High Temperature Electrolysis Test Stand

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2020 Annual Merit Review

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Project ID # TA018

Overview

Timeline
Project Start Date: 4/1/2017
End Date: currently planned through FY20; Project continuation and direction determined annually by DOE

Budget
FY17 DOE Funding: $1.49M
FY18 DOE Funding: $800k
FY19 DOE Funding: $800k
FY20 DOE Funding: $700k

Barriers
This project addresses the following technical barriers from the Technology Validation section of the FCTO MYRDD Plan:

(G) Hydrogen from Renewable Resources
- little operational, cost, durability, and efficiency information for large integrated renewable electrolyzer systems that produce hydrogen

(H) Hydrogen and Electricity Co-Production
- Cost and durability of hydrogen fuel cell or alternative-power production systems and reformer systems for co-producing hydrogen and electricity need to be validated at user sites.

Partners
- US DOE: Project Sponsor and Funding
- NREL: Power converter and front-end controller integration
- PNNL: HTE stack design and fabrication
- SNL: front-end controller development and testing with respect to grid interactions

Relevance

Objectives:

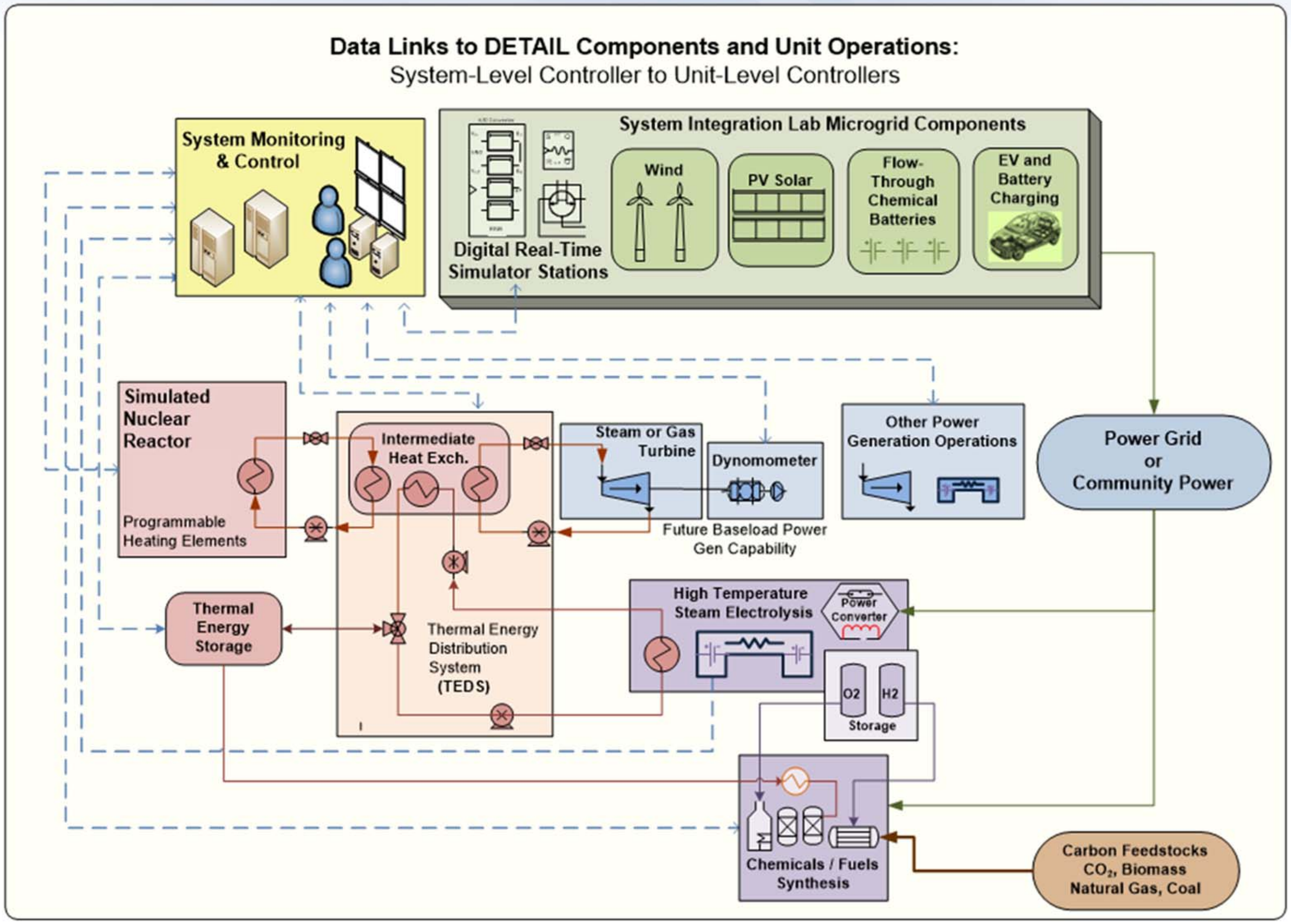
- Advance the state of the art of High Temperature Electrolysis (HTE) technology while demonstrating grid and thermal energy integration and dynamic performance characteristics
- Perform long-term HTE stack tests for characterization of stack performance and degradation rates; engage multiple stack manufacturers
- Develop infrastructure to support integrated HTE operations up 250 kW scale

Barrier	Impact
little operational, cost, durability, and efficiency information for large integrated renewable electrolyzer systems that produce hydrogen	• 25 kW HTE Facility is now fully operational • facility has been deployed in the INL Systems Integration Laboratory which includes a microgrid and renewable energy sources
Cost and durability of hydrogen fuel cell or alternative-power production systems and reformer systems for co-producing hydrogen and electricity need to be validated at user sites.	• Project will provide long-term operational data of large-scale HTE systems, with a focus on stack performance durability • Plans have been developed for deployment of large-scale HTE systems at nuclear power plants for operational and grid stability demonstration

Approach

- Deploy, integrate, and operate flexible 25 – 250 kW HTE test facilities in the INL Dynamic Energy Transport and Integration Laboratory (DETAIL)
  - Promote wider use of carbon-free renewable and nuclear energy in coordinated configurations
  - Demonstrate and characterize simultaneous coordinated multi-directional transient distribution of electricity and heat for multiple industrial process heat applications
  - Characterize system performance under long-term and flexible operating conditions
  - Simulate broader systems using real-time digital simulators with hardware-in-the-loop configurations
  - Document HTE operational and performance characteristics in a grid-dynamic environment
- Evaluate the potential of HTE systems to achieve efficient, low-cost hydrogen production with optimized operational profiles designed to take advantage of intermittent low-cost electricity and integrated process heat
  - Document overall stack performance, degradation rates, and mechanisms
  - Document performance characteristics associated with intermittent HTE operations
  - Investigate the impacts of grid instability on HTE operations
  - Demonstrate the utility of HTE thermal integration with co-located systems

Approach



INL Dynamic Energy Transport and Integration Laboratory showing HTE System Integration

Approach - Milestones

Milestone	Date	Status
FY19 Q3. Demonstrate HTE module response rates to support grid net load generation curtailment	6/30/2019	complete
FY19 Q4 Conduct an HTE stack degradation test with real-time measurement of stack performance	9/30/2019	complete
FY20 Q1. Characterization of HTE performance under dynamic grid conditions based on coupling with the DRTS as Hardware-In-the-Loop.	10/31/2019	complete
FY20 Q2. Complete a minimum of 2,100 hours testing of a commercially provided 5-20 kWe stack set to benchmark stack performance.	3/21/2020	In progress
FY20 Q4. FY20 Q4 Complete a minimum of 1,000 hours of testing of 5-20 kWe stacks provided by two additional providers.	9/30/2020	In progress

Accomplishments and Progress

- Completed Installation and Commissioning of 25 kW HTE Test Facility
- Completed Initial Test Campaign at the 5 kW scale, with long-term operation over 1000 hours
- Demonstrated integrated operation with remote supervisory control of stack operation, including multiple voltage-current sweeps

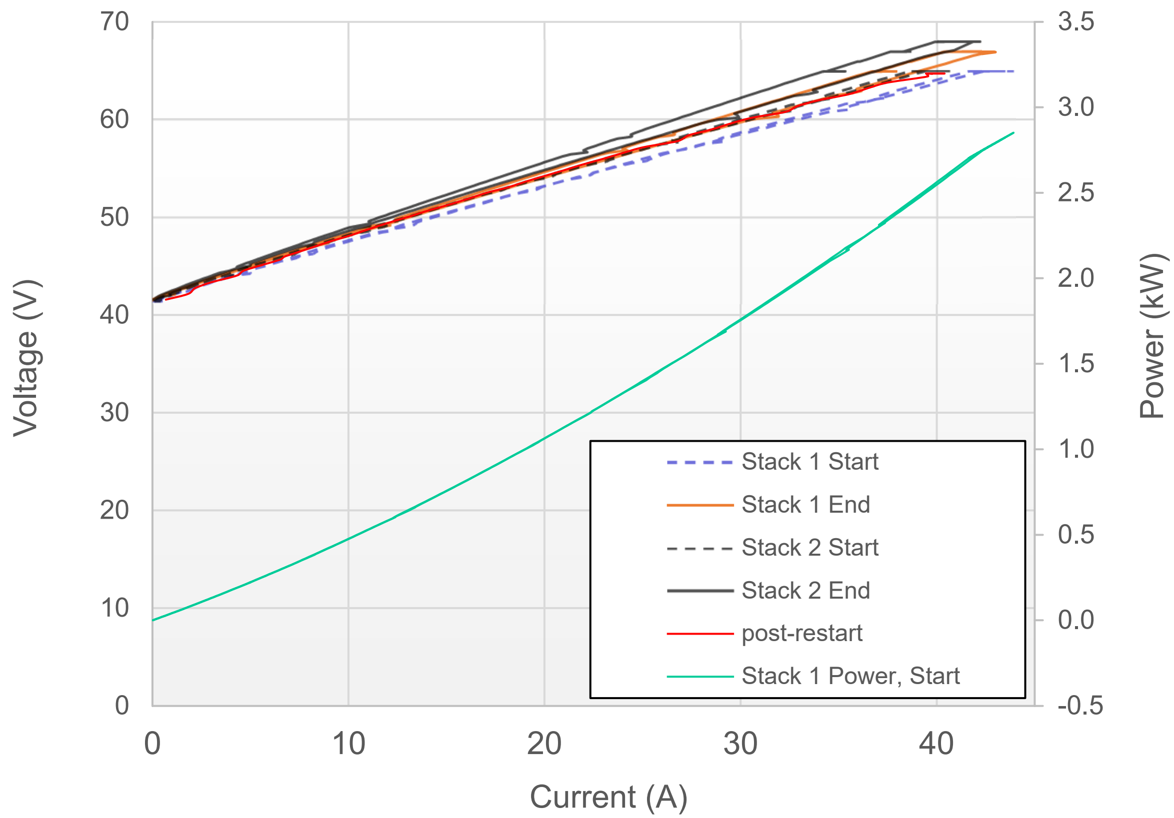
25 kW HTE Facility

5 kW stack installed in hot zone

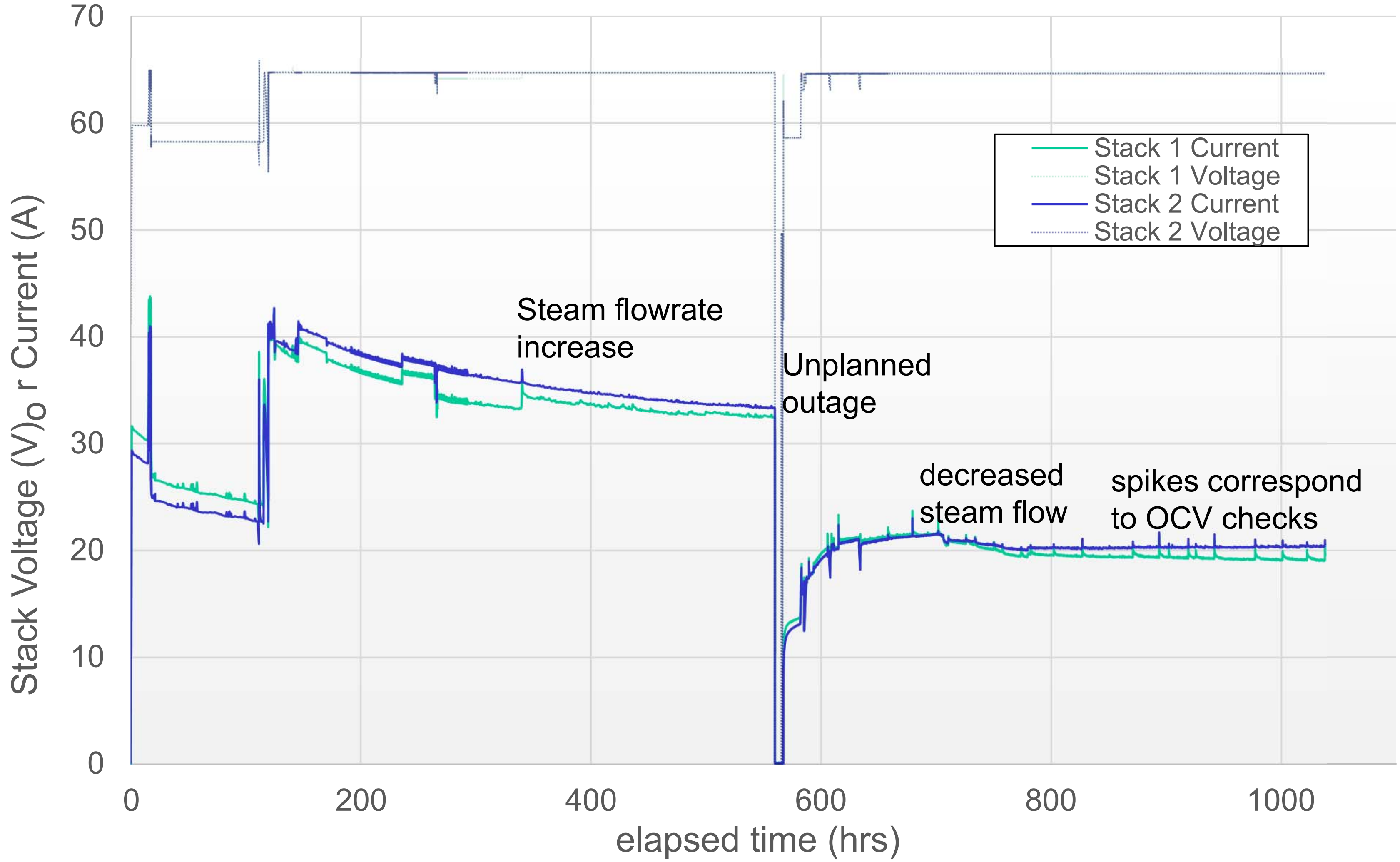
Accomplishments and Progress

- Completed Installation and Commissioning of 25 kW HTE Test Facility
- Completed Initial Test Campaign at the 5 kW scale, with long-term operation over 1000 hours
- Demonstrated integrated operation with remote supervisory control of stack operation, including multiple voltage-current sweeps

Results of initial and final cyclic voltammetry for the two OxEon stacks



Accomplishments and Progress

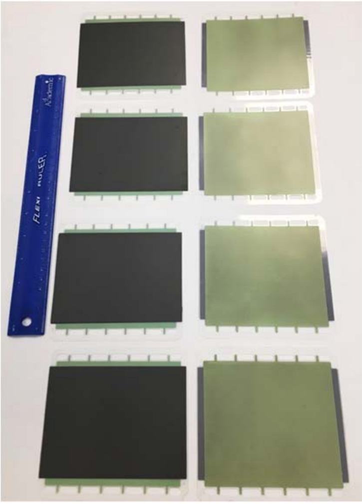


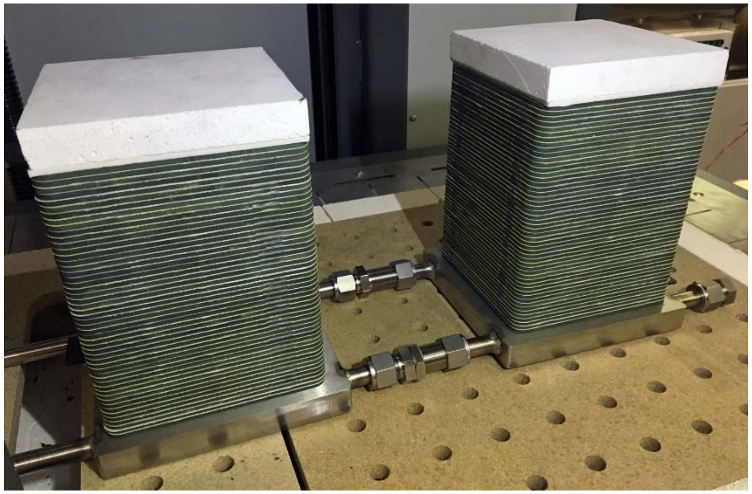
Time history of 5 kW stack voltage and current, 1000-hour test

Accomplishments and Progress

SOEC Stack Development – Subcontract with OxEon Energy

SOEC Stack Fabrication in progress for INL 10 kW SOEC Tests





Stacks delivered to INL for 5 kW Test Campaign, May 2019

Component production

Interconnects
- New interconnect lot of 720 parts has been delivered and coated

Electrolytes
- Fabrication complete

Cells
- electrode inks produced and qualified

Reviewer Comments

"The collaborations with industry seem appropriate. However, it does seem like this project is quite separated from other energy system experts across other national laboratories, such as NREL. It would seem appropriate to implement more collaboration with these laboratories, especially to bring context to the testing results."

- We are strengthening our collaborations with NREL and PNNL. The NREL collaboration includes remote data access to their low-temperature electrolysis units with real-time data feed to INL. We will be providing similar real-time data from the HTE units for grid stability studies. PNNL is working to provide state-of-the-art SOEC stacks to INL for operation in the 25 kW test facility.

"The project has activity-based goals and targets rather than clear performance-based goals. For maximum relevance, it needs clear goals tied to hydrogen production targets."

- The ultimate performance targets are related to the per-kg cost of hydrogen produced using HTE. The current focus is on stranded nuclear/renewable power that may enable low-cost hydrogen production during high energy supply/low demand time periods. INL is working closely with several utilities to develop strategies and demonstrations designed to achieve low-cost carbon-free hydrogen production, competitive with steam methane reforming, using a flexible-grid approach.

Reviewer Comments

"The relevance of working on oxygen-producing units (i.e., solid oxide electrolysis [SOE] and the Mars Oxygen ISRU Experiment [MOXIE]) is not clear. There should be clearer tie-ins to hydrogen production and plans for redesigning or repurposing these units to optimize hydrogen production rather than oxygen."

- Oxygen is always produced as part of the high-temperature electrolysis process whether the electrolysis gas is carbon dioxide, steam, or a combination of the two. The hardware required to electrolyze CO_2 for oxygen production is identical to the hardware used for steam electrolysis. The relevance of the technology details that were developed for the Mars oxygen production demonstration is related to the fact that these units incorporated matched-CTE interconnects and glass seals. These features have been included in the larger scale stacks tested at INL. These features provide tolerance to thermal cycling and hermetic seals.

Collaboration and Coordination

DOE Partnerships

- DOE-NE / DOE-EERE Collaboration
  - Integrated Energy Systems

Industrial Partnerships

- OxEon Energy
  - Stack development and testing
- Nexceris
  - SOEC stack development
- Fuel Cell Energy
  - Large-scale systems
- Exelon
  - Grid stability, non-electric markets for nuclear
- Small Modular Nuclear Reactor
  - Joint-Use Modular Plant

Collaboration and Coordination

National Laboratory Partnerships

- PNNL
  - HTE Stack development
- NREL
  - Power converter and Front-End Controller testing
- SNL
  - Front-End Controller development and testing with respect to grid interactions

Remaining Challenges and Barriers

- Long-term performance of Solid Oxide Electrolysis Cell (SOEC) stacks
  - Demonstrate long-term low-degradation stack performance using stacks from several providers
  - Degradation must be <~0.5%/khr or lower for economic viability
  - Intermittent operation and thermal cycling may accelerate degradation
  - Reversible operation may improve long-term degradation characteristics
  - Effects of grid instability on HTE system performance must be determined
- Optimization of HTE operation in dynamic environment for achievement of low-cost H_2 production while providing grid stabilization services and new revenue streams
- Reduction of HTE system capital costs
- Effective thermal integration and thermal management for integrated and intermittent/ reversible operation

Proposed Future Work

Remainder FY20

- Perform additional long-term HTE testing in new facility at the 10 kW scale (OxEon stacks to be delivered in 5/20)
  - Steady-state, baseline testing; long-term degradation
  - Effects of intermittent operation and thermal cycling
- Complete HTE test campaigns with stacks from other suppliers
  - Haldor Topsoe
  - PNNL
  - Steady-state, baseline testing; long-term degradation
  - Effects of intermittent operation and thermal cycling
  - Operation with variable front-end power profiles
- Support the advancement of HTE stack technology, working with industry partners, for robust performance even with the demanding load profiles associated with deployment in flexible hybrid energy systems

FY20/21

- Conduct 25 kW grid demand response exercises, documenting the thermal energy latency and system electrical characteristics
- Establish large-scale (250 kW) test capability at INL

Note: Any proposed future work is subject to change based on funding levels

Technology Transfer Activities

- Working with large companies to identify new markets for large-scale hydrogen production with thermal integration
  - Direct-reduced iron
  - Grid stabilization
  - Enhanced profitability for existing light-water reactor fleet (non-electric application)
  - Synthetic liquid fuels

Summary

Objective: Advance the state of the art of High Temperature Electrolysis (HTE) technology while demonstrating grid and thermal energy integration and intermittent/reversible operation

Relevance: The growing contribution of renewable sources of electric power onto the grid requires increased flexibility in dispatchable energy producers. Appropriately staged hydrogen production via HTE provides a potential high-value product for increased profitability

Approach: Deploy, integrate, and operate flexible 25 – 250 kW HTE test facilities in the INL Dynamic Energy Transport and Integration Laboratory (DETAIL); Evaluate the potential of HTE systems to achieve efficient, low-cost hydrogen production with optimized operational profiles designed to take advantage of intermittent low-cost electricity and integrated process heat

Accomplishments: Completed Installation and Commissioning of 25 kW HTE Test Facility; Completed Initial Test Campaign at the 5 kW scale, with long-term operation over 1000 hours; Demonstrated integrated operation with remote supervisory control of stack operation, including multiple voltage-current sweeps

Collaborations: Collaborations have been established with several National Laboratory and industry partners.

Technical Backup Slides

Nominal operating conditions for full 25 kW testing

Assumptions

Acell = 12 cm x 12 cm
Ncells = 50
Nstacks = 4
ASR = 0.6 Ω cm^2
i = 0.67 A/cm^2
steam utilization, U = 0.6
inlet mole fraction steam: 0.7, 0.9
inlet mole fraction H2: 0.1
inlet mole fraction N2: 0.2, 0.0
Air sweep gas, Nstoichs = 0.5

Flow Rates	With N2	No N2	units
H2 in	32.0	24.9	SLPM
H2 Production rate	134.5	134.5	SLPM
H2 out	166.5	159	SLPM
H2O in (liq)	180	180	gm/min
H2O in (liq)	10.8	10.8	kg/hr
H2O in (steam)	224	224	SLPM
H2O out (steam)	89.6	89.6	SLPM
N2 in	64	0	SLPM
Total Cathode gas flow in	320.2	249	SLPM
Air in	160	160	SLPM
O2 Production rate	67.2	67.2	SLPM
Air+O2 out	227	227	SLPM
	8.03	8.03	SCFM
Recycle Flow Rates			
Recycle compressor flow rating (@150 psig discharge pressure)	6.1	6.1	SCFM
Recycle compressor VFD setting	100	75	% of FS
H2 through beds (avg)	1.131	0.879	SCFM
H2O into beds (avg)	0.0038	0.0021	SCFM
N2 Through beds (avg)	0.435	0	SCFM
H2 through beds (during compressor operation)	4.285	4.221	SCFM
H2O through beds (during compressor operation)	0.014	0.0103	SCFM
N2 Through beds (during compressor operation)	1.648	0	SCFM
N2 added after recycle	1.826	0	SCFM
Stack Electric			
Cell voltage	1.309	1.302	V
Stack voltage	65.5	65.1	V
Stack current	96.5	96.5	A
Module current	385.9	385.9	A
Module Power	25.3	25.1	kW
Hot Zone			
Operating Temp	800	800	°C
Heater Power Requirements			
Steam generator (H2O from 20 to 150 C)	8.1	8.1	kW
Superheater (H2 +N2 from 20 to 800 C + steam from 150 C to 800 C)	5.87	4.15	kW
Air heater/ superheater	2.87	2.85	kW