Advanced Materials for RSOFC Dual Operation with Low Degradation

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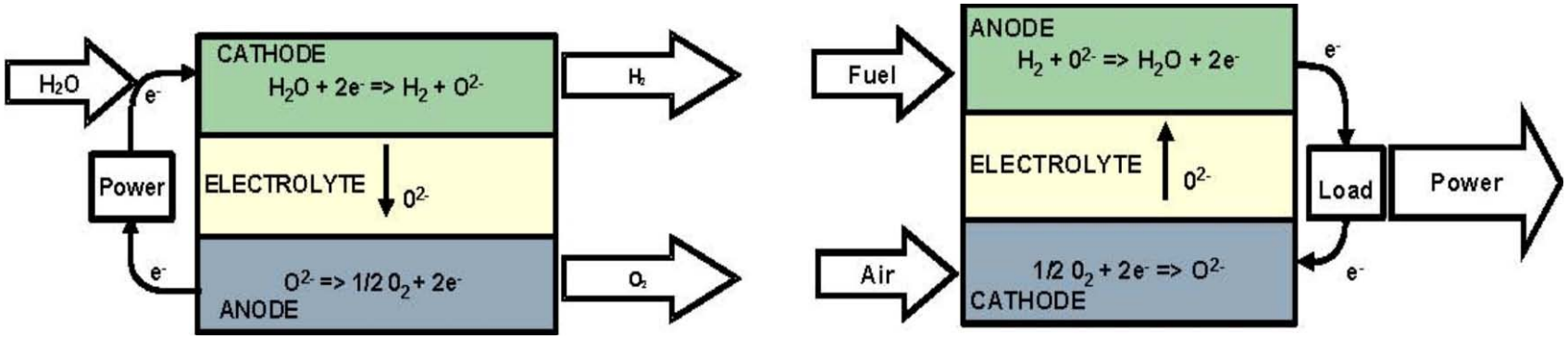
Project ID: FC042

Overview

- Timeline
  - Start: September 2009
  - End: September 2011
  - 50% Completed (Ahead of Schedule)
- Barriers
  - G. Capital cost
  - H. System efficiency
  - I. Grid electricity emissions (for distributed power)
  - J. Renewable electricity generation integration (for central power)
- Budget
  - $1,994,618 total project
    - $1,595,694 DOE share
    - $398,924 VPS share
  - No funding for FY09
  - $1,162,686 for FY10
- Partners
  - Boeing
  - SECA
  - Idaho National Laboratory (INL) in future work

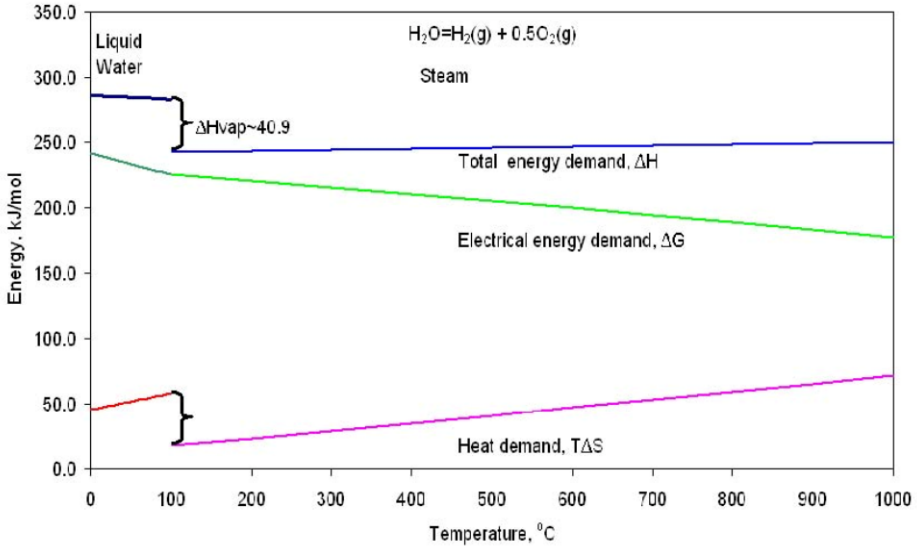
Project Background



Relevance

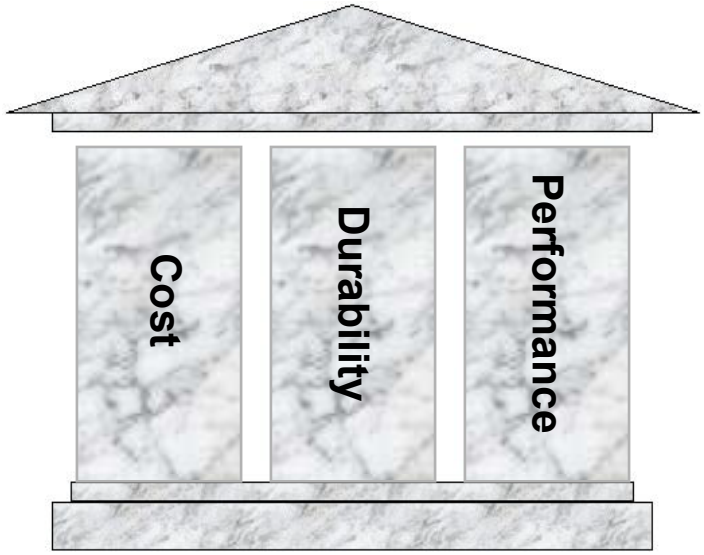
- Reversible Solid Oxide Fuel Cells (RSOFCs) are energy conversion devices. They are capable of operating in both power generation mode (SOFC) and electrolysis mode (SOEC)

- RSOFC can integrate renewable production of electricity and hydrogen when power generation and steam electrolysis are coupled in a system, which can turn intermittent solar and wind energy into “firm power”



Project Objectives

- To advance RSOFC cell stack technology in the areas of endurance and performance through RSOFC materials development and reversible stack design
- To meet the following performance targets in a kW-class RSOFC stack demonstration:
  - RSOFC dual mode operation of 1500 hours with more than ten SOFC/SOEC transitions
    - Grid Emissions (I), Renewables (J)
  - Operating current density of more than 300 mA/cm^2 in both SOFC and SOEC modes
    - Cost (G), Efficiency (H)
  - Overall decay rate of less than 4% per 1000 hours of operation
    - Cost (G), Efficiency (H)



Relevance

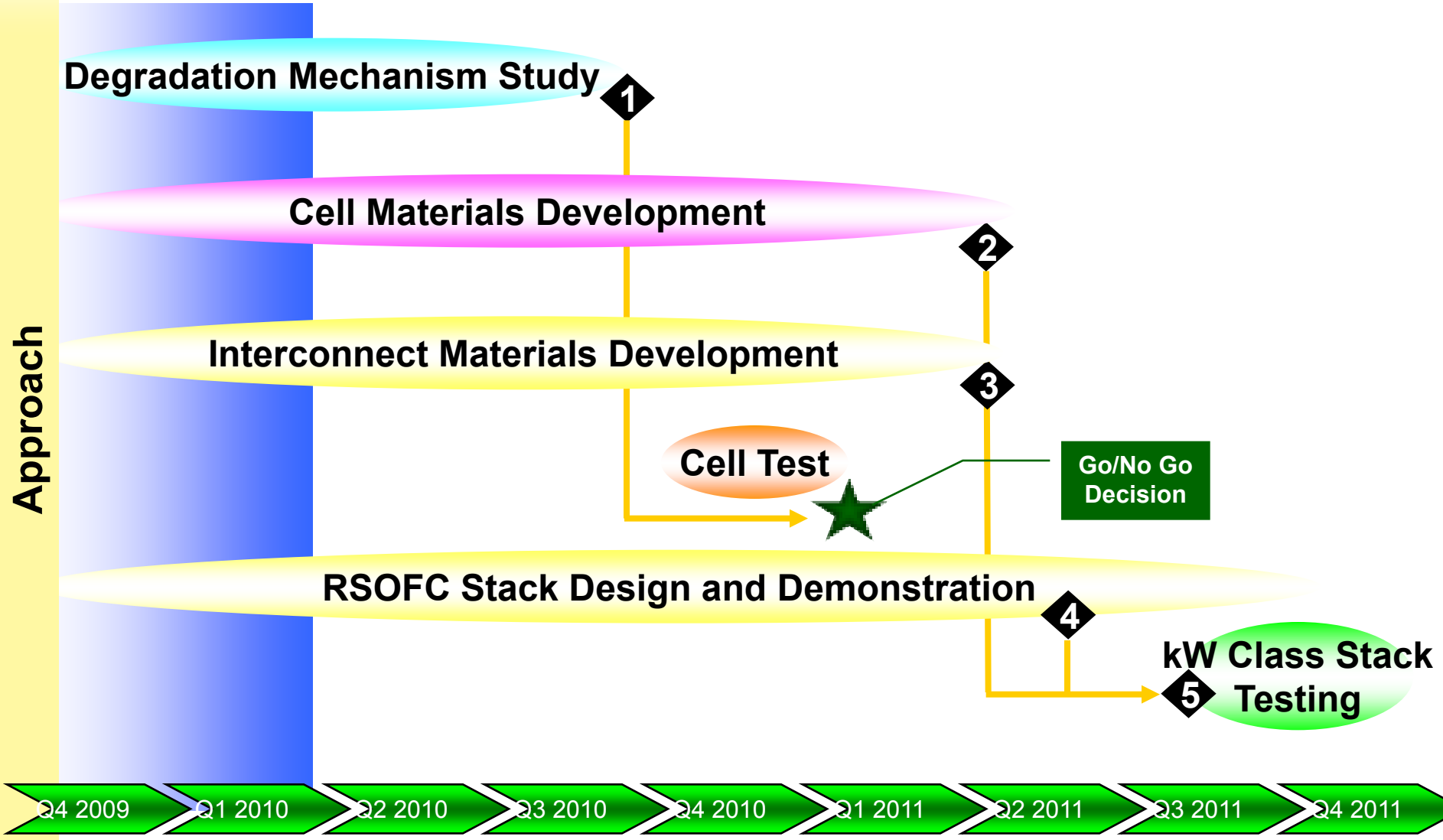
How Objectives Address Barriers

Relevance

	Hurdle	Targets
Endurance	**Performance decay in SOEC mode is too high for RSOFC system development** ▶ Materials system is not stable at SOEC operating mode with a decay rate more than 20% per 1000 hours ▶ Performance decay during transient between SOEC and SOFC is high	**Reducing decay to under 4% per 1000 hours for both SOFC and SOEC** ▶ Meet endurance target in a 1000 hour single cell test (month 15) ▶ Meet endurance target in a 1500 hours kW-class stack (month 24) ▶ Demonstrate transient capability with more than 10 FC/EC transients
Performance	**Performance in SOEC mode is not sufficient for viable RSOFC system development** ▶ ASR is more than 1.0 Ω-cm^2 at 750 C and below in SOEC mode	**Improve performance at 750 C in SOEC mode by reducing ASR to less than 0.3 Ω-cm^2** ▶ Meet performance technical target in a single cell test (month 15) ▶ Operate kW-class RSOFC stack at more than 300 mA/cm^2

Project Timeline, Milestones, Decision Points

Approach



Decision Points and Milestones

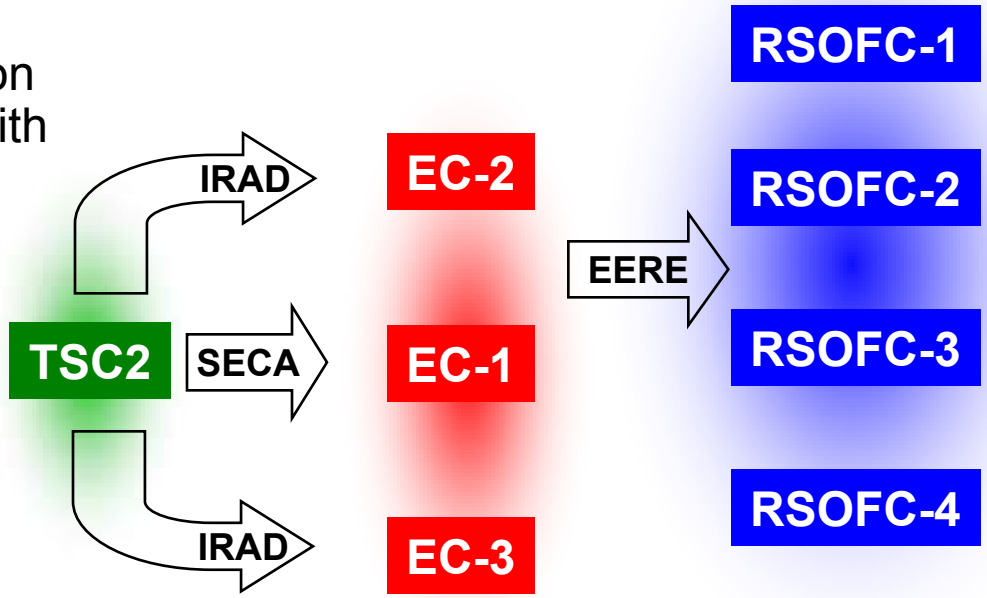
- At month 15, a go/no-go will be made based on 1000 hour single cell test relative to the following performance and endurance metrics:
  - RSOFC area specific resistance of less than 0.3 Ω-cm^2 in both SOFC and SOEC operating modes
  - Operating current density of more than 300 mA/cm^2 in both SOFC and SOEC modes
  - Overall decay rate of less than 4% per 1000 hours of operation
- Five technical milestones will be tracked and measured throughout the project
  1. Task 1: Completion of degradation mechanisms study of baseline cells (4th quarter)
  2. Task 2: Completion of RSOFC cell materials selection (6th quarter)
  3. Task 3: Completion of RSOFC interconnect materials selection (6th quarter)
  4. Task 4: Completion of RSOFC stack design (7th quarter)
  5. Task 4: Starting end of the project RSOFC stack metrics test (8th quarter)

Approach

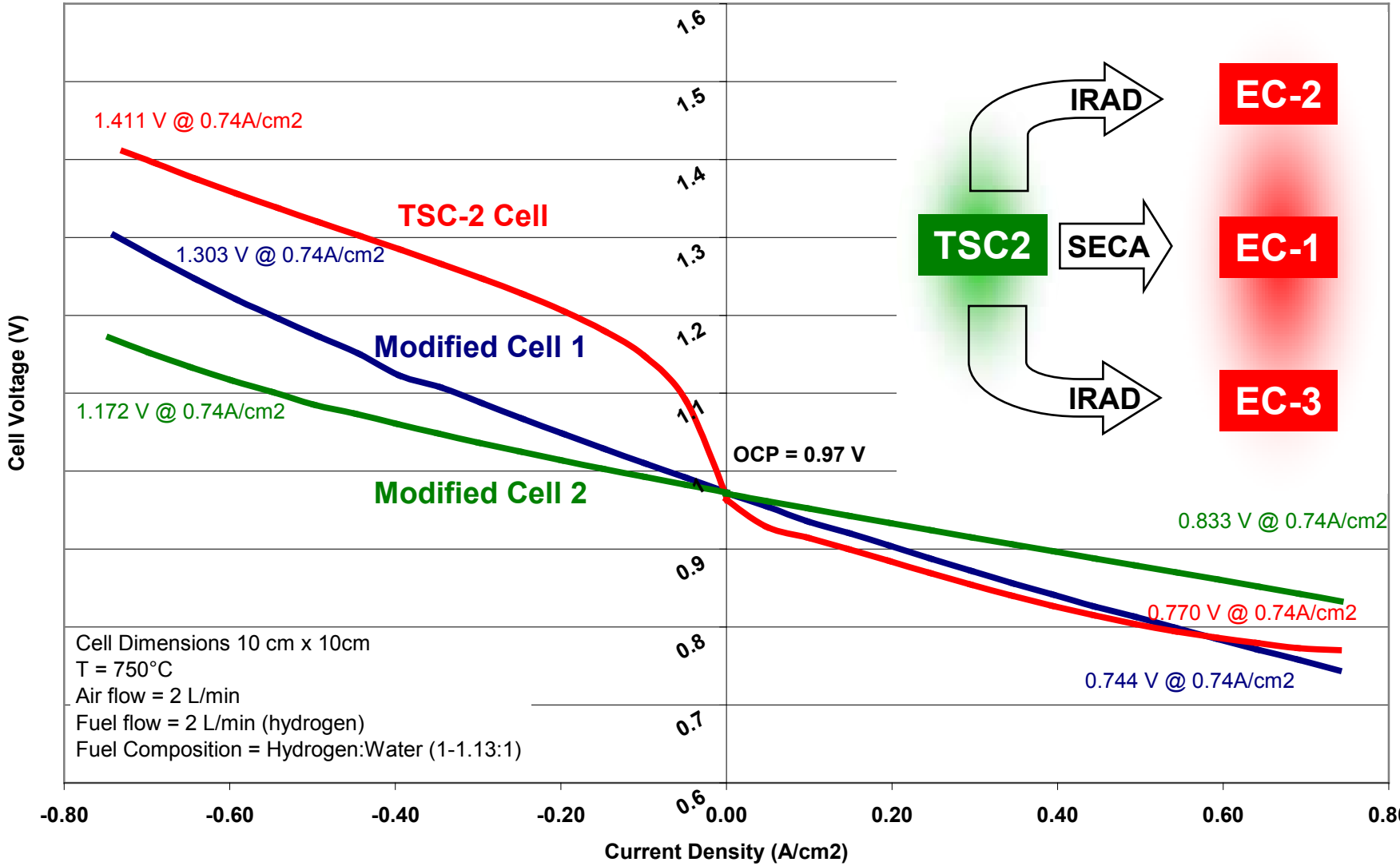
RSOFC Development Path

Approach

- Building on VPS' strong SOFC cell and stack baseline
- Leveraging cell and stack advancements from the DOE-SECA SOFC project
- Addressing RSOFC degradation mechanisms in SOEC mode with innovative cell and stack repeat unit configurations
- Conducting parallel materials development activities and integrating them with cell production technology development
- Completing RSOFC stack and process designs to address durability, performance, and cost in both SOFC and SOEC operating modes

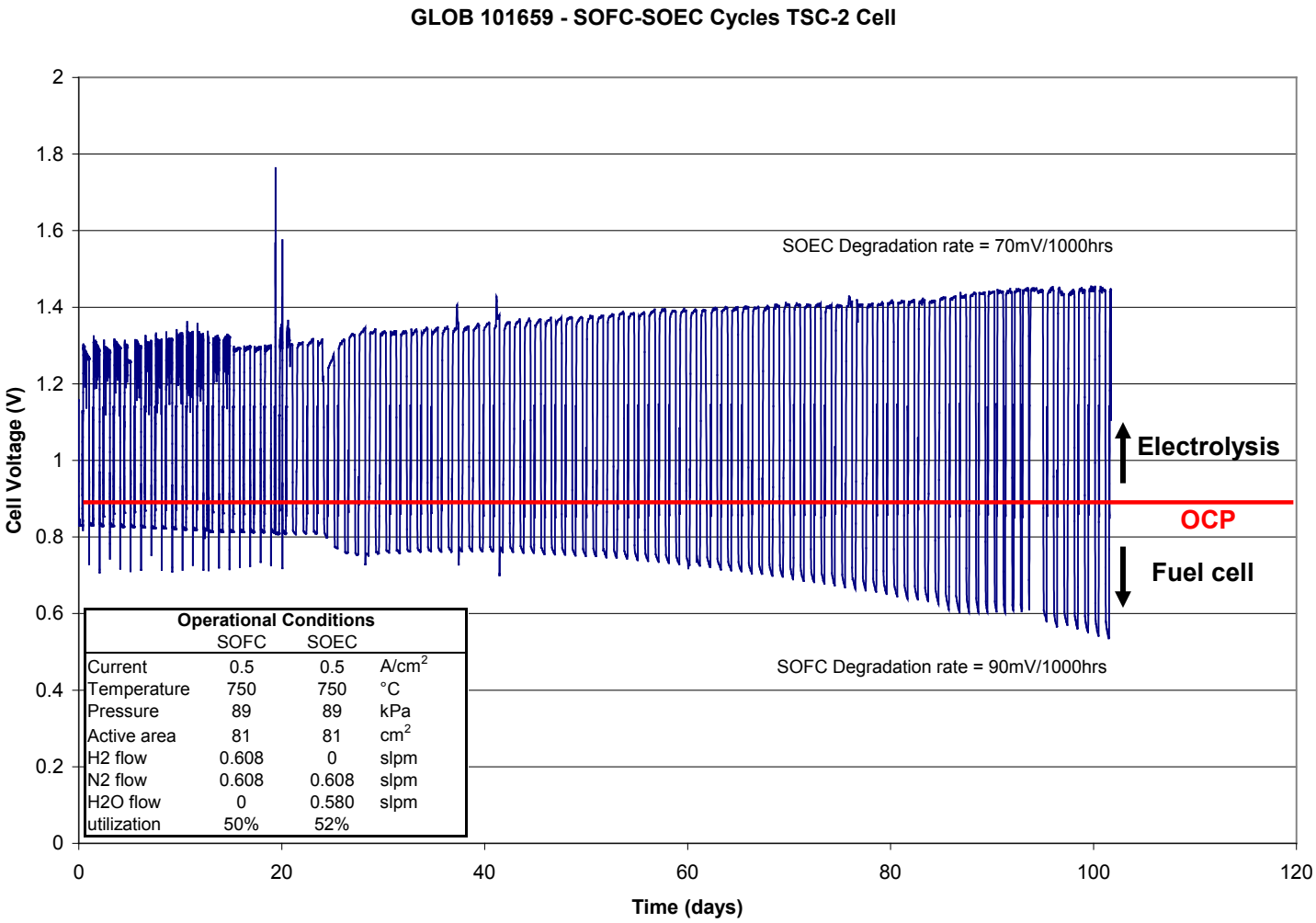


Pre-Award Cell Development



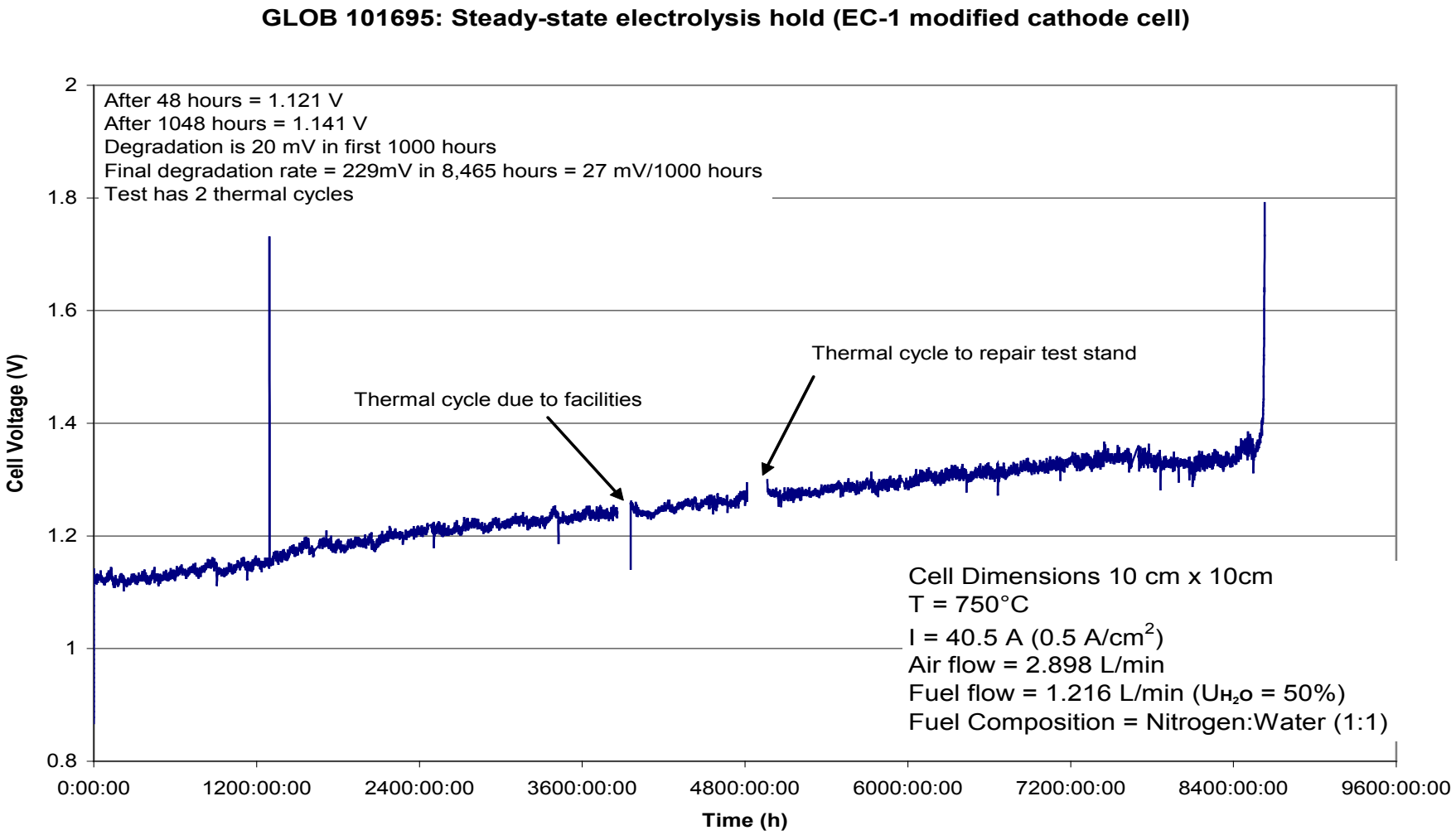
Leveraging SECA cell improvements

Single Cell Electrolysis/Fuel Cell Cycling Test



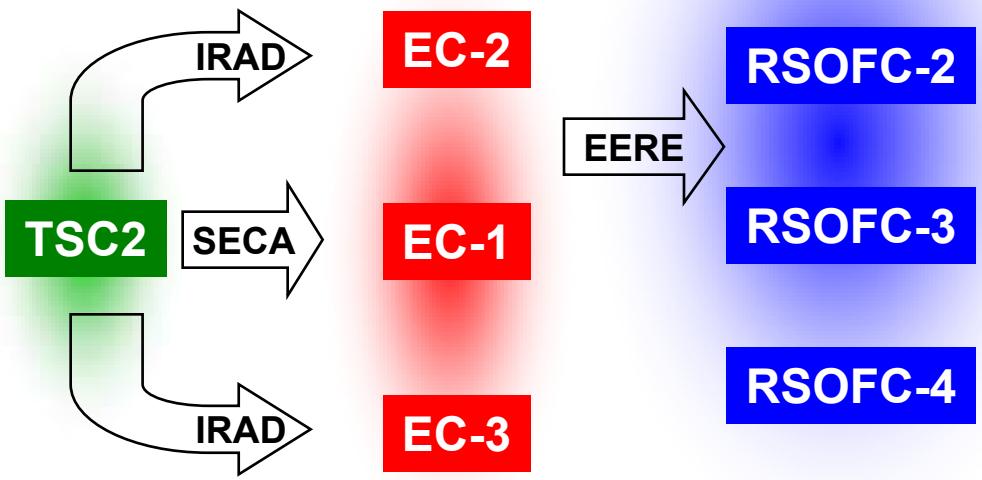
Demonstrated 100 electrolysis/fuel cell mode cycles

Steady-State Electrolysis Test



Demonstrated electrolysis mode degradation of less than 3% per 1000 hours for over 8000 hours (one year)

RSOFC Cell Performance Development Status

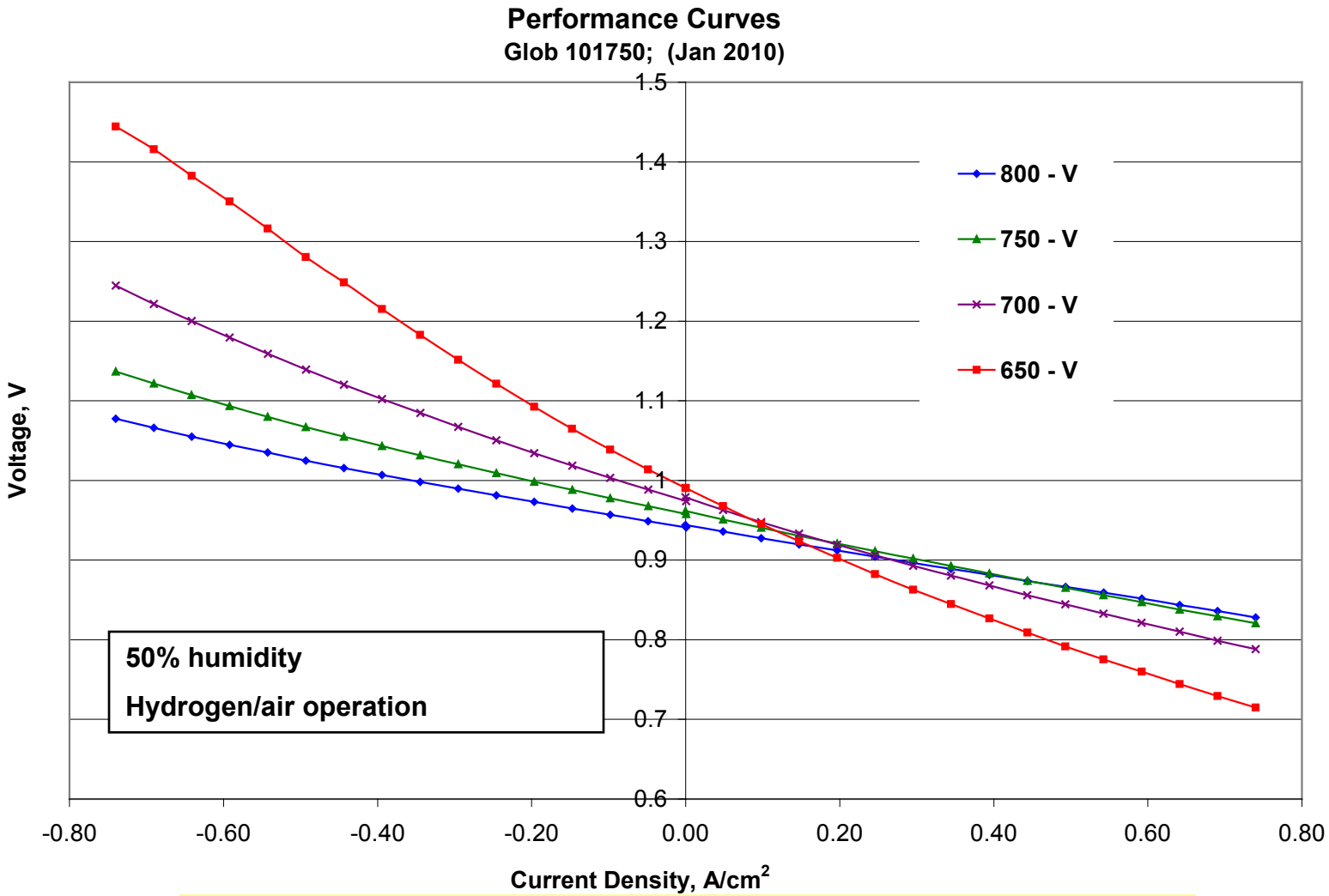


Cell Type	SOEC ASR (mΩ-cm²)	SOFC ASR (mΩ-cm²)
TSC-2	375	180
EC-1	366	281
EC-2	362	393
EC-3	278	251
RSOFC-1	308	245
RSOFC-2	285	295
RSOFC-3	386	283
RSOFC-4	268	238

- Fuel Cell (SOFC) ASR at 3% humidity and 750°C
- Electrolysis (SOEC) ASR at 50% humidity and 750°C

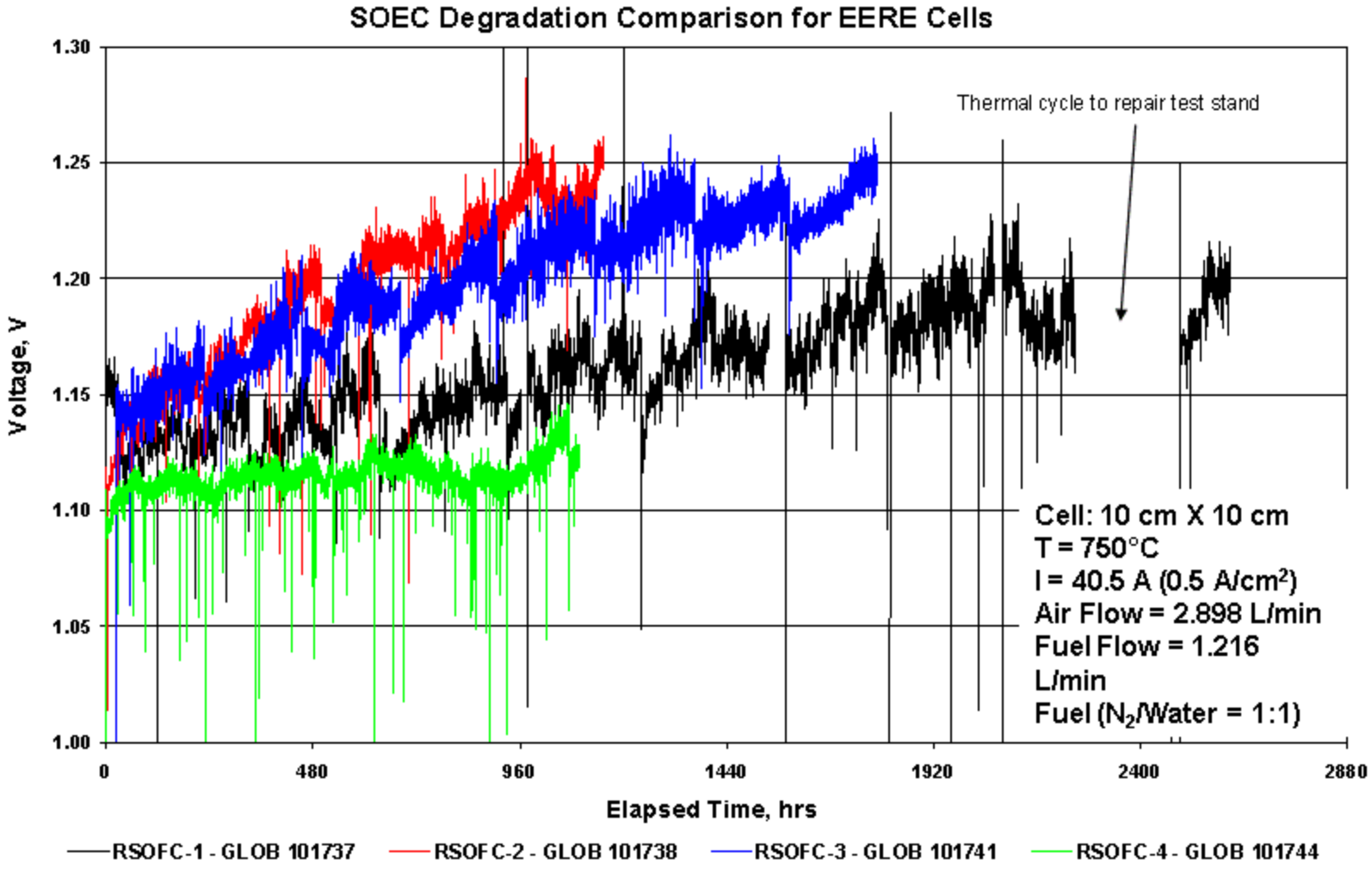
Both RSOFC-2 and RSOFC-4 passed the performance criteria of ASR less than 300 mΩ-cm² in both SOFC and SOEC modes

RSOFC-4 Cell Performance



High performance of RSOFC-4 can reduce hydrogen production cost in SOEC mode and improve efficiency in SOFC mode

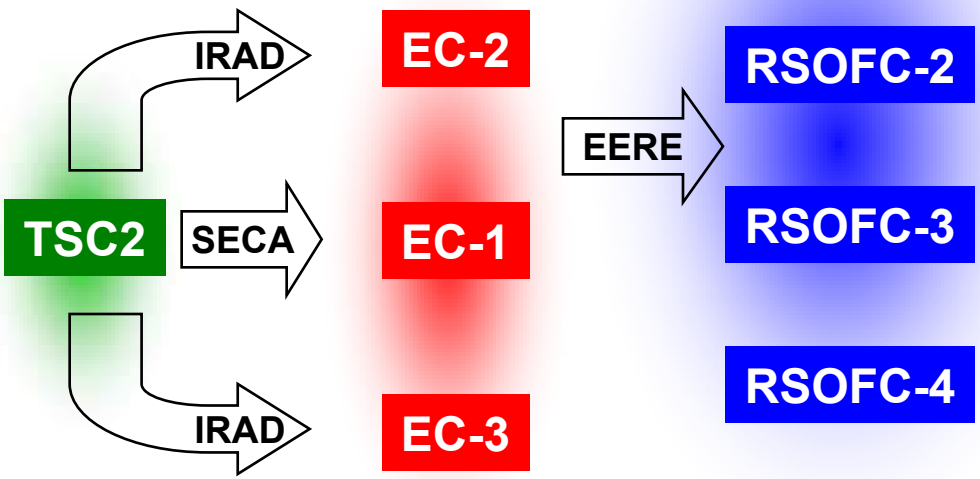
RSOFC Long Term Electrolysis Tests



Conducting long term steady-state SOEC tests to validate the endurance characteristics of the RSOFC cells

Electrolysis Degradation: Status

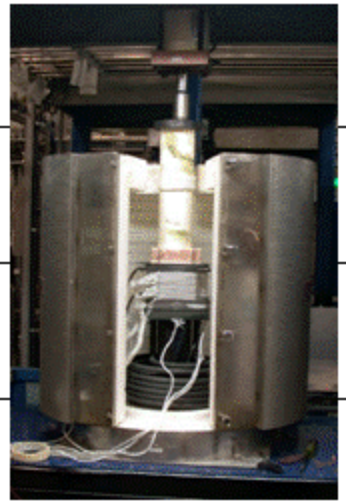
Summary of Cell Degradation Rates under Fixed Electrolysis Operation



Cell Type	Electrolysis (SOEC) Degradation		
	mV / 1000 hrs	% / 1000 hrs	Duration (hrs)
Target	< 50	< 4	> 1000
TSC-2	91	7.3	2893
EC-1	27	2.2	8465
EC-2	~0	~0	2400
EC-3	72	5.8	1792
RSOFC-1	< 30	< 2.4	2248
RSOFC-2	120	9.6	1152
RSOFC-3	62	5.0	1789
RSOFC-4	25	2.4	1096

RSOFC-4 has passed the degradation criteria of less than 4%/1000 hours in SOEC mode as well as performance criteria

RSOFC Stack Development



Test Conditions:
47 A (0.39 A/cm^2) - 28 EC-1 cells
49.5 g/hr H_2 production
Air side : 47 slpm
Fuel side: 21.7 slpm H2, 21.7 slpm H_2O

Conducted long term electrolysis test on a kW-class RSOFC stack and demonstrated degradation rate of 3.8% per 1000 hours for over 2500 hours

Collaborations

- Boeing
  - Collaborated on and funded initial RSOFC development work through both Boeing and DARPA funded efforts
  - Anticipate follow-on DARPA award this calendar year
- SECA
  - As subcontractor to FuelCell Energy in SECA, VPS has advanced SOFC cell and stack technology which has been applied in this program
- INL
  - Eventual integration of SOEC technology for hydrogen production with Next Generation High Temperature Nuclear Reactor
  - Demonstrate suitability of VPS SOEC technology for this application at the kW-class stack level

Proposed Future Work

- FY2010
  - Complete degradation mechanism study
    - Conduct single cell tests at various operating conditions (temperature, current, steam utilization)
    - Conduct post test analysis with detailed microscopic analysis (TEM, SEM and EDX)
  - Complete test facility improvements
  - *Potential Additional Scope:* Conduct additional stack testing early in the project

- FY2011
  - Complete Go/No-go decision point test
  - Complete cell and interconnect materials development
  - Down select material systems for RSOFC stack development
  - Complete the final project metric test with kW-class RSOFC stack
  - *Potential Additional Scope:* Explore the option of developing larger (up to 20 kW) stack for RSOFC operation

Versa Power Systems

Summary

Relevance	▶ RSOFC can integrate renewable production of electricity and hydrogen when power generation and steam electrolysis are coupled in a system, which can turn intermittent solar and wind energy into “firm power”
Approach	▶ Developing high performance and low degradation RSOFC cell and stack technology is critical for the reversible SOFC/SOEC system
Technical Progress	▶ Two types of RSOFC cells developed have met the electrochemical performance target and RSOFC-4 met both performance and degradation criteria ▶ A steady-state single cell test has run in electrolysis for one year with a degradation rate of less than 3% per 1000 hours ▶ A baseline 28-cell stack (kW-class) test has run in electrolysis for over 2500 hours at a 3.8% per 1000 hours degradation rate
Collaboration	▶ Boeing/DARPA, SECA, and INL
Proposed Future Research	▶ In addition to executing the original project scope, additional development activities are under consideration to accelerate RSOFC stack development

Supplemental Slides

RSOFC Cell Development: Operating Envelope Investigation

Summary of Cell ASR under SOFC and SOEC Operation

Cell Type	Electrolysis (SOEC) ASR (mΩ-cm²) at 50% humidity				Fuel Cell (SOFC) ASR (mΩ-cm²) at 3% humidity			
	650°C	700°C	750°C	800°C	650°C	700°C	750°C	800°C
Target	< 300				<300			
TSC-2	687	504	375	302	657	293	180	161
EC-1	954	587	366	266	474	350	281	241
EC-2	--	526	362	284	--	521	393	374
EC-3	726	422	278	221	425	311	251	218
RSOFC-1	784	466	308	245	405	298	245	214
RSOFC-2	754	422	285	229	502	365	295	254
RSOFC-3	1003	623	386	279	495	359	283	238
RSOFC-4	711	413	268	203	397	293	238	207