

# **CIRRUS Program**

## **Subfreezing Start/Stop Protocol for an Advanced Metallic Open-Flowfield Fuel Cell Stack**

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Nuvera Fuel Cells  
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Project ID #  
fc\_38\_conti

# Overview

## Timeline

- Actual start: 7/1/2007
- Planned end: 6/30/2010
- ~ 60% complete

## Budget

- Total project funding
  - \$4.970 Million (DOE)
  - \$2.160 Million (Cost Share)
- FY08 funding: \$1.875 Million
- FY09 funding: \$2.200 Million

## Barriers

- Barriers addressed
  - (D) Water Transport within the Stack
  - (G) Start-up and Shut-down Time and Energy/Transient Operation

## Partners

- W. L. Gore & Associates
- SGL Technologies
- University of Delaware

# Objectives

The **objective** of the CIRRUS Program is to demonstrate a PEM fuel cell stack meeting DOE 2010 cold start targets:

Table 3.4.2 Technical Targets for Automotive Applications: 80-kW <sub>e</sub> (net) Integrated Transportation Fuel Cell Power Systems Operating on Direct Hydrogen <sup>a</sup>					
Characteristic	Units	2003 Status	2005 Status	2010	2015
Cold start-up time to 50% of rated power					
@-20°C ambient temp	seconds	120	20	30	30
@+20°C ambient temp	seconds	60	<10	5	5
Start up and shut down energy <sup>f</sup>					
from -20°C ambient temp	MJ	N/A	7.5	5	5
from +20°C ambient temp	MJ	N/A	N/A	1	1
Unassisted start from low temperatures <sup>i</sup>	°C	N/A	-20	-40	-40

FY08 goals	Status
Achieving -20C cold start target respecting the energy budget	Completed
Identifying electrochemical material freeze cycle aging modes	In progress
FY09 goals	
Proving reliability and durability of -20C startup procedure	In progress
Achieving -40C cold start target (enabled by new stack technology)	In progress

# Approach

2007				2008								2009								2010															
Q3		Q4		Q1		Q2		Q3		Q4		Q1		Q2		Q3		Q4		Q1		Q2													
J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J

INVESTIGATION

SELECTION

QUALIFICATION

VALIDATION

**Understand**  
Status of the Art

**Select**  
Startup strategy

**Prove**  
Strategy robustness

**Validate**  
Optimized materials  
& architecture  
(with DOE inputs)

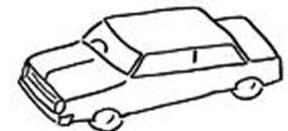
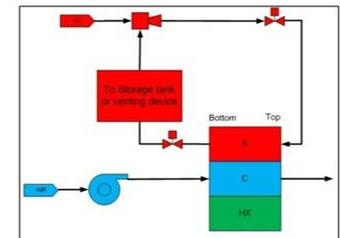
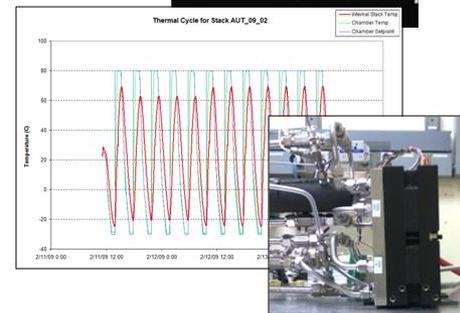
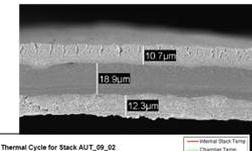
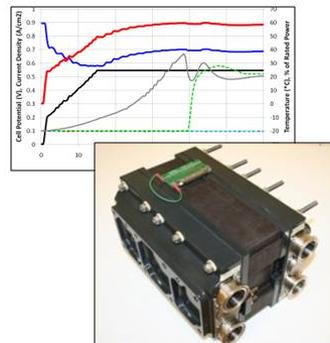
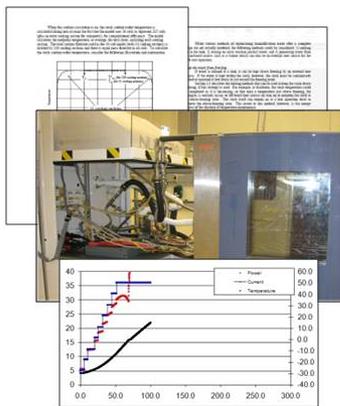
**Prepare**  
Test Capability

**Select**  
1<sup>st</sup> Set of Materials

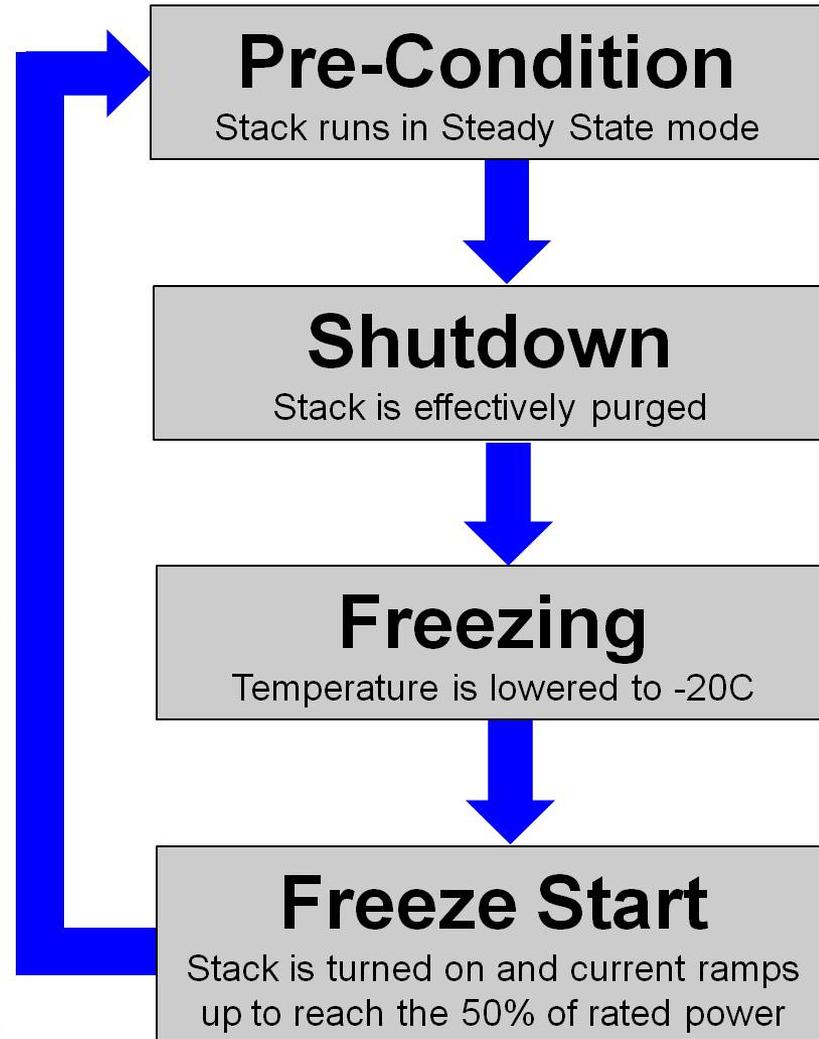
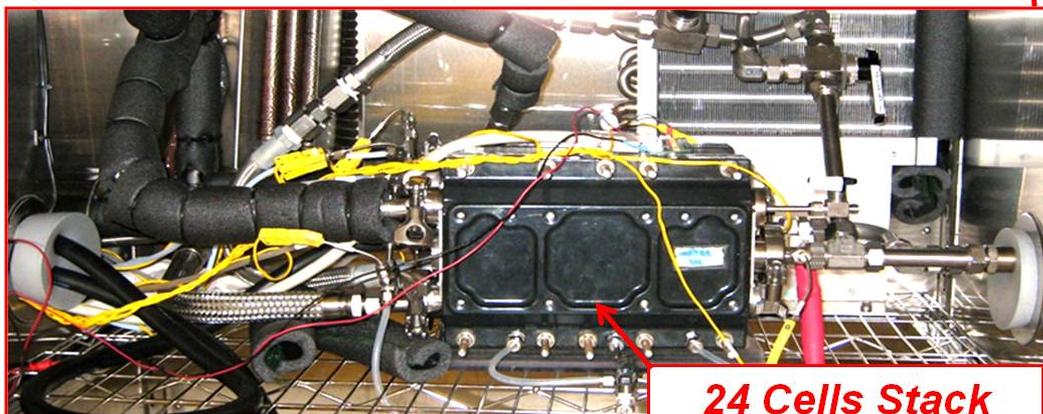
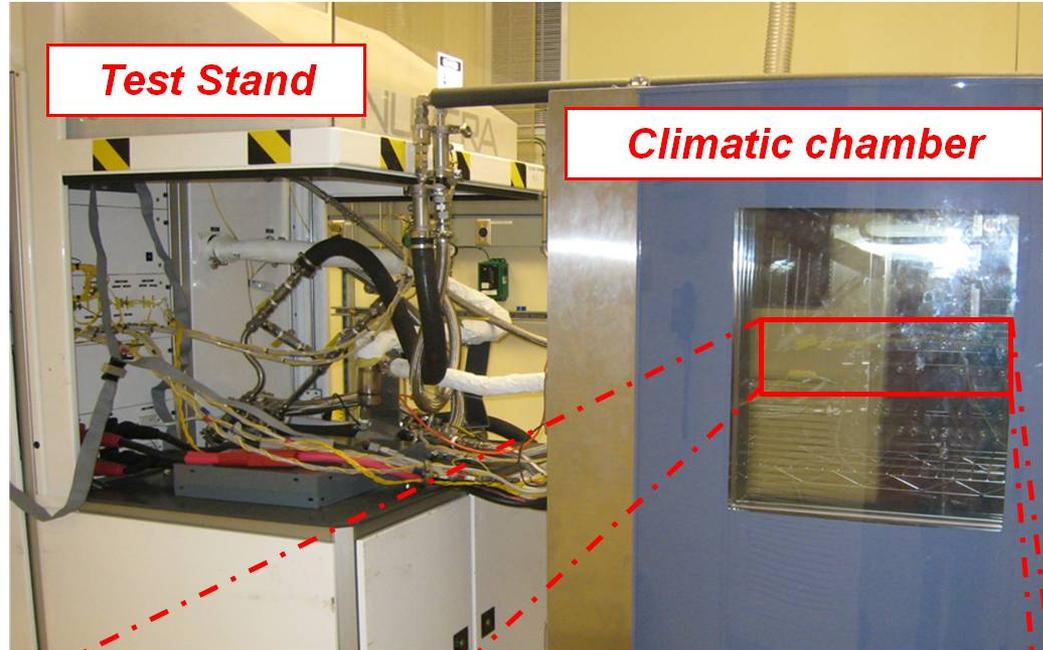
**Prove**  
Materials durability

**Establish**  
Modeling Capability

**Improve by Iterations**  
Architecture, materials,  
procedure



# Freeze Startup: how is the test performed?

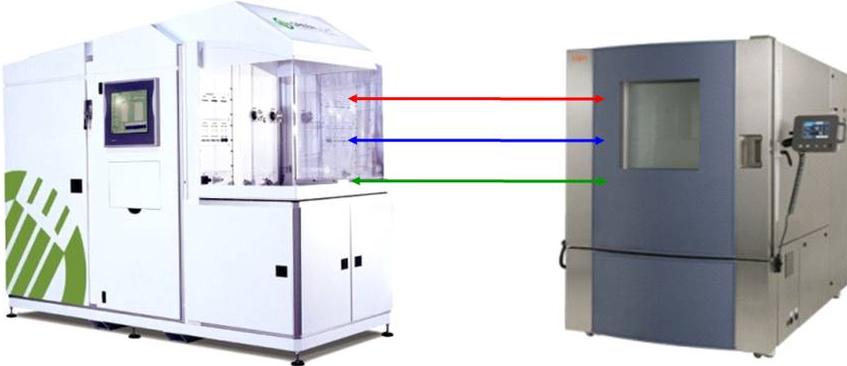


# Freeze Startup: Shutdown & Purging

	FY2008	Q1 2009
<b>Anode compartment</b>	Purge via constant flow	High P, instantaneous purge
<b>Cathode compartment</b>	Purge via constant flow	Purge via constant flow
<b>Coolant compartment</b>	Purging with air	Purging with air
<b>System implications</b>	H2 recirculation pump is needed to provide constant flow	H2 purged has to be collected: - H2 recirculation tank OR H2 purged has to be vented: - H2 is diluted in air stream - H2 is burned in catalytic converter
<b>Shutdown duration</b>	8 minutes	2 minutes

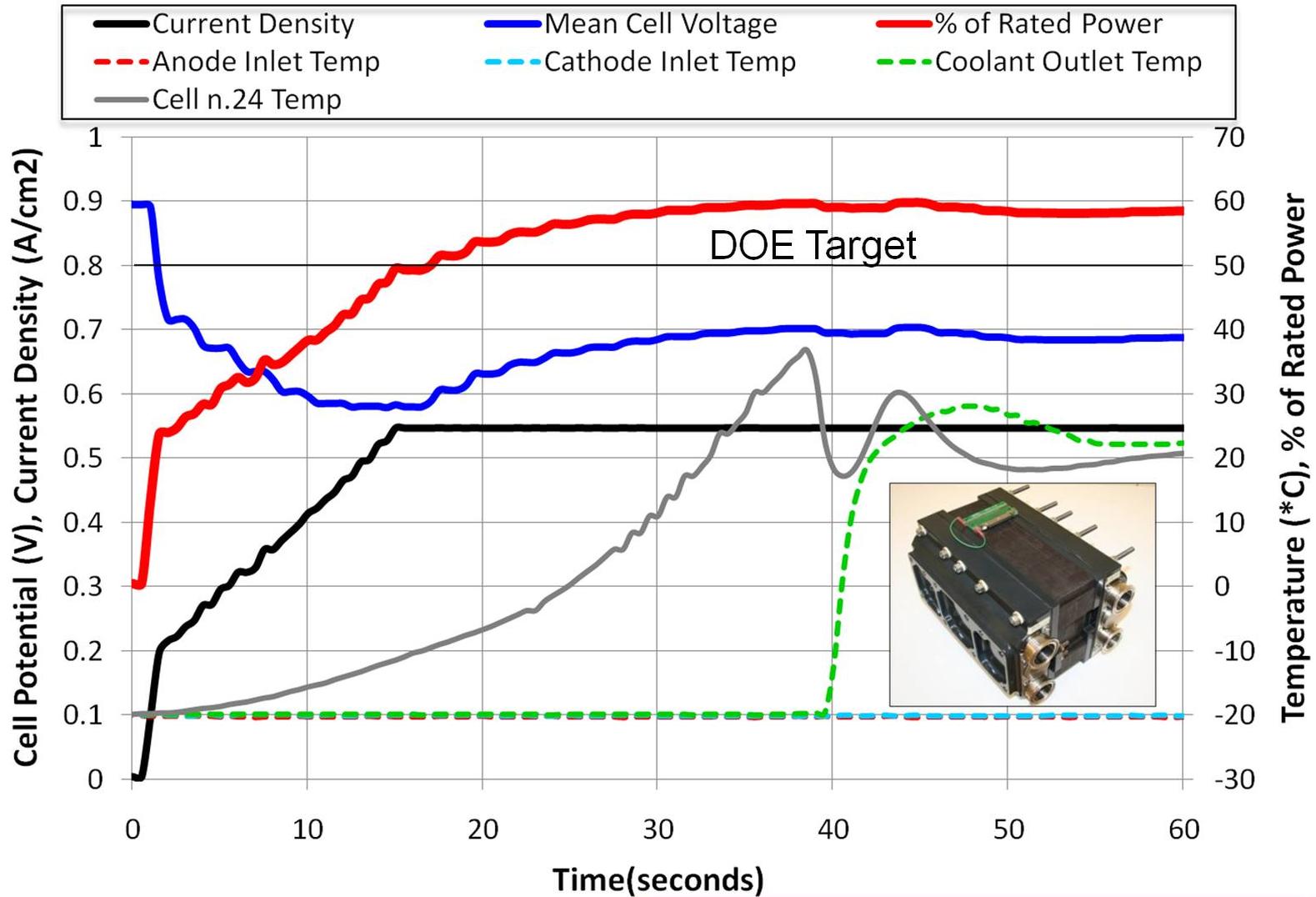
**Purging procedure has been optimized to offer system compatibility**

# Freeze Startup: freezing & testing

	FY2008	Q1 2009
<b>Equipment</b>	Commercial freezer 	Climatic Chamber integrated with Test Stand 
<b>Freezing time</b>	8 hours	60 min
<b>Temperature monitoring</b>	Test Stand (Cathode outlet)	Stack (Direct measurement in cooling cells)
<b>T stack</b>	$\leq -20\text{C}$	$\leq -20\text{C}$
<b>T environment</b>	Ambient	$\leq -20\text{C}$
<b>T reactants</b>	Ambient	$\leq -20\text{C}$

**Equipment offers a fair representation of real phenomena**

# Startup from -20C: $T_{stack} = T_{env} = T_{gas}$



**Successful start from -20C to 50% of power in ~ 18 secs**

# Energy accounting for an 80kW system

<b><i>During Shutdown...</i></b>	
<b>Air compressor parasitic</b> (LHV of H2 consumed to power compressor during purging phase)	0.564 MJ
<b>H2 wasted in purges</b> (LHV of H2 vented or burned)	0.450 MJ
<b><i>During Startup...</i></b>	
<b>H2 used during startup</b> (LHV of H2 consumed to produce electric power in first 30 sec)	2.292 MJ
<b>TOTAL</b>	<b>3.306 MJ*</b>

\* It was 5.6MJ in FY08, 26 MJ in FY07, H2 at startup was not considered.

**Energy consumption to start from -20C  
is ~ 30% below DOE target**

# What are the freeze aging modes?

## Membrane degradation.

- RH cycles
- Thermal cycles

## Interface damage produced by freeze.

- Catalyst delamination.

## Reactants compartments blockage.

- Electrode damage
- Corrosion
- Pt Dissolution

## GDL damage.

- Cracking

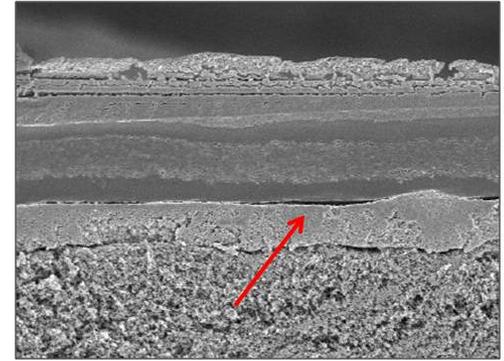
### Aging modes identification through:

- Startup optimization process
- Collaboration with partners
- Collaboration with FC Community

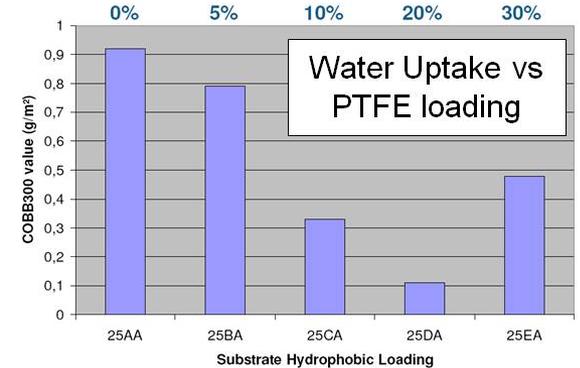
# Collaboration with Partners



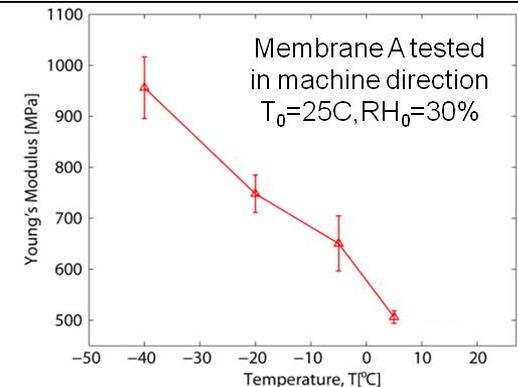
- Analysis:** SEM on sample subjected to Freeze Start highlighted suspect catalyst delamination.
- Supplies:** research of MEA resistant to RH cycling (imposed by shutdown/purging).



- Analysis:** ongoing characterization of thermal conductivity and water uptake/removal on GDL.
- Supplies:** new GDL tested looks promising to reduce cell to cell variation.



- Measurement:** mechanical properties characterization of membrane.
- Modeling:** optimization of mechanical model to predict stresses as function of T and RH.



# PEMFC Freeze Workshop

- **Workshop held at Nuvera on February 20, 2009.**
  - 38 members of FC Community: DOE, OEMs, Materials suppliers, University and National Labs.
  - 23 Technical presentations on Freeze Topic: Industry perspective, System, Stack, Materials.



- **More teamwork and industry collaboration is required.**
  - DOE coordination role.
  - IP issues.
  - Sharing tools/infrastructure.
- **Additional targets are needed.**
  - Durability.
  - Time to X% power (e.g. X=25%, 90%).
- **Value of subscale testing needs to be rationalized.**

# What are the main challenges?

## **Startup from extreme temperatures.**

- Reduce thermal mass.

## **Enhance system compatibility.**

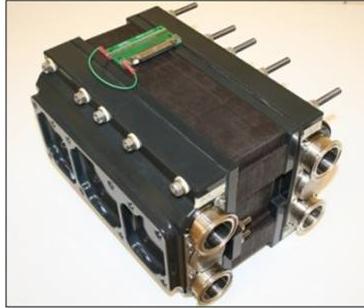
- Decrease thermal mass to keep coolant in stack during startup.
- Minimize volume of H<sub>2</sub> purged.

## **Compatibility and durability of materials**

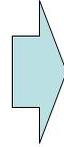
- Understand impact of T and RH cycling.
- Understand impact of Ice formation and H<sub>2</sub>/Air Starvation.

# Start from -40C, system compatibility

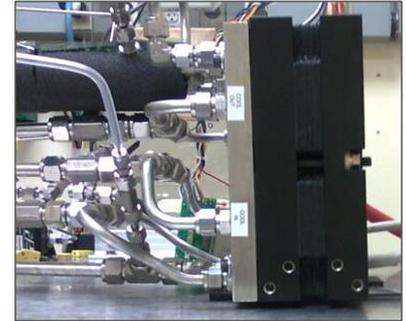
## Andromeda



- Designed for 1 A/cm<sup>2</sup>
- Heat capacity<sup>1,2</sup>: **~120kJ/K**
- Hydrogen compartment volume<sup>1</sup>: **~11 liters**
- Open flowfield enabled operation @ 3A/cm<sup>2</sup>



## Orion



- Designed for 2 A/cm<sup>2</sup>
- Heat capacity<sup>1,2</sup>: **50kJ/K**
- Hydrogen compartment volume<sup>1</sup>: **~8 liters**
- Reduced Cost

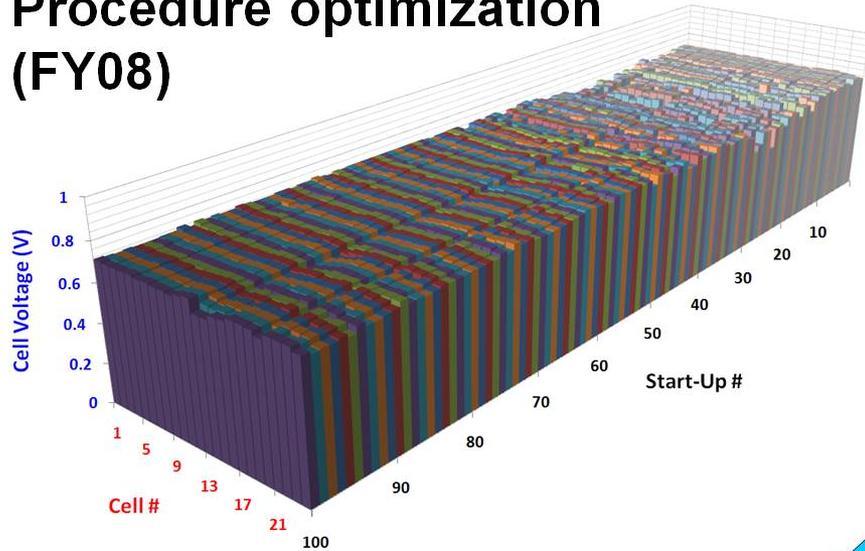


*1 Estimated for a real scale stack (80kW net power).*

*2 Coolant thermal mass is included in calculation, endplates contribution is not considered.*

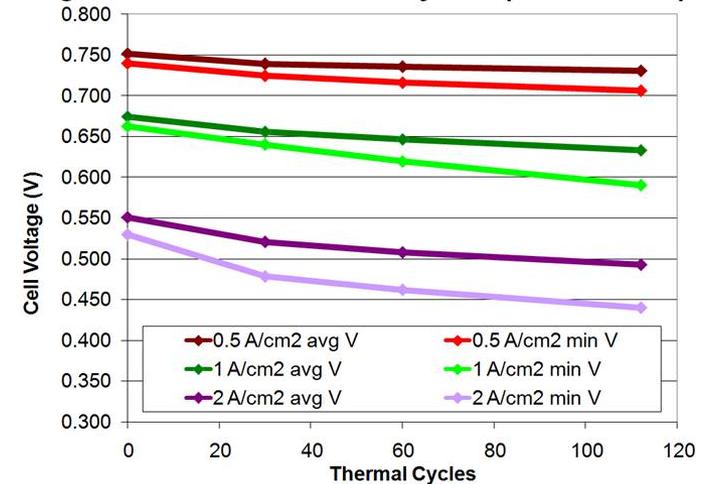
# Materials Durability & compatibility

## Procedure optimization (FY08)

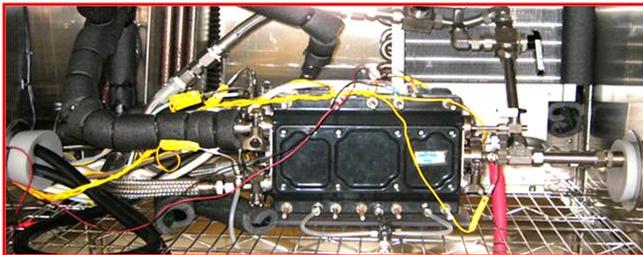


## Thermal cycling of non-operating stack (FY09)

Degradation with Thermal Cycles (-20C -> 60C)



## Freeze start/shutdown cycling (FY09)



## Diagnostic & PM Analysis

# Summary

- Successful startup from -20C meeting 2010 DOE target.  
( 50% of rated power reached in 18 seconds using 3.3MJ).
- Identification of main failure mechanisms with Fuel Cell Community help.
- FY09 focus: understand materials compatibility & durability through thermal cycling, freeze start cycling and Post Mortem diagnostics.
- FY09 focus: perform start from extreme temperature (-40C) and improve system compatibility using Orion technology.