High Temperature Electrolysis Test Stand

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Overview

Timeline

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

Barriers

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

- (G) Hydrogen from Renewable Resources
- (H) Hydrogen and Electricity Co-Production

Budget

FY17 DOE Funding: $1.49M
FY18 DOE Funding: $800k

Partners

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

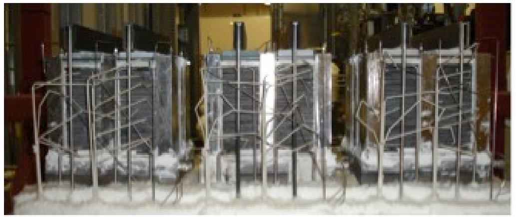
Relevance

Overall Objective:

I. Advance the state of the art of High Temperature Electrolysis (HTE) technology by discovering, developing, improving and testing thermal/electrical/control interfaces for highly responsive operations

II. Support the DOE-NE/EERE collaboration in Nuclear-Renewable Hybrid Energy Systems Integration

- Develop infrastructure to support systems integration HTE operations up 250 kW scale
- Support HTE research and system integration studies
- Measure cell-stacks and performance and materials health under transient and reversible operation
- Characterize dynamic system behavior to validate transient models used for process control
- Demonstrate integrated operation with co-located dynamic thermal energy systems including a high-temperature, high-pressure water flow loop and a thermal energy distribution and storage system
- Operate the HTE test station with co-located digital real-time simulators fo dynamic performance evaluation and hardware-in-the-loop simulations



Three 5-kW_{DC} HTE stacks used in INL 15 kW integrated pilot plant testing (ca. 2012)

Impact to date vs Barriers

- Facility will be commissioned for initial HTE hydrogen production at the 5 kW scale this month

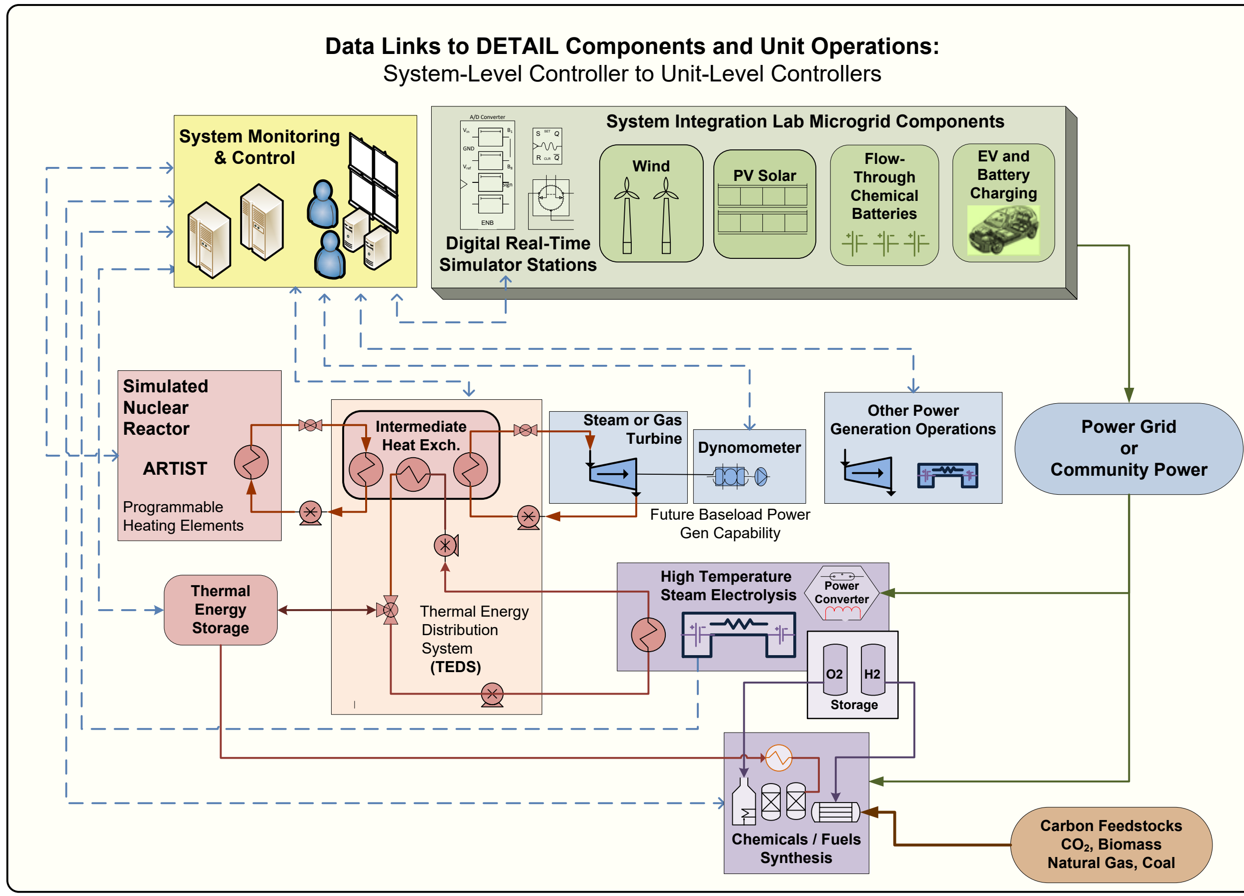
Approach

- Deploy flexible 25 kW_{DC} multi-stack and 250 kW_{DC} HTE testing units in the INL Dynamic Energy Transport and Integration Laboratory (DETAIL)
  - Provide a testing platform to HTE technology developers to test stack performance under dynamic operating conditions
  - Demonstrate and characterize simultaneous coordinated multi-directional transient distribution of electricity and heat for multiple industrial process heat applications
  - Characterize system performance under flexible operating conditions
  - Simulate broader systems through the use of real-time digital simulators with hardware-in-the-loop
  - 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
  - Help industry identify HTE technology gaps relative to optimized stack and systems designs for hybrid systems applications
  - 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

NE-EERE Collaboration: Experimental Demonstration of Integrated Systems

Dynamic Energy Transport and Integration Laboratory (DETAIL)

Objective: Demonstrate simultaneous, coordinated, controlled, and efficient multi-directional transient distribution of electricity and heat for power generation, storage, and industrial end uses.



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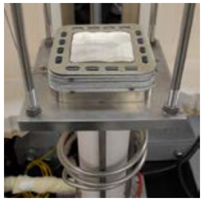
Approach: HTE Stack Integration and Control Scheme

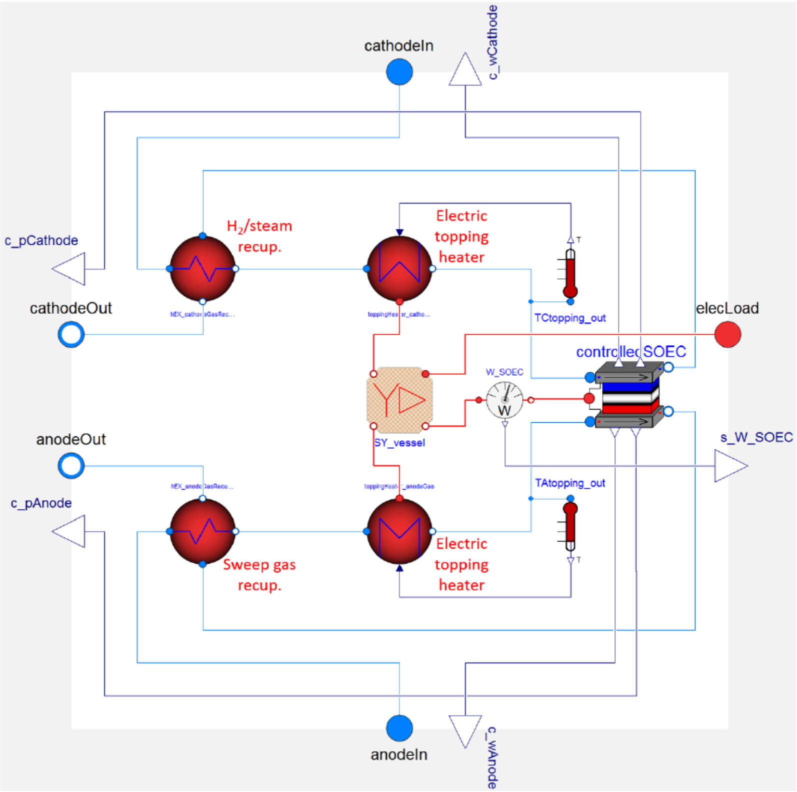
- Stacks for cyclic operations
- Heat integration improvements
- Modular units
- Reversible operation
- Co-electrolysis
- Oxygen recovery

Test Article	Electrolysis Power at Design Condition (1.2 V, 0.5 A/cm^2)
Button cell (2.5 cm^2)	1.5 W
Single cell (16 cm^2)	9.6 W
Small stack (100 cm^2,10 cells)	600 W
Large Stack (100 cm^2, 50 cells)	3 kW
Multiple-stack modules (4 large stacks)	12 kW

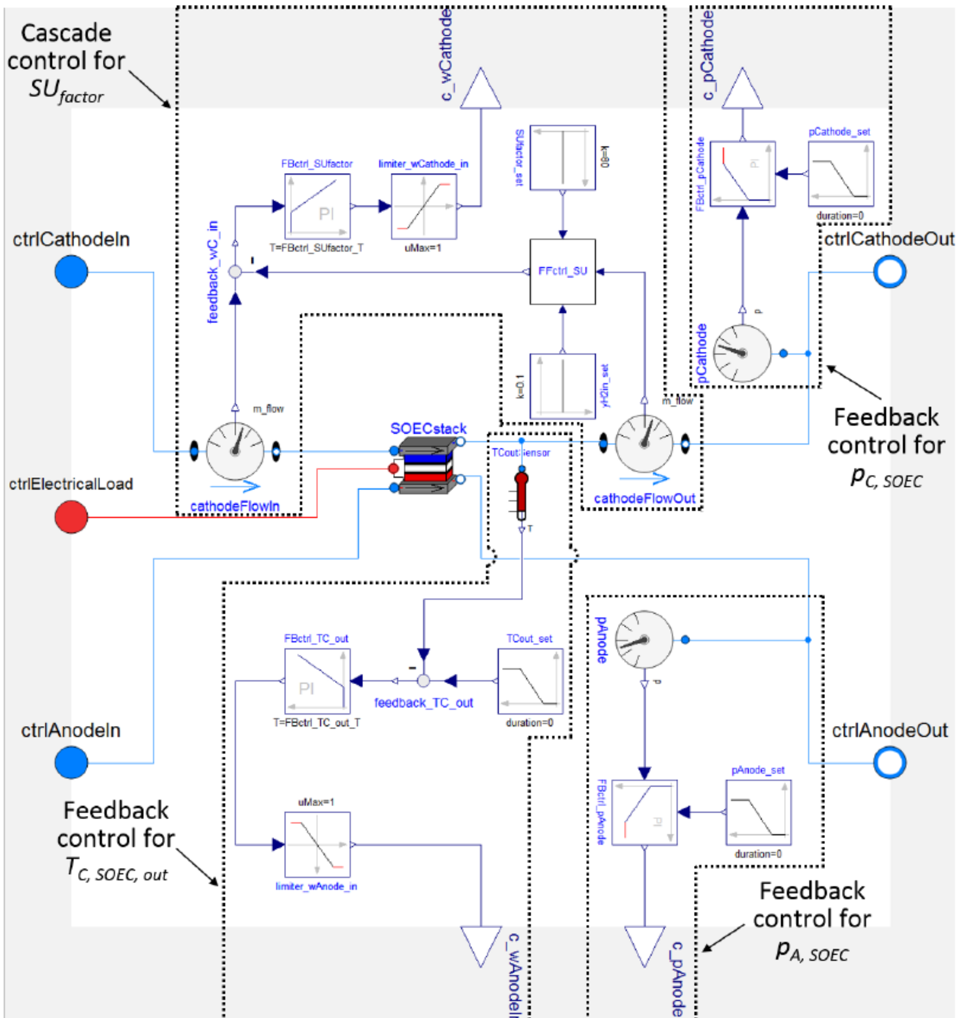





Stack integration with heat supply & recovery



Approach:
HTE Stack Integration and Control Scheme



HTE system model with regulatory control schemes

What's new?

- Versatile design for larger, User-Provided stacks
- Grid-level Front-End Controller (FEC)
- Responsive power converter tied to digital real-time simulation of grid and FEC
- Controllable steam supply
- Connected to Thermal Energy Distribution System
- Stack instrumentation and monitoring
- Connection to H_2 user (e.g. chemical synthesis with CO_2 feedstock)

Approach

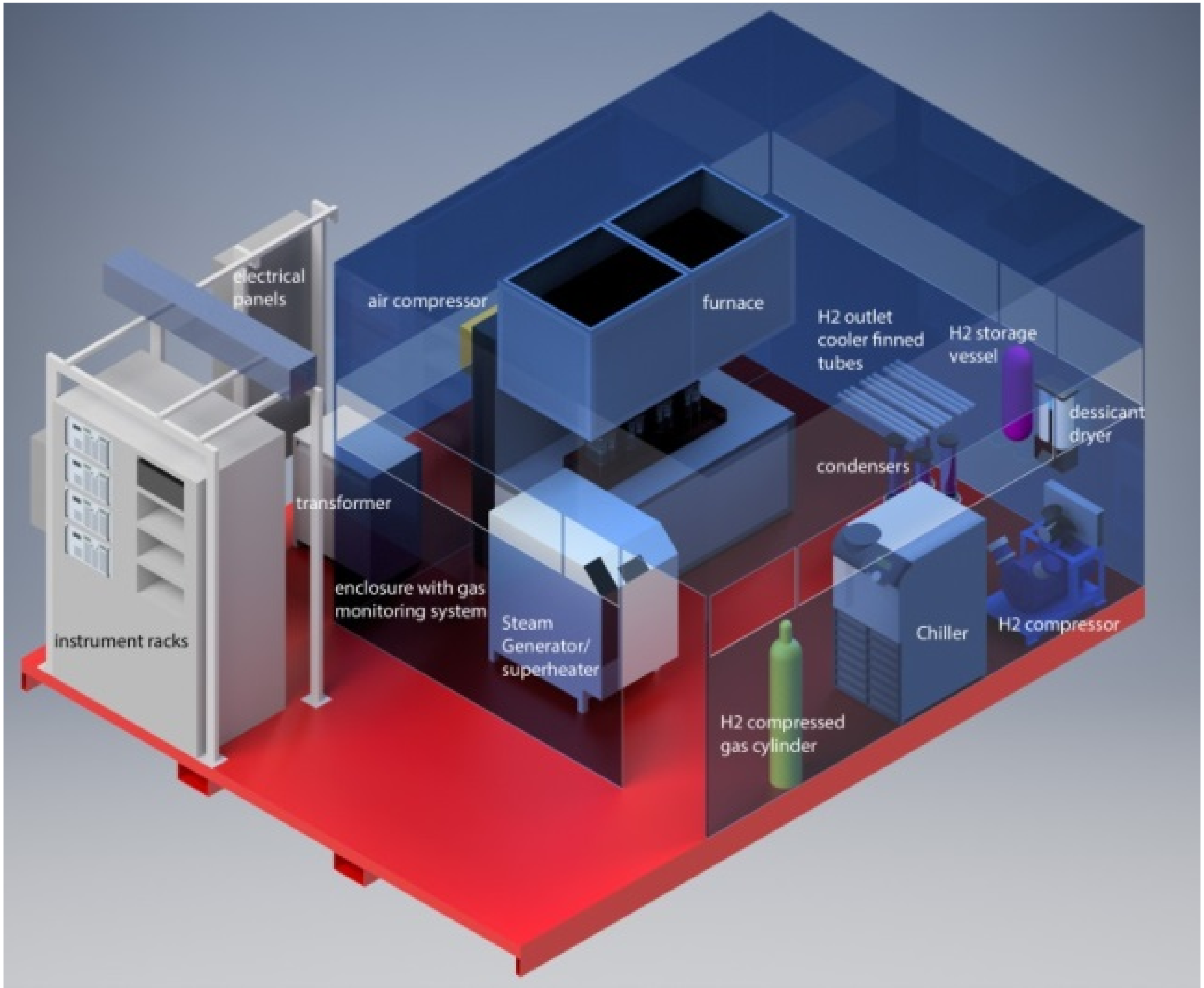
Milestone	Date	Status
Report on 25 kW HTE test systems design and stakeholder value	12/31/2017	complete
Demonstrate operability and data management of 25 kW HTE test station	3/31/18	Expected 6/15/18
Demonstrate HTE module response rate of 0-95% capacity in 30 minutes or less, with an electricity demand response rate of 0-98% capacity in 10 minutes or less.	9/30/2018	On schedule

Go/No-Go Decision	Date	Status
Successful initial operation of the flexible HTE 25 kW station	3/31/18	pending

Accomplishments and Progress

- Completed Design and Installation of Facility Support Infrastructure

✓ Power,
✓ DI water system,
✓ drain, enclosure,
✓ ventilation system,
✓ H_2 vent,
✓ gas monitoring,
✓ safety interlocks,
✓ fire protection,
✓ structural support

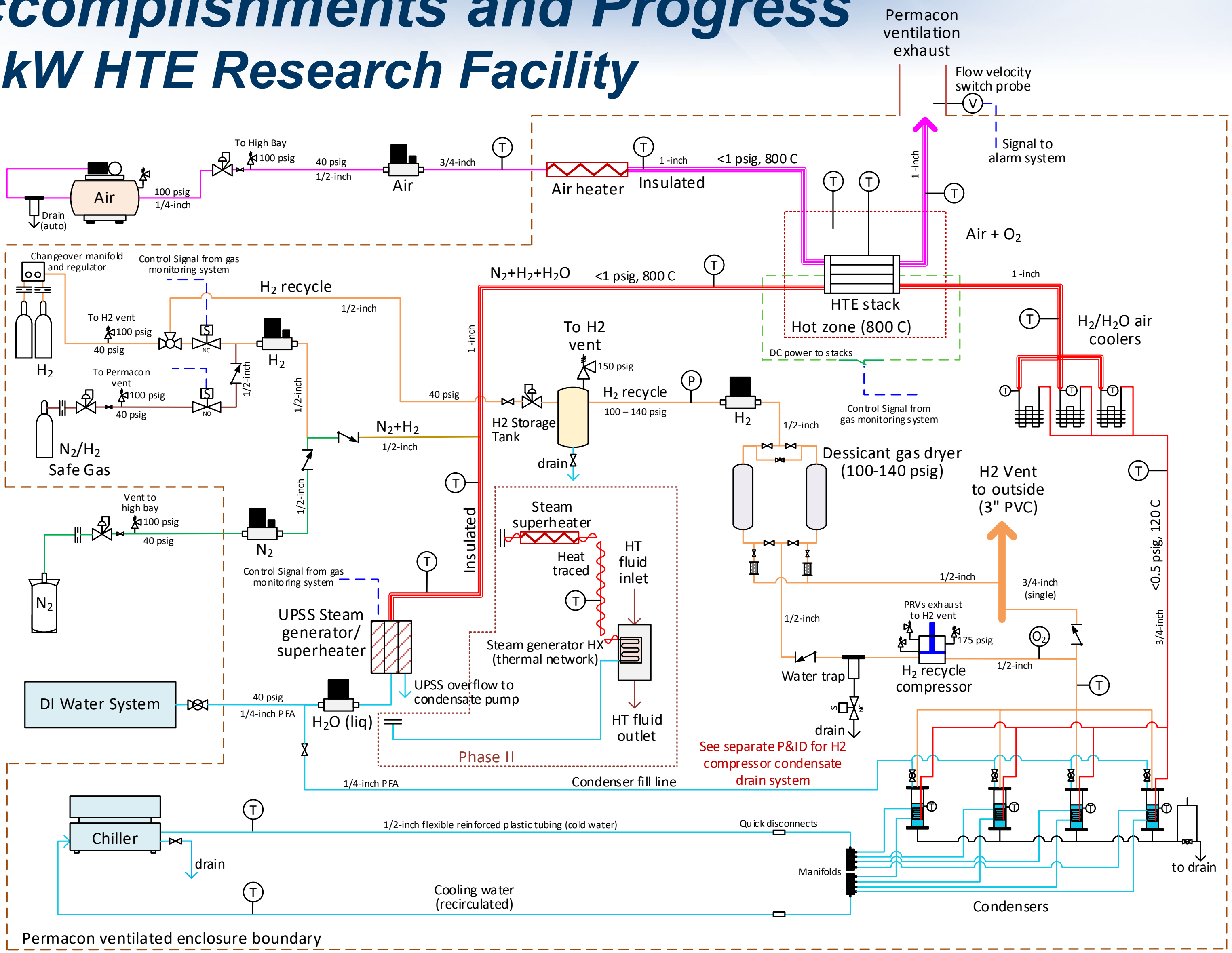


Accomplishments and Progress

- Completed Design and Installation of 25 kW HTE Test Facility
- Initial testing is currently under way
  - ✓ High-temperature furnace
  - ✓ High-temperature air supply for sweep gas
  - ✓ N_2 purge systems
  - ✓ Gas dryer and hydrogen recycle system
  - ✓ Gas monitoring system with interlocks
    Instrumentation
  - ✓ Methanol synthesis integration

Accomplishments and Progress

25 kW HTE Research Facility



Accomplishments and Progress

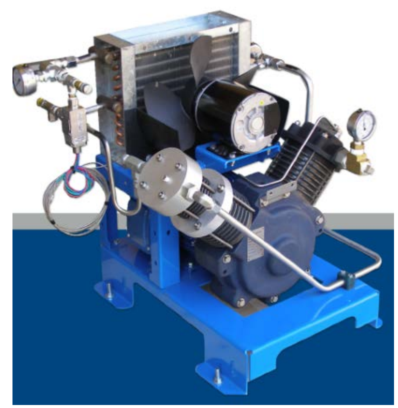
High Bay location of DETAIL within the INL Energy Systems Laboratory

DI Water System

4 kW HTE test stacks at INL, 2012

Steam Generator

Furnace



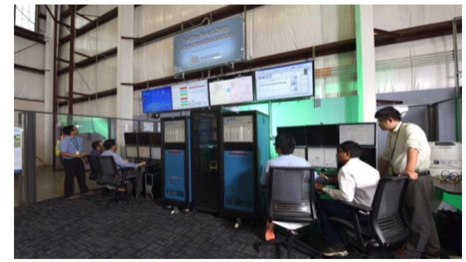
Hydrogen recycle compressor

Condenser array

Accomplishments and Progress (Coordination)

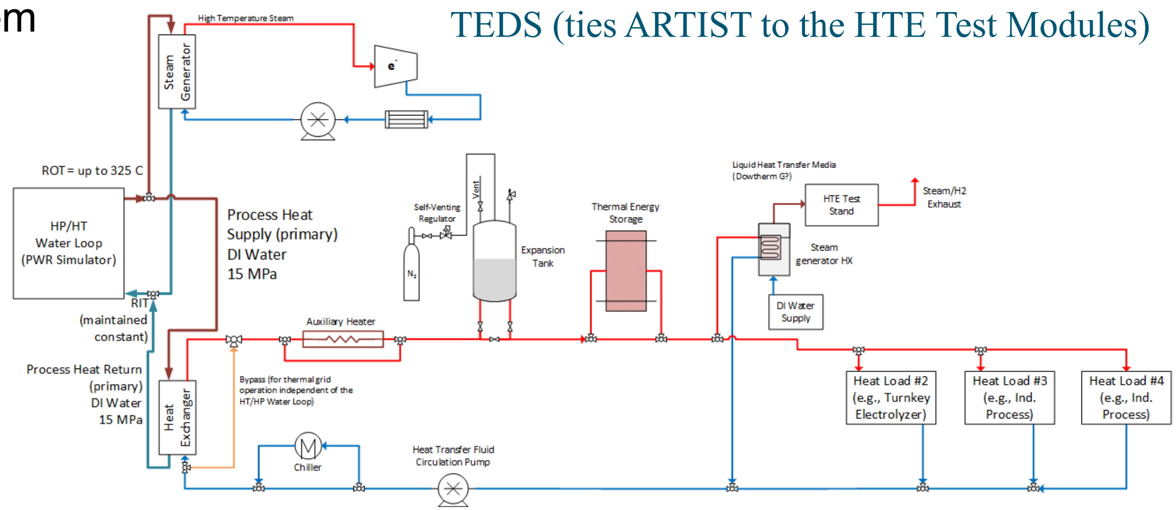
Established Technical and Functional Requirements for Dynamic Energy Transport and Integration Lab (DETAIL)

- Thermal and electrical integration to represent commercial-scale units
- Monitoring and controls performed locally, in communication with Power Systems/Grid Real-Time Digital Simulation (RTDS, right)
- Thermal energy relay to match nuclear reactor thermal hydraulics test loop
- Design of Phase I for Advanced Reactor Technology Integrated System Testing completed
- Thermal Energy Delivery System design underway



INL Power Systems/Grid Real-Time Digital Simulation (RTDS)

ARTIST Thermal Hydraulic Test Loop



TEDS (ties ARTIST to the HTE Test Modules)

Reviewer Comments

This project was not reviewed last year

Collaboration and Coordination

DOE Partnerships

- DOE-NE / DOE-EERE Collaboration
  - Nuclear-Renewable Hybrid Energy Systems

Industrial Partnerships

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

OxEon Energy Ruggedized Hermetic CTE-Matched Solid Oxide Electrolysis Stack (graphic used with permission)

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
  - Degradation must be 0.5%/k-hr 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
- Reduction of HTE system capital costs
- Effective thermal integration and thermal management for intermittent/ reversible operation

Proposed Future Work

Remainder FY18

- Complete Initial HTE testing in new facility at the 5 kW scale
  - Steady-state, baseline testing; long-term degradation
  - Effects of intermittent operation and thermal cycling
- Complete initial HTE test campaign at 25 kW scale (FY18/19)
  - Exercise full system capacity
  - 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

FY19

- Thermal integration of 25 kW system with the DETAIL thermal network
- Conduct 25 kW grid demand response exercises, documenting the thermal energy latency and system electrical characteristics

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

Technology Transfer Activities

- Working with HTE Systems Integration Companies
  - FuelCell Energy
  - OxEon
  - Boeing Company
  - Others…
- CRADAs with Industry
  - Exelon/Fuel Cell Energy (Poster No. h2052)
  - TerraPower
  - Terrestrial Energy, USA
- 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

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: Establish a large-scale High-Temperature Electrolysis test capability within the INL Dynamic Energy Transport and Integration Laboratory for demonstration and characterization of simultaneous coordinated multi-directional transient distribution of electricity and heat for multiple industrial process heat applications

Accomplishments: Design and installation of a flexible 25 kW HTE test facility has been completed and initial testing is in progress

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