE representatives. The first Customer Advisory Board meeting was held on May 2, 2006, during the Electric Power Conference in Atlanta. To obtain direct input, a standard customer needs assessment methodology, as shown in Figure 7, was employed. To initiate this effort, a survey was drafted in order to capture the IGCC market drivers, constraints and enablers. The attendees at the first Board meeting were asked to respond to the survey. The respondents agreed that fuel costs (natural gas versus coal), reduced CO_2 emissions and CO_2 sequestration are the major drivers for IGCC. It was considered important to the customer that the IGCC plant have the ability to operate on natural gas when the gasifier is down, maintain adequate plant efficiency, have condition based maintenance versus equivalent operating hours maintenance and engage in emissions trading. Capital cost, investment cost, cost of electricity and maintenance costs all tend to be major constraints to IGCC success. Providing tax incentive and enforcing carbon emission regulations are the government actions that customers foresee can enable IGCC plants. A web survey will be sent to Board Members who were unable to attend the first meeting to get a better picture of customer requirements and direction for the Advanced Hydrogen Turbine Development.

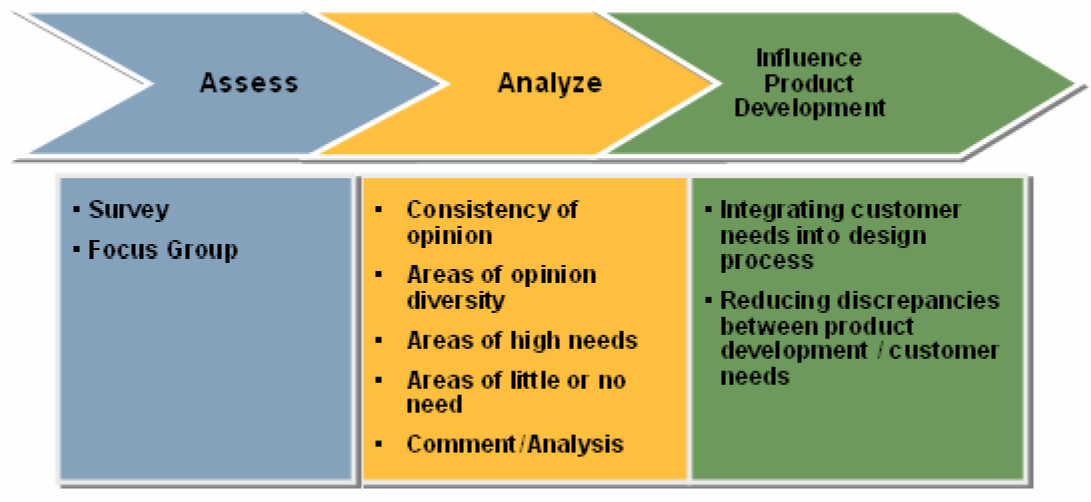

Figure 7. Customer Needs Analysis Influence on Product Development

SUMMARY

Under U.S. DOE sponsorship, Siemens Power Generation has embarked on a 2-Phase, 6-year Advanced Hydrogen Turbine Development Project to develop an advanced GT for incorporation into future coal-based IGCC plants. A comprehensive and very detailed Research & Development Implementation Plan, describing how the DOE program goals will be achieved, has been prepared and submitted for DOE review. A three-step GT-IGCC plant development roadmap was proposed to show how the Siemens and DOE near term (2007-2009), intermediate (2010-2012) and long term (2013-2017) goals will be achieved. An IGCC plant based on an advanced version of the SGT6-6000G GT is being developed. The Design of Experiments process was employed to determine the optimum cycle firing temperature and pressure ratio, as well as the ASU type. New or enhanced technologies development was initiated in compressor, combustion system, rotor, casings and materials. Plant performance was estimated for syngas-fueled 2x1 SGT6-5000F and SGT6-6000G IGCC plants and 10 cases of hydrogen-fueled advanced GT-IGCC plants. The first price estimation was carried out on the hydrogen-fueled advanced GT-IGCC plant. The estimated $/kW was less than the current IGCC plant value, but above the target value. It is expected that for a syngas-fueled IGCC plant the $/kW value will be considerably lower. A customer Advisory Board for the Advanced Hydrogen Turbine Development was constituted and the first Board meeting was held in May. This program will result in considerable public as well as internal Siemens' benefits.

It will foster IGCC plant commercialization, utilization of secure and abundant energy source, emissions reduction, high technology jobs creation, trade deficit reduction and technology downflow to current Siemens' GT frames. The program is progressing on schedule and within budget and to date has met all its milestones.

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PERMISSION FOR USE

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