FINAL REPORT
DE-EE0003229
Solid Oxide Fuel Cell Systems PVL Line

Revised May 1, 2012

SUBMITTED BY

Stark State College
6200 Frank Avenue NW
Canton, OH 44720

PRINCIPAL INVESTIGATOR

Susan Shearer
(330) 494-6170 x4680 (phone)
sshearer@starkstate.edu

SUBMITTED TO

U.S. Department of Energy
Golden Field Office
Project Manager: Jesse J. Adams

1.0 EXECUTIVE SUMMARY

In July 2010, Stark State College ("SSC"), received Grant DE-EE0003229 from the U.S. Department of Energy ("DOE"), Golden Field Office, for the development of the electrical and control systems, and mechanical commissioning of a unique 20kW scale high-pressure, high temperature, natural gas fueled Stack Block Test System ("SBTS"). SSC worked closely with subcontractor, Rolls-Royce Fuel Cell Systems (US) Inc. ("RRFCS") over a 13 month period to successfully complete the project activities. This system will be utilized by RRFCS for pre-commercial technology development and training of SSC student interns. In the longer term, when RRFCS is producing commercial products, SSC will utilize the equipment for workforce training.

In addition to DOE Hydrogen, Fuel Cells, and Infrastructure Technologies program funding, RRFCS internal funds, funds from the state of Ohio, and funding from the DOE Solid State Energy Conversion Alliance ("SECA") program have been utilized to design, develop and commission this equipment. Construction of the SBTS (mechanical components) was performed under a Grant from the State of Ohio through Ohio's Third Frontier program (Grant TECH 08-053). This Ohio program supported development of a system that uses natural gas as a fuel. Funding was provided under the Department of Energy ("DOE") Solid-state Energy Conversion Alliance ("SECA") program for modifications required to test on coal synthesis gas. The subject DOE program provided funding for the electrical build, control system development and mechanical commissioning. Performance testing, which includes electrical commissioning, was subsequently performed under the DOE SECA program.

Rolls-Royce Fuel Cell Systems is developing a megawatt-scale solid oxide fuel cell ("SOFC") stationary power generation system. This system, based on RRFCS proprietary technology, is fueled with natural gas, and operates at elevated pressure. A critical success factor for development of the full scale system is the capability to test fuel cell components at a scale and under conditions that can be accurately extrapolated to full system performance. This requires specially designed equipment that replicates the pressure (up to 6.5 bara), temperature (about 910°C), anode and cathode gas compositions, flows and power generation density of the full scale design. The SBTS fuel cell anode gas is produced through the reaction of pipeline natural gas with a mixture of steam, CO_2, and O_2 in a catalytic partial oxidation (CPOX) reactor. Production of the fuel cell anode gas in this manner provides the capability to test a fuel cell with varying anode gas compositions ranging from traditional reformed natural gas to a coal-syngas surrogate fuel.

Stark State College and RRFCS have a history of collaboration. This is based upon SSC's commitment to provide students with skills for advanced energy industries, and RRFCS' need for a workforce that is skilled in high temperature fuel cell development and testing. A key to this approach is the access of students to unique SOFC test and evaluation equipment. This equipment is designed and developed by RRFCS, with the participation of SSC interns. In the near-term, the equipment will be used by RRFCS for technology development. When this stage is completed, and RRFCS has moved to commercial products, SSC will utilize this equipment for workforce training.

The RRFCS fuel cell design is based upon a unique ceramic substrate architecture in which a porous, flat substrate (tube) provides the support structure for a network of solid oxide fuel cells that are electrically connected in series. These tubes are grouped into a ~350-tube repeat configuration, called a stack/block. Stack/block testing, performed at system conditions, provides data that can be confidently scaled to full scale performance. This is the basis for the specially designed and developed test equipment that is required for advancing and accelerating the RRFCS SOFC power system development program.

All contract DE-EE0003229 objectives were achieved and deliverables completed during the period from March 1, 2010 through March 31, 2011. As a result of program completion, the Stack Block Test System was ready to support installation and electrical operation of a RRFCS solid oxide fuel cell (SOFC) stack block in the second quarter of 2011.

2.0 OBJECTIVES VS. ACCOMPLISHMENTS

The objective of this program was to complete the build of the SBTS for full-scale block testing of fuel cell tubes produced by the RRFCS Print Verification Line ("PVL"). A second objective was to mechanically commission SBTS operations and functionality for testing SOFC stacks at system design operating conditions.

All program objectives were met. The planned testing to support mechanical commissioning of the SBTS was completed in November, 2010. The SBTS electrical build was completed in February 2011. Completion of these objectives readied the SBTS for electrical commissioning in 2011.

3.0 ACTIVITY SUMMARY

Background

The Stack Block Test System (SBTS) was designed to support testing of a single RRFCS fuel cell block at prototypic pressure (up to 6.5 bara), temperature (maximum of about 910°C) and anode/cathode gas compositions. As shown in Figure 3.1, the block assembly is replicated in the Generator Module vessel to provide ~250kW units. The Generator Module can be replicated to provide a MW-scale distributed power system.

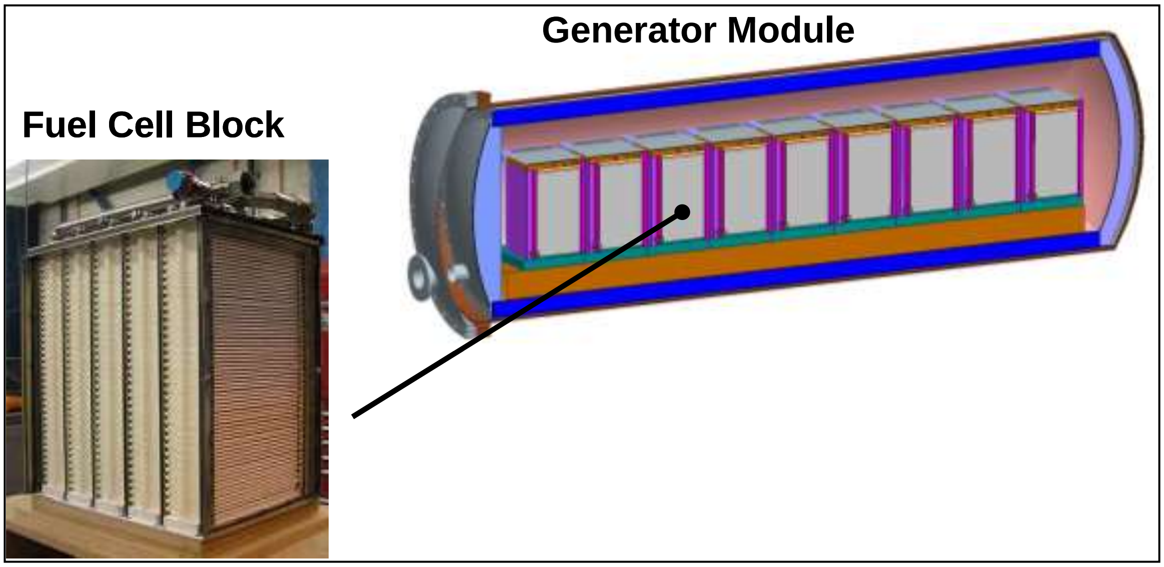

Figure 3.1. Fuel Cell Block (during assembly) and arrangement within the Generator Module

A comparison between the RRFCS fuel cell cycle with a single block and the SBTS cycle is shown in Figure 3.2. As shown, the SBTS cycle is simplified over the RRFCS fuel cell cycle with the following notable differences:

i) SBTS uses a once-through anode loop while the RRFCS fuel cell cycle includes an anode loop ejector that allows anode gas recycle,
ii) SBTS uses a catalytic partial oxidation (CPOX) reactor external to the pressure vessel to provide the anode gas to the fuel cell vs. an internal natural gas reformer in the RRFCS fuel cell cycle,
iii) SBTS requires a H_2-fueled burner to provide system heat for maintenance of stack inlet temperature at low fuel cell operating power vs. a heat exchanger in the RRFCS cycle
iv) Use of the burner in (iii) at low load operation results in “wet” cathode air as compared with a “dry” (ambient water vapor only) cathode air flow in the RRFCS fuel cell cycle. The dry air condition is preferable for cathode performance and as a result, SBTS operation at low power is minimized.

The SBTS operated at pressures prototypic of the RRFCS cycle with pressure control via a system (not shown) that used water spray to quench the cathode and anode exhaust temperatures to 200°C (mixture temperature below auto-ignition) before combining the two exhaust streams into a single flow. The cooled flow passed through a back pressure regulator to maintain SBTS operating pressure with the gas mixture discharged to the atmosphere through the facility flare.

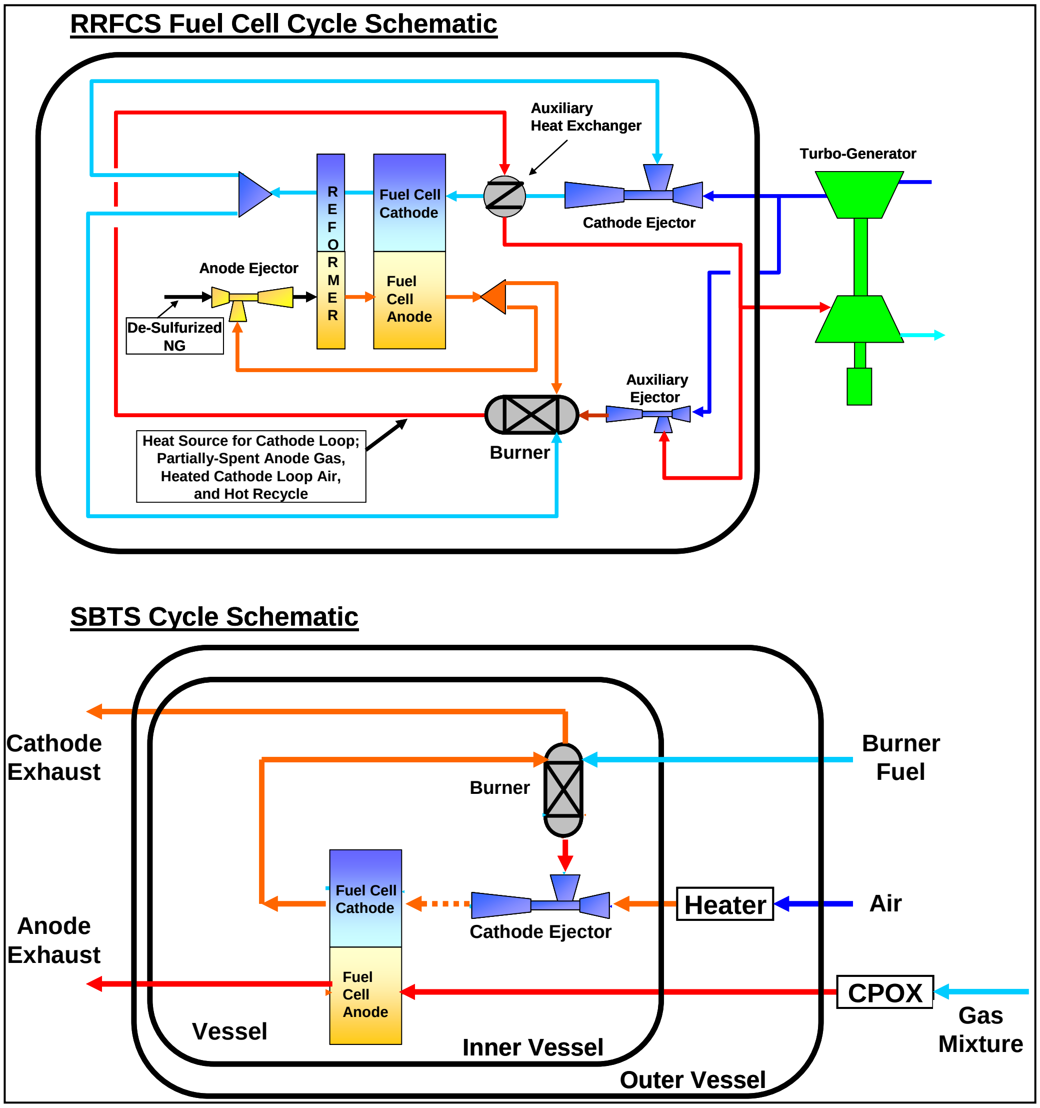

Figure 3.2. Comparison of SBTS and RRFCS fuel cell cycle schematics

A picture of the SBTS internals used for the Phase 1 commissioning test is shown in Figure 3.3. Major components shown include the fuel cell block, cathode ejector, burner assembly, instrumentation, and cathode and anode plumbing. The Phase 1 test block was used to exercise the mechanical performance of the system and as such, electrical connections to this block were not installed. The Phase 2 electrical commissioning test, including the first installation of an electrically active fuel cell block in the SBTS, is scheduled for the second quarter of 2011.

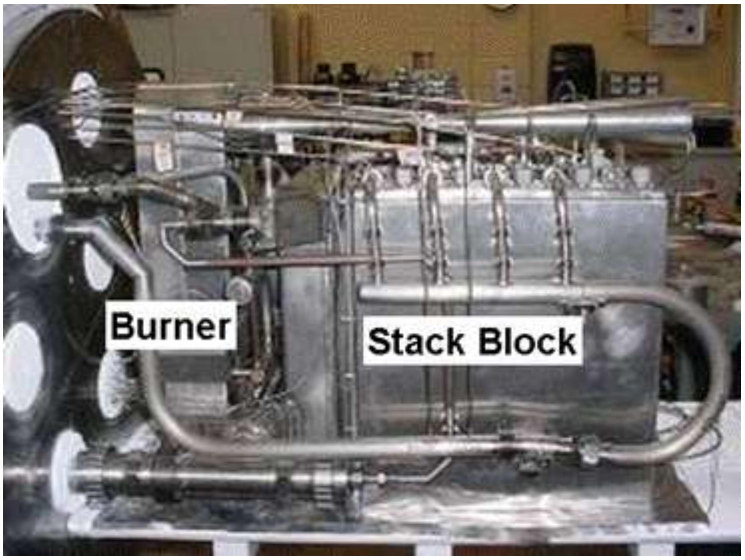

Figure 3.3. SBTS block and internal components ready for test

The SBTS block internals shown in Figure 3.3 were installed in an inner vessel that was lined with a high-temperature microporous insulation. This vessel was installed in an outer vessel, with significantly lower vessel wall temperature, that provided pressure containment for the system. Included in the longitudinal gap between the outer and inner vessel as shown in Figure 3.2 and 3.4 was a 480VAC, 24kW air heater for air preheating to reduce the burner heat demand. In the RRFCS fuel cell cycle the air heating is accomplished with heat input from the turbocompressor, ejector and heat exchanger. Figure 3.4 shows the inner vessel installed inside of the outer pressure vessel prior to outer vessel head installation. Various inlet/outlet connections are also labeled in the Figure for reference to the SBTS cycle schematic of Figure 3.2.

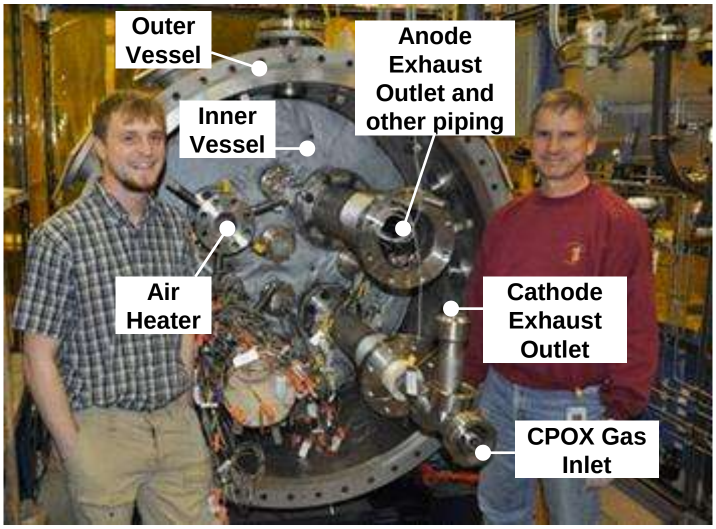

Figure 3.4 SBTS vessel assembly

The final step in assembly of the SBTS fuel cell vessels involved installation of the outer vessel head which captures the various inlet and outlet piping, instrumentation and electrical heater connections. Figure 3.5 shows the outer pressure vessel with the closure head installed and the CPOX reactor connected. Not clearly visible in the picture are the anode and cathode exhaust pipes connected to the exhaust quench (water spray) vessels prior to joining for a single flow line to the back pressure regulator that establishes the fuel cell operating pressure.

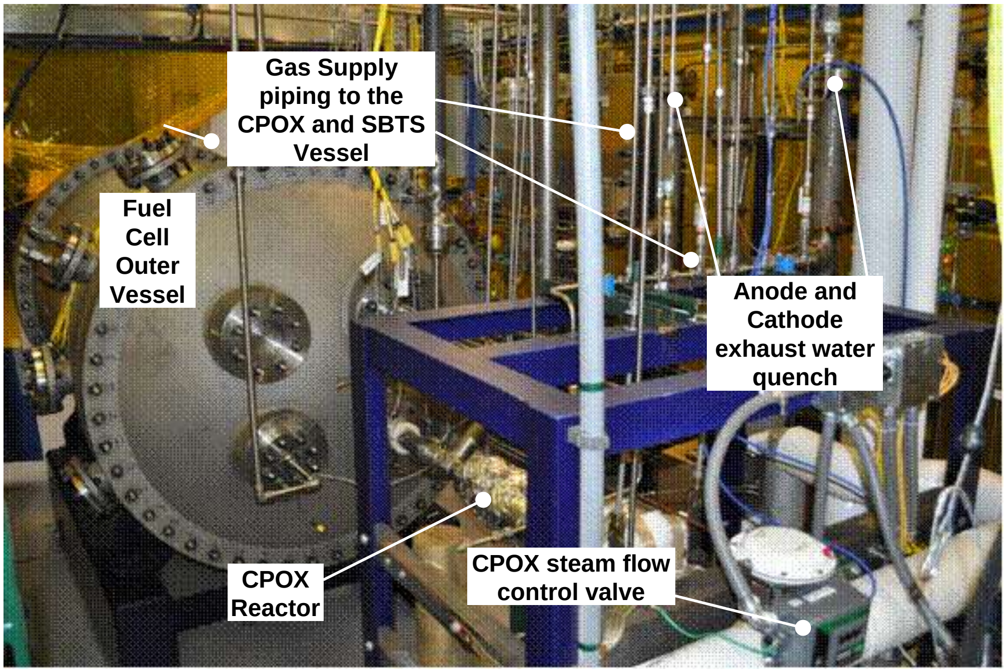

Figure 3.5 Assembled SBTS outer vessel with CPOX reactor attached

The report sections that follow state the original contract task description of the three work scope tasks, progress completed against each and a brief discussion of lessons learned. The three tasks were: 1) Controls software development and implementation, 2) Facility electrical and controls wiring and 3) Commissioning of the rig. The planned scope was completed for each task, thereby transitioning SBTS to support electrical performance testing of a RRFCS fuel cell stack beginning in the second quarter of 2011.

Task 1 – Controls Software

<u>Contract Task Description</u> – The control software initiated under the ODOD Grant TECH 08-053 will be completed. The control software will allow for unattended operation of the SBTS during heat-up, normal powered operation and shut-down. The control system will also provide a first line of defense for mitigating operational transients and control issues rather than safety system handling through an Emergency Shutdown (ESD). At the completion of this task, the control system software, together with the HMI (Human-Machine Interface), will be exercised and validated as part of Task 3.

<u>Results and Discussion</u> – The control and safety system software implementation initiated under the ODOD Grant TECH 08-053 has been completed. A PLC-based control system was developed to allow automated operation of the Stack Block Test System. The control system architecture used a Rockwell Automation ControlLogix 1756-L62 controller with ControlLogix I/O modules that serviced analog inputs, analog outputs, thermocouple inputs, digital inputs, and digital relay outputs. In addition, an independent PLC-based safety system was designed to serve as additional mitigation against potential hazards that might occur in the system during operation. The safety system also used a Rockwell Automation ControlLogix 1756-L62 controller with ControlLogix I/O modules for analog inputs, analog outputs, thermocouple inputs, digital inputs,

and digital relay outputs, and a non-safety Ethernet network connection. A heartbeat circuit connected the control PLC with the safety PLC. Heartbeat signals were continuously passed between the two PLC's. If one failed to respond properly, this was inferred as an indication of a PLC problem, and SBTS shutdown followed. Safety relays driven by the safety PLC controlled the SBTS and facility safety devices. In the event of a safety system detected incident, the safety system caused a safety relay to shut off fuel, turn off a heater, shutdown the system (i.e., emergency shutdown, or ESD), or any appropriate action deemed necessary to protect personnel and property. Figure 3.6 shows a high level schematic of the control and safety system architecture.

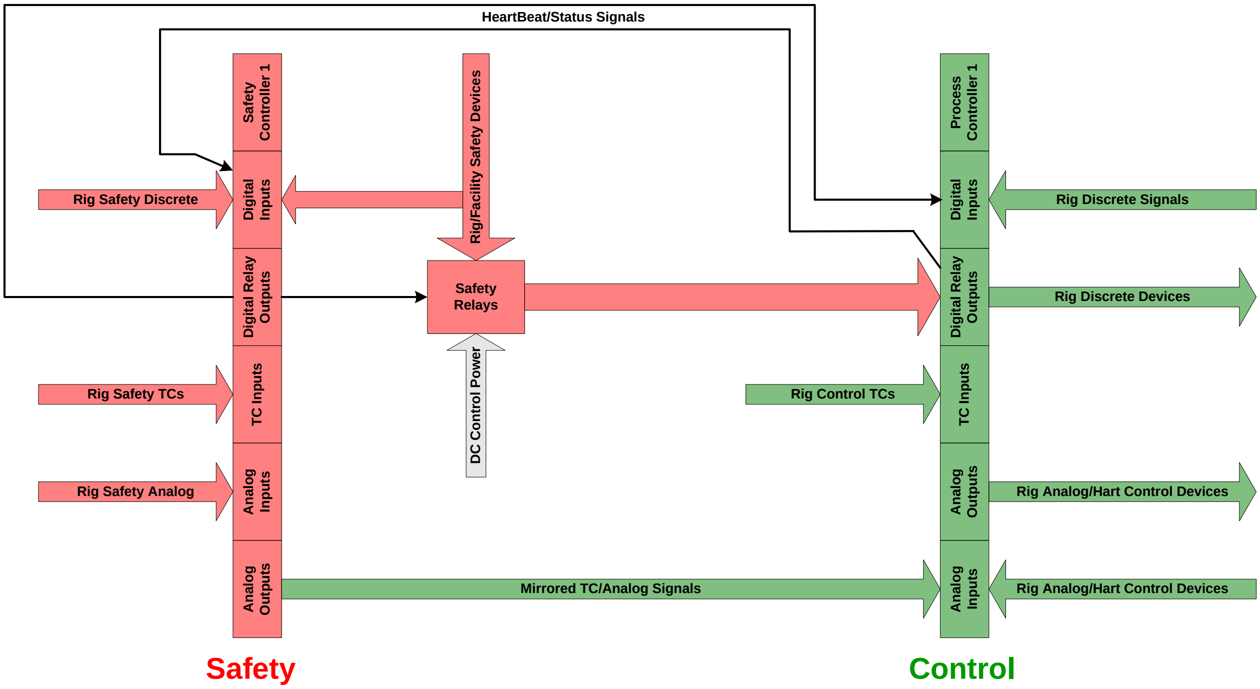

Figure 3.6 Control and safety system SBTS architecture

The control and safety system software were developed using Rockwell Automation's RSLogix 5000 design and configuration software. The HMI was developed with Rockwell Automation's FactoryTalk View, using FactoryTalk View SE Server and SE Client for SBTS deployment. Real-time and historical data logged to the RRFCS LAN-based server were displayed and analyzed using OSIsoft PI ProcessBook and PI DataLink (data link to Microsoft Excel).

The control software supported unattended operation of the SBTS during heat-up, normal powered operation, and shut-down. The control system also provided a first line of defense for mitigating operational transients and control issues rather than safety system handling through an ESD. The control system was also set up for operation in manual mode. In this mode, direct access to any control device was allowed – an important feature during the commissioning of the rig and operational software.

At the completion of this task the control system software, together with the HMI, were exercised and validated as part of Task 3 Commissioning. Examples of SBTS response during various automatic control functions are shown in Task 3 of this report.

An example of the automatic control functions implemented in the SBTS control system is shown in the following Table. This is not a complete list but provides an indication of the level of control needed to support SBTS operations.

Control Loop Name	Control Loop Function
CL_ANODE_GAS_OUT_TEMP	Controls the anode gas exhaust temperature in the pressure control system to a setpoint by varying the amount of water that is sprayed into the gas stream using a variable-speed pump
CL_CATHODE_GAS_OUT_TEMP	Controls the cathode gas exhaust temperature in the pressure control system to a setpoint by varying the amount of water that is sprayed into the gas stream using a variable-speed pump
CL_CPOX_REACTOR_OUT_TEMP	Controls the CPOX reactor outlet temperature at an operator-selected value by varying the temperature of the reactor inlet heater to maintain a desired syngas composition
CL_CPOX_STEAM_SH_OUT_TEMP	Controls the temperature of the superheated steam entering the CPOX reactor at a predetermined value by varying heat input to the superheater
CL_CPOX_PREHEATER_OUT_TEMP	Controls the temperature of the mixed-gas stream entering the CPOX reactor at a predetermine value by varying heat input to the mixed-gas preheater
CL_MA_TEMP_RAMP	Controls the electrical input to the main air heater to control the main air temperature at a predetermined value
CL_A2C_DP_CONTROL	Maintains a preset pressure difference between the anode and cathode.
CL_STACK_AUTO_TMP_CNTL	Used during heat-up of the tier to achieve a desired stack inlet temperature. After achieving the desired temperature, this control loop maintains that temperature during other operations.
CL_CPOX_O2_CONTROL	Adjusts the CPOX oxygen to attain a CPOX reactor temperature

More than 20 safety functions were used in the SBTS safety system including CPOX reactor operation, burner operation, pressure vessel temperature, pressure vessel pressure, outer to inner vessel differential pressure, heater temperatures, electrical cabinet temperatures, loss of air flow, loss of instrument air pressure, etc.

<u>Lessons Learned</u>

Transition from an emergency shutdown (ESD) event to automatic control and resumption of SBTS operation at pressure and without SBTS cool down to near-ambient conditions was more difficult to implement than originally planned. The difficulty arose from the numerous points at which the ESD event could occur and subsequent reset of the control system to the new operating state. The originally budgeted schedule did not allow for all detail to be implemented nor validation of the same. As a result SBTS operation in automatic mode required restart of SBTS from near-ambient conditions. As operating experience is gained and such knowledge transferred into the control software, it is expected that the time to recover from an ESD following root cause understanding will be greatly reduced.

Task 2 – Facility Electrical and Controls Wiring

Contract Task Description – The electrical, instrument and controls wiring initiated under ODOD Grant TECH 08-053 will be completed. The primary activities to be performed include install of the wiring (power, instruments and controls) for the CPOX reactor that provides the proper fuel composition to the fuel cell stack; install of the high voltage wiring from the stack connections to the power load controller; and wiring of the stack thermocouples to the control cabinet terminations. Also included in this task is the chemical cleaning of the oxygen supply tubing to the CPOX reactor and install of the water piping associated with the chiller for the fuel cell stack power load controllers. At the completion of this task, the SBTS will be ready for Task 3 Commissioning.

Results and Discussion – All wiring tasks were completed. Wiring, electrical components and controls needed to support the CPOX reactor operation were installed in 2010 as discussed in the Task 3 commissioning of the CPOX later in this report. By the end of January 2011, installation of the high voltage (~1200 VDC) SOFC stack bus bar wires to the high voltage DC cabinet and load controllers needed for Phase 2 electrical commissioning were completed. Operational checks of the eight load controllers and calibration of associated current and voltage transducers were completed including communications to the control system and HMI. All instrumentation associated with SBTS (except the fuel cell stack voltage and current transducers), including completion of the stack thermocouple wiring referenced in the contract task description, was operated during mechanical commissioning. Cleaning of the oxygen supply tubing and cooling water connection to the load controllers were completed.

The SBTS electrical design included 3 major subsystems:

i) 480VAC, 3-phase power distribution (Figure 3.7),
ii) 1200VDC fuel cell power distribution and input to the eight (8) load controllers (Figure 3.8) and
iii) Control and safety system hardware (Figure 3.9).

The following Figures show the completed wiring and cabinets associated with these electrical subsystems.

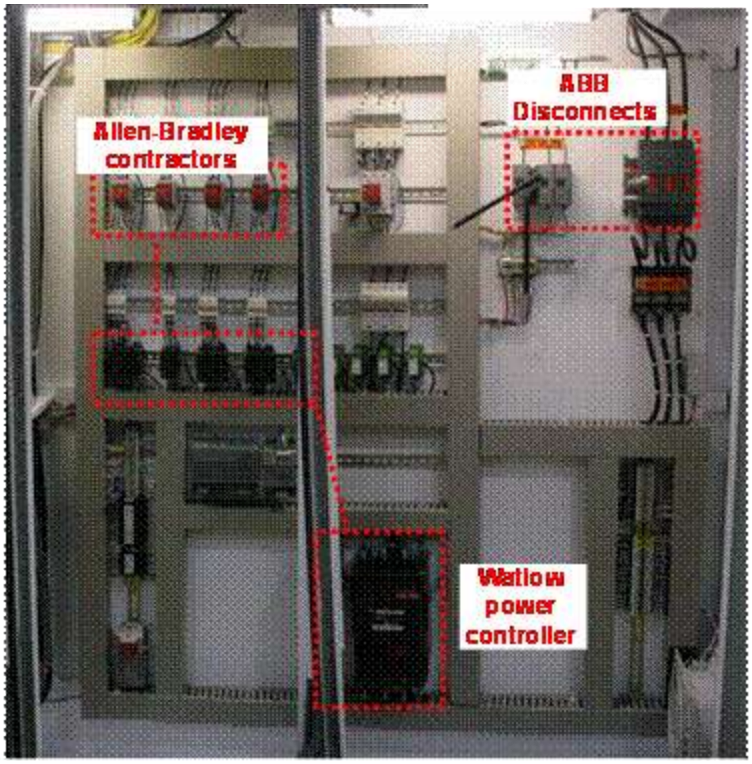

Figure 3.7 480 VAC power distribution

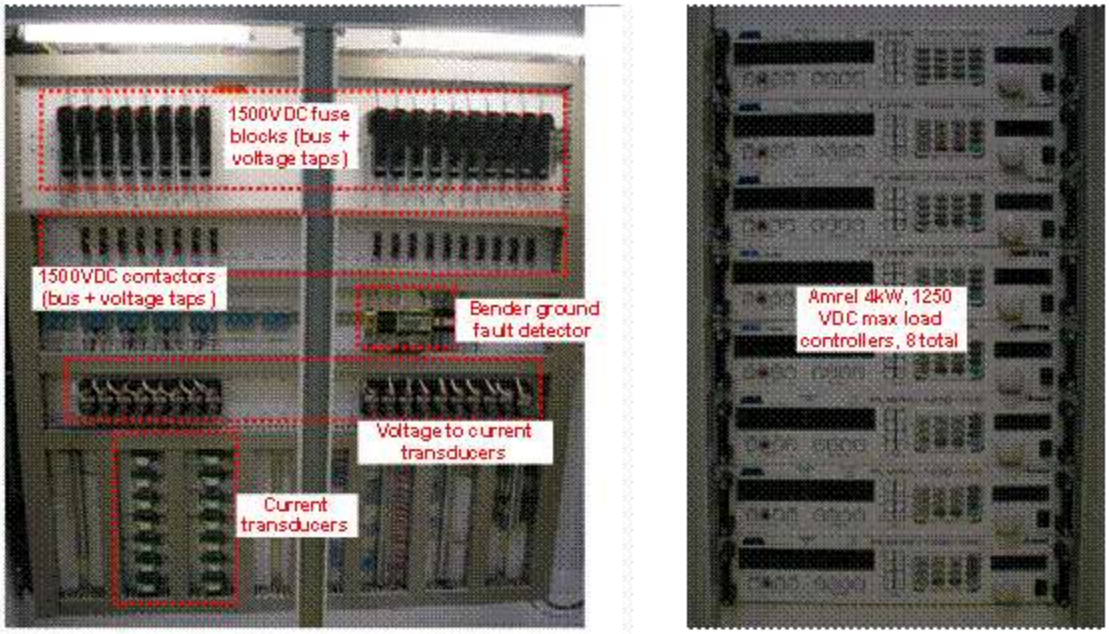

Figure 3.8 1200 VDC fuel cell bus components and load controllers (8 sets)

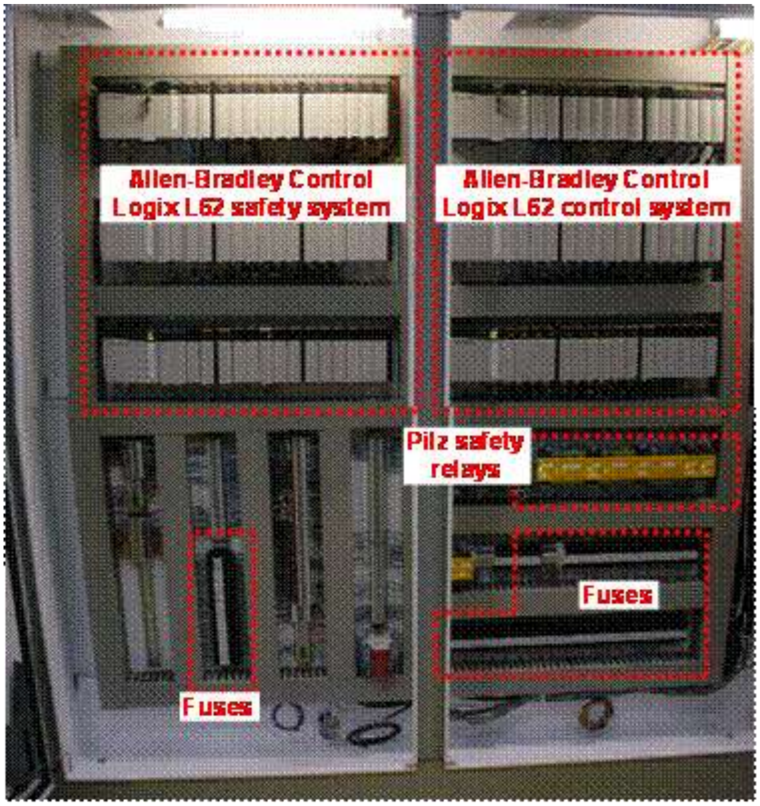

Figure 3.9 Safety and controls components

Check-out of the voltage transducers and display to the HMI were performed for each of the eight (8) fuel cell bus bar measurements using a calibrated voltage source. Figure 3.10 shows the response for 4 of the 8 voltage transducers. Similar checks were made for each of the eight bus bar current transducers using a calibrated current source.

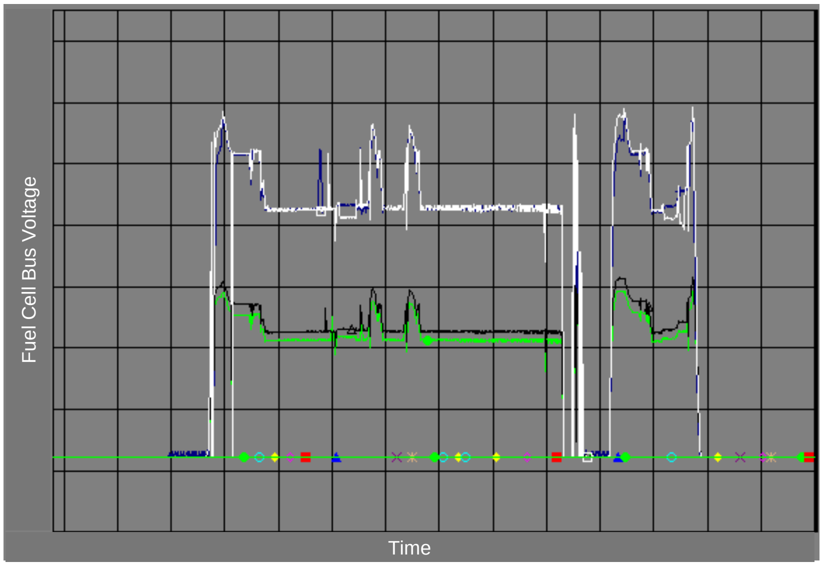

Figure 3.10 Fuel cell bus bar voltage measurements

Lessons Learned
Utilize shared I/O between the safety system and control systems for cost reduction and increased reliability. The present design mirrored the safety system instrument signal input to the control system thereby requiring wiring and duplicate I/O modules. A future design will simply let the control system read the safety system I/O points.

Increase the use of 24VDC components in the electrical cabinets to reduce cabinet safety issues. For example, 110VAC cabinet lighting can be replaced by 24VDC components.

Task 3 – Commissioning

Contract Task Description – The SBTS will be commissioned in two stages. Stage 1 will use an older "alpha-technology" stack that has fully representative anode and cathode flow circuits, but without electrical bus bar connections. These tests will demonstrate operation of the SBTS and debug/prove the functionality of the control system, control hardware and instrumentation during SBTS startup from ambient temperature to hot conditions required for stack electrical power loading. Stage 2 commissioning will install a next generation electrically active "epsilon-technology" stack with full anode and cathode flow circuits, and electrical functionality to demonstrate electro-chemical and powered operation. This two-step commissioning strategy is consistent with other large-scale test stands wherein the facility and control/safety system is functionally proven before installing the stack and risking its damage from non-electrical stack operating issues. The subject contract work scope includes Stage 1 commissioning with Stage 2 commissioning planned for another program.

Stage 1 commissioning scope includes the following:

- Hardware and configuration. Electrical continuity, component operation and instrument continuity are verified through the control Programmable Logic Controller (PLC) and HMI. Data storage to disk for each instrument is verified.
- Instrument calibration. Operation and calibration check of each flow meter will be performed.
- Facility and safety system. Verify operability of natural gas, compressed air, and steam boiler delivery systems; system flare, exhaust pressure control system, and facility safety system/alarms. Exercise the CPOX reactor to demonstrate its functional performance and operating procedure.
- System operation. The entire SBTS will be operated as a system from ambient temperature startup to hot stack operation at a condition ready for electrical power loading (Stage 2 commissioning). Normal control system shutdown and safety system emergency shutdown will be demonstrated. Control loop tuning will be performed as needed to achieve acceptable response and stability during normal operation and expected transients.

Results and Discussion – All of the planned Stage 1 commissioning tasks described by the above bulleted items were completed by the middle of November, 2010.

Hardware and configuration. Following SBTS assembly the 220+ instrument connections were verified from point of measurement to the control programmable logic controller (PLC) or other termination and to the control human-machine interface HMI displays. Verifications were accomplished in various ways including simple instrument disconnect while observing the HMI display value or graphic, instrument disconnect and input of a control signal with control action and HMI display output change and monitoring instrument readings during SBTS operation. SBTS components such as valve actuators, heaters, controllers, steam boiler, etc. were each operated/controlled and held at operating conditions to verify operation and control system performance. The safety system software and its logic structure for 30+ safety functions were checked from instrument input to safety function response and hardware actions.

Instrument calibration. The SBTS flow (thermal mass flow sensors, Coriolis mass flow meters and orifice mass flow meter), pressure, differential pressure and H_2 gas concentration measurements were entered into the RRFCS calibration management system along with initial calibration data. Thermocouples were not added to the management system but separately accounted for in the project instrument list.

- Facility and safety system. The facility systems identified in the contract task description were operationally verified including the compressed natural gas supply, compressed air, and steam boiler delivery systems; system flare, exhaust pressure control system, and facility safety system/alarms. The CPOX reactor was exercised to demonstrate its functional performance and operating procedure. SBTS controls were tuned and performed as required for manual and automatic control functions.

  A lessons learned from the steam boiler operation would have located the 6 kW Chromalox electric steam boiler closer to the test facility rather than in the facility utility room. This change would reduce the steam piping length from more than 100-ft to about 20-ft resulting in reduced startup time for the steam-line electric heat tracing and reduced condensate losses in the steam supply line. The trace heater system and its dedicated control on the supply piping worked well.

System operation. The SBTS was operated with individual component checks (e.g., heater operation, control valve operation and tuning, boiler, etc.), subsystem checks (e.g., CPOX reactor operation, fuel cell stack back-pressure control, etc.) and finally with the full SBTS operation using automatic control and safety system monitor. Examples of these operations are shown in the remainder of this section.

Operation and tuning of the CPOX reactor controls were exercised and completed prior to full SBTS operation. Figure 3.11 shows the typical reactor operation in automatic control with control states including: i) reactor catalyst preheat, ii) fuel introduction and catalyst light-off, iii) steady-state operation, iv) reactor trip from the operating state to standby and ready for fuel introduction and v) reactor shut-down with fuel purge and cool down to ambient.

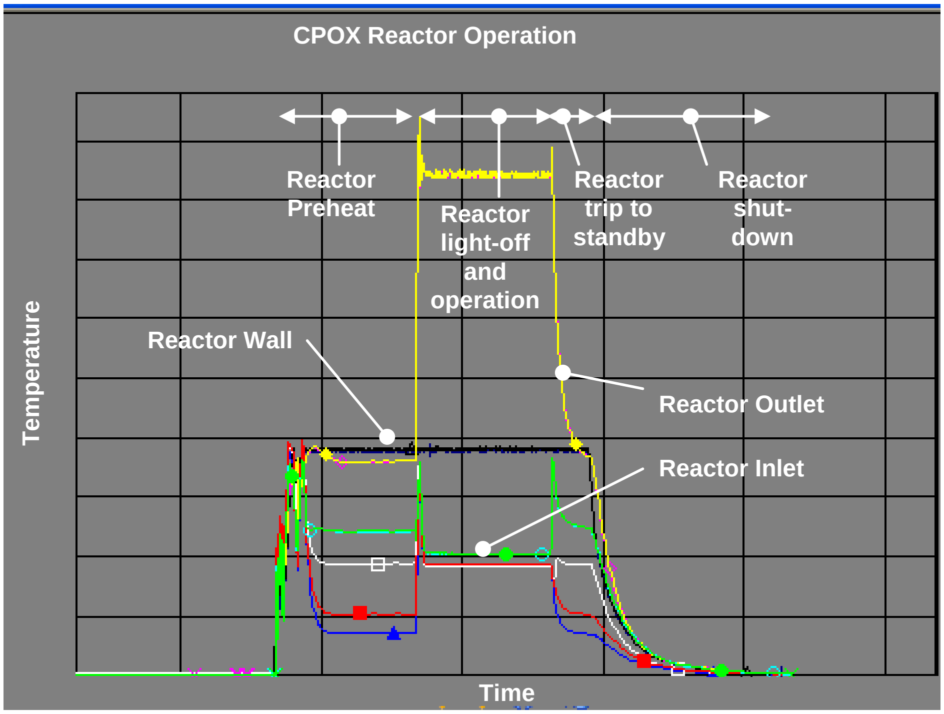

Figure 3.11 CPOX reactor operations

The back pressure control that involved water spray into the hot anode and cathode exhaust streams, and use of a back pressure valve regulator worked well as shown in Figure 3.12. Another component associated with the control involved an Alicat pressure controller that used the fuel cell block pressure to modulate the back pressure regulator dome pressure to maintain the block at its required operating pressure.

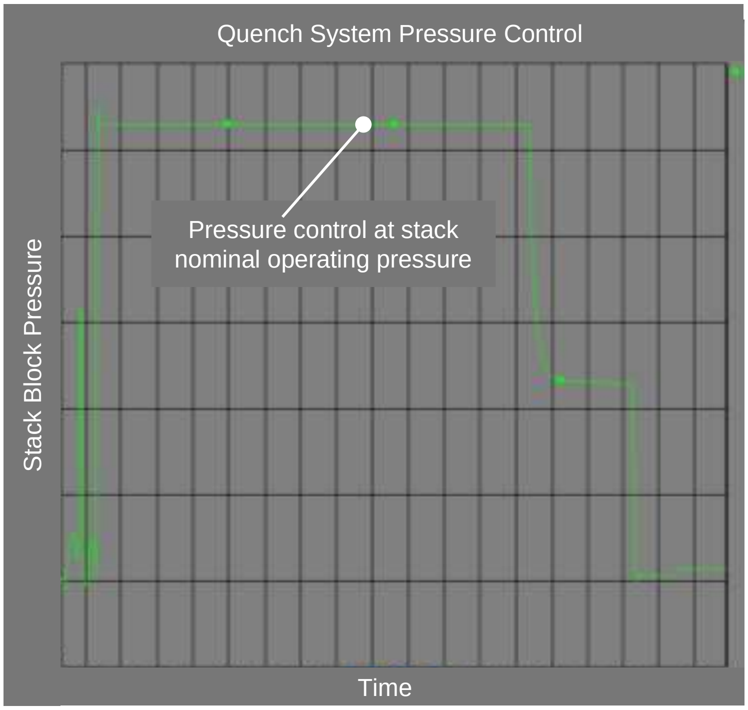

Figure 3.12 SBTS stack block pressure control

Operation and automatic control of the burner was established. Figure 3.13 shows the stack block temperature during air heater operation, burner light-off and stack block heat-up until reaching the maximum required stack block temperature. Burner light-off and temperature were controlled with a H_2/N_2 mixture flow. Following burner light-off, stack block heat-up continued with the air heater operational at constant temperature and burner fuel flow control to achieve the temperature needed for either stack reduction (new fuel cell) or stack electrical operation for a previously reduced block. In all instances, the automatic control functions provided control of air flow and air heater temperature, burner fuel composition and flow, stack block temperature ramp, etc. during burner operation to maintain stack block temperature rise within acceptable limits. Insulation performance was recorded at the maximum temperature and determined to be acceptable.

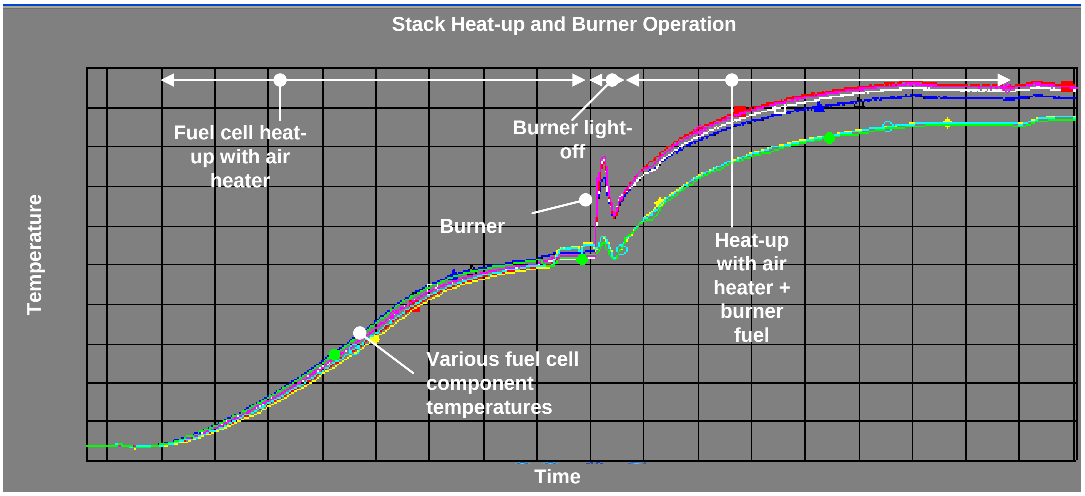

Figure 3.13 Stack heat-up showing burner light-off

Following controls setup and tuning, SBTS was exercised to demonstrate acceptable control for planned SBTS operations. Figure 3.14 is an excerpt from one test in which the stack was heated from ambient to maximum operating temperature including air heater and burner heat sources, maneuvered with auto control to stack block temperatures of interest, and shut-down with normal cool down and emergency shut-down modes of control.

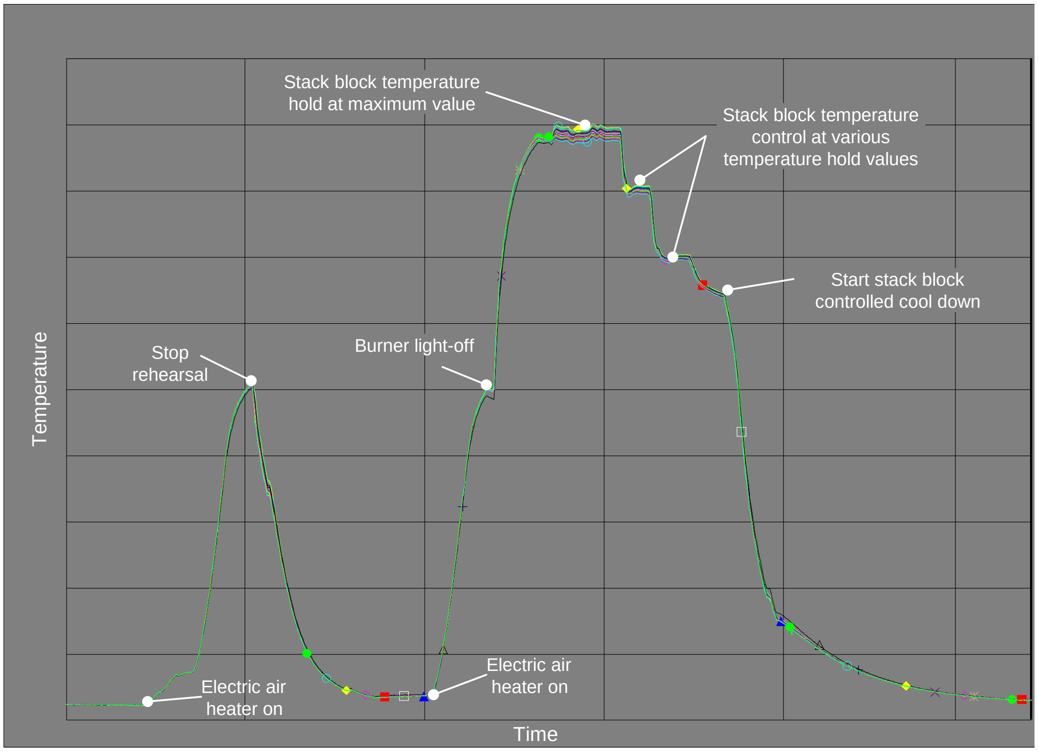

Figure 3.14 SBTS operation with stack temperature control in all operating modes

The SBTS commissioning in preparation for electrical testing of the stack was completed as demonstrated by successful SBTS performance at the various operating states and ability to service each using the implemented control and safety functions. Electrical testing of SBTS was planned to begin by the second quarter of 2011 as part of the Department of Energy's SECA program contract DE-FE0000303.

Lessons Learned

An operating issue during SBTS cool down allowed water from the pressure control system to erroneously flow into the stack region of the vessel with microporous insulation damage. The vessel was removed and returned to the supplier for insulation replacement. A hardware change was made to the SBTS facility water supply that isolated it from the pump by an intermediate storage tank and float-level shut-off valve. This fix prevented water flow to the pressure control system except from pump operation. The pump water supply occurred only when either the anode or cathode exhaust flows were above the 200°C control temperature in the pressure control system. The program schedule was minimally impacted during vessel insulation replacement. During this time the CPOX reactor was able to be operated in stand-alone mode with full operation and controls tuning completed.

Durability and operating life of the custom, high-temperature (e.g., 800°C), compact and high-power density air heater proved challenging. Early heater element failure was not repeatable and measured in hours at the start of the program as compared to a 1-year (or greater) target life. Heater operation was finally achieved through close workings with the supplier and recognition that poor tuning of the heater controller was the primary factor for observed failures. Once the control was properly tuned and minor mechanical improvements implemented, heater performance was satisfactory.

Task 4 – Post-Operation Inspection

SOPO Approach – At completion of Task 3 commissioning, the vessel heads will be removed to inspect the stack and hot-zone components. The inspection will look for indications of hardware mechanical damage on components surrounding the fuel cell (e.g., reformer shell, ejector, bellows and tubing assemblies, instruments, etc.) resulting from the multiple thermal cycles (fuel cell stack heat-up and cool-down) completed during the commissioning test. Prior experience suggests that such damage would not be expected but this hardware does include features not present on previous RRFCS test rigs.

Results and Discussion – Following Task 3 test completion, inspection of the fuel cell stack and hot zone components was made. In general, the internals were found to be in good condition except for the presence of significant carbon deposited in the burner inlet fuel line and some damage (over-temperature operation) to the burner mixing plates. The burner was replaced prior to Phase 2 electrical commissioning and burner gas-mixture adjustments made to its control to reduce the flame temperature.

Lessons Learned

Unacceptable amounts of carbon deposits were found in the SBTS burner fuel line. The burner fuel was initially a mixture of CO, H_2 and N_2. Decomposition of the CO to form carbon in the burner fuel line was not anticipated based on no preheating of the burner fuel and a short residence time in the line. A low temperature (< 350C) was required to limit the kinetic rate for CO decomposition. SBTS testing showed that the heat-up of the gas mixture due to tier environment was sufficiently fast to allow the CO to decompose and form carbon prior to reaching the burner. There was not an appropriate design fix that would allow use of CO and it was decided to discontinue use of CO. As a result, the water vapor content of the burner exhaust was higher than desired for the fuel cell cathode during stack block heat-up. However, burner operation in this mode was determined to be acceptable for the relatively short exposure time between burner use and stack electrically powered operation wherein the burner was either not required or burner heat duty significantly reduced.

4.0 TECHNOLOGY TRANSFER ACTIVITIES

As noted previously, SSC worked closely with RRFCS on execution of the project. The SBTS has been made available to RRFCS for the on-going development of its solid oxide fuel cell technology and training of SSC student interns. SSC has provided and will continue to provide skilled technicians for operation of the SBTS and other test equipment located in the Fuel Cell Prototyping Center. Once RRFCS is producing commercial products, SSC will utilize the SBTS for workforce training.