High Efficiency Reversible Solid Oxide System

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May 30, 2020

2020 DOE Hydrogen and Fuel Cells Program Review

Project ID# FC330

Overview

Timeline

- Project Start Date: 10/1/2019
- Project End Date: 5/31/2022

Barrier

- Key barriers addressed in the project are:
  - F. Capital Cost
  - G. System Efficiency and Electricity Cost
  - J. Renewable Electricity Generation Integration

Budget

- Total Project Budget: $2,500,000
- Total Recipient Share: $ 500,000
- Total Federal Share: $2,000,000
- Total DOE Funds Spent: $ 0

* As of 5/30/2020

Partner

- FuelCell Energy (FCE) – Project Lead
- Versa Power Systems (VPS)

Project Background

Objective:

Develop an energy storage technology based on Reversible Solid Oxide Fuel Cell (RSOFC) system capable of round trip efficiency of 70% and projected energy cost of less than $100/kWh

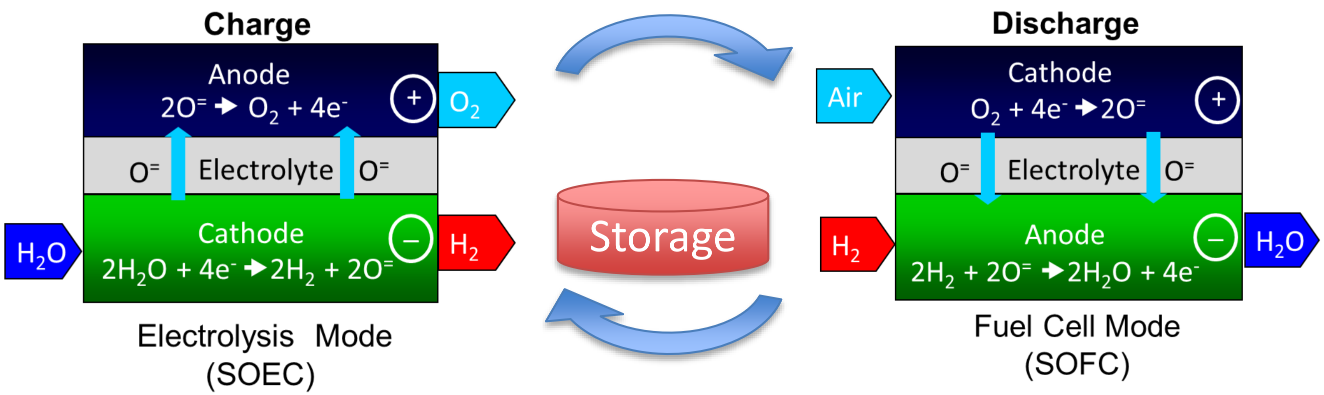
Project Goals:

- Validate RSOFC stack performance of less than 0.5% RTE degradation per 100 cycles of testing
- Identify operating conditions that maximize the potential of the RSOFC stack towards meeting RTE performance and degradation goals
- Demonstrate that better than 50% RTE (equivalent to >60% RTE when extrapolated to a large system) and 5%/1000-cycles RTE degradation are achievable via testing of a subscale integrated porotype system
- Establish the plans for transformation of RSOFC technology from laboratory to commercial products
- Verify that the stretch-goals of 70% RTE and cost of <$1000/kW resulting in energy cost of <$100/kWhr are achievable for commercial products

Relevance

Technology Development Approach

The project key approach is focused on development of high temperature Reversible Solid Oxide Fuel Cell (RSOFC) systems achieving the RTE and cost goals



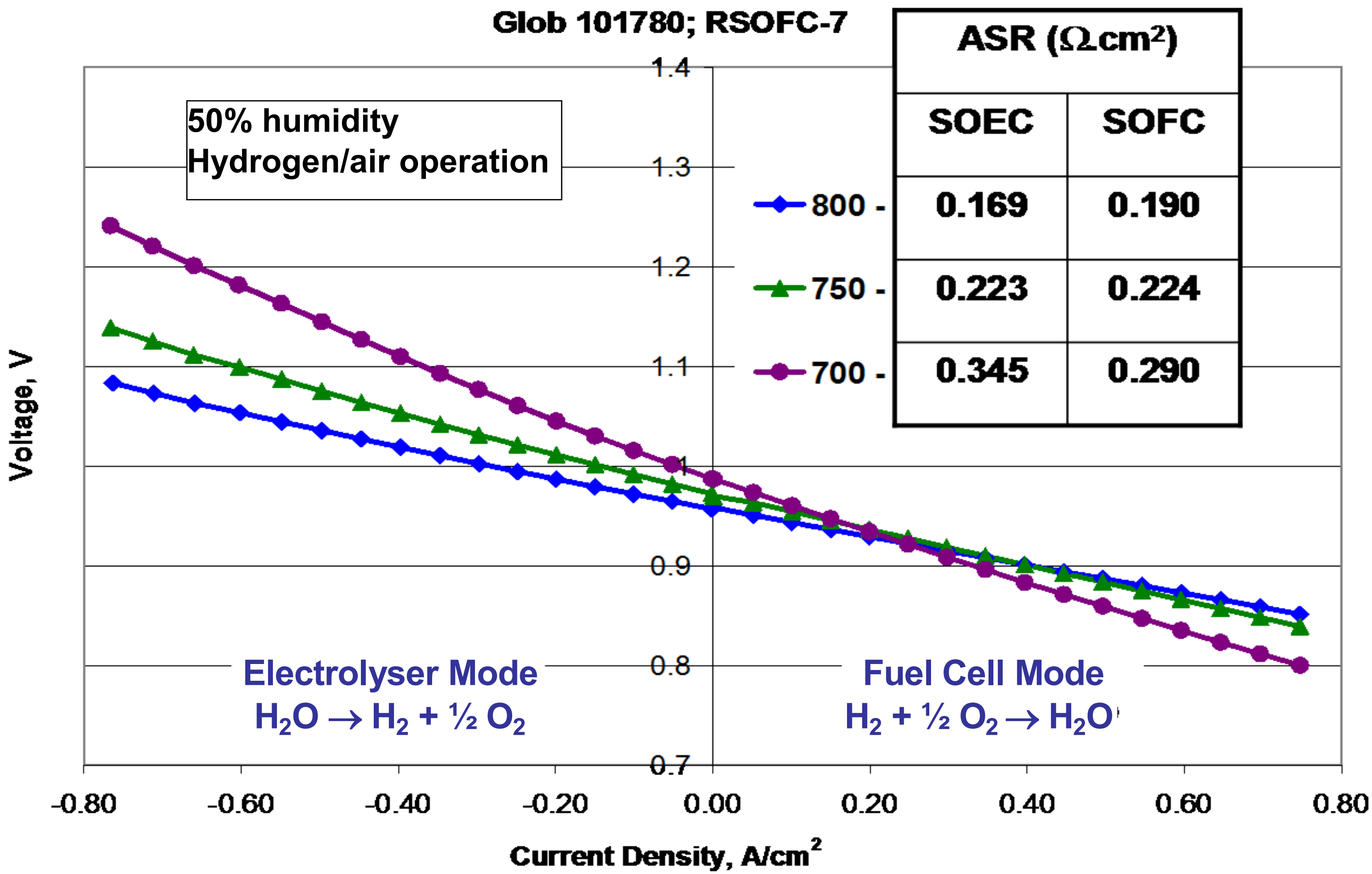
- Develop storage system design and Identify operating conditions that maximize the potential of the RSOFC stack and materials technology in meeting RTE performance and degradation goals
- Perform RSOFC stack testing to validate system-identified operating conditions (such as stack pressure of up to 10 bar) and to verify less than 5%/1000 cycles RTE degradation over 100 cycles between fuel cell and electrolysis operating modes
- Build and test a thermally self-sustaining RSOFC demonstration system, rated at 3 kWe output and 15 kWe input, and verify >50% RTE (equivalent to >60% RTE in larger systems) and degradation of less than 5%/1000 cycles RTE degradation
- Develop Technology-to-Market (T2M) plan including commercialization strategies and product specifications by organizing an industry committee consisting of utilities and potential users
- Perform Techno-Economic Analysis (TEA) for RSOFC commercial products using system simulation modeling and components costing to determine the cost of the plant per kW and cost of energy storage per kWhr of power discharge

FY2020 & FY2021 Milestones

Approach

Milestone #	Subtask Title	Project Milestones	Completion Date	Percent Complete	Progress Notes
1.1.1	Stack Development and Testing	Complete technology stack degradation characterization over 50 fuel cell-electrolyzer cycles targeting operating conditions that will provide ≤5% RTE degradation/100 cycles	Q2		
GN1.1.2	Stack Development and Testing	Demonstrate <5% round trip efficiency degradation per 1000 cycles over 100 cycles between fuel cell and electrolysis operating modes for a reversible SOFC 45-cell stack operating at constant fuel cell current density>200 mA/cm2 and voltage >0.85 V/cell and electrolysis current density of >500 mA/cm2 and voltage <1.3 V/cell in each cycle of > 20 minutes)	Q4		
1.2.1	Stack Manufacturing for System Test	Complete stack manufacturing and qualification testing meeting acceptance criteria and system requirements including minimum open circuit voltage (>1.0 V/cell), high fuel cell fuel utilization voltage (>0.80 V/cell) for all individual cell blocks within the stack	Q6		
2.1.1	Demonstration System Design	Issue preliminary process design for the RSOFC system and identify target stack operating conditions for technology stack characterization testing	Q1		
2.1.2	Demonstration System Design	Demonstration of RSOFC system design complete, incorporating the thermal storage system and stack qualification requirements issued to achieve 70% system RTE	Q3		
2.2.1	Demonstration System Fabrication	RSOFC prototype system fabrication and commissioning complete	Q5		
2.3.1	Demonstration System Test	Demonstrate high efficiency thermal storage sub-system with >80% storage efficiency after 12 hours storage (useful heat extracted/heat stored)	Q7		
2.3.2	Demonstration System Test	Demonstrate a complete, pressurized ~3 kW fuel cell/~15 kW electrolysis unitized RSOFC system with less than 5% round trip efficiency degradation per 1000 cycles over 100 fuel cell-electrolysis cycles, with a demonstrated RTE >50%, reaching >60% when extrapolated to a large system	Q8		
3.1.1	Industry Committee Input and Requirements	Use preliminary input from the industry committee to define system operating targets, including duty cycle, for the RSOFC system demonstration.	Q4		
3.1.2	Industry Committee Input and Requirements	Identify customer operation points (including duty cycles) of interest. Demonstrate system model RTE ≥70% at customer relevant conditions and load cycles	Q7		
3.2.1	RSOFC Large Scale System Techno-Economic Analysis	Report system TEA with <\$1000 /kW and <\$100/kWh capital costs, targeting <0.1 \$/kWh-cycle and validating ≥70% RTE system design	Q8		

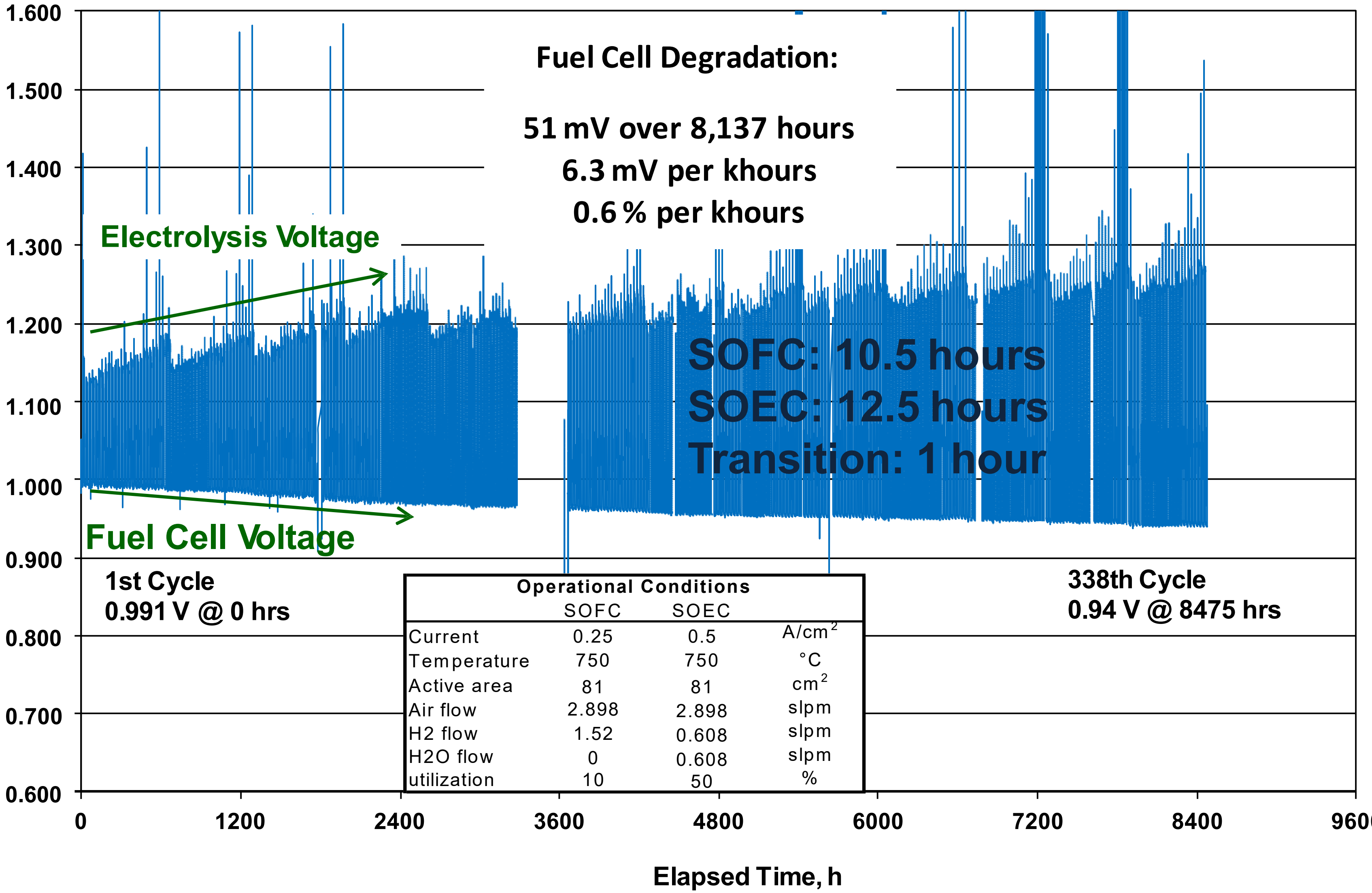
Prior Work: Cell Performance



ASR (Ωcm^2)	
SOEC	SOFC
0.169	0.190
0.223	0.224
0.345	0.290

Performance of RSOFC-7 Cell in Both Fuel Cell Mode and Electrolysis Mode

Prior Work: Stack Repeat Unit Cell Daily Cycling

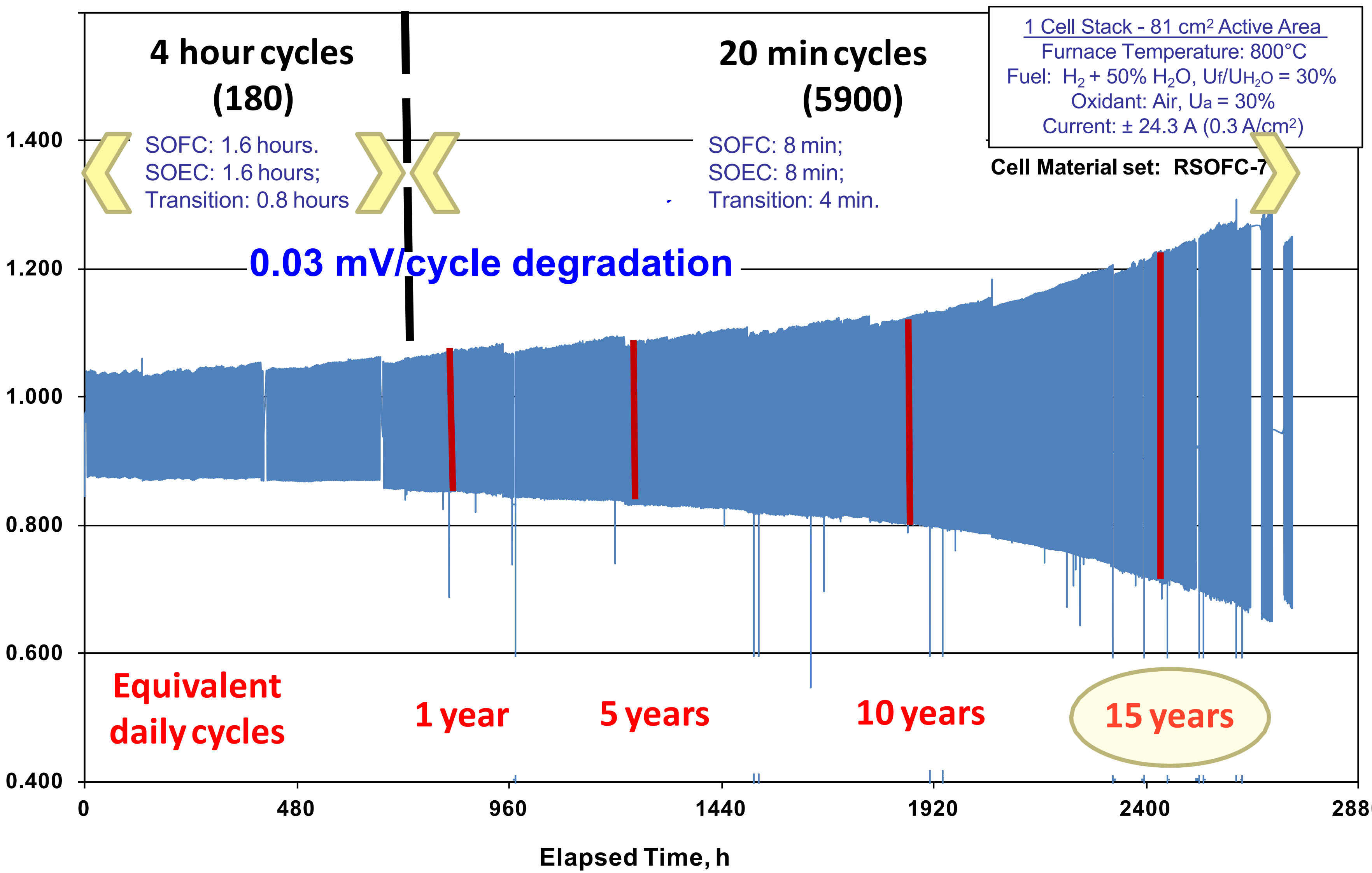


Operational Conditions

	SOFC	SOEC	
Current	0.25	0.5	A/cm^2
Temperature	750	750	°C
Active area	81	81	cm^2
Air flow	2.898	2.898	slpm
H2 flow	1.52	0.608	slpm
H2O flow	0	0.608	slpm
utilization	10	50	%

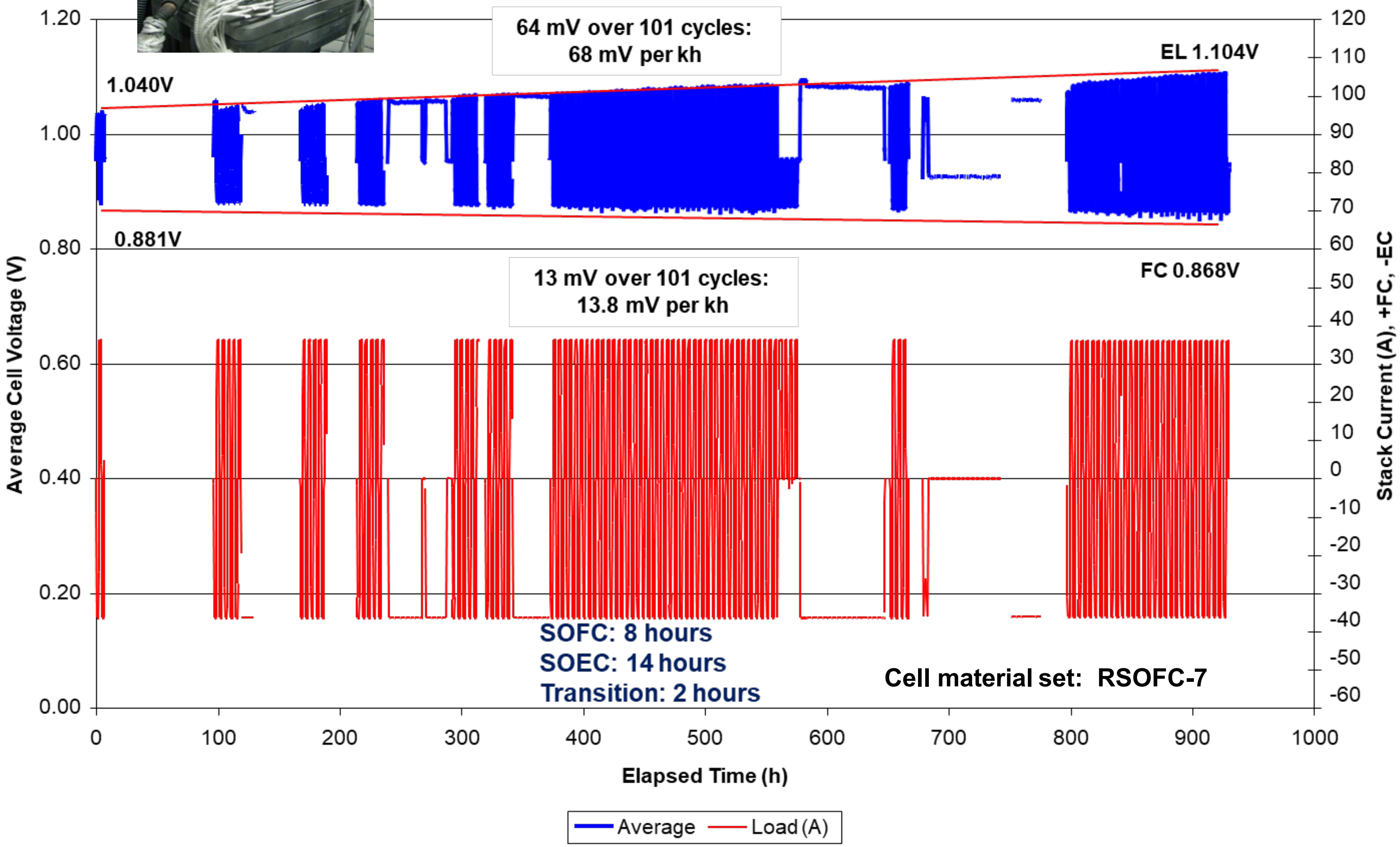
Simulated RSOFC Operating Profile – 24hr daily cycle

Prior Work: Stack Repeat Unit Cell Cycling



Stack Repeat Unit: Accelerated Cycling (6,080 Cycles)

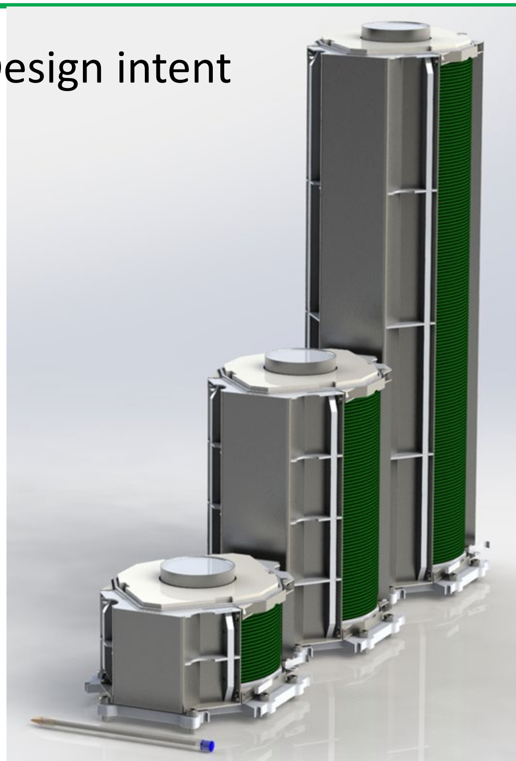
Prior Work: kW-Class Stack Daily Cycle Test



Next generation Compact SOFC Architecture (CSA) design eliminates the thermomechanical stress issues in cyclic operation

CSA Stack Platform

Design intent



Now realized with operating stacks in three sizes

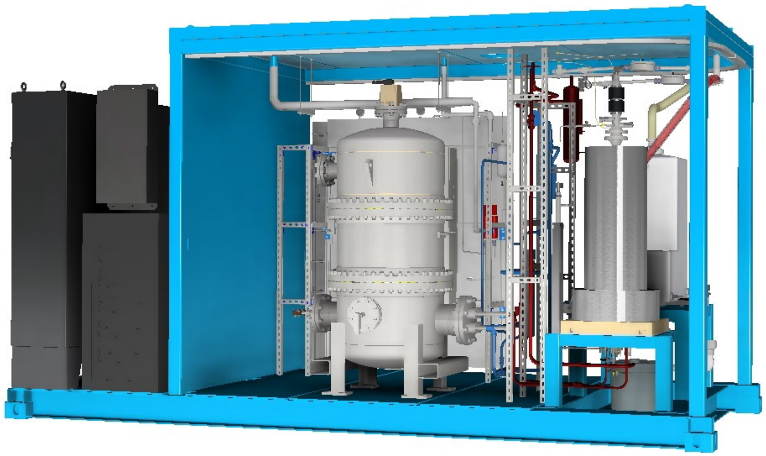
This Project's Focus

Property	Scale			Comments
	Short	Mid	Full	
Cell count	45	150	350	Nominal count
Fuel Cell Voltage, V	43	143	333	At 0.950 V/cell
Electrolysis Voltage, V	58	192	448	At 1.280 V/cell
Stack Efficiency, % LHV	74% / 100%	74% / 100%	74% / 100%	Electrochemical eff FC / EL
Power, kW	0.87 / 1.6	2.8 / 5.4	6.7 / 12.7	At 0.25 / -0.35 A/cm^2
Height, mm (in)	91 (3.6)	211 (8.3)	440 (17.3)	

Conditions selected to emphasise storage efficiency

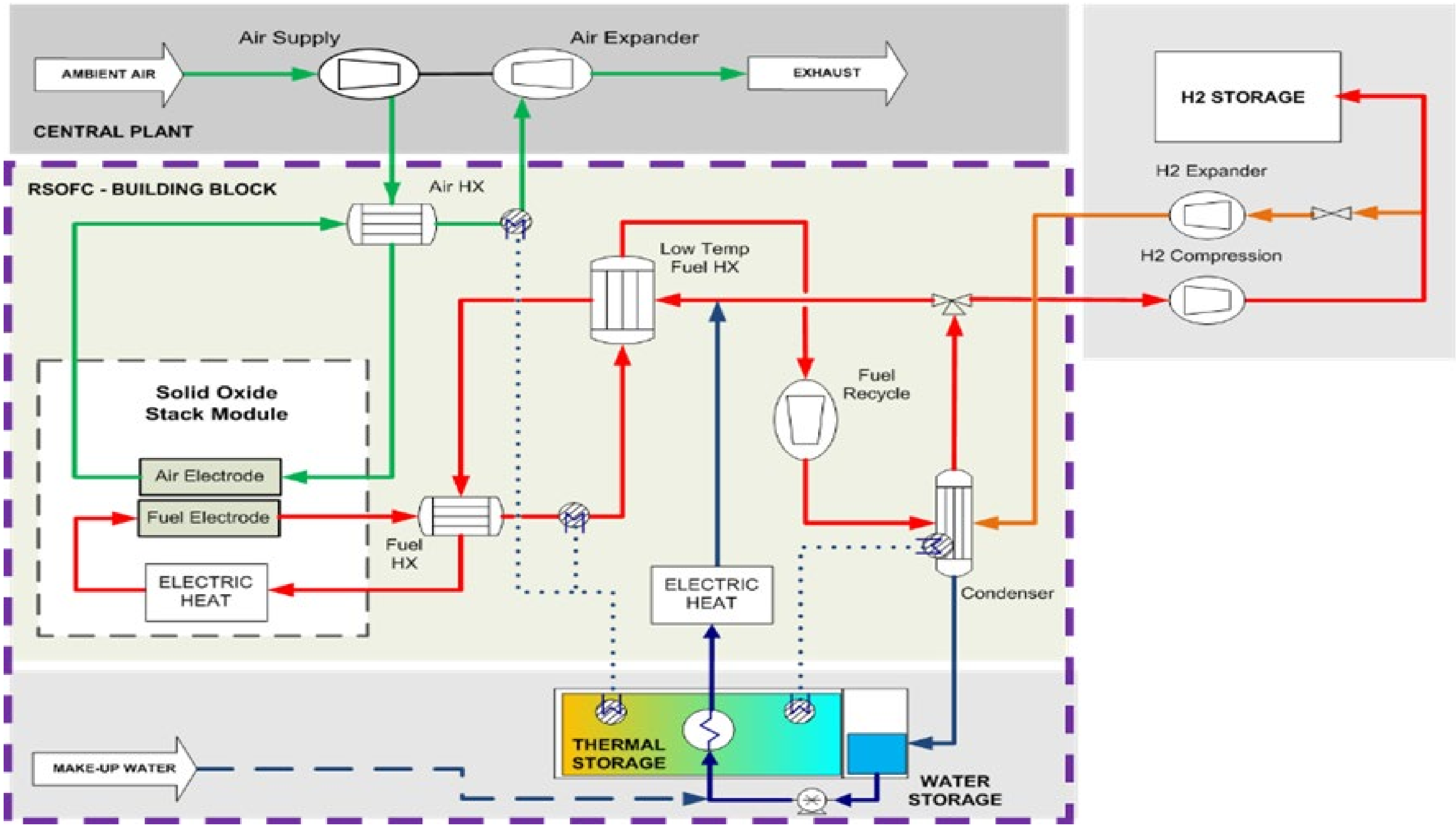
System Design Approach

- Size: ~3 kWe FC / ~15 kWe EC
- Basis: Modular SOEC System project (DE-EE0007646) 4 kg/day demonstration system
- Addition of Thermal Energy Storage subsystem
- Develop operating strategies to maintain high RTE
- Define/revise stack operating conditions as required to achieve efficiency (and degradation) targets

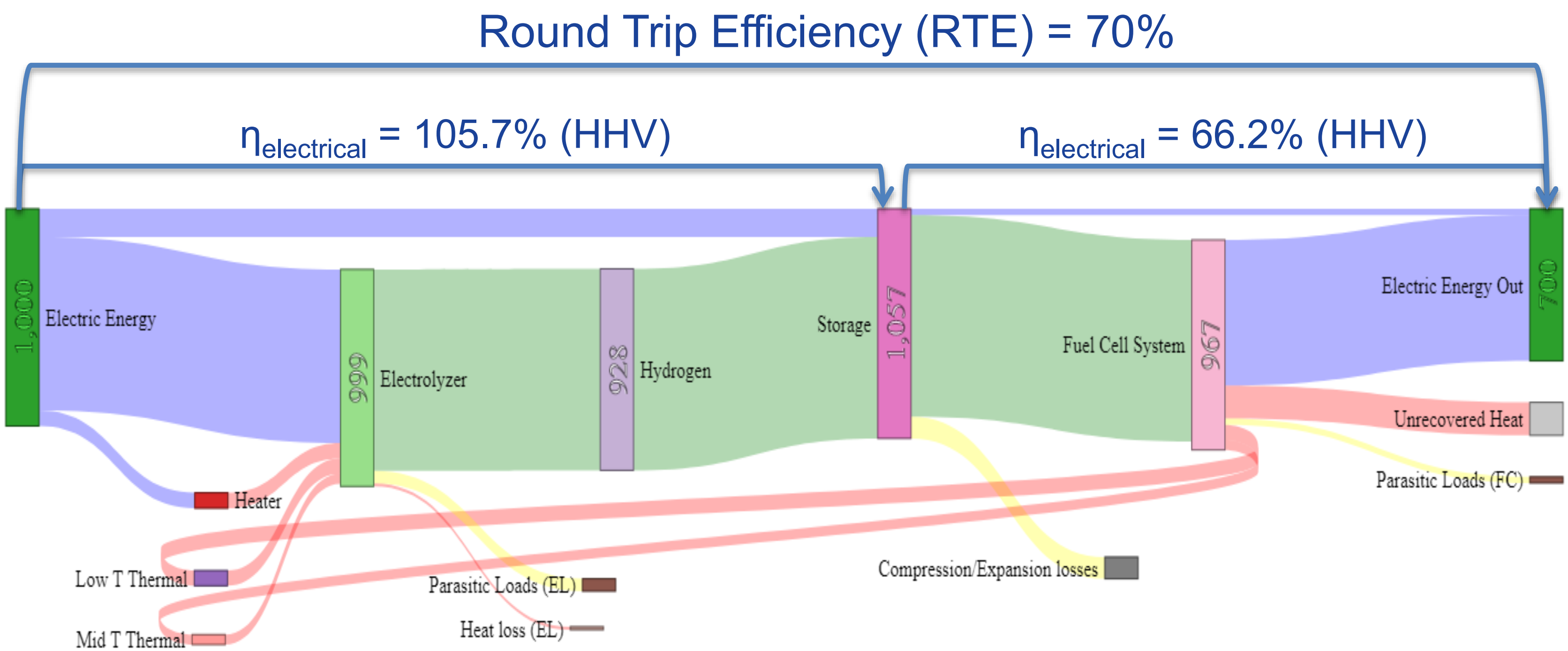


- Detailed design:
  - Process (P&IDs, Equipment specs, HAZOP safety analysis, Controls)
  - Mechanical (Hot Module, equipment integration, solid modelling)
  - Electrical (power supply/load bank integration, instrumentation and control hardware)
- Metrics
  - ≥60% RTE, validating path to ≥70% RTE (via heat and mass balance models)
  - ≤5% round trip efficiency degradation per 1000 cycles, over 100 cycles
  - Demonstrate TES with >80% heat recovery after 12 hours (useful heat extracted/heat stored)

Process Configuration



- System configuration builds upon the prototype system (DE-EE0007646) design, incorporating Thermal Energy Storage (TES) for high round trip efficiency



Path to achieve high RTE

- Thermal storage plays a small but significant role in supporting the overall cycle efficiency
- Minimizing high quality heat loss and operating in a nearly closed cycle are key aspects of achieving high efficiency
- Optimize fuel cell operating parameters for efficiency
  - High steam & fuel utilization (90%+)
  - Near thermo-neutral electrolysis operation (1.285 V/cell)
  - High-voltage FC operation (0.95-1 V/cell)

fuelcellenergy

Collaborations

An Advisory Board will be formed to provide guidance for product definition and specifications; and to oversee the development of the energy storage RSOFC systems

- Preliminary list of Industry committee members to explore:
  - Exelon
  - EPRI
  - Linde
  - National Resource Defense Council (NRDC)
  - National Rural Electric Coop Association (NRECA)
  - TriState G&T
  - Southern Company
  - Xcel
- Identify preliminary committee input for storage requirements
- Define system operating conditions and characteristics (size, cycle duration, etc.)
  - CHEMCAD model will be developed based on this input

Remaining Challenges and Barriers

- Reduction of stack performance degradation down to <5% per 1000 cycles:
  - Thermo-mechanical design of the stack
  - Maintaining good electrical contact between electrode and inerconnect during the cyclic operation

- System demonstration:
  - Efficient thermal storage design
  - Low degradation of RSOFC performance
  - Achieving RTE targets >50% in a 3 kWd demonstration system

- Techno-economic targets:
  - System cost of <$1000/kW resulting in energy cost of <$100/kWhr

Future Work

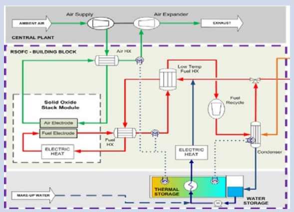
- Build two technology stacks (≥45 cells each) for testing of up to 100 cycles between fuel cell and electrolysis operating modes, while adjusting the operating condition parameters in each mode to optimize performance and reduce degradation:
  - Inlet compositions, e.g. H_2/H_2O ratio
  - Reactant utilizations
  - Current density (between 0.2 and 2.0 A/cm^2)
  - Operating temperature (650°C to 800°C)
  - Operating pressure (ambient to 10 bar)
- Complete design of the 3kWd demonstration unit for operation in BP2
- Perform Techno-economic Analysis
  - RSOFC product configuration
  - Stack and system cost at high volume production
  - Operating and maintenance costs

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

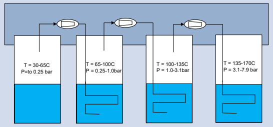
Proposes Future Work

Product Development Process

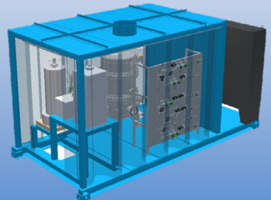
Technology Transfer Activities



System design and modelling



Thermal capture and storage



Demonstration

Industry Committee

Techno-Economic Analysis

Product Definition

Summary

- Project contract was signed by DOE on May 12, 2020
- System flowsheet and analysis were initiated
- Prospective members of the Advisory Board for product characterization were contacted