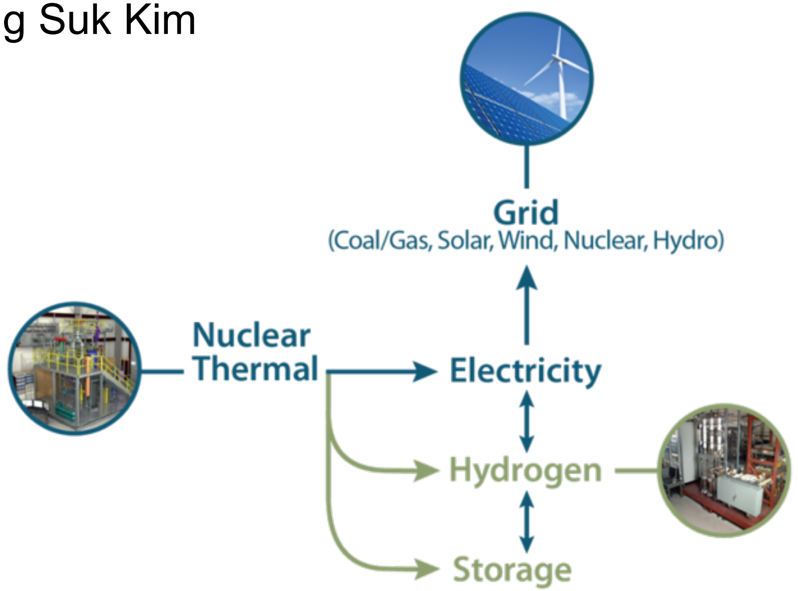
High Temperature Electrolysis Test Stand

PI: James O'Brien
Team: Richard Boardman,
Carl Stoots, Rob Hovsapian,
Shannon Bragg-Sitton, Jong Suk Kim

Project ID: TV040
Idaho National Laboratory

June 7, 2017



This presentation does not contain any proprietary, confidential, or otherwise restricted information

Overview

Timeline

- **Start:** August 2016
- **End:** Funding planned through FY18 subject to funding priorities

Budget

FY17 funding direction: $1.5M

- Project plan
- 25 kWe test station design, installation, and start-up

FY18 request: $1.5M

- R&D operations: 25 kWe test station
- Complete infrastructure for 250 kWe vendor-packaged systems integration

Barriers

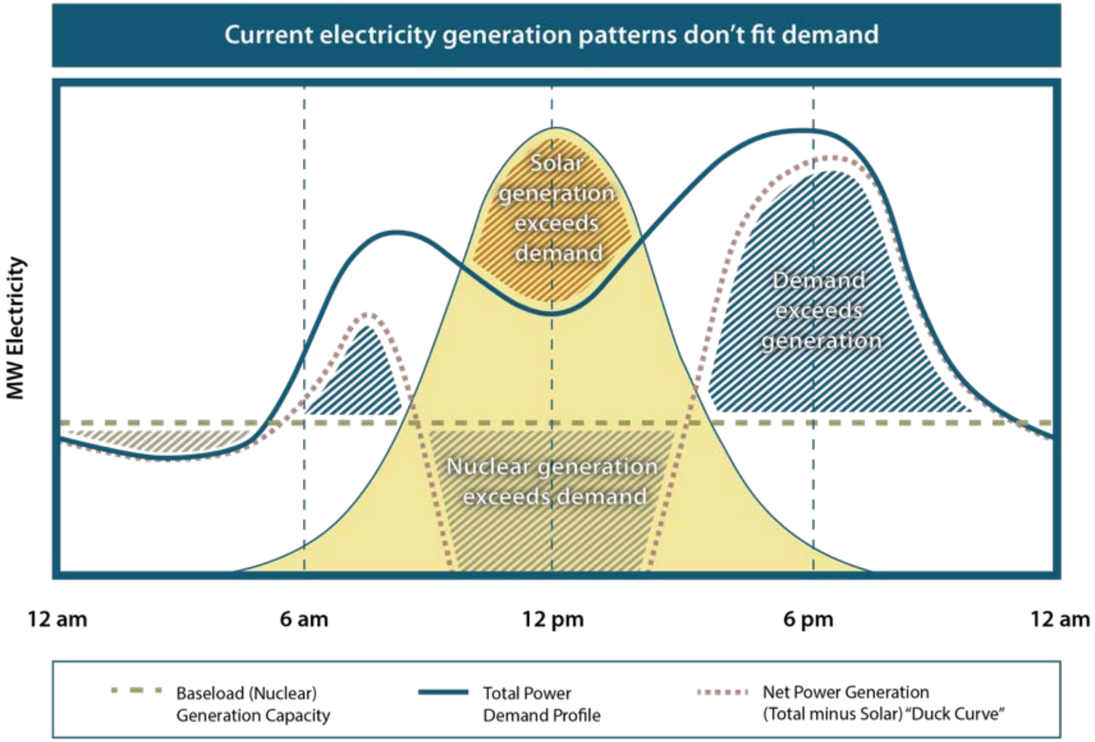
- Reduce capital costs associated with HTE **[MYRD&D Plan 3.1.5. F]**
- Address improvements in BOP efficiency and durability and operation with thermal energy and electrical duty cycles **[MYRD&D Plan 3.1.5. G,L,M]**
- Operation of distributed HTE when cost of electricity is suppressed by excess electricity generation in given grid **[MYRD&D Plan 3.1.5.I,M]**
- Reduce material stresses and failure **[MYRD&D Plan 3.1.5. L, M]**
- Regulatory licensing and public acceptance of co-located nuclear plants with H_2 production [DOE-NE Program]
- Design and operating conditions for co-electrolysis using CO_2 for enhanced chemical production **[MYRD&D Plan 3.1.5. L]**

Partners

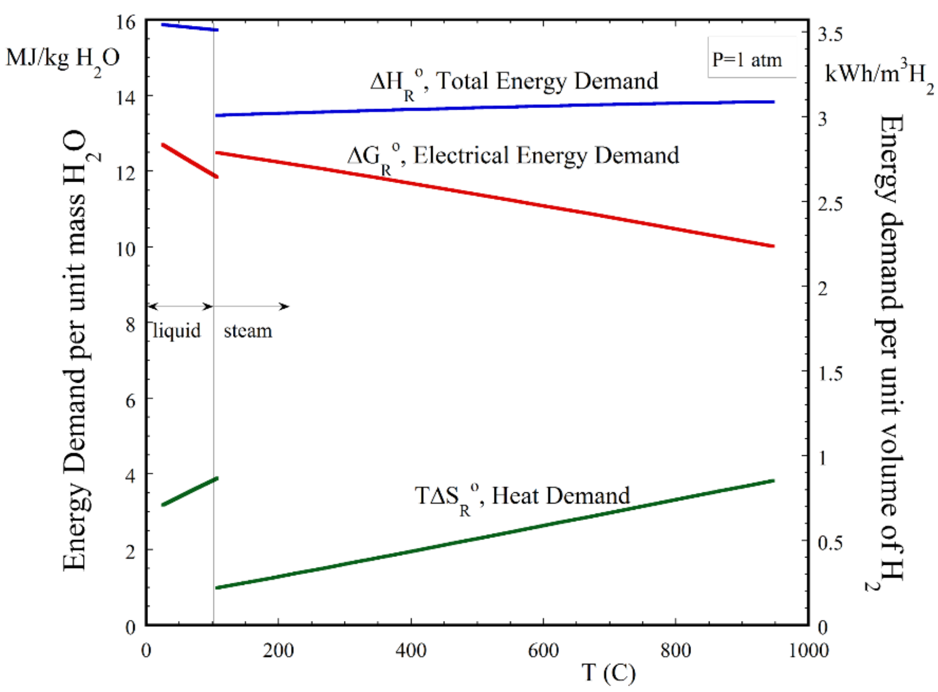
- DOE Nuclear Energy Office for Nuclear Technology Demonstration and Deployment
- U.S. developers/manufacturers of solid oxide electrolyzer cells (SOEC), stacks, & turnkey integrated modular systems
- U.S. hydrogen gas suppliers
- EPRI, utilities (baseload power generation assets)
- H_2/O_2, syngas consumers (petroleum refineries, steel makers, ammonia/fertilizer producers)

Relevance: Fitting Generation to Demand

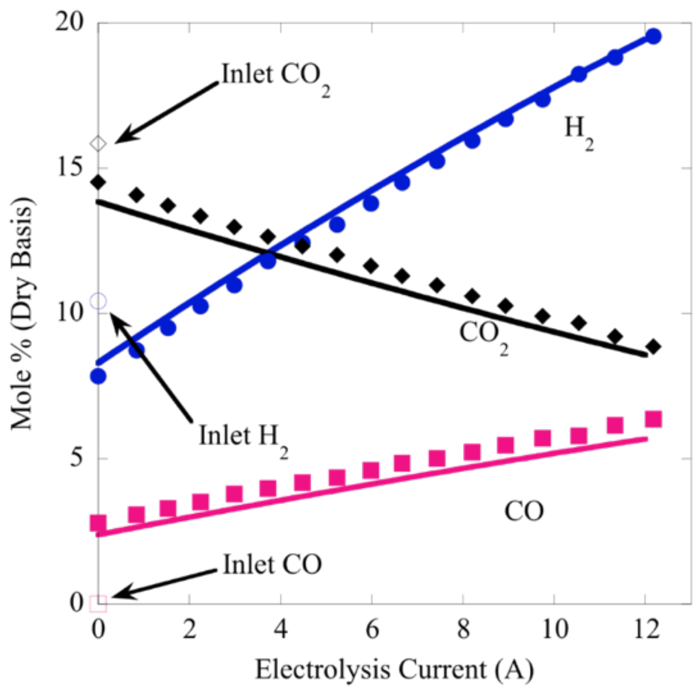
- Today's grid is stressed in multiple ways when generation doesn't match demand.
- Diverting excess energy to make hydrogen (H_2) would better utilize existing resources.
- Commercially viable solutions will require systems integration, testing, demonstration and validation.



Relevance: Fundamental Advantages of SOEC Technology



Thermodynamics favors high-temperature water splitting



Solid oxide electrolysis can also be used for direct production of syngas
(co-electrolysis of H_2O and CO_2); demonstrated at INL (INL Patents)

Relevance

Objective: Optimize HTSE for cyclic operation. **Validate that high temperature electrolysis (HTE) can be frequently cycled from hot-standby to full production** in concert with electricity price profiles and grid services

- **Ensures grid services and grid reliability are maintained** concurrent with buildup of renewable energy
- **Provides viable approach to flexible operation of nuclear power plants** as load-following plants that switch to hydrogen production based on market signals
- **Achieves higher capital efficiency and higher revenue** for current and future nuclear reactors
- **Provides large-scale energy storage option** based on diurnal and seasonal electricity demand

Objective: Attain FCTO target of clean, **H_2 production under $2/gasoline-gallon equivalent (GGE)** in large centralized plants or distributed plants that may be located on the site of and industrial user plant that provides thermal energy

- **Motivates commercial growth** in U.S. fuel cell vehicles industry and H_2-based manufacturing
- **Significantly reduces air pollution** with zero-emissions H_2 and O_2 production
- **Enables an option for repurposing some nuclear reactors** within the existing LWR nuclear fleet
- **Enables a worldwide market** for U.S. small modular nuclear reactors (SMRs), HTE technology, and clean industrial processes

Objective: **Pilot plant test platform** to carry out technology development & validation

- **Reduces technical and commercial risks** associated with complex systems integration via electrical grid, hardware, and controls-in-the-loop testing
- **Demonstrates dynamic thermal/electrical energy transport** to HTE on the largest practical scale to reduce technical risks
- **Validates nuclear-HTE integration models** needed for commercial design and dynamic operation
- **Raises HTE technology readiness level** (TRL)
- **Enables full-scale nuclear-HTE coupling**

Approach: Five Phase Project Plan (1-2)

1. Establish HTE R&D needs and H_2 requirements

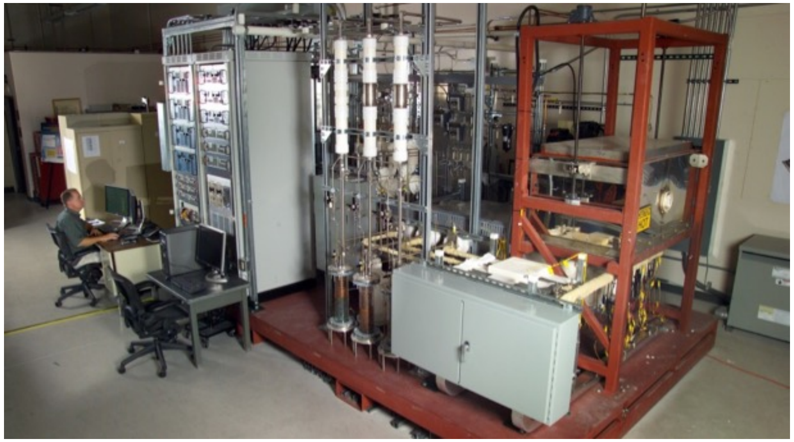
FY16 Q4 – FY17 Q1

- ✓ Survey of SOEC stack and systems developers/suppliers state-of-technology and needs
- ✓ Conduct stakeholder meetings: utilities, nuclear plant operators, hydrogen consumers
- ✓ Develop Figures of Merit (FOM) and update technology down-selection and evaluations criteria
- ✓ Develop technical and functional requirements in association with NE Thermal Energy Integration Test Stand

2. Design & engineering for 25 kWe pilot plant test stand

FY17 Q2 – Q3

- ✓ Conceptual design and cost estimate completed
- ❑ Engineering design per DOE requirements under INL Work Control and Quality Control for buildings, test facilities, and operations



INL 15 kWe Integrated HTE Test Stand

This project is a part of a cross-cutting collaboration between two DOE program offices (NE and EERE).

Approach: Five Phase Project Plan (3-5)

3. Install test stand and conduct SO tests

FY17 Q4 – FY18 Q1

- ❑ Equipment purchases, construction, and installation in accordance with INL Work Control Procedures
- ❑ SOEC and Module fabrication by vendor(s)
- ❑ Start-up & operational demonstration under INL authorized operating procedures

4. Conduct 25 kWe Stack-Module R&D relevant to thermal & grid integration

FY18 Q2 – TBD

- ❑ Commence test objectives relative to thermal/electrical integration and transient operability
- ❑ Continue testing relevant to system operability and component performance

5. Provide 250 kWe turnkey HTE plug-in test facility in dynamic environment

FY19 – TBD

- ❑ User/Guest project-specific testing
- ❑ High Temperature SMR thermal integration

Progress: Phase 1 (Establish R&D Needs)

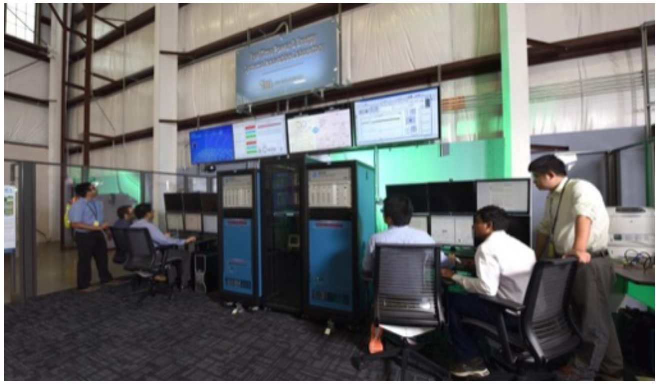
- Assessed national & international developers' & vendors' interests and testing activities
- Surveyed state-of-the art solid oxide electrolyzer cell (SOEC) systems
- Developed Figures of Merit (FOM) and updated technology down-selection and evaluation criteria
- Developing technical and functional requirements in association with DOE Office of Nuclear Energy's Thermal Energy Integration Test Stand

Conclusions:

- SOEC integrated systems technology readiness level is uncertain
- High commercial risk remains to nuclear power plant repurposing
- Electrical/thermal cycling of SOEC cells and balance of plant (BOP) have not been sufficiently addressed
- Confirmed vendor interests in integrated nuclear-renewable-HTE test bed [Dynamic Energy Transport and Integration Lab (DETAIL)]

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

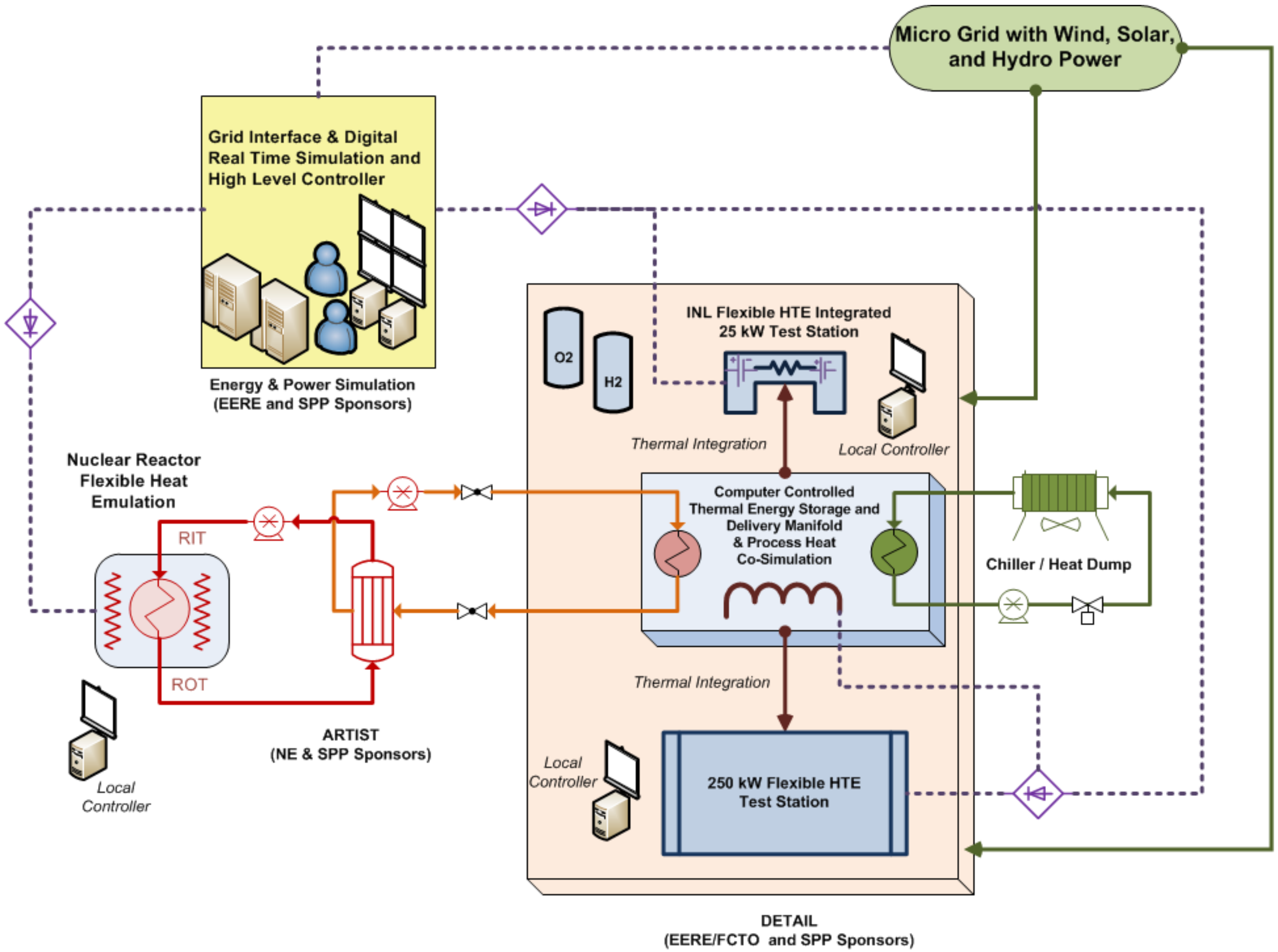
- Thermal and electrical integration to represent commercial-scale units
- Monitoring and controls performed locally, in communication with Power Systems/Grid Real-Time Digital Simulation (RTDS, right)
- Thermal energy relay to match nuclear reactor thermal hydraulics test loop
- Reconfigurable test stand for vendor-specific SOEC stacks/modules
- Infrastructure for turnkey 250 kWe integrated large-scale fully packaged systems



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

Thermal Hydraulic Test Loop

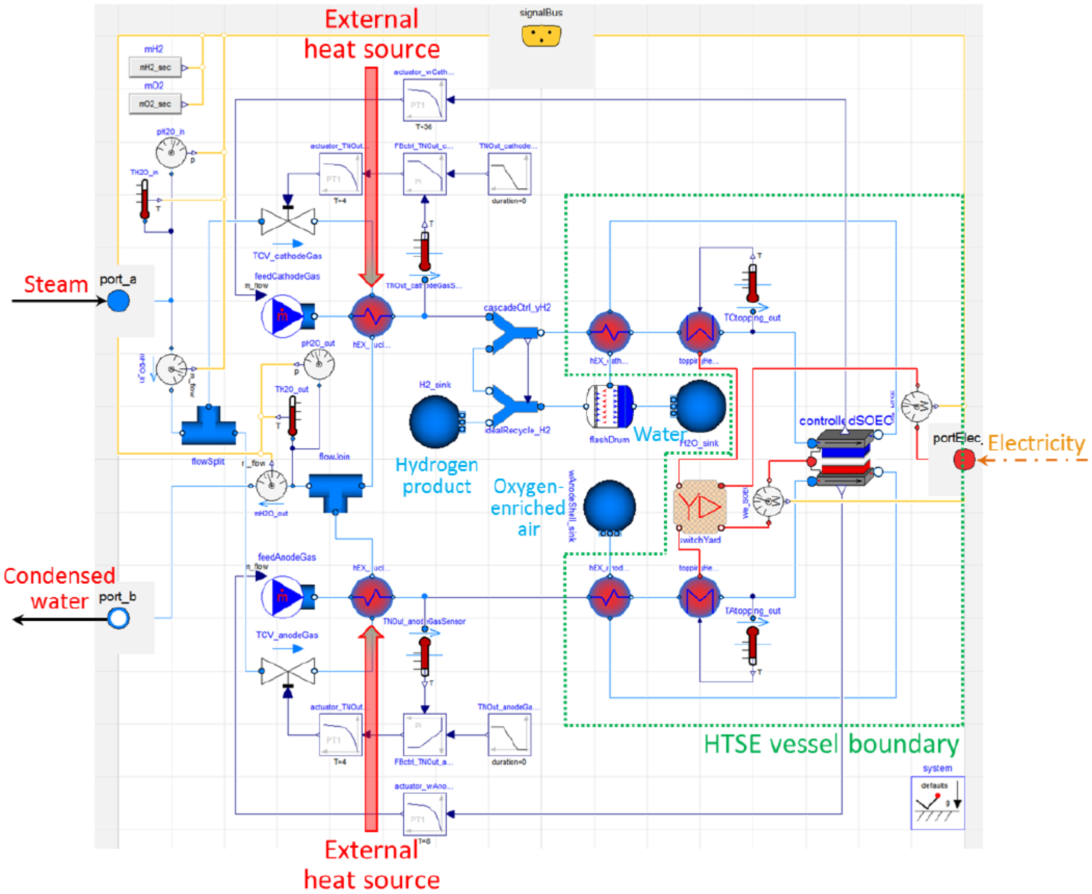
Progress: Established Technical and Functional Requirements for DETAIL

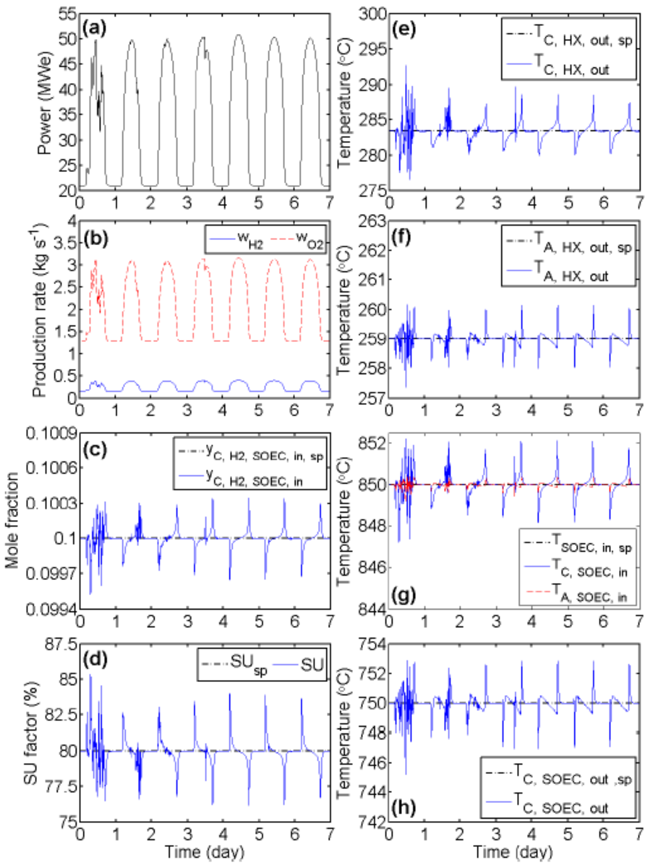


- 200 kW thermal capacity
- 250 kW electrical HTE capacity
- Heat transport loop circulation and interface with multiple heat tenant
- Independent unit operation control systems interface with high level system operator
- Data links in accordance with RTDS communications protocol
- Hazardous gas monitor and emissions management
- Flexible operation with power from microgrid or city power line

Progress: Dynamic Nuclear-HTE Process Model Developed in Modelica

Transient response of system and components verified for nuclear-wind hybrid electrical/hydrogen systems (report: INL/EXT-16-40305)





Progress: Response to Reviewers' Comments

This project is a new start under FCTO so there has been no previous annual review of this activity.

Collaborations: Strategic Partners

Strategic Partners for SOEC/Modules Integrated Systems

- **Complements FCTO Technology Validation Projects**
  - SOEC Stack and Modular Assembly Design
  - Dynamic Modeling and Validation of Electrolyzers in Real-Time Grid Simulations (HTE test stand will be linked to Power Systems and Grid Real-Time Digital Simulation capability)

State and International Dialog

- Scientific Advisory Committee for International Conference on Electrolysis (ICE-2017)
- DOE Gen IV Hydrogen Production Project Management Board Partnership Management Board for Hydrogen (7 member nations)
- Hydrogen in the U.S. Hydrogen Nuclear Energy Sciences & Technologies (NEST)
- U.S./India Civil Nuclear Energy Working Group for Hydrogen
- Steering Committee for Comprehensive and Coordinated Approach to Carbon Capture and Utilization (4CU)
- Utah State Energy Advisor for Economic Development

Collaborations: DOE Program Teaming

DOE partnership for NE-EERE Hybrid Systems

- **Part of the NE-EERE collaboration on Integrated Energy Systems**
- **Supporting accomplishments in FY16-FY17:**
  - ✓ Technical and market feasibility of Nuclear-Renewable SMRs and HTE hybrids reported
  - ✓ Industrial heat market study completed, including H_2 production and use
  - ✓ Guiding report on figures of merit for NE-Hydrogen Systems completed

Strategic partnership for Nuclear Energy

SMR developers funded techno-economic assessments
- ✓ NE/HTE systems predict prices that will be competitive with steam-methane reforming with the advent of these reactors
- ✓ Heat recuperation enables thermal integration with all classes of nuclear reactors, including light water reactors

EPRI/utilities and owners of existing nuclear power plants
- ✓ Studies of H_2 production under flexible plant operations
- ✓ Daily and seasonal energy storage considerations

Industrial H_2 user, steel and ammonia industries

Remaining Challenges and Barriers

SOEC performance degradation and component failure

- State of Technology: stack performance degradation rate of ~1%/khr
- Target: stack degradation <0.5%/khr and component failures of less than 1% per year
- Solution: BOP design and materials joining needed to overcome fatigue failures resulting from transient operation of HTE systems

Mass manufacturing to reach commercial targets

- State of Technology: Estimated to be around $700/kWe (installed) for central plant
- Target: <$400/kWe (installed) is needed to be competitive with incumbent steam methane reforming based on AEO price projections for Natural Gas

Proposed Future Work: Phases 3-5

Phase 3: **Install test stand, conduct SO tests** (FY17 Q4- FY 18 Q1)

- Equipment purchases, construction, and installation in accordance with INL Work Control Procedures
- SOEC and Module fabrication by vendor(s)
- Start-up & operational demonstration under INL authorized operating procedures

Phase 4: **Conduct 25 kWe Stack-Module R&D** (FY18 Q2-TBD)

- Commence test objectives relative to thermal/electrical integration and transient operability
- Continue testing relevant to 1) system operability and 2) component performance

Phase 5: **Provide dynamic 250 kWe turnkey HTE plug-in** (FY19 - TBD)

- User/Guest project-specific testing
- High Temperature SMR thermal integration

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

Technology Transfer Activities

PATENTS

Methods and Systems for Syngas Production and for Efficient, Flexible Energy Generation (pending, Attorney Docket 2939-P13468US)

High Temperature Electrolysis for Syngas Production (US Patent 7,951,283 B2)

Methods and Systems for Producing Syngas (US Patent 8,366,902 B2)

Electrolytic/Fuel Cell Bundles and Systems Including a Current Collector in Communication with an Electrode Thereof (US Patent 8,389,180 B2)

CRADAs

Joint Use of Modular Plants (JUMP); Public/Private demonstration of nuclear energy for hydrogen production

Strategic Partnership Projects Technical/Economic Assessments

Summary

Why HTE? Why nuclear-renewable energy?

- HTE exploits thermal energy sources with higher thermodynamic efficiency
- Helps renewable energy AND existing nuclear power plants provide the lowest cost energy
- Zero-emissions energy reduces air pollution; large-scale H_2 production is possible using excess electricity generation capacity

How will this project help overcome barriers?

- Providing this platform will demonstrate HTE system operability and durability under real-world conditions and will demonstrate 250 kWe vendor turnkey systems to reduce commercialization and project risks for first movers
- Demonstrate the interface technology and coordinated operation necessary to design and verify dynamic thermal and electrical energy delivery systems from nuclear power plants and HTE during flexible operation of nuclear power plants

Approach and Accomplishments

- INL will establish an integrated nuclear-renewable-HTE test bed (DETAIL)
  - Engineering design ongoing, strategic partners involved, vendor interest expressed
  - A Power System / Grid RTDS and renewable micro-grid are in place
  - The nuclear reactor emulator and thermal loop is under construction
  - HTE test skid work plan completed and funding determination made
- Technical and economic assessments have verified market potential
- A dynamic process model for renewable-nuclear-HTE coupling has been developed and will be validated under this project