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 #
FC055

Overview

Timeline

- Actual start: 7/1/2007
- Planned end: 6/30/2010
- ~ 90% 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)
  - $2.380 Million (Cost Share)
- FY09 funding: $1.588 Million
- FY10 funding: $ 0.880 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

FY09 goals	
Proving reliability and durability of -20C startup procedure	Completed
Achieving -40C cold start target (enabled by new stack technology)	In progress

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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

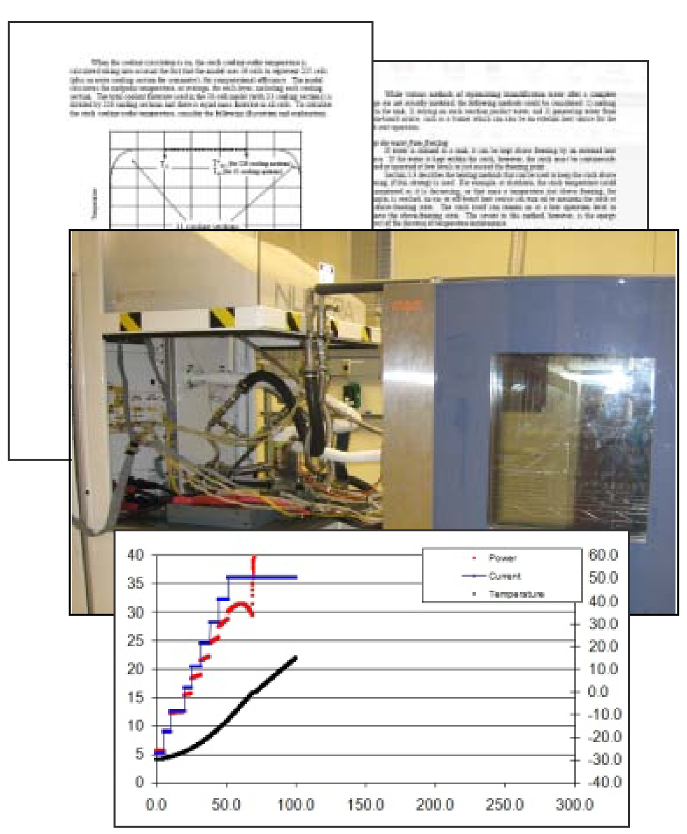
Prove
Strategy robustness

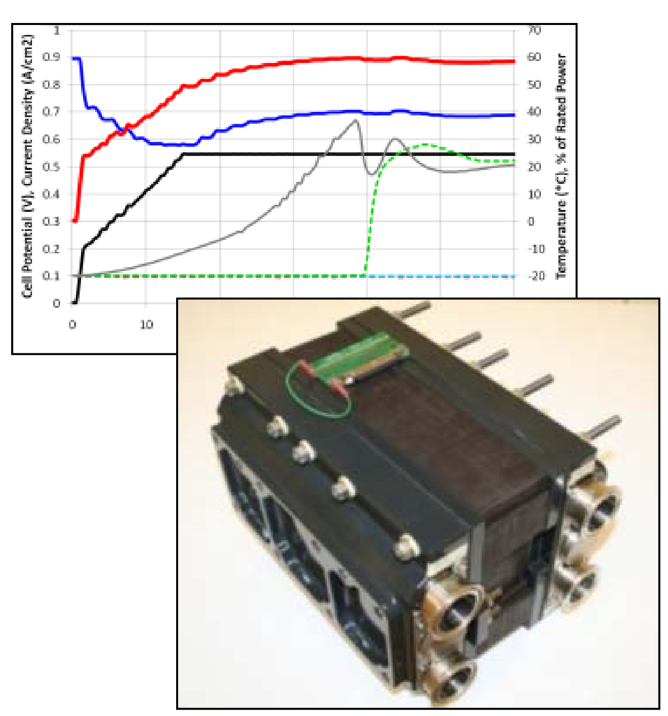
Prove
Materials durability

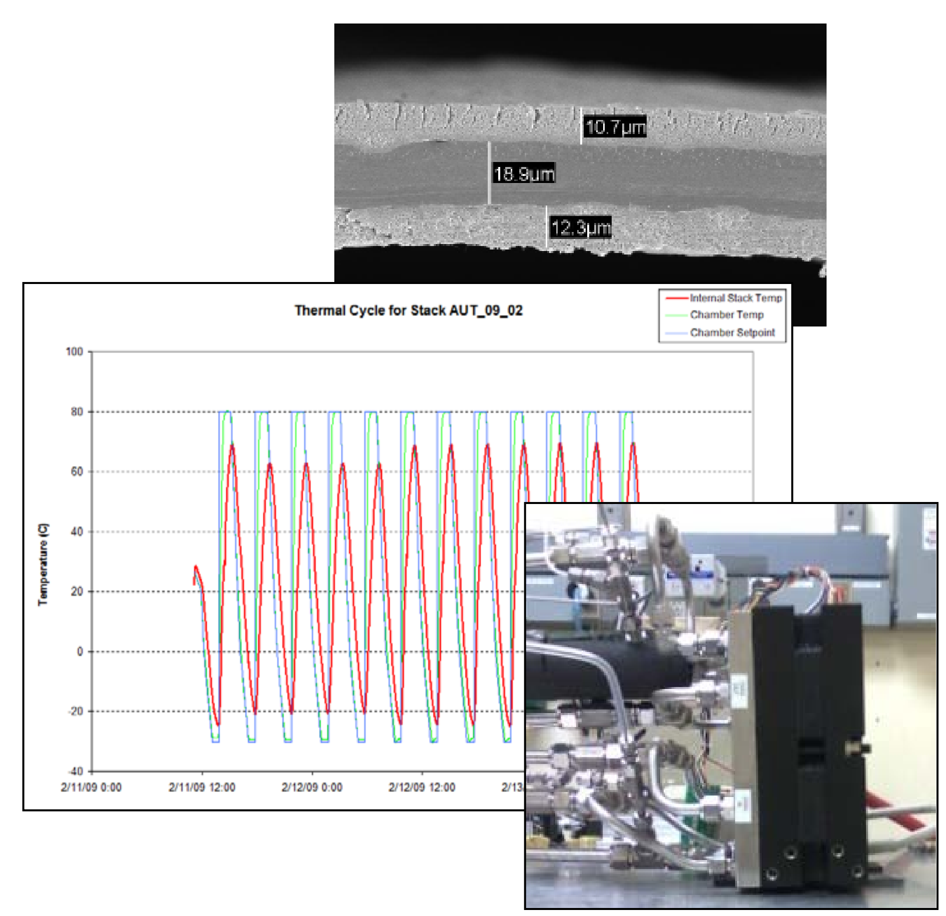
Improve by Iterations
Architecture, materials, procedure

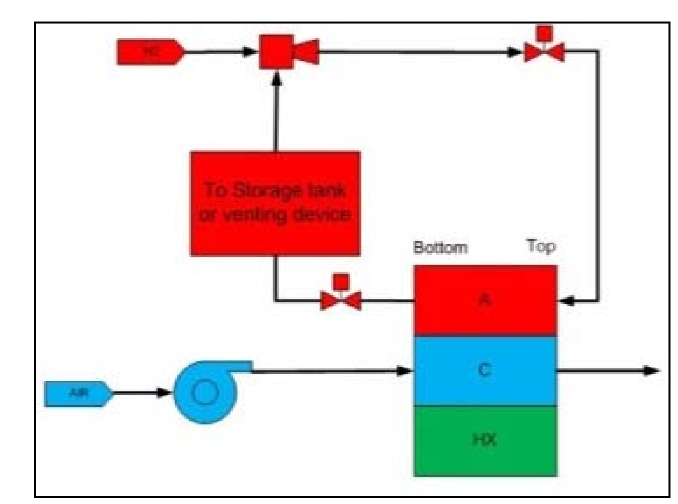
VALIDATION

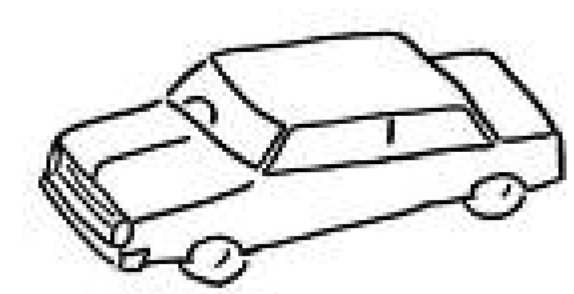
Validate
Optimized materials & architecture (with DOE inputs)











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Reliability and Durability of -20C startup strategy

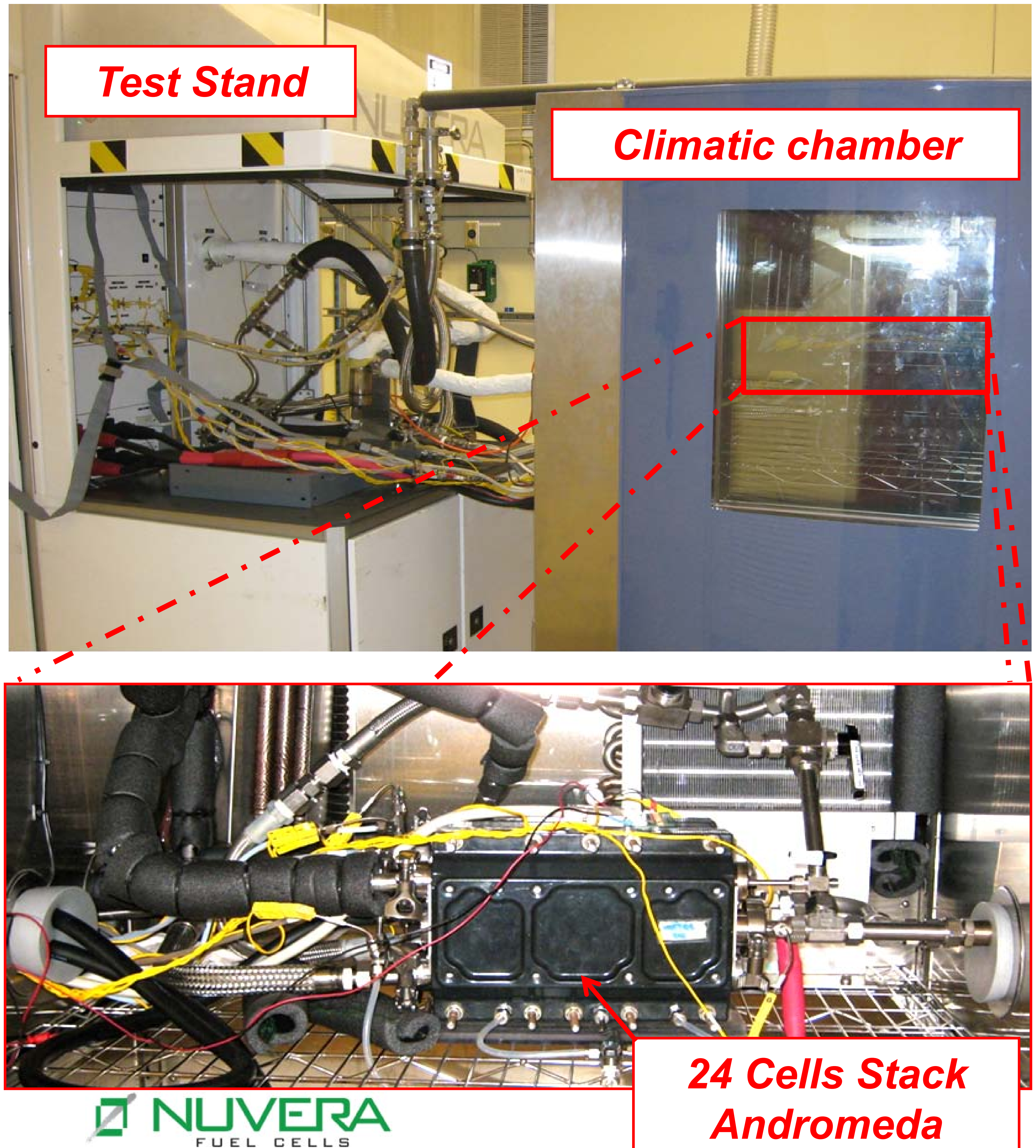
Strategy tested on Andromeda stack architecture

- Active Area: 360cm2.
- Rated current density: 1A/cm2.
- BOL Voltage @ 1A/cm2: 0.664V.
- Rated Power density: 0.664W/cm2.
- High thermal mass prevents startup with resident coolant.

Strategy tested in climatic chamber integrated with testing equipment

- Temperature of Stack, environment and process gases kept to -20C.
- Time to freeze stack: 60 min.
- Partially automated procedure.

How is the test performed?



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

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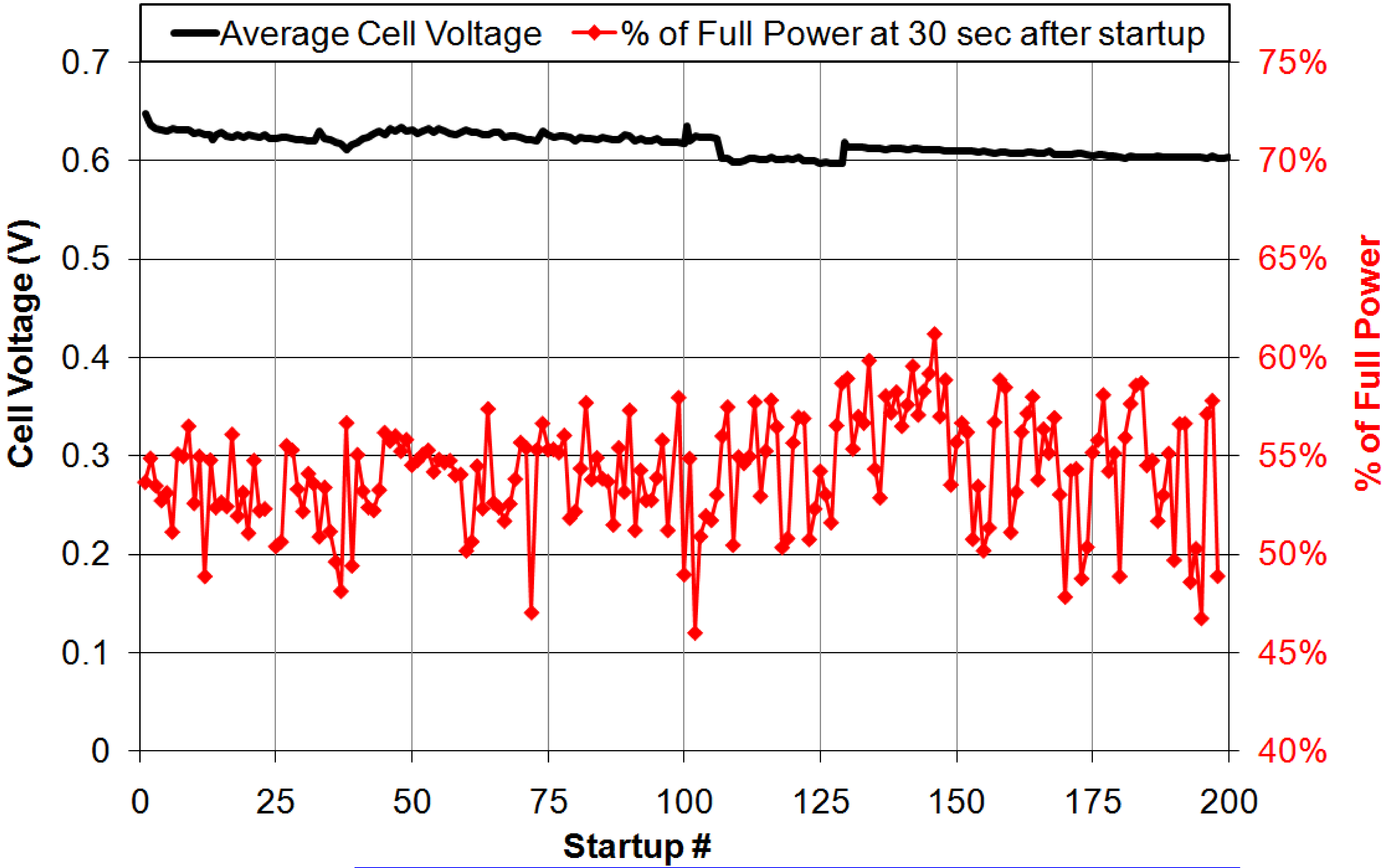
Reliability & Durability results



200 successful startup from -20C proved robustness of strategy identified

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Reliability & Durability – Key Learning

Voltage decay measured is almost entirely related to increase in Ohmic resistance

•Leading root cause is non-optimized compression system that allows stack relaxation under thermal cycling (with subsequent increase of contact resistance).

Control of membrane hydration is critical

•Cells too dry are prone to development of cross-over failures.

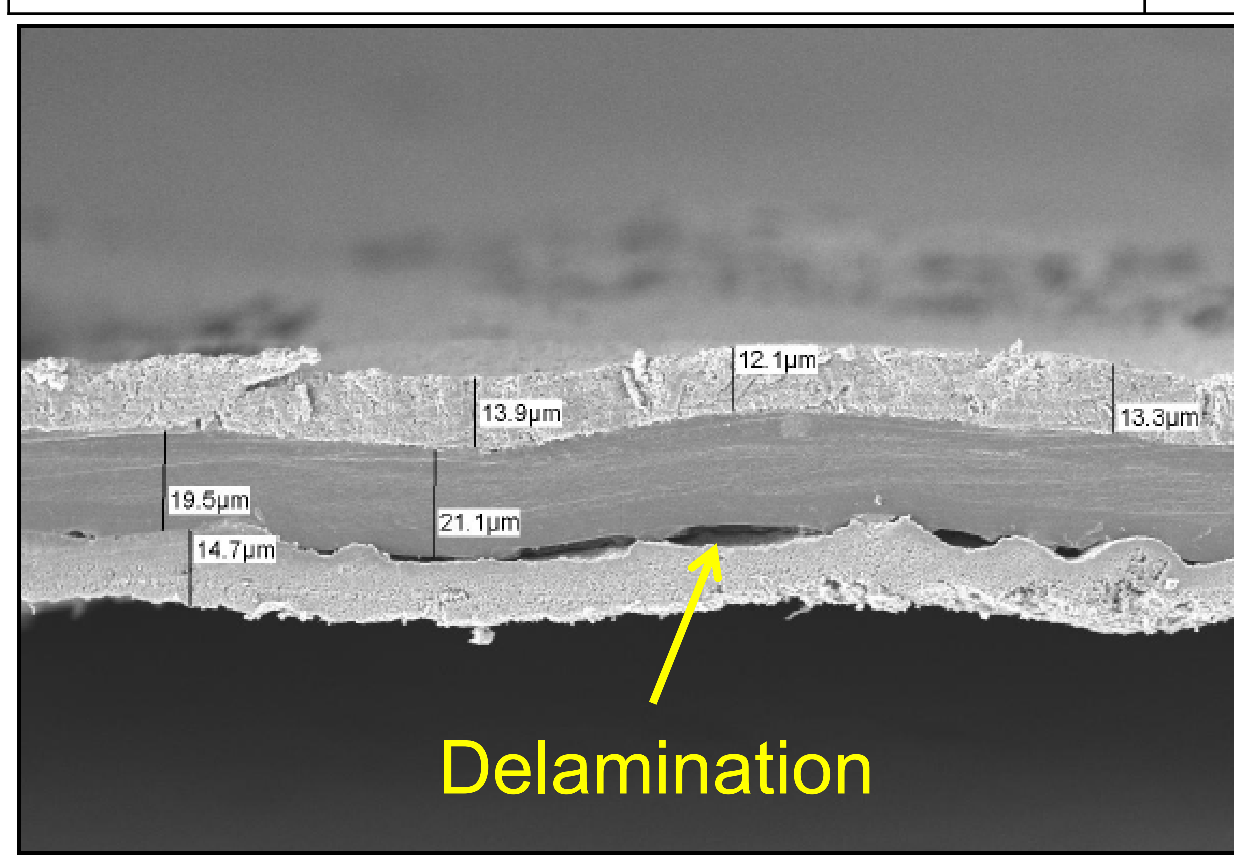
•Cells too wet start with difficulty and could lead to failures as result of H2 starvation.

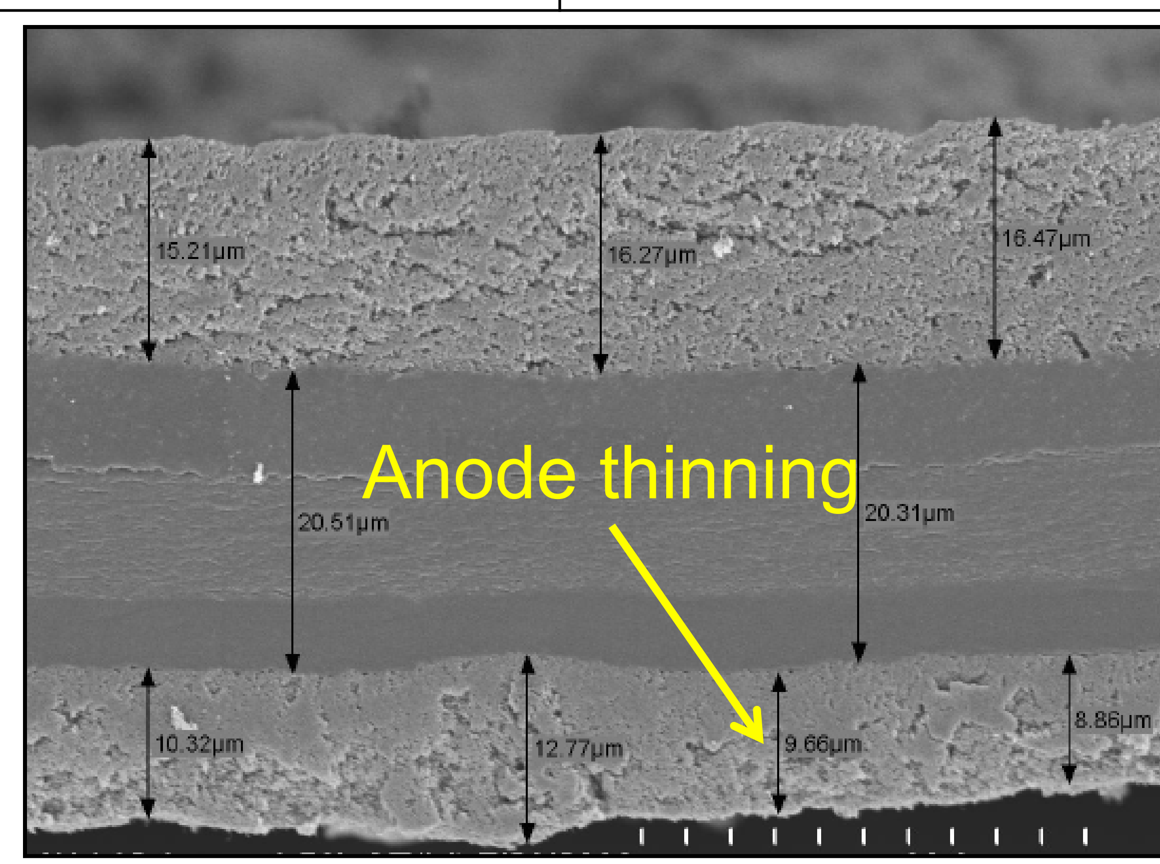
Post-Mortem analysis didn't highlight significant signs of degradation

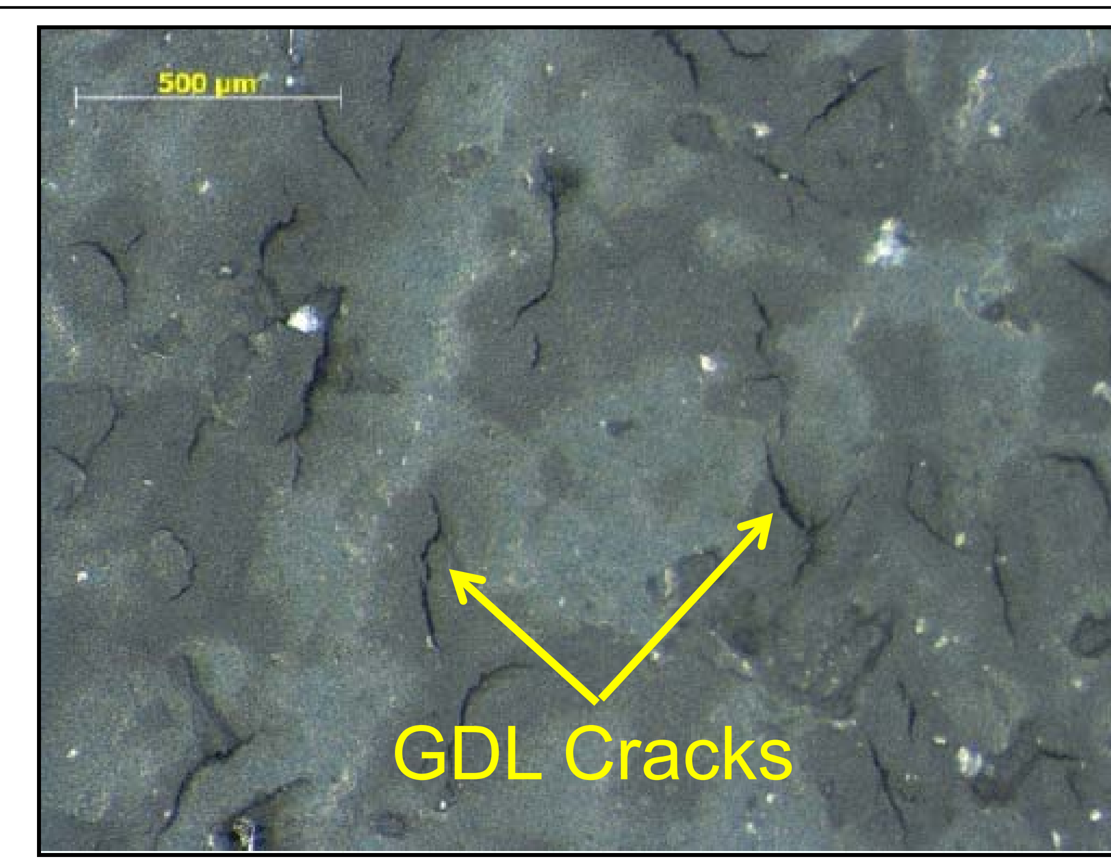
After 200 freeze cycles there are no major concerns in ability to achieve durability

Reliability & Durability – PM analysis

Aging mode	Analysis performed	Learning
Membrane degradation (1) •RH cycles •T cycles	SEM of MEA	No evidence of damage due to RH cycling. Evidence for localized high compression leading to extrusion of ionomer into electrode cracks.
Interface damage (1) •Catalyst delamination	SEM of MEA	No evident sign. Some delamination observed is compatible with initial status of MEA
Gas compartment blockage (1) •Electrode damage •Corrosion •Pt dissolution	SEM of MEA Backscatter imaging TEM EDS	No strong trends found for Pt particle size in anode or cathode. Some signs of a Pt precipitation band found in the membrane. Slight signs of anode thinning detected in some instances.
GDL damage (2) •Cracking	SEM of GDL (SGL)	Some cracks detected but no significant increase in number or extension of the cracks noticed on samples analyzed after 100 and 200 cycles.







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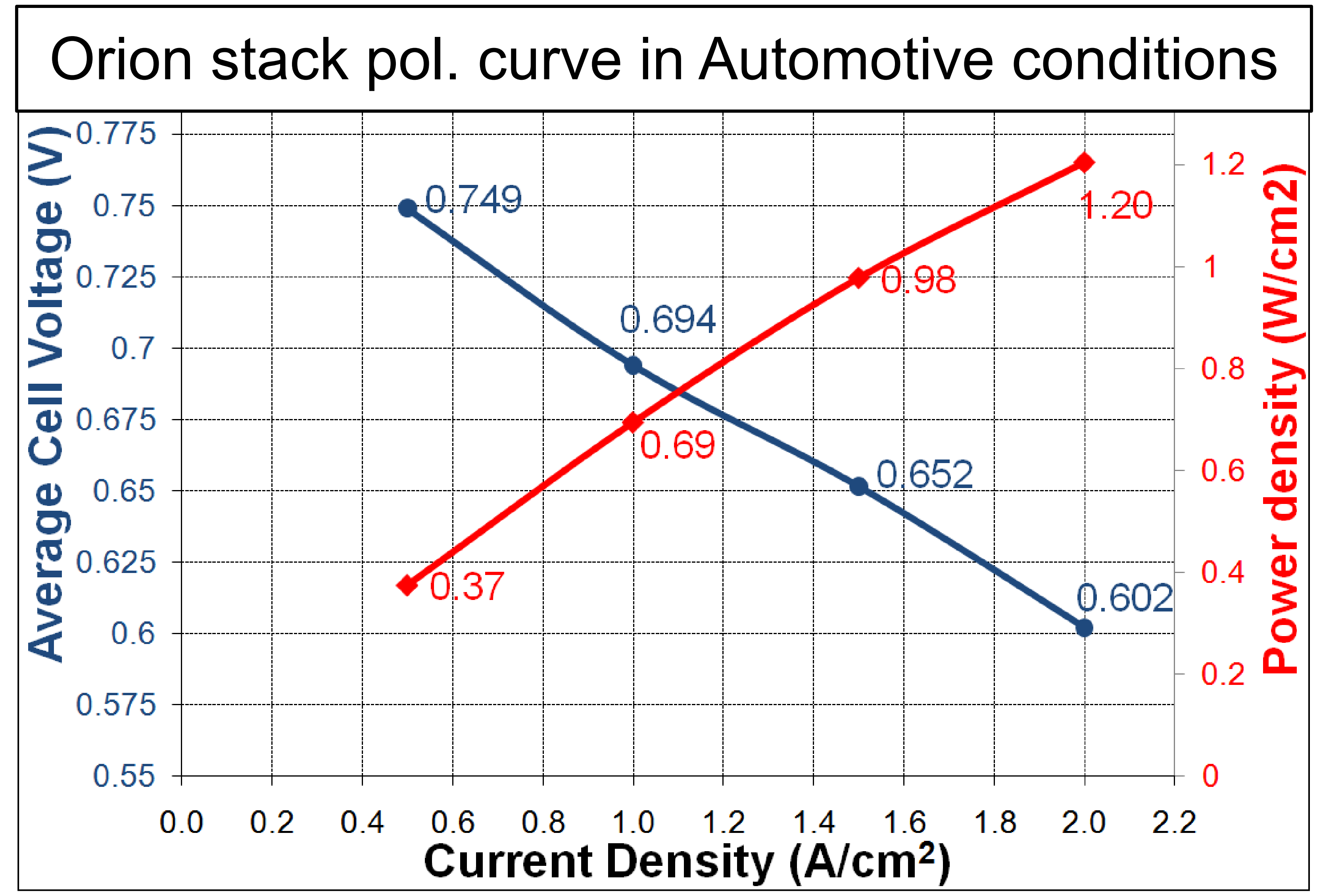
(1) Analysis performed by W.L.Gore
(2) Analysis performed by SGL Technologies

New stack technology: Orion (250cm2)

Designed for high power density and low thermal mass

Prototypes meet design specs (1.2W/cm2) enabling cost reduction and enhancing freeze start ability



New compression system efficiently maintains the load over time

MEA selected provides superior performance in dry conditions

•GORESELECT® Membrane M730.

•Tolerance to dry conditions enables more effective purging of all the cells.

•Possibility to run with lower hydration level reduces energy consumed on average over range of operations.

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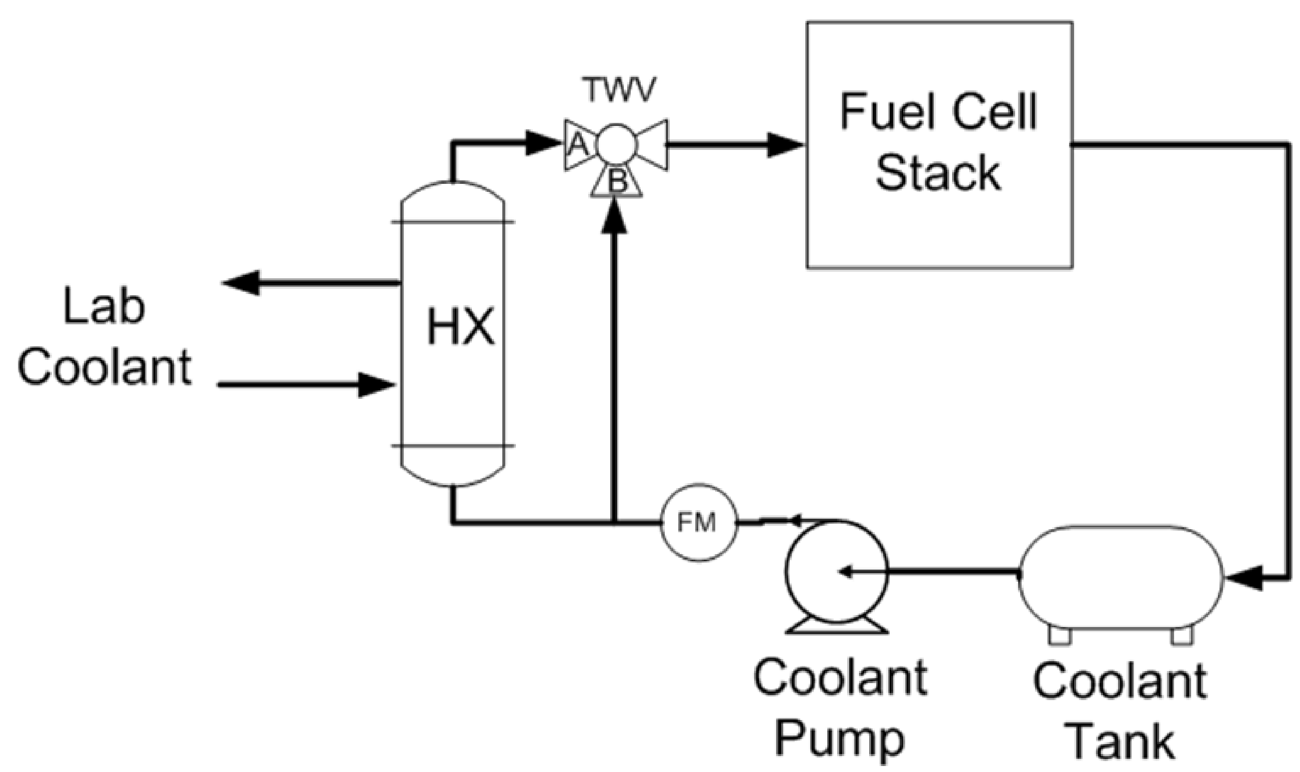
Orion startup: how is the test performed?

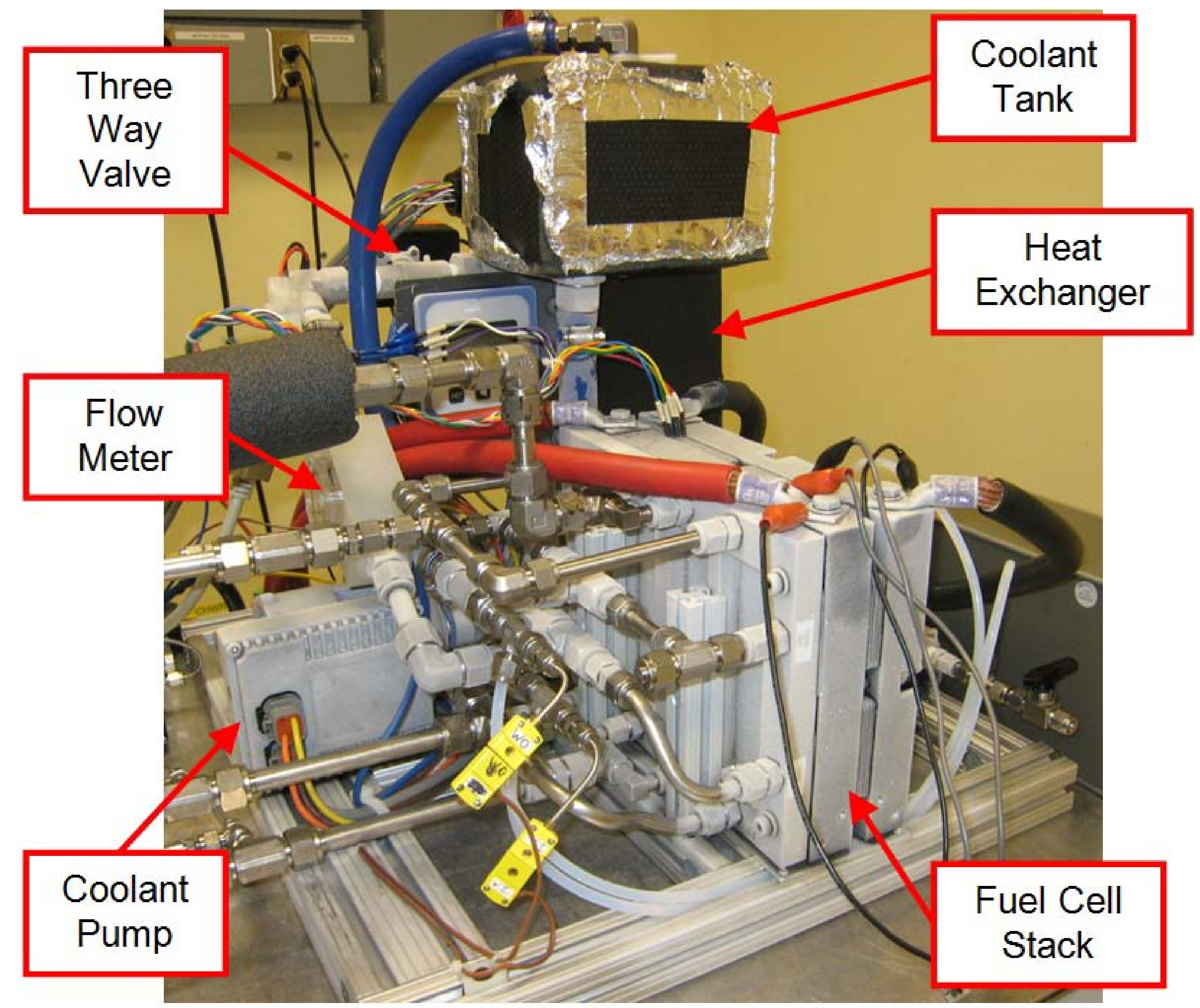
Test steps followed on Orion and Andromeda are identical

Pre-Condition, Shutdown, Freezing, Freeze Start.

Subsystem integrates Orion stack and dedicated coolant loop

Coolant used is Ethylene Glycol.



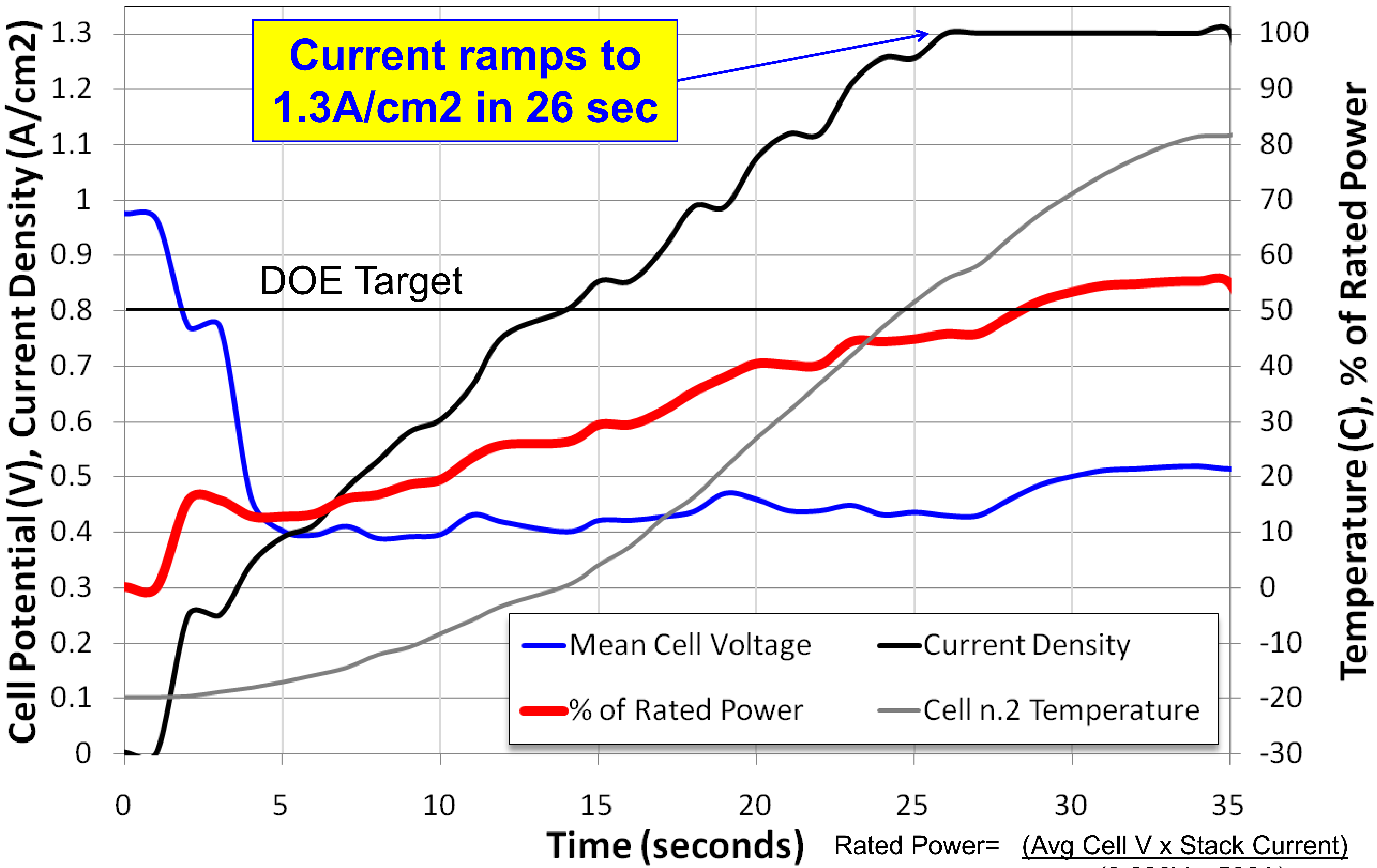


Subsystem is frozen in chamber not integrated with test stand.

Manual installation is needed prior to every cycle.

Coolant (@ -20C) is kept resident in stack during Freeze Start

Orion Startup from -20C



Rated Power= $\frac{\text{(Avg Cell V x Stack Current)}}{\text{(0.600V x 500A)}}$

Successful start from -20C to 50% of power in ~ 28 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 – 90 sec)	0.517 MJ
Coolant pump parasitic during shutdown (LHV of H2 consumed to power the coolant pump during purging phase)	0.142 MJ
H2 wasted in purges (LHV of H2 vented or burned – No purge necessary)	0.0 MJ
During Startup…	
H2 used during startup (LHV of H2 consumed to produce electric power in first 30 sec)	2.273 MJ
Air compressor parasitic during startup (LHV of H2 consumed to power compressor before stack is producing power)	0.006 MJ
TOTAL	**2.937 MJ**

Energy consumption to start from -20C is ~ 41% below DOE target

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Conclusive work

Startup from extreme temperatures.

•Preliminary tests (startups from -30C) seem to confirm advantage of Orion low thermal mass. More tests will be performed to achieve startup from -40C before the end of the program.

Explore sensitivity to conditions prior to purging

•Wet and dry conditions will be applied to Orion before shutdown to understand stack response during freeze start.

Characterize stack thermal profile during startup

•Thermocouples will be inserted in different locations of a stack to map the temperature during the freeze shutdown/startup

Summary

- Robustness of procedure identified has been proved through 200 freeze startup/shutdown cycles
- Diagnostic analysis hasn't shown significant degradation of materials after 200 cycles.
- Successful startup of Orion from -20C with resident coolant exceeding DOE targets
- FY10 focus: perform startup on Orion from extreme T and explore sensitivity to pre-conditions