High-Temperature Electrolysis Test Stand

James O'Brien (Primary Contact),
Richard Boardman
Idaho National Laboratory (INL)
MS 3870
2525 Fremont Ave.
Idaho Falls, ID 83415
Phone: (208) 526-9096
Email: james.obrien@inl.gov

DOE Manager: Jason Marcinkoski
Phone: (202) 586-7466
Email: jason.marcinkoski@ee.doe.gov

Subcontractor:
L&L Mechanical, Inc., Blackfoot, ID

Project Start Date: August 1, 2016
Project End Date: Project continuation and direction determined annually by DOE

Overall Objectives

- Deploy a 25-kW high-temperature electrolysis (HTE) flexible test facility at the Idaho National Laboratory (INL) Energy Systems Laboratory.
- Integrate the HTE system with colocated thermal energy systems, including a high-temperature, high-pressure water flow loop and a thermal energy storage system.
- Integrate the HTE test station with colocated digital real-time simulators for dynamic performance evaluation and hardware-in-the-loop simulations.
- Perform HTE stack testing using hardware obtained from industry partners; focus on flexible intermittent and reversible operation and the effects of flexible operation on long-term performance.
- Work with HTE industry partners to demonstrate performance of flexible intermittent operation of large HTE systems.

Fiscal Year (FY) 2018 Objectives

- Complete installation of 25-kW HTE system including:
  - Mechanical and electrical utilities/infrastructure to support operation of the 25-kW HTE flexible test station
  - Installation of experiment components within a Perma-Con enclosure; electrical hookups and process piping
  - Installation of system instrumentation: mass flow controllers, pressure transducers, thermocouples, etc.
- Prepare and submit experiment laboratory instruction to review committee for approval of research operations and activities.
- Complete configuration and Labview programming of data acquisition/instrument control system.
- Conduct stand-alone testing of components to verify expected performance.
- Conduct system checkout and shakedown testing.

Technical Barriers

This project addresses the following technical barriers from the Technology Validation section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan[1]:

(G) Hydrogen from Renewable Resources

(H) Hydrogen and Electricity Co-Production.

Contribution to Achievement of DOE Technology Validation Milestones

This project will contribute to achievement of the following DOE milestones from the Technology Validation section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan:

- Milestone 3.5: Validate distributed production of hydrogen from renewable liquids at a projected cost of $5.00/gasoline gallon equivalent and from electrolysis at a projected

[1] https://www.energy.gov/eere/fuelcells/downloads/fuel-cell-technologies-office-multi-year-research-development-and-22

cost of $3.70 with an added delivery cost of <$4/gasoline gallon equivalent. (4Q, 2018)

- Milestone 3.9: Validate large-scale system for grid energy storage that integrates renewable hydrogen generation and storage with fuel cell power generation by operating for more than 10,000 hours with a round-trip efficiency of 40%. (4Q, 2020)

FY 2018 Accomplishments

- Completed installation/assembly of laboratory mechanical and electrical utilities/infrastructure.
- Completed welding of high-temperature SS 310 pipe fittings.
- Completed installation of experiment components and support systems within the Permacon enclosure, including electrical power and process piping.
- Submitted laboratory instruction governing HTE research activities and operations for approval.
- Completed installation of system instrumentation and development of the Labview data acquisition/system controller program.
- Completed development of Labview-based data acquisition and instrument control system.
- Completed testing of all major components.
- Demonstrated hydrogen recycle operations.

INTRODUCTION

High-temperature electrolysis of steam for hydrogen production is an advanced water-splitting technology that exhibits high electric-to-hydrogen efficiency, especially when coupled to an integrated high-temperature process heat source. INL developed a world-class HTE laboratory and test capability under the DOE Office of Nuclear Energy Nuclear Hydrogen Initiative during the 2002–2012 time period. The focus of the current project is to establish a new HTE research and demonstration facility at INL to enhance the existing INL core capability in HTE and to support systems integration, systems operation, HTE model validation, and technical performance characterization of advanced hydrogen production by high-temperature water splitting. The initial thrust of this project is the development of a 25-kW flexible test station to support integrated operation of state-of-the-art HTE stack technologies from multiple industry partners. Establishment of the 25-kW HTE system will be followed by deployment of a test skid with infrastructure support for up to 250-kW HTE turnkey systems.

The new HTE test capability will be designed for integrated operation with the INL Power Systems Test Bed (comprising real-time digital/real-time simulation units and a renewable-power microgrid) and the forthcoming Dynamic Energy Transport and Integration Laboratory (DETAIL). The HTE system will be colocated with a high-temperature high-pressure pressurized water reactor flow loop, which will be thermally integrated with the HTE system via a Thermal Energy Distribution System (TEDS) that is currently in the final detailed engineering design phase, with funding from the DOE Office of Nuclear Energy, under the Nuclear-Renewable Hybrid Energy Systems initiative. TEDS will have its own high-temperature (up to 340°C) heater to support independent operation as a heat source. It will also include a large (200-kWh) thermal energy storage system based on a packed-bed thermocline tank with a solid alumina particulate sensible heat storage medium. System integration will enable assessment and characterization of dynamic HTE operation to simulate load-leveling capability with intermittent power from renewables and a fluctuating demand profile. This project leverages emerging and demonstrated high-temperature water splitting by HTE and high-temperature solid oxide cell technology, which may include reversible HTE/solid oxide fuel cell operation.

APPROACH

The new HTE Technology Validation capability under development at INL will include a 25-kW flexible HTE test station as well as infrastructure support for up to 250-kW HTE turnkey systems. At the 25-kW scale, this approach will enable thermal integration with colocated thermal energy sources as well as integrated operation with the INL Power Systems Test Bed. The 25-kW system will be flexible, allowing HTE operation from the 5-kW to the 25-kW scale, with support for intermittent and reversible operation. INL will work with various industrial partners to supply the HTE stacks and to design the test matrices. The 250-kW infrastructure installation will support demonstration and testing of industry-supplied pilot-scale turnkey systems with grid integration and variable operation.

The flexible HTE test station has been designed to support HTE operations in the 5- to 25-kW range. At the 25-kW scale, the hydrogen production rate will be approximately 135 standard liters per minute or 12.1 g/min. For a typical solid oxide electrolysis cell active area and current density of 144 cm^2 and 0.67 A/cm^2, respectively, and four stacks, the current and voltage will be 96.5 A and 65 V per stack. The test station includes four DC power supplies, each rated at 100 V and 100 A to supply electrolysis power to the stacks. The HTE system was assembled on a skid with all the hydrogen components positioned inside of a ventilated enclosure with an active gas monitoring system that is interlocked to the hydrogen production process for safety.

RESULTS

Assembly of the 25-kW HTE system has been completed. An overview photograph of the installation is provided in Figure 1. Major system components include a large top-hat furnace, steam generator/superheater, air compressor, chiller, hydrogen compressor, air-cooled hydrogen outlet finned tube array, water-cooled condensers, a hydrogen storage tank, plus associated instrumentation including mass flow controllers, pressure transducers, and thermocouples. The ventilation exhaust duct from the experiment enclosure is visible in the top of Figure 1. A blower that is mounted outside of the building draws air from the surrounding high bay laboratory through the experiment enclosure and through the exhaust duct to the outside blower. The hydrogen vent line can also be seen in the top of Figure 1.

Figure 1. Overview of the 25-kW HTE experiment skid and enclosure within the INL System Integration Laboratory

The steam generator is an inductively heated unit that delivers high-temperature superheated steam (up to 900°C) directly from an inlet flow of room-temperature liquid deionized water. The HTE system will also include a heat exchanger option (Phase II) for process-heat-based steam generation when the DETAIL thermal network is complete. The furnace that will house the HTE stacks has a movable top hat that lifts up to expose the hot zone for installation of test articles. The electrolysis stacks will be positioned within the hot zone for testing at 800°C. The steam generator and furnace are shown installed inside the experiment enclosure in Figure 2. The inlet flow to the electrolysis stacks will include steam plus hydrogen. Hydrogen must be included on the inlet side in order to maintain reducing conditions on the electrolysis cell cathodes. During start-up, hydrogen will be supplied from compressed gas cylinders, but for long-term operation, a fraction of the hydrogen that is produced by steam electrolysis is recycled from the electrolyzer outlet flow back to the inlet after steam is removed by a combination of low-pressure condensation, compression, and high-pressure condensation. Condensation is aided by cooling the condenser units and the counterflow heat exchanger using chilled water at 5°C delivered from a refrigerated chiller. A finned-tube air-cooled natural convection heat exchanger is used for the initial cooling of the outlet hydrogen/steam flow that exits the hot zone at high temperature. The finned-tube array and the chilled-water-cooled condensers are shown in Figure 3. The hydrogen recycle system, including the compressor and hydrogen storage tank, is shown in Figure 4. Nitrogen is included as an inert carrier gas and a purge gas. Air is supplied to the anode side of the HTE stacks as a sweep gas to remove electrolytically produced oxygen from anode side of the stacks. Compressed air is produced by an air compressor, metered by a precision mass flow controller, and preheated to 800°C using a high-temperature in-line gas heater prior to entering the hot zone.

Figure 2. Superheated steam generator and high-temperature furnace in experiment enclosure

Figure 3. Finned-tube steam coolers and water-cooled condensers

Figure 4. Hydrogen recycle compressors system compressor, storage tank, and counterflow heat exchanger

In terms of safety, because this system has been deployed in a large, high-bay laboratory, all hydrogen-related components are positioned inside a ventilated enclosure (12 ft x 14 ft x 10 ft), which includes a gas monitoring system. The enclosure is shown in Figure 1. The gas monitoring system is interlocked to the hydrogen gas supply and the electrolyzer power supplies such that hydrogen gas inlet flows and hydrogen production in the electrolyzer are both terminated in the event of a hydrogen gas alarm. An alarm condition will also initiate the flow of "safe gas" through the cathode side of the stacks. Safe gas is a mixture of nitrogen and hydrogen (3.96% H_2) that will continue to flow through the cathode side of the electrolysis stacks to prevent oxidation damage to the cathodes until normal operations can be resumed or the system is shut down. The ventilation system also includes an airflow switch that will generate an alarm signal in the event of loss of ventilation flow. In addition to the automated interlock features of the gas monitoring system, the system will notify laboratory occupants of the presence of a potentially hazardous buildup of these gases. The system has relay outputs, display readout, visual and audible alarms, and an autodialer.

CONCLUSIONS AND UPCOMING ACTIVITIES

A new 25-kW flexible HTE test station has been installed at INL in the Energy System Laboratory Building, Systems Integration Laboratory. This test station will serve as an experimental platform for the advancement of HTE technology as well as system integration studies. The test station has been designed for stand-alone operation, but it will also be thermally integrated with colocated systems via a thermal energy distribution system, and electrically integrated with a controllable microgrid, allowing for demonstration and characterization of dynamic hybrid energy concepts.

Fully integrated non-electrolysis operational testing of all HTE systems will be completed by the end of November 2018. Initial electrolysis testing at the 5-kW scale will be performed in the February 2019 time frame. A request for proposals has been released to three domestic suppliers of solid-oxide electrolysis stacks for bid. Procurement of stacks for support of 25-kW testing will be pursued, budget permitting, later in FY 2019, with full-scale testing to follow. Thermal integration of the HTE test stand with the high-temperature water loop will be implemented during FY 2020, after the installation and qualification of TEDS. This integration will require procurement of a heat exchanger to support boiling of the liquid water feedstock, plus a separate steam superheater.

FY 2018 PUBLICATIONS/PRESENTATIONS

1. J.E. O’Brien, “A 25-kW High-Temperature Electrolysis Facility for Flexible Operation and System Integration Studies,” conference paper in preparation, 2018.