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

Barriers

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

Budget

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

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$_e$ (net) Integrated Transportation Fuel Cell Power Systems Operating on Direct Hydrogen [a]

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 [f]					
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 [i]	°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

Understand
Status of the Art

Prepare
Test Capability

Establish
Modeling Capability

SELECTION

Select
Startup strategy

Select
1st Set of Materials

QUALIFICATION

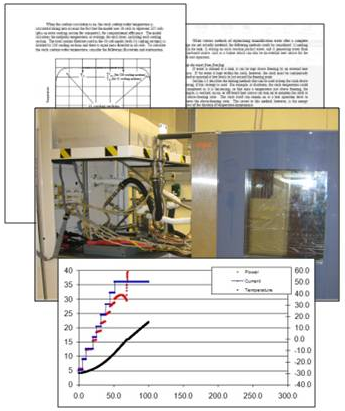
Prove
Strategy robustness

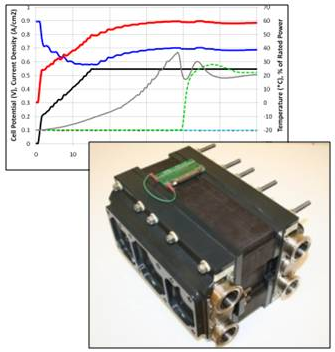
Prove
Materials durability

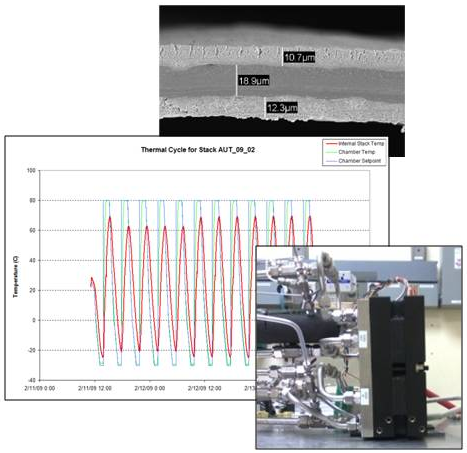
Improve by <u>Iterations</u>
Architecture, materials, procedure

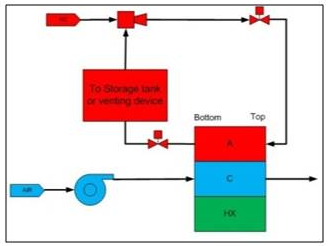
VALIDATION

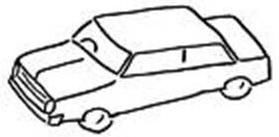
Validate
Optimized materials & architecture (with DOE inputs)











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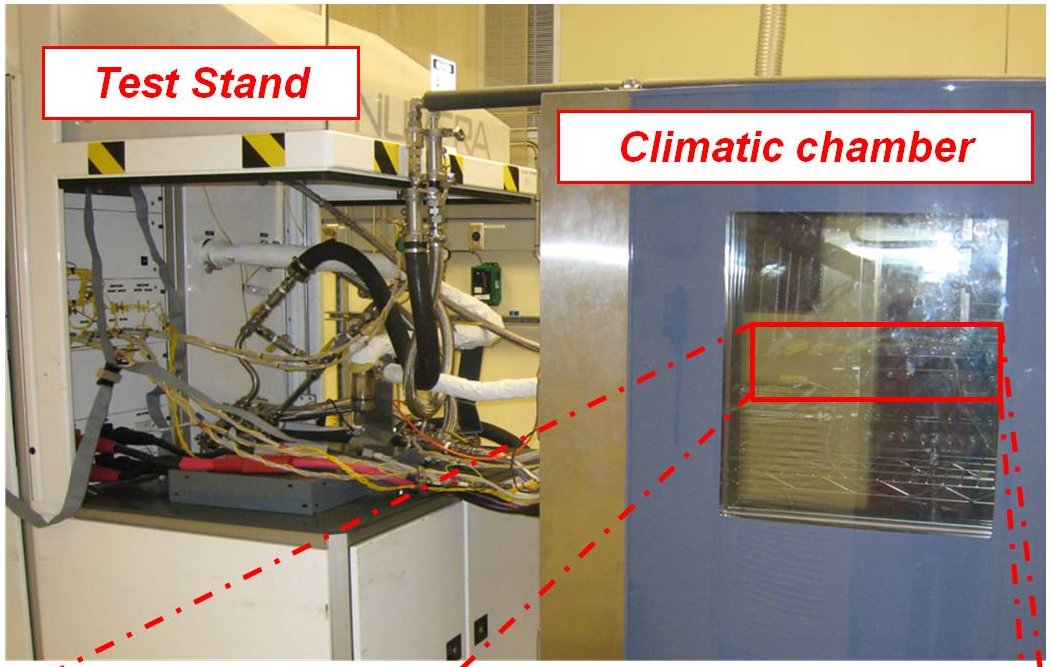
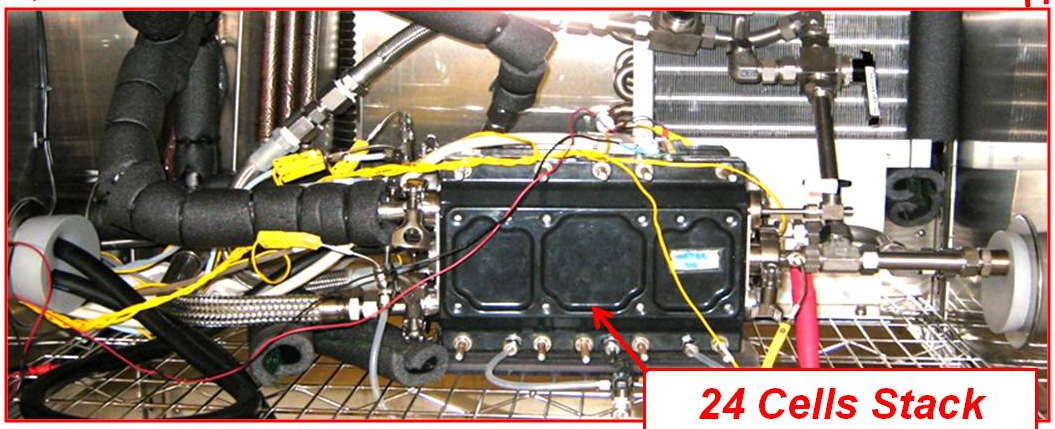
Freeze Startup: how is the test performed?





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Pre-Condition
Stack runs in Steady State mode

Shutdown
Stack is effectively purged

Freezing
Temperature is lowered to -20C

Freeze Start
Stack is turned on and current ramps up to reach the 50% of rated power

Freeze Startup: Shutdown & Purging

	FY2008	Q1 2009
Anode compartment	Purge via constant flow	High P, instantaneous purge
Cathode compartment	Purge via constant flow	Purge via constant flow
Coolant compartment	Purging with air	Purging with air
System implications	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
Shutdown duration	8 minutes	2 minutes

Purging procedure has been optimized to offer system compatibility

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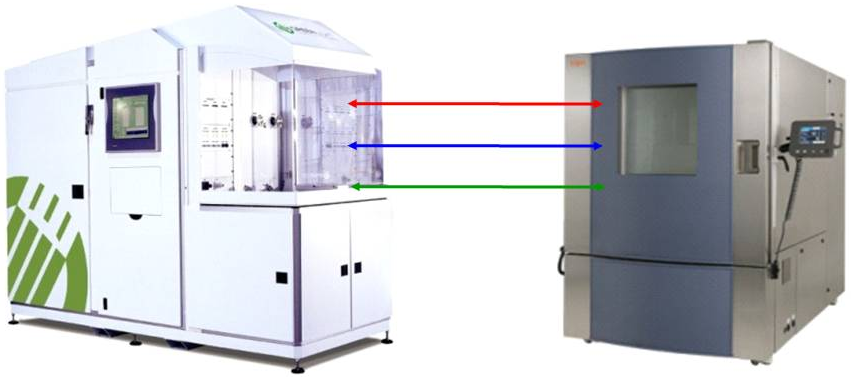
Freeze Startup: freezing & testing

	FY2008	Q1 2009
Equipment	Commercial freezer 	Climatic Chamber integrated with Test Stand 
Freezing time	8 hours	60 min
Temperature monitoring	Test Stand (Cathode outlet)	Stack (Direct measurement in cooling cells)
T stack	<= -20C	<= -20C
T environment	Ambient	<= -20C
T reactants	Ambient	<= -20C

Equipment offers a fair representation of real phenomena

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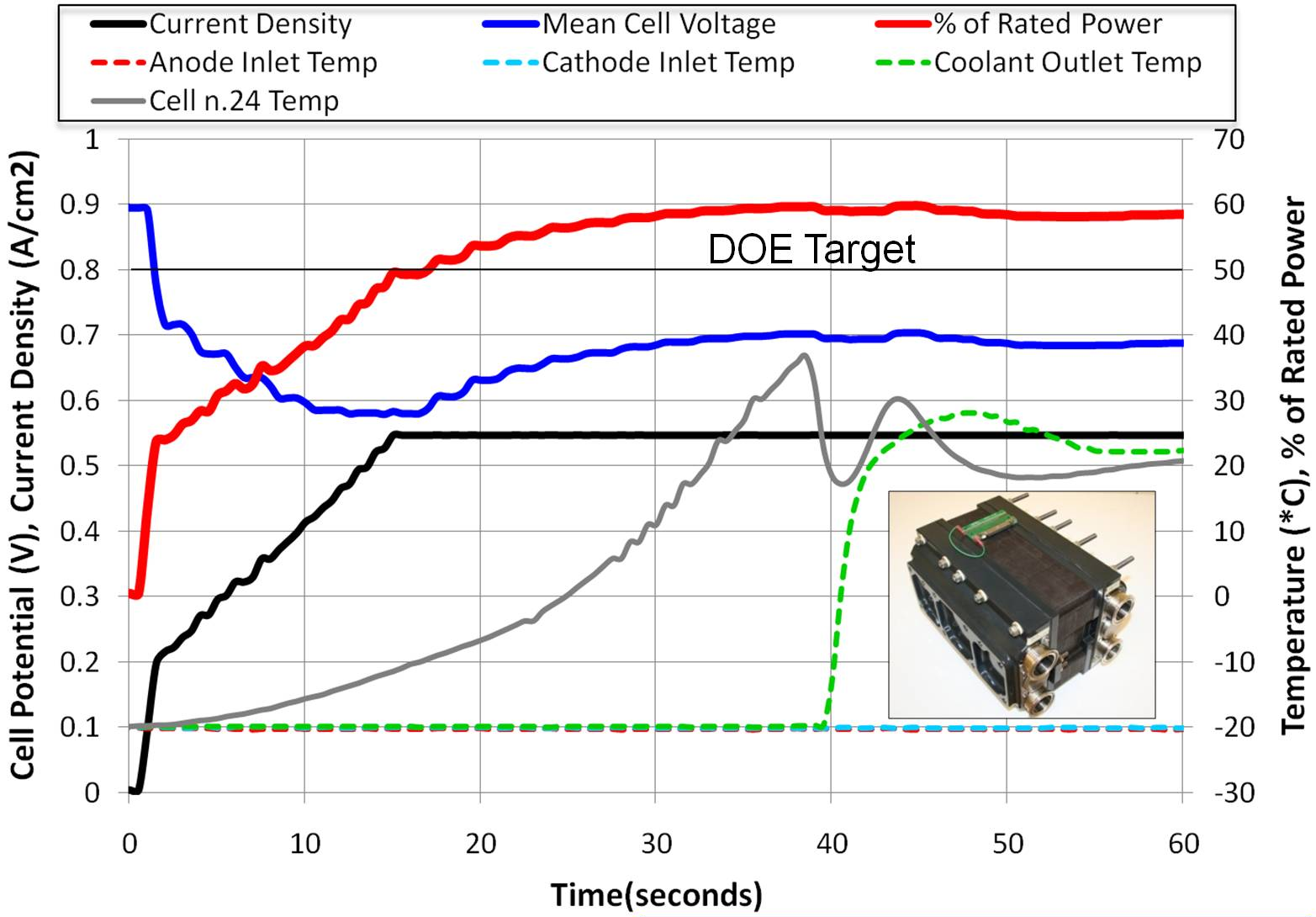
Startup from -20C: $T_{stack}=T_{env}=T_{gas}$



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

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Energy accounting for an 80kW system

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

* *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

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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**

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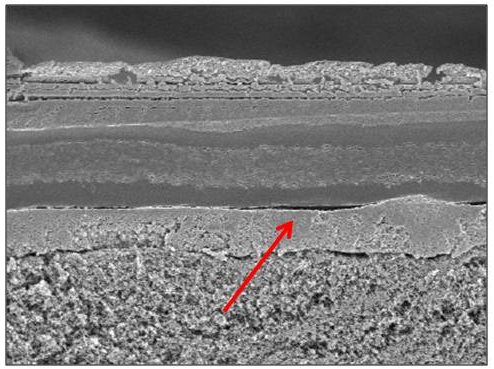
Collaboration with Partners

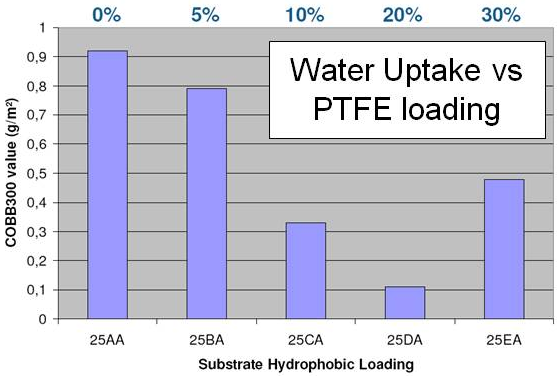
GORE
Creative Technologies Worldwide

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



SGL GROUP
THE CARBON COMPANY

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



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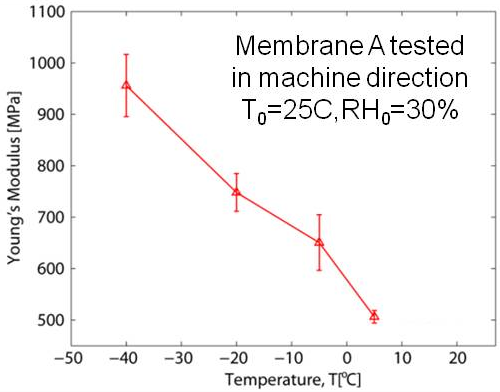
- **Measurement:** mechanical properties characterization of membrane.
- **Modeling:** optimization of mechanical model to predict stresses as function of T and RH.



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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.

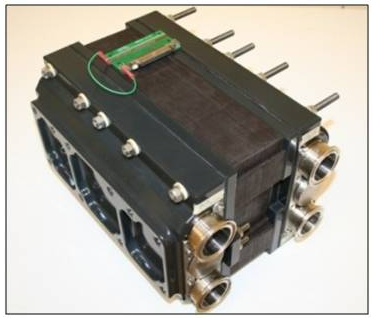
•Decrease thermal mass to keep coolant in stack during startup.
•Minimize volume of H2 purged.

Compatibility and durability of materials

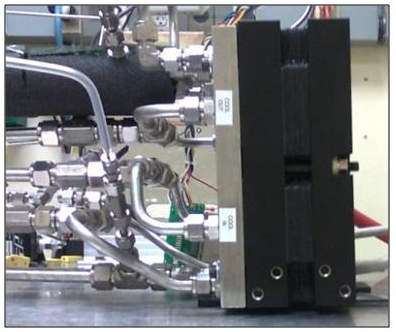
•Understand impact of T and RH cycling.
•Understand impact of Ice formation and H2/Air Starvation.

Start from -40C, system compatibility

Andromeda



Orion



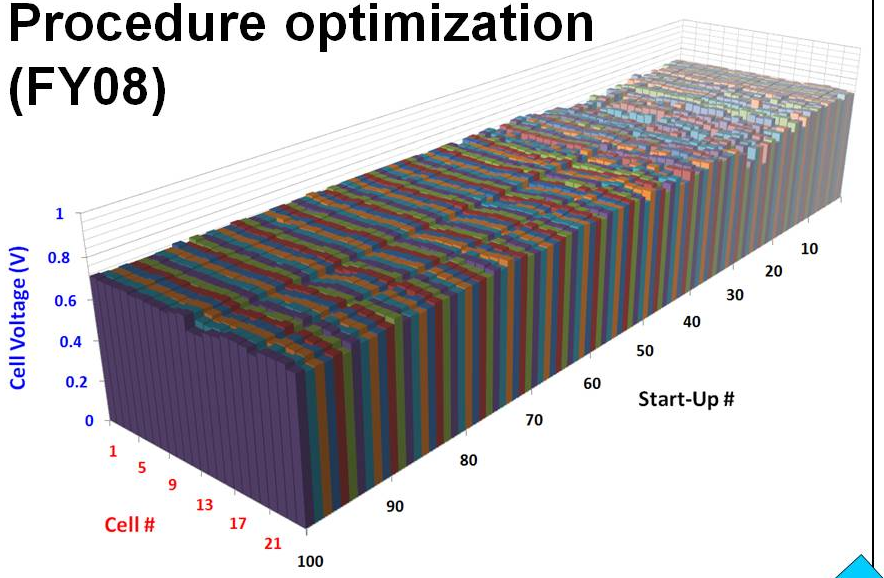
- Designed for 1 A/cm2
- Heat capacity[1,2]: **~120kJ/K**
- Hydrogen compartment volume[1]: **~11 liters**
- Open flowfield enabled operation @ 3A/cm2

- Designed for 2 A/cm2
- Heat capacity[1,2]: **50kJ/K**
- Hydrogen compartment volume[1]: **~8 liters**
- Reduced Cost

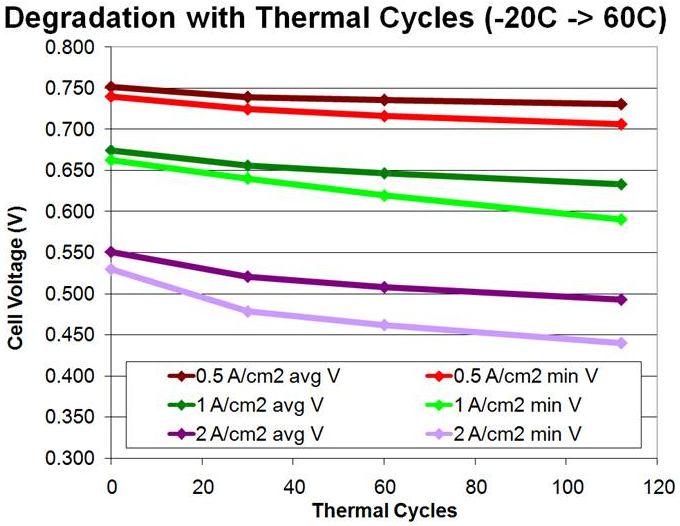
1 Estimated for a real scale stack (80kW net power).
2 Coolant thermal mass is included in calculation, endplates contribution is not considered.

Materials Durability & compatibility

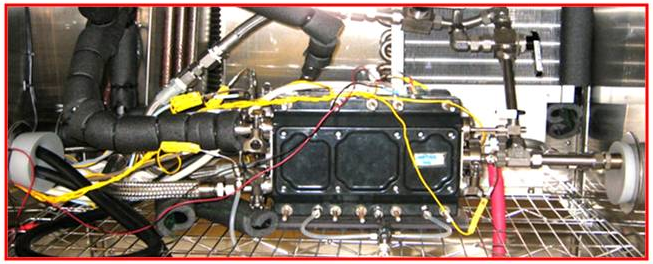
Procedure optimization (FY08)



Thermal cycling of non-operating stack (FY09)



Freeze start/shutdown cycling (FY09)



Diagnostic & PM Analysis

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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.