VII.D.2 High Temperature Electrolysis Test Stand

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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 INL Energy Systems Laboratory.
- Integrate the HTE system with co-located thermal energy systems, including a high-temperature, high-pressure water flow loop and a thermal energy storage system.
- Integrate the HTE test station with co-located 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.
- Deploy infrastructure for up to 250 kW HTE turnkey systems.
- Work with HTE industry partners to demonstrate performance of flexible intermittent operation of large HTE systems.

Fiscal Year (FY) 2017 Objectives

- Complete design of 25 kW HTE system, including operating and design specifications, piping and instrumentation diagram, system layout, and laboratory infrastructure requirements.
- Identify and procure system components and vendors.
- Begin installation and assembly of HTE experimental system (to be completed in FY 2018).
- Prepare research documentation, including Quality Level Determination and Laboratory Instruction.

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.

(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/gge and from electrolysis at a projected cost of $3.70 with an added delivery cost of <$4/gge (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 2017 Accomplishments

- Completed research plan, documenting overall objectives, technical and commercial barriers, HTE test objectives, summary of previous HTE research at INL, test stand design requirements, installation and operational requirements, and system integration plan.
- Completed system design, including functional and operational requirements documentation, piping and instrumentation diagram, identification and specification of components and vendors, procurement of components, design and fabrication of test skid, and design of supporting laboratory infrastructure (ventilation, power, water, drain, etc.).
- Engaged INL engineering group on laboratory infrastructure requirements and design.

- Contacted HTE industry representatives concerning HTE stack specifications and procurement options.
- Completed research documentation including Quality Level Determination and Laboratory Instruction.

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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 integrated high-temperature process heat sources. 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 this project is to establish a new HTE 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 for demonstration 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 (comprised of 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 co-located with a high-temperature high-pressure water flow loop, which is the first leg of the Advanced Reactor Technology Integral System Test Facility that will be installed under an Office of Nuclear Energy Hybrid Energy Systems project. 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. Thermal integration with co-located thermal energy sources including a high-temperature flow loop and thermal energy storage systems can also be demonstrated. This project leverages emerging and demonstrated high-temperature water splitting by HTE and high-temperature solid oxide fuel cell technology which may include reversible HTE/solid oxide fuel cell operation.

APPROACH

The new HTE Technology Validation demonstration capability under development at INL will include both a 25 kW flexible test station plus infrastructure support for up to 250 kW HTE turnkey systems. At the 25 kW scale, this approach will enable demonstration of thermal integration with co-located 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.

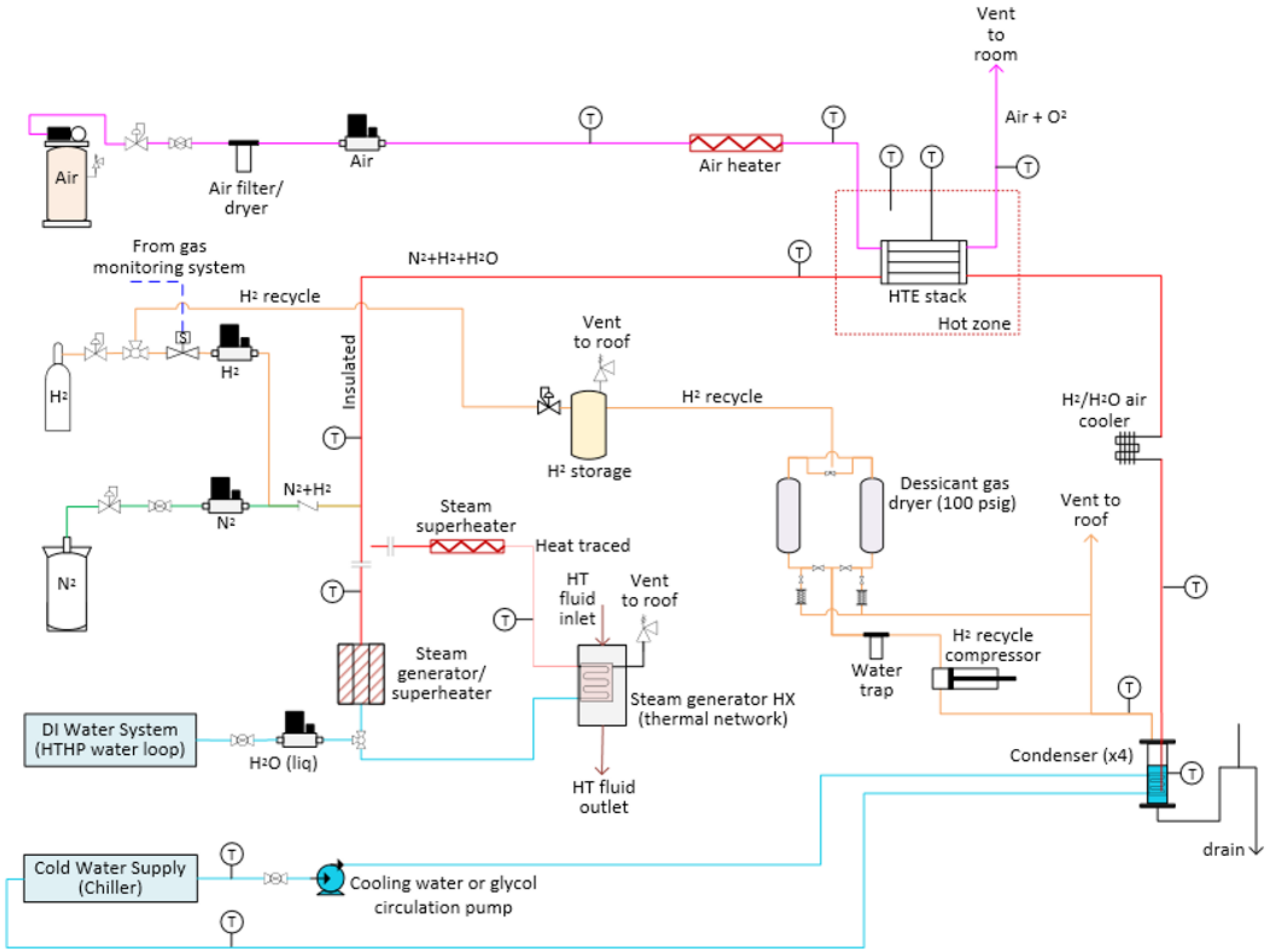
RESULTS

This is a new experimental project. Progress to date is represented by the system design and supporting analyses.

A schematic of the 25 kW HTE testbed is provided in Figure 1. The system has been designed to be as simple as possible, with all major components obtained commercially, rather than custom-designed and fabricated. The steam generator is an inductively heated unit that provides high-temperature superheated steam directly from liquid water. The system will also include a heat exchanger option for process-heat-based steam generation when the DETAIL thermal network is complete. The electrolysis stacks are positioned within the hot zone for testing at 800°C. The inlet flow 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 startup, hydrogen will be supplied from a gas cylinder, but for long-term operation, a fraction of the produced hydrogen will be recycled from the outlet flow back to the inlet after steam is removed by a combination of condensation, compression, and desiccant drying. Nitrogen is included as an inert carrier gas and a purge gas.

A three dimensional computer aided design model of the 25 kW HTE system layout has been prepared, as shown in Figure 2. Major components include a large lift-top furnace, steam generator/superheater, air compressor, chiller, hydrogen compressor, air-cooled hydrogen outlet finned tube array, water-cooled condensers, hydrogen storage tank, and a desiccant dryer. In terms of safety, since this system will be deployed in a large, high-bay laboratory, all hydrogen-related components are positioned inside of a ventilated enclosure (12 ft x 14 ft x 10 ft) which includes a gas monitoring system. The gas monitoring system is interlocked to the hydrogen gas supply (see solenoid valve in Figure 1) and electrolyzer power supplies such that hydrogen gas inlet flows and hydrogen production in the electrolyzer are both stopped in the case of a hydrogen gas alarm situation.

Operating specifications for 25 kW testing are listed in Table 1. The values listed in Table 1 are based on four 50-cell electrolysis stacks with active area of 144 cm^2. The cell area specific resistance value is assumed to be 0.6 $\Omega\ cm^2$ and the



HT – high temperature; HTHP – high temperature high pressure

FIGURE 1. Schematic of 25 kW high-temperature test stand

current density is 0.67 A/cm^2 (these are conservative values). Steam utilization of 0.6 and a hydrogen inlet mole fraction of 0.1 are assumed. Instrumentation such as gas mass flow controllers have been specified based on these operating conditions. In addition, tubing sizing has been based on these flow rates.

CONCLUSIONS AND UPCOMING ACTIVITIES

Assembly of the 25 kW HTE demonstration facility will be completed during the first and second quarters of FY 2018. This will include shakedown testing and initial stack testing at the 5 kW scale. Procurement of stacks for support of 25 kW testing will also occur in the second quarter of FY 2018. Full-scale testing is planned for later in third and fourth quarters of FY 2018. Thermal integration of the HTE test stand with the high-temperature water loop will be implemented during FY 2018. This integration will require procurement of a heat exchanger to support boiling of the liquid water feedstock, plus a separate steam superheater.

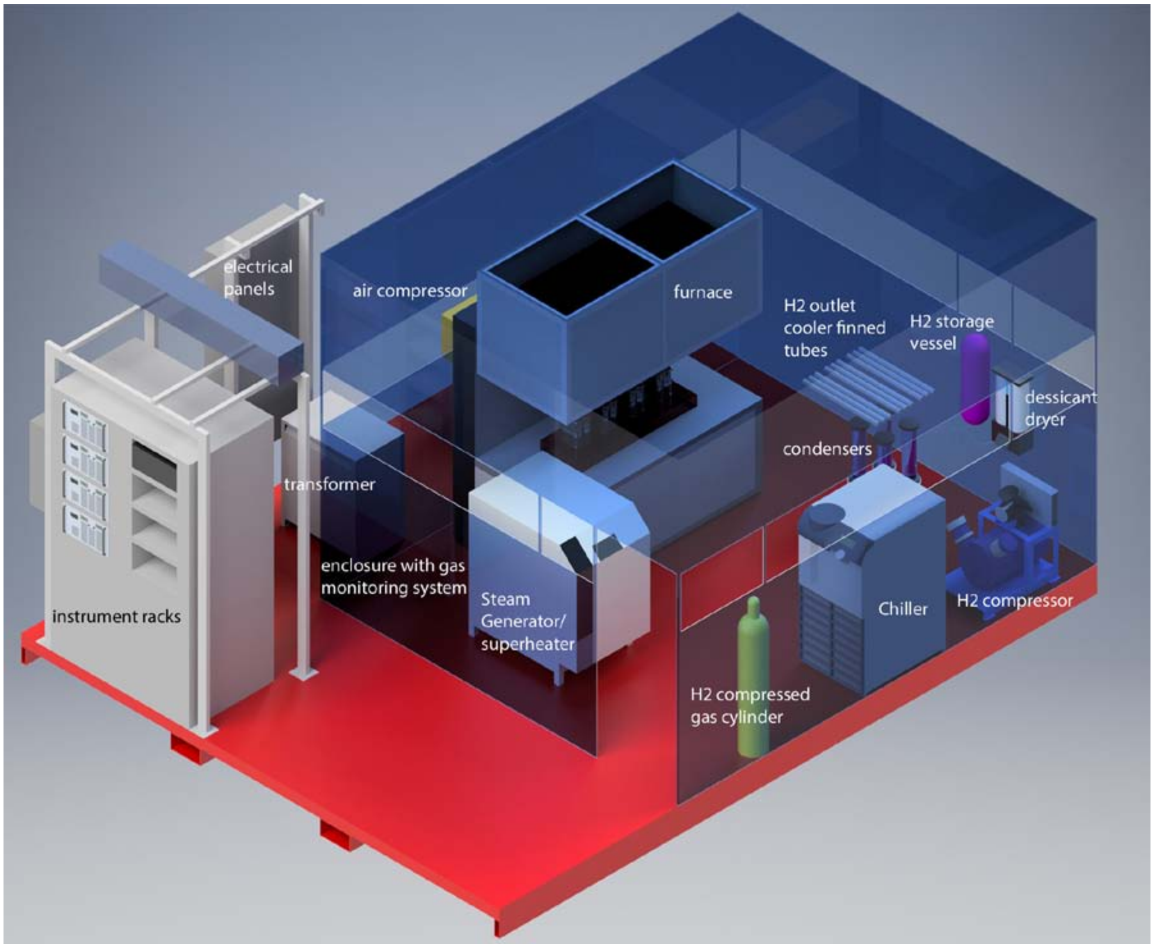


FIGURE 2. Layout for 25 kW HTE test facility

TABLE 1. Electrolyzer Operating Specification for 25 kW Operation

Flow Rates		Units
H_2 in	24.9	SLPM
	0.879	SCFM
H_2 production rate	134.5	SLPM
H2 out	159	SLPM
H_2O in (liq)	180	gm/min
H_2O in (liq)	10.8	kg/h
H_2O in (steam)	224	SLPM
H_2O out (steam)	89.6	SLPM
N_2 in	0	SLPM
Total cathode gas flow in	249	SLPM
	8.79	SCFM
Air in	160	SLPM
	5.65	SCFM
O_2 production rate	67.2	SLPM
Air+O_2 out	227	SLPM
	8.03	SCFM
Recycle Flow Rates		
H_2 through beds (avg)	0.879	SCFM
H_2O into beds (avg)	0.014	SCFM
Recycle compressor flow	5.8	SCFM
N_2 through beds (avg)	0	
N_2 added after recycle	0	
H_2 compressor run time	29.9	s
H_2 compressor idle time	162	s
Stack Electric		
Cell voltage	1.302	V
Stack voltage	65.1	V
Stack current	96.5	A
Module current	385.9	A
Module power	25.1	kW
Hot Zone		
Top	800	°C
Heater Power		
Steam generator (H_2O from 20°C to 150°C)	8.1	kW
Superheater (H_2 +N_2 from 20°C to 800°C + steam from 150°C to 800°C)	4.15	kW
Air heater/superheater	2.85	kW

SLPM – standard liters per minute; SCFM – standard cubic feet per minute; liq – liquid; avg – average