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Solid Oxide Based Electrolysis and Stack Technology with Ultra-High Electrolysis Current Density and Efficiency

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Project ID: PD124

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Overview

- Timeline
  - Start: June 2015
  - End: May 2017
- Budget
  - $1,241K total project funding
    - $992K DOE share
    - $249K VPS share
    - $0 DOE Funds Spent
- Barriers
  - F. Capital cost
  - G. System efficiency and electricity cost
  - J. Renewable electricity generation integration (for central power)

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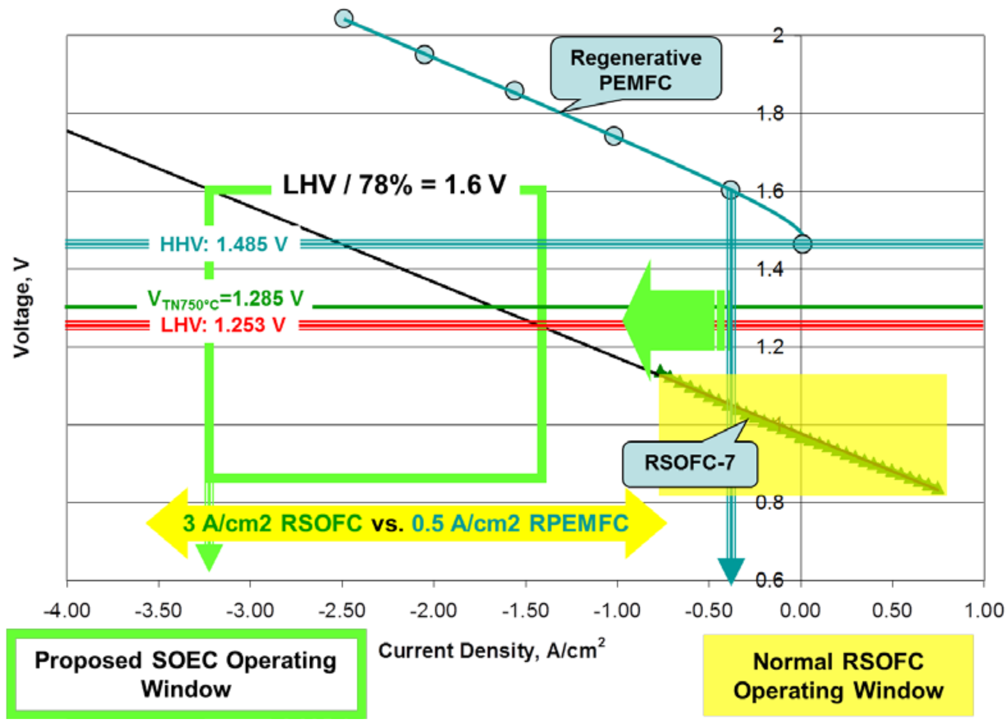
Achieving High Electrolysis Efficiency

Relevance

- To reach the DOE 2020 water electrolysis stack efficiency (LHV) target of 78%, an upper limit of 1.6 V was chosen for the electrolysis operating voltage. At this upper limit voltage, VPS's RSOFC-7 cell may deliver more than 3 A/cm^2 (assuming the linear V-I projection holds).
  - The yellow shaded area represents a previously tested operating range.

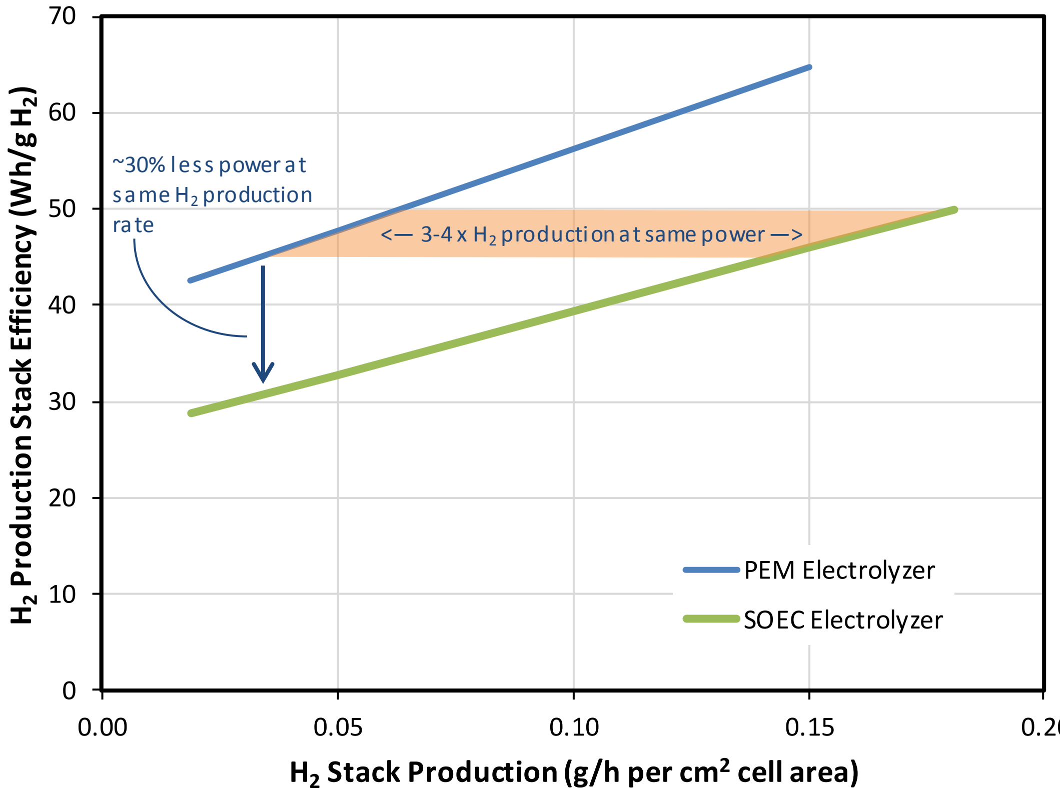


- In comparison, a PEM-based regenerative cell will have a much lower current density of less than 0.5 A/cm^2 at this voltage.
- Decreased operating costs resulting from increased efficiency is a significant driver for delivering economical hydrogen. Improvements in stack current density result lead to a corresponding decrease in capital cost, which contributes to reduced hydrogen costs to a lesser extent.

Advantages of High Temperature Electrolysis

Relevance

- At the stack level, the lower cell voltage of SOEC cells results in about 30% lower power consumption at any given hydrogen production rate or three to four times more hydrogen production (in the range of about 45 to 50 Wh/g).



- An SOEC system with higher maximum operating current limit will better match the charging rates for solar and wind based renewable energy sources. This leads to better integration to meet the energy conversion and storage needs from a wider variety of renewable energy sources.

Project Objectives

Relevance

- Research and development of SOEC technology capable of operating at ultra-high current density (> 3 A/cm^2) with an operating voltage upper limit of 1.6 V. Anticipated results include:
  - Single cell
    - Develop a solid oxide electrolysis cell platform capable of operating with current density up to 4 A/cm^2 at an upper voltage limit of 1.6 V
    - Demonstrate stable solid oxide electrolysis cell operation with high current density of more than 3 A/cm^2 for 1000 hours
  - Stack
    - Design a solid oxide electrolysis stack platform capable of operating with the high current density (>3 A/cm^2) cell technology at an upper voltage limit of 1.6 V
    - Demonstrate stable solid oxide electrolysis stack operation with high current density of more than 2 A/cm^2 for 1000 hours
  - System
    - Complete a solid oxide electrolyzer process and system design that accommodates the ultra-high operating current density platform
- All objectives intended to contribute to meeting DOE 2020 targets for advanced water electrolysis technologies

How Objectives Address Barriers

Relevance

Barrier	Project Objectives
To meet or exceed DOE 2020 water electrolysis stack efficiency target of 78% (LHV)	SOEC technology capable of reaching 78% (LHV) efficiency via an ultra-high electrolysis current of more than 3 A/cm^2 at an upper limit voltage of ~1.6 V.
System efficiency	SOEC system design that delivers the same H_2 production rate with 30% less power consumption than PEM technology.
Capital cost	SOEC system design that generates more than four times the H_2 per unit active area compared to a regenerative PEM electrolyzer at the same efficiency.
Renewable electricity generation integration (for central power)	SOEC system design with higher operating current to better match the charging rates for solar and wind based renewable energy sources. This leads to better integration to meet the energy conversion and storage needs from a wider variety of renewable energy sources.

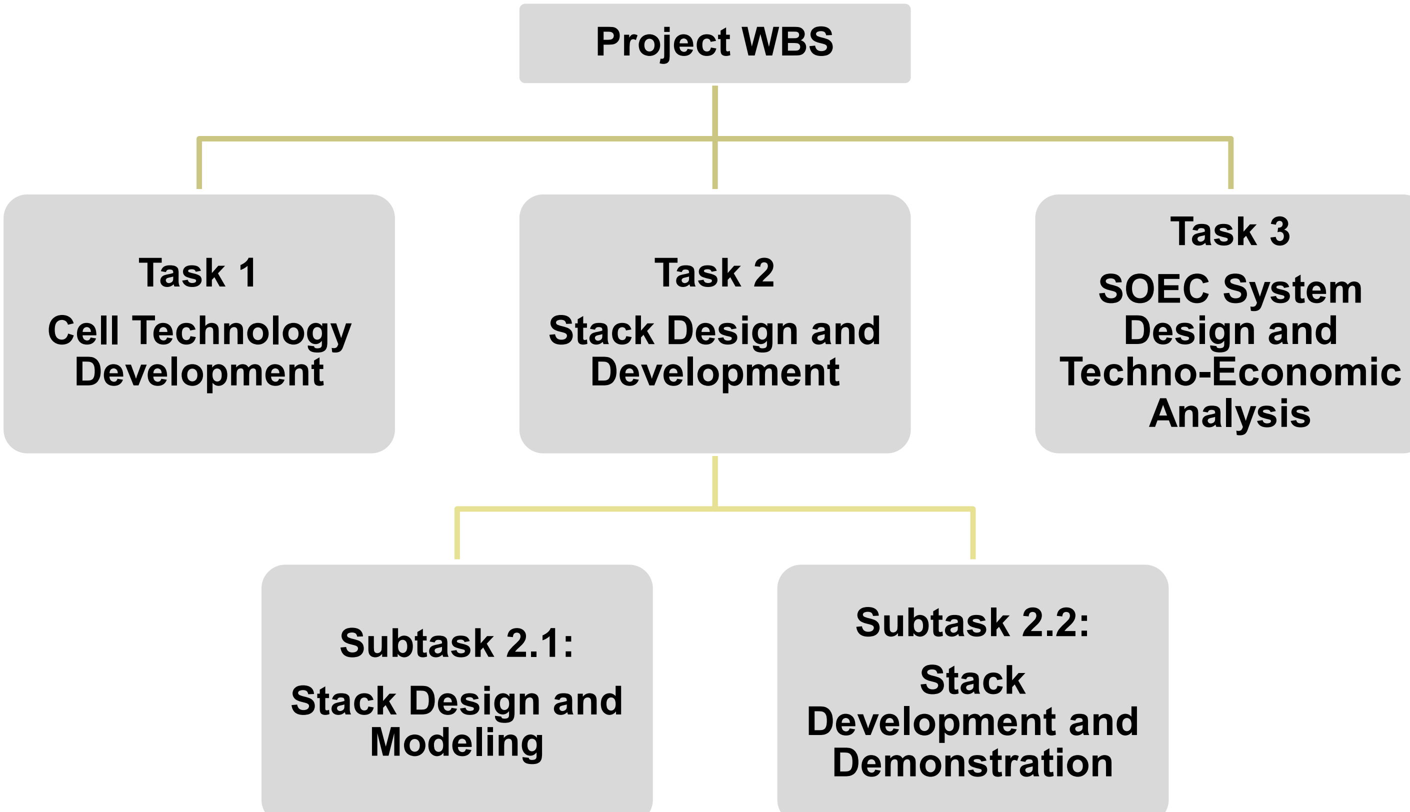
Development Path

Approach

Building on VPS's strong solid oxide cell and stack development in the previous EERE sponsored project (Advanced Materials for RSOFC Dual Operation with Low Degradation), and leveraging cell and stack advancements from the other VPS projects (GLE, DOE SECA, and DARPA projects) over the last 15 years, the project objectives will be met by executing the following scope:

- **Materials:** Addressing high current density electrolysis cell performance limitations by conducting materials development and cell design of experiments and integrating them with cell production technology development.
- **Stack Design:** Developing SOEC stack engineering modeling and process fabrication designs to address high current density operating requirements and identify key operating parameters for the design of an integrated, SOEC-based energy conversion and storage system for renewable energy sources.
- **Validation Testing:** Down-selecting and demonstrating high current density SOEC operation via single cells and stacks tests.
- **System Analysis:** Investigating high current density solid oxide electrolyzer system and its integration with renewable energy sources to meet DOE 2020 Advance Electrolysis Technologies target.

Work Breakdown Structure



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Task 1: Cell Technology Development

Approach

- Task Summary
  - SOEC cells with ultra-high current density of up to 4 A/cm^2 will be designed, developed, and demonstrated in this task. Key activities will focus on the development of a new fuel electrode and substrate.

Milestones		
	1.1	Baseline characterization of the performance and degradation rate of the VPS SOEC cell technology in single cell tests with a current density of more than 3 A/cm^2 (month 3).
	1.2	Develop and demonstrate SOEC cell technology capable of 4 A/cm^2 at 1.6 V (month 9).
	1.3	Complete the final SOEC cell design with 1000 hour stable electrolysis operation (< 4% degradation per 1000 hours) at 3 A/cm^2 (month 21).

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Task 2: Stack Design and Development

Approach

- Task Summary
  - SOEC stacks with ultra-high current density of more than 3 A/cm^2 will be designed, developed, and demonstrated. SOEC stack level modeling will be conducted with an upper electrolysis voltage limit of 1.6 V/cell.

Milestones		
	2.1.1	Complete preliminary stack process design and modeling. Unit cell modelling will establish basic design for thermal and flow management as projected operational envelope of the stack (month 6).
	2.2.1	Demonstrate a short SOEC stack operating with ultra-high current density of more than 3 A/cm^2 at less than 1.6 V (78% LHV stack electrical efficiency for hydrogen production) (**Go/No Go**, month 12).
	2.2.2	Complete 10 kWe rated SOEC stack design freeze incorporating final design changes suggested by stack test results and any further modeling effort as well as final design elements that permit stacking into a 10 kW stack package (month 18).
	2.2.3	Demonstrate an SOEC stack with hydrogen production of 250 g/hour as well as demonstrating stable operation at a current density of more than 2 A/cm^2 (month 24).

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Task 3: SOEC System Design and Techno-Economic Analysis

Approach

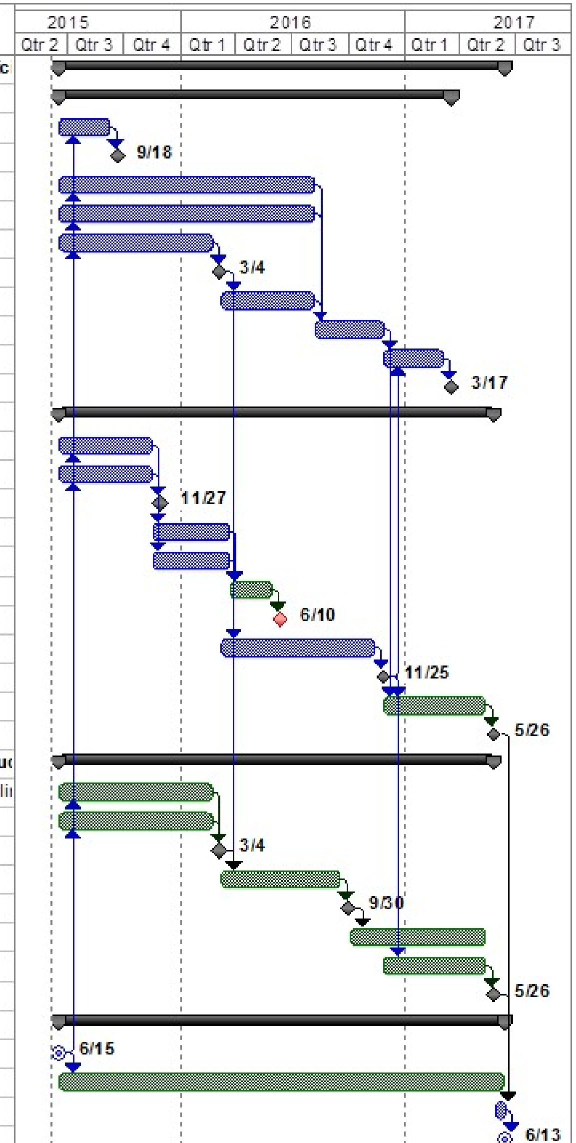
- Task Summary
  - A conceptual SOEC system design with an in-depth SOEC hot module configuration design will be developed.
  - VPS will conduct ultra-high current SOEC system modeling using VPS custom tools and Aspen-HYSYS® process modeling tools (or similar).
  - A comprehensive techno-economic study of the integration of an ultra-high current density SOEC system with renewable energy sources will be conducted.

Milestones	3.1	Complete preliminary ultra-high current density SOEC system conceptual design (month 9).
	3.2	Complete in-depth SOEC hot module configuration design to include stacks, pressure containment, insulation, instrumentation, and process connections, integrated into a single package (month 15).
	3.3	Complete a comprehensive techno-economic study of an ultra-high current density SOEC system including integration with renewable energy sources (month 24).

Project Schedule

Approach

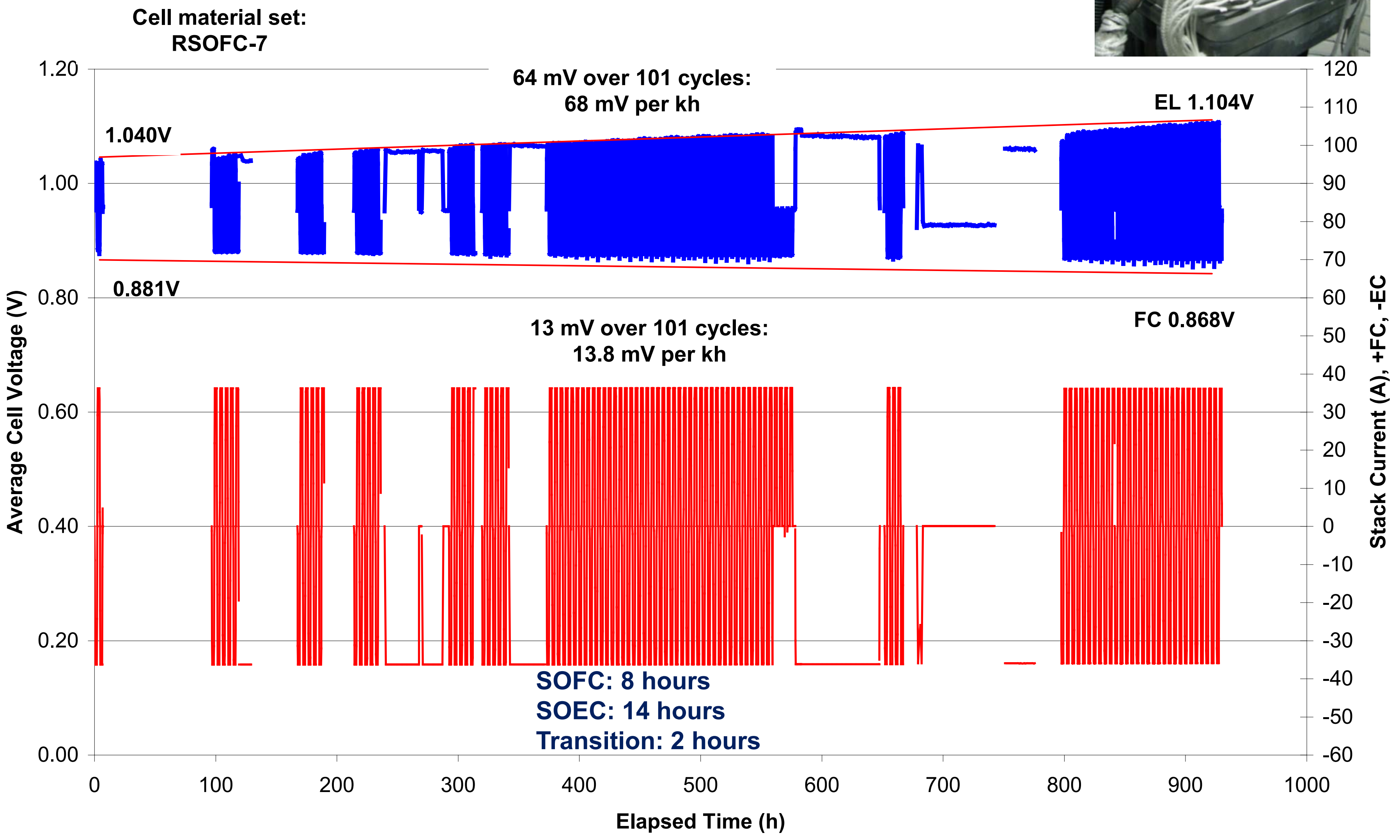
ID	Task Name
1	**SOEC Technology with Ultra-High Current Density and Effic**
2	**Task 1 Cell Technology Development**
3	Baseline Performance and Degradation Test
4	M1.1
5	Electrode Development
6	Electrolyte Development
7	Operating Condition Investigation
8	M1.2
9	SOEC Cell Integration
10	RSOFC Cell Process Development
11	Long Term SOEC Cell Degradation Validation Test
12	M1.3
13	**Task 2 Stack Design and Development**
14	Stack Process Design
15	Stack CFD Modeling
16	M2.1.1
17	Stack Mechanical Design
18	Stack Testing Facility Development
19	Short Development Stack Tests
20	**M2.2.1 Go/No-Go Decision Point**
21	Full Size SOEC Stack Development and Tests
22	M2.2.2
23	Full Size SOEC Stack Validation Tests
24	M2.2.3
25	**Task 3 SOEC System Design and Techno-Economic Stu**
26	Ultra-High Current and Efficiency SOEC System Modeli
27	Conceptual System Design
28	M3.1
29	SOEC Hot Module Configuration Design
30	M3.2
31	SOEC Hot Module Construction and Testing
32	Techno-Economic Study
33	M3.3
34	**Task 4 Project Management**
35	Project Starting Date
36	Project Management
37	Final Report
38	Project Completion Date



Relevant Results from Previous Work

- Part of the foundation for this work is an earlier EERE project entitled *Advanced Materials for RSOFC Dual Operation with Low Degradation*
  - RSOFC = reversible solid oxide fuel cell (capable of running both as a fuel cell and as an electrolyzer)
- That project's objectives were to meet performance and endurance targets in a kW-class RSOFC stack demonstration
  - Cycling (transitions between fuel cell and electrolysis modes)
  - Operating current density in both fuel cell and electrolysis modes
  - Overall decay rate per 1000 hours of operation
- Final report is available online
  - http://www.osti.gov/scitech/biblio/1058912

RSOFC Project: kW-Class Stack Cyclic Test



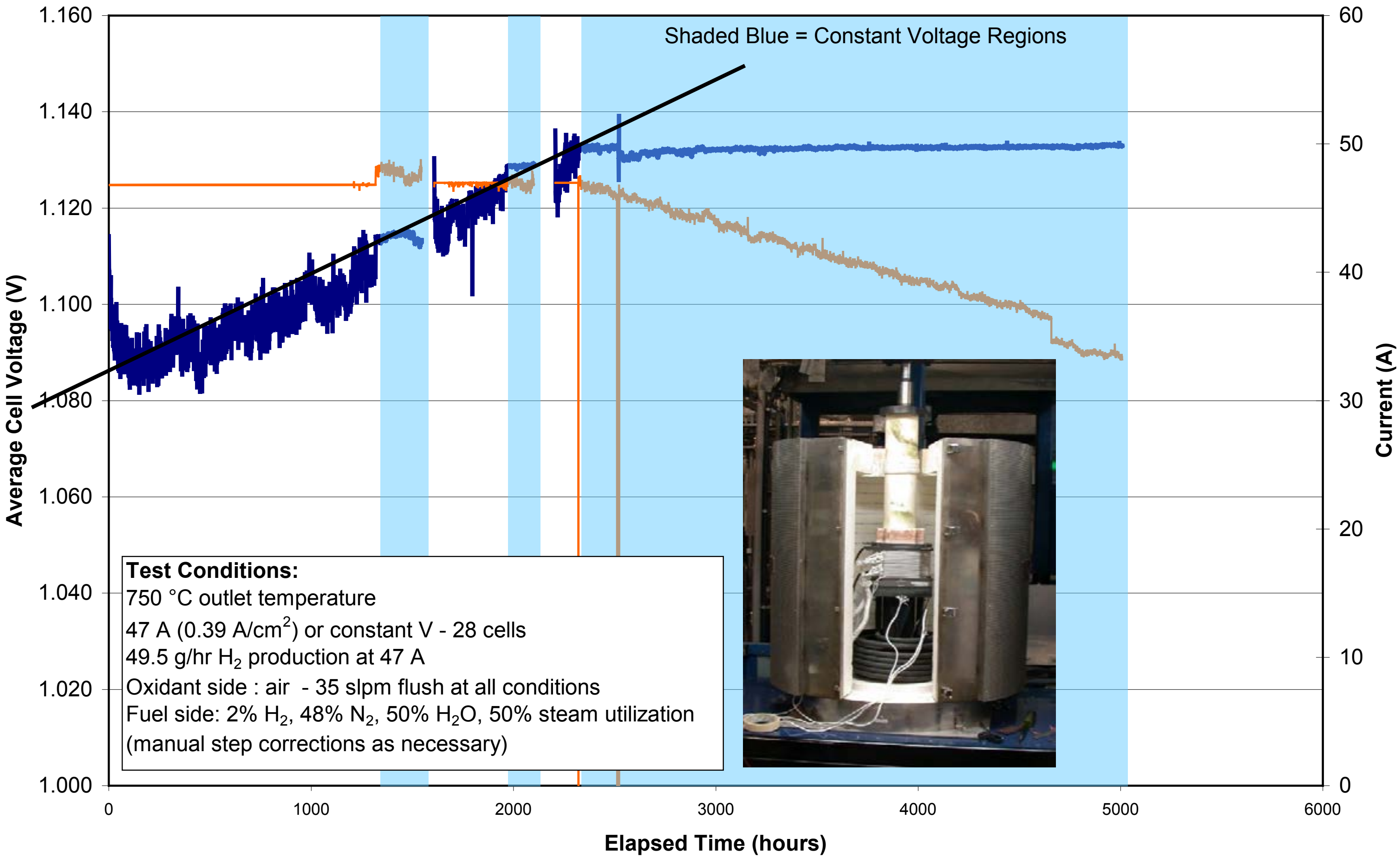
Approach Foundation: Prior Results

Approach Foundation: Prior Results

RSOFC Project: 5000-Hour kW-Class Stack Testing

Cell material set: RSOFC-1

Constant Current Degradation: ~20 mV/khr
Constant Voltage Degradation: ~5 A/khr



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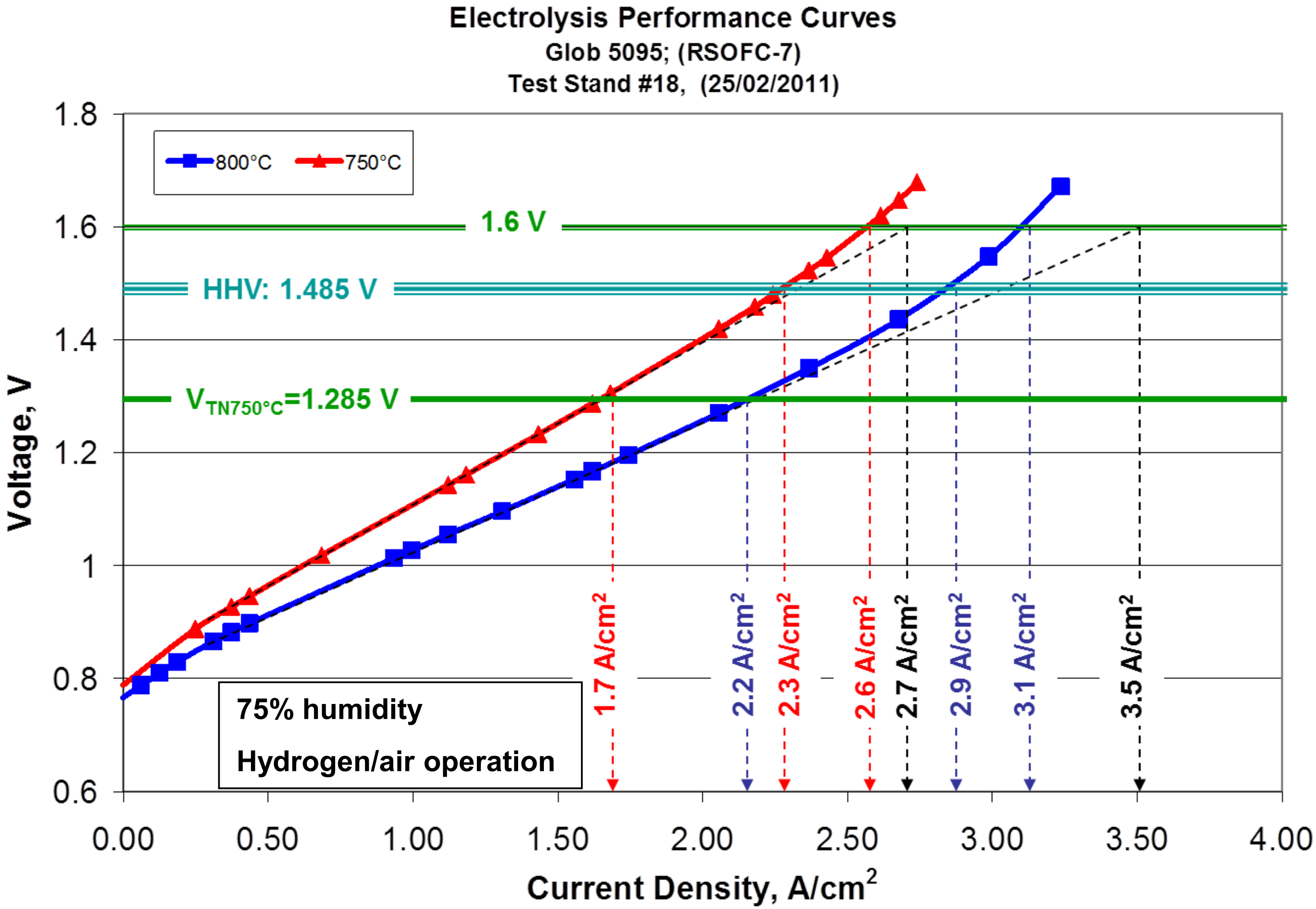
RSOFC Project: Cell Performance at Ultra-High Current Density

Approach Foundation: Prior Results



Collaborations and Leveraging Opportunities

- Boeing
  - Collaborated on and funded initial RSOFC development work through both Boeing and DARPA funded efforts
  - Subcontractor to Boeing for ongoing DARPA Vulture Phase 2 project
- DOE SECA
  - As subcontractor to FuelCell Energy in SECA, VPS has advanced SOFC cell and stack technology, some of which has been applied in this program

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Summary

Relevance	Improving electrolysis efficiency, and thereby operating and capital costs, is a key aspect for enabling the competitiveness of both distributed and central hydrogen production. This project addresses efficiency and cost barriers with an innovative ultra-high current solid oxide electrolyzer.
Approach	This effort will address high current density electrolysis limitations by conducting materials development and cell design, stack modeling and design, cell and stack validation testing, and system design and analysis. Milestones include cell current densities of 3 to 4 A/cm^2, stack current densities of 2 to 3 A/cm^2, stack efficiency of 78% (LHV), endurance and degradation metrics, and a techno-economic study of the integration of an ultra-high current density SOEC system with renewable energy sources.
Technical Progress	This project has not yet started therefore there is no progress to report.
Collaboration	Boeing/DARPA and DOE SECA
Proposed Future Research	This project has not yet started therefore the entire scope is future work.