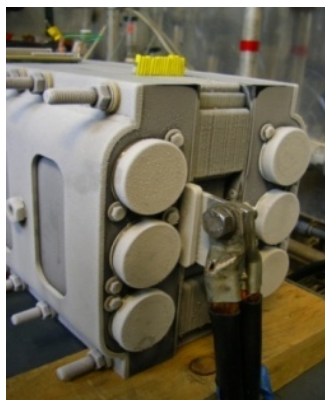


# CIRRUS

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



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Nuvera Fuel Cells, Inc.  
June 12, 2008

Project ID #  
**FC32**

# Overview

## Timeline

- 3 year program
- Actual start: 7/1/2007
- Planned end: 6/30/2010

## Budget

- Total project funding
  - \$4.970 Million (DOE)
  - \$2.160 Million (Nuvera)
- FY07 funding = \$619K
- FY08 funding = \$1,881K

## 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
- Los Alamos National Lab

# Objectives

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

Table 3.4.3 Technical Targets: 80-kW <sub>e</sub> (net) Transportation Fuel Cell Stacks 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 temperature @ +20°C ambient temperature	seconds	2	20	30	30
	seconds	<1	<10	5	5
Start up and shut down energy <sup>l</sup> from -20°C ambient temp from +20°C ambient temp	MJ	N/A	7.5	5	5
	MJ	N/A	N/A	1	1
Unassisted start from low temperature <sup>l</sup>	°C	N/A	-20	-40	-40

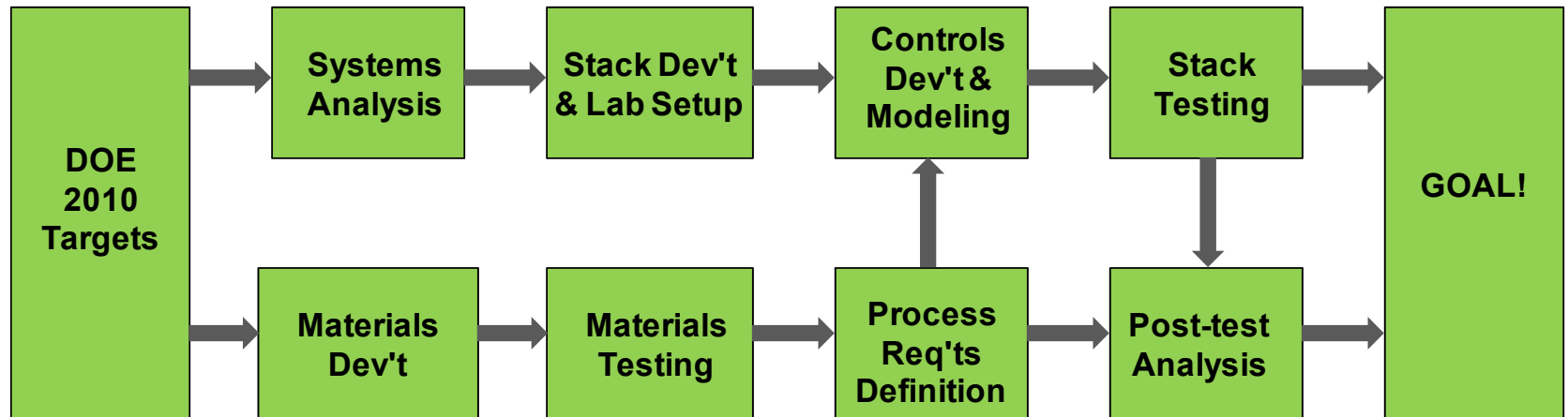
Specific **FY08 goals** include:

- Achieving -20C cold start target respecting the energy budget
- Identifying electrochemical material freeze cycle aging modes

# FY08 Milestones

- ***Achievement of -20C startup goal***
  - *Reference Stack Technology*
  - *Conditioned gas temperatures (environmental chamber)*
  - *Optimized procedure using dynamic model*
  - *System-compatible strategy*
  - *>50% rated power in 30 seconds*
  - *Auxiliary energy use < 5 MJ*
- ***Identification of freeze/thaw decay/failure modes***
  - *Detailed post-test analyses of freeze cycled MEAs and GDM*
  - *MEA stress evaluation from -40C to 65C at variable RH*
- ***Articulation of 2010 Technology***
  - *Performance specifications & design attributes*
  - *Freeze start performance forecast*

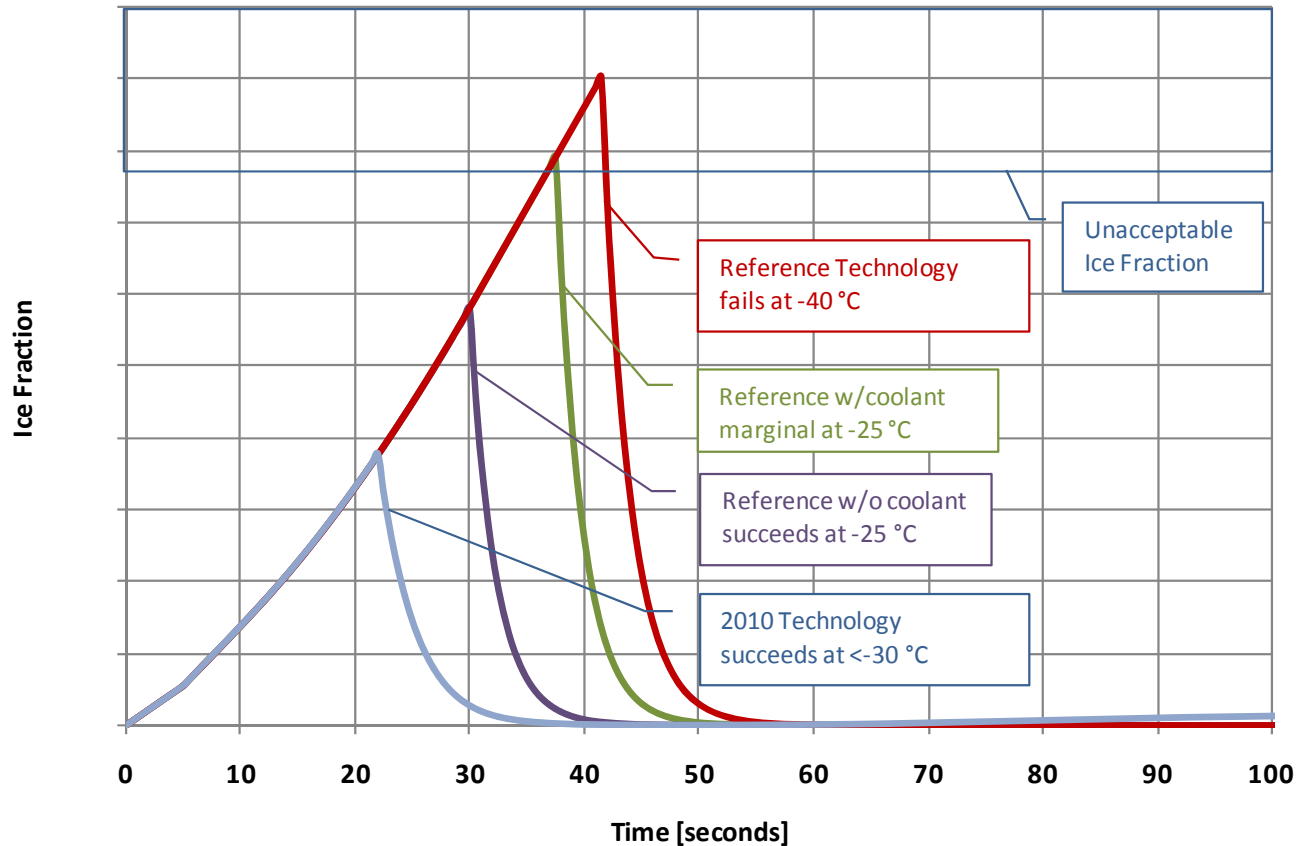
# Approach



**Program allows for one iteration:**

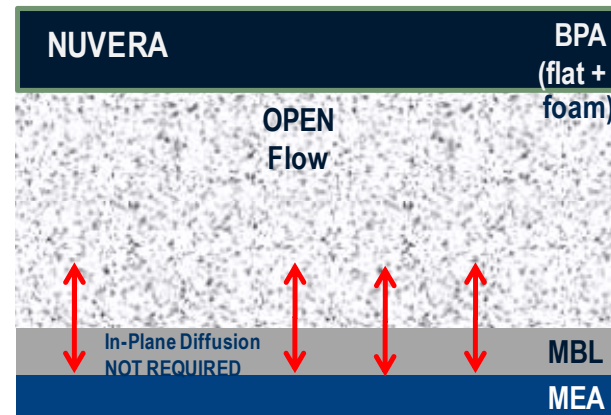
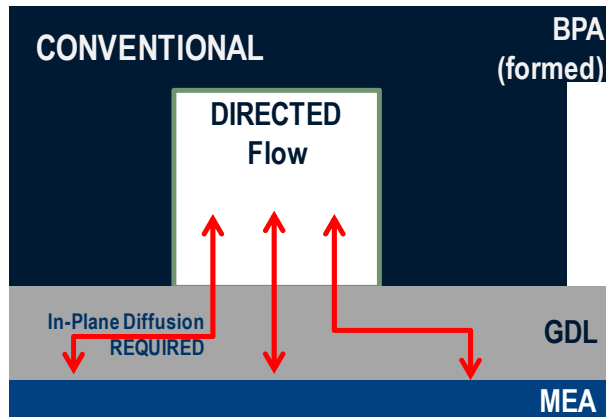
**Reference Technology: Q3/2007 -- Q1/2009**  
**2010 Technology: Q2/2009 -- Q2/2010**

# Systems Analysis



**Progress in stack thermal mass reduction is essential for meeting freeze start targets**

# Stack Development



Nuvera SYSTEM Advantages	Size	Efficiency	Durability	Freeze	Cost
Higher catalyst utilization	✓	✓	✓	✓	✓
Elimination of mass transfer limit	✓			✓	✓
Reduced cell pressure drop		✓		✓	✓
Reduced stress on MEA			✓	✓	
Enhanced cell stability			✓	✓	
Reduced electrical resistance	✓	✓	✓	✓	✓

Open flowfield is hypothesized as favored for meeting PEMFC freeze start requirements

# Laboratory Setup



- Reference technology
- 32 cells, 360 cm<sup>2</sup> AA/cell
- Commercial freezer

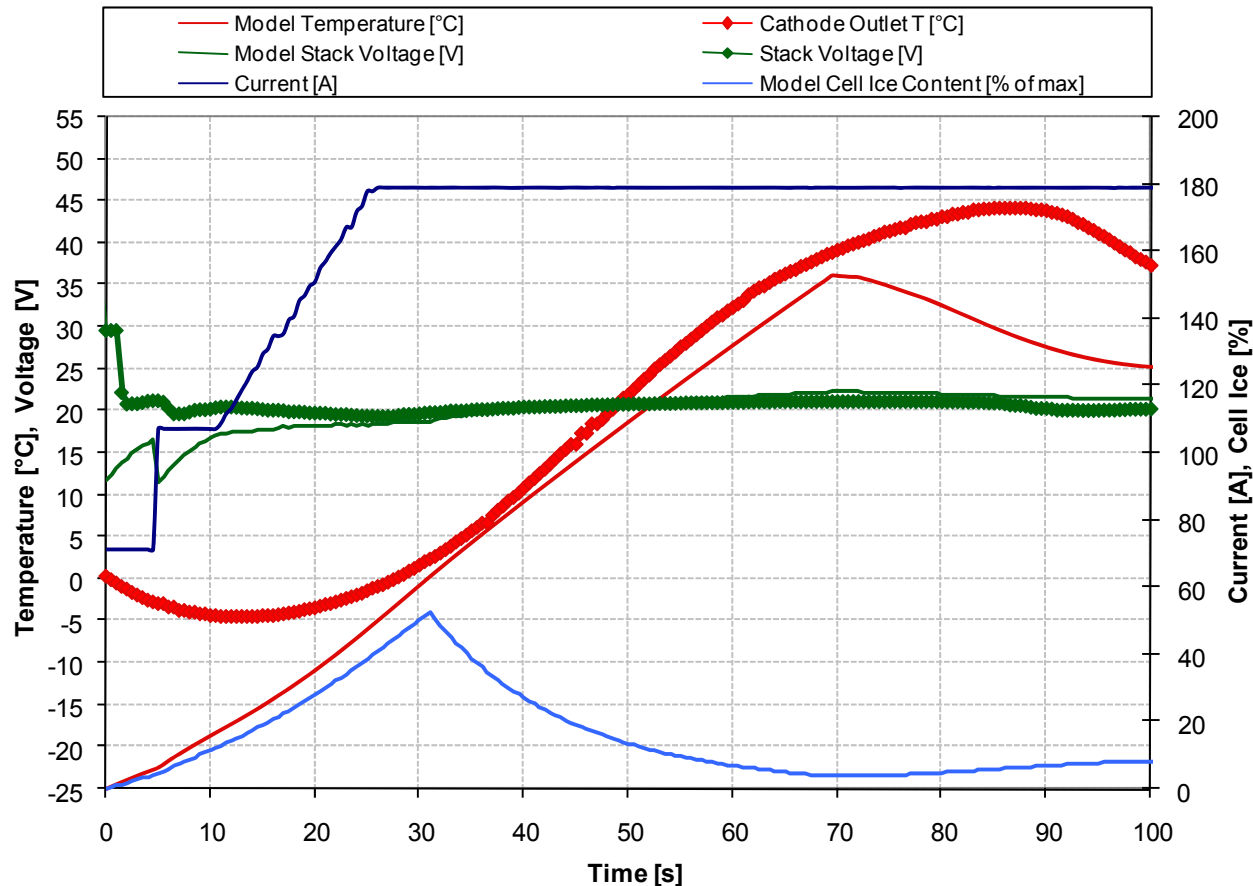


- 30 kWe Greenlight station
- Fully automated
- Adding env'l chamber Q3 08

**Primary testing infrastructure has been fully commissioned, with 36 freeze tests to date**

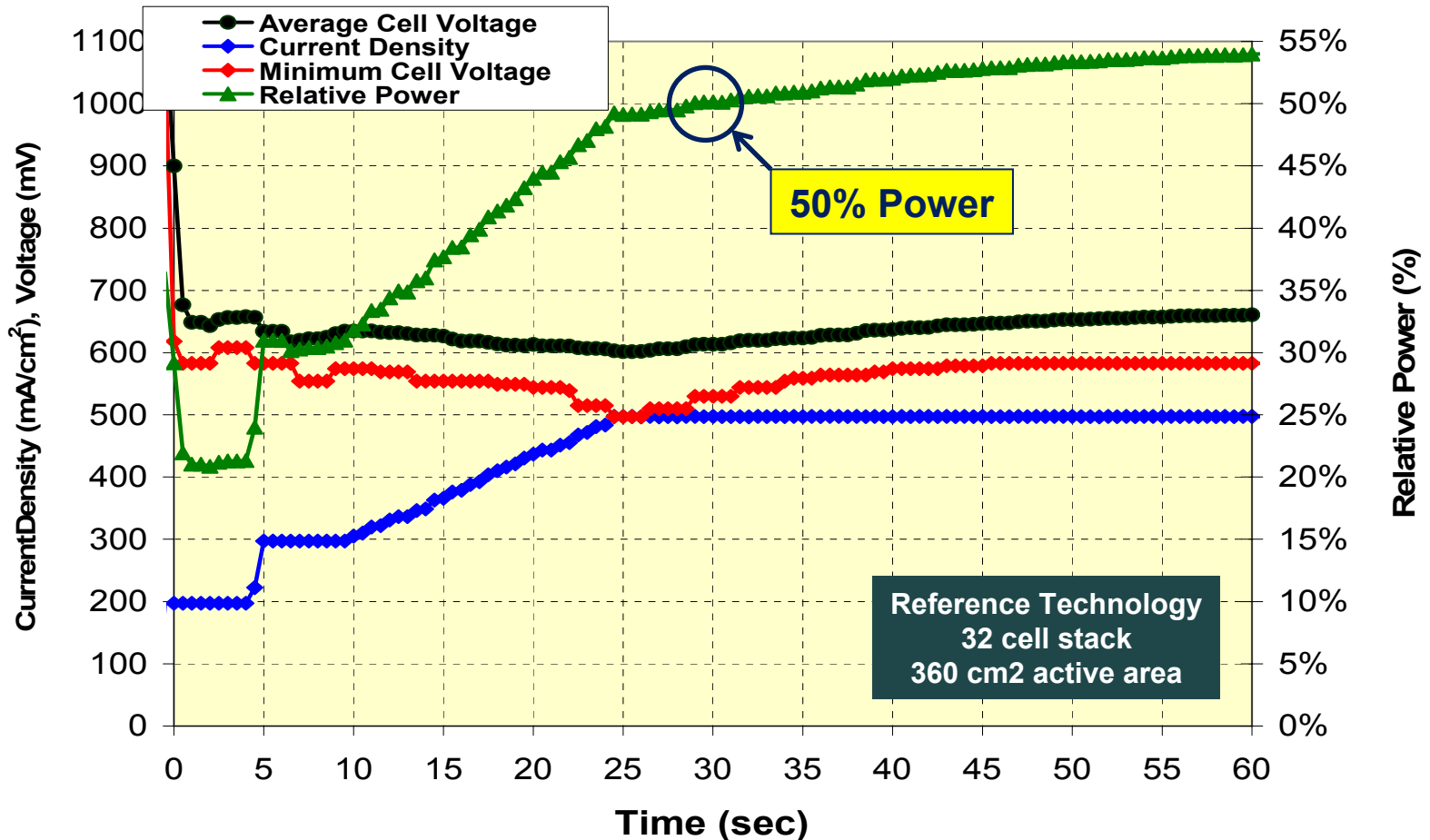


# Controls Development & Modeling



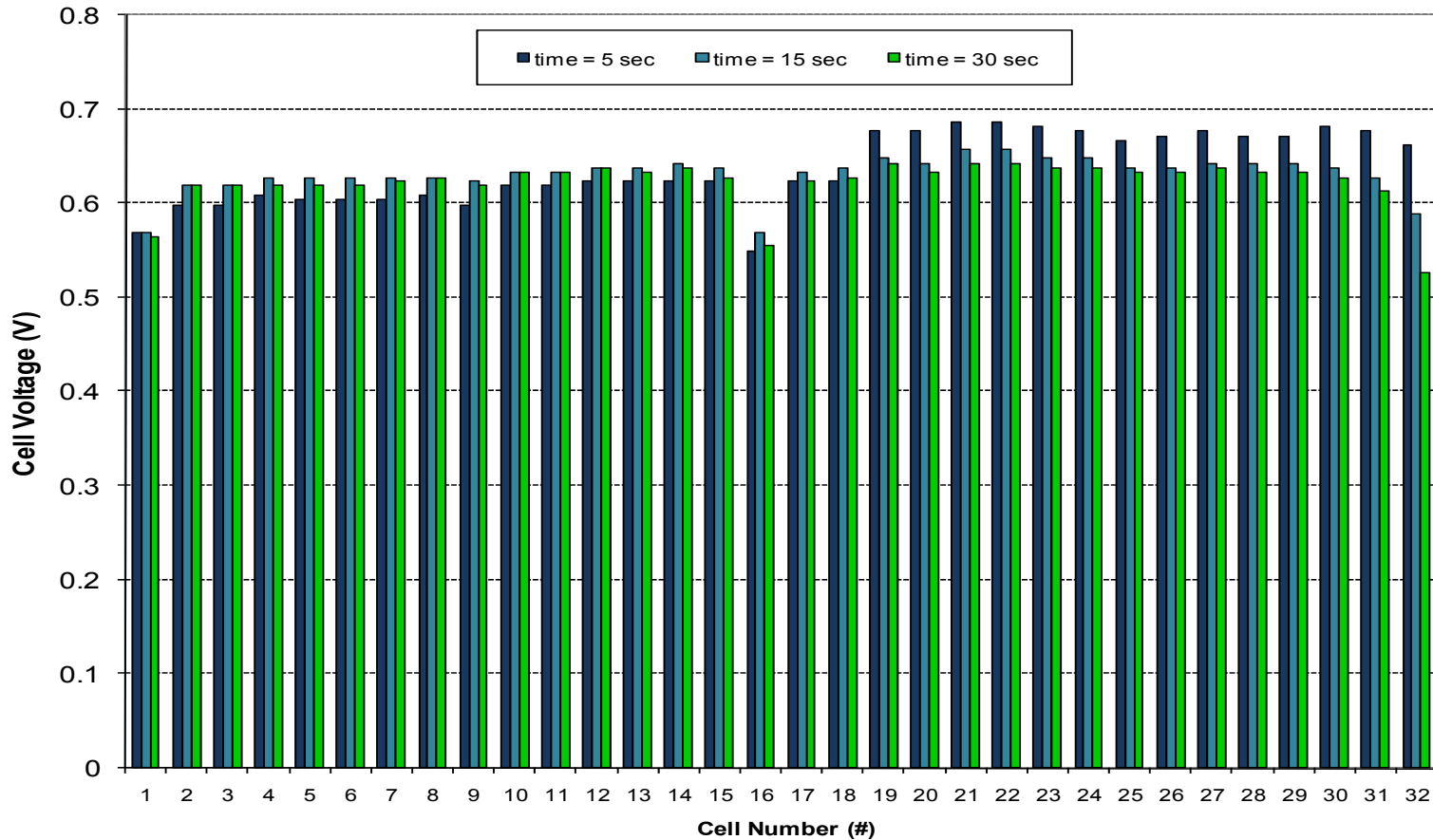
**Dynamic modeling offers important guidance for selection of operating protocols**

# Stack Testing



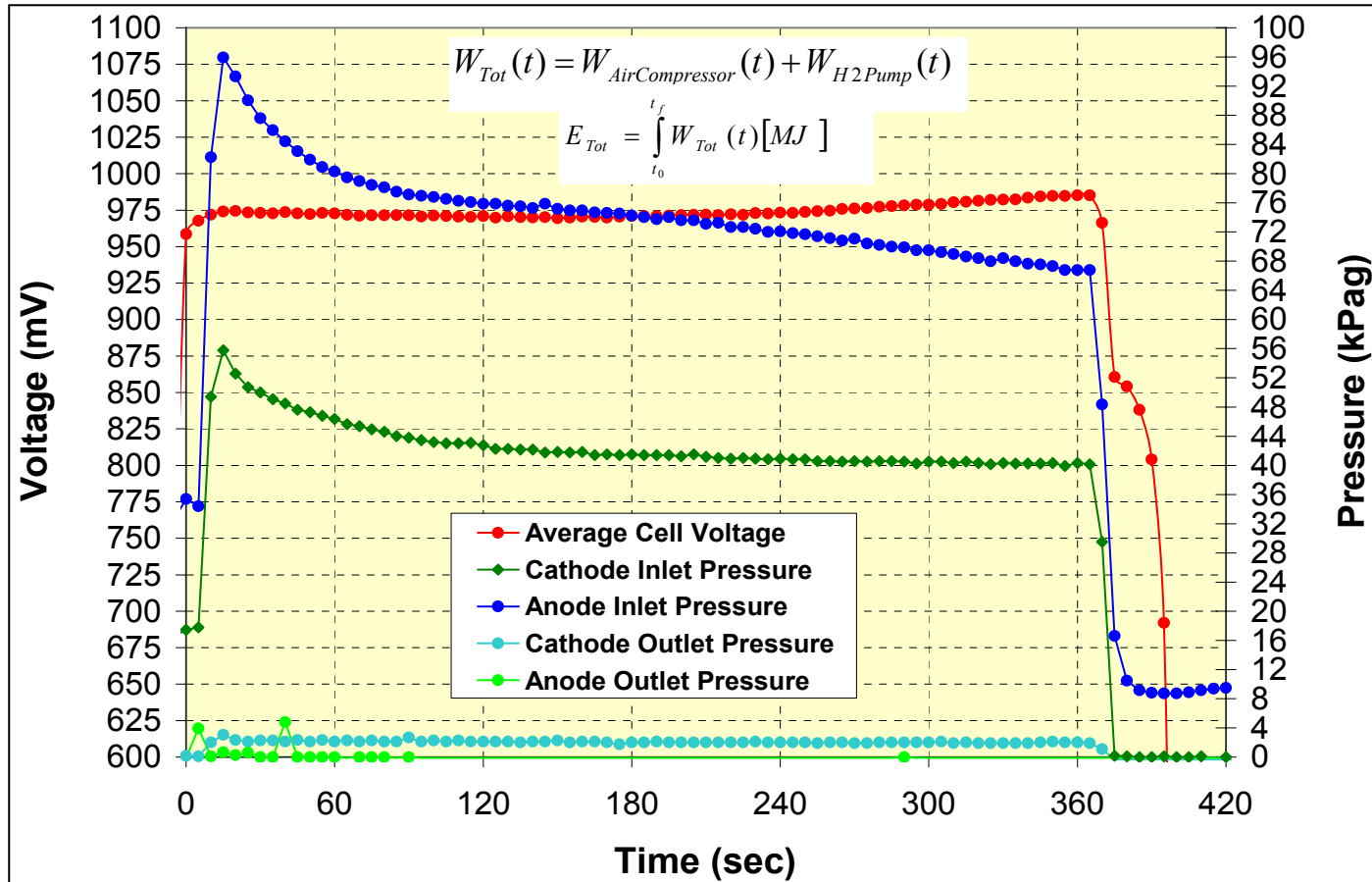
**Startup target of 50% rated power in 30 seconds has been achieved using Reference Technology**

# Cell Stability



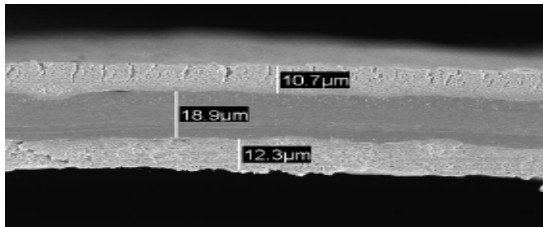
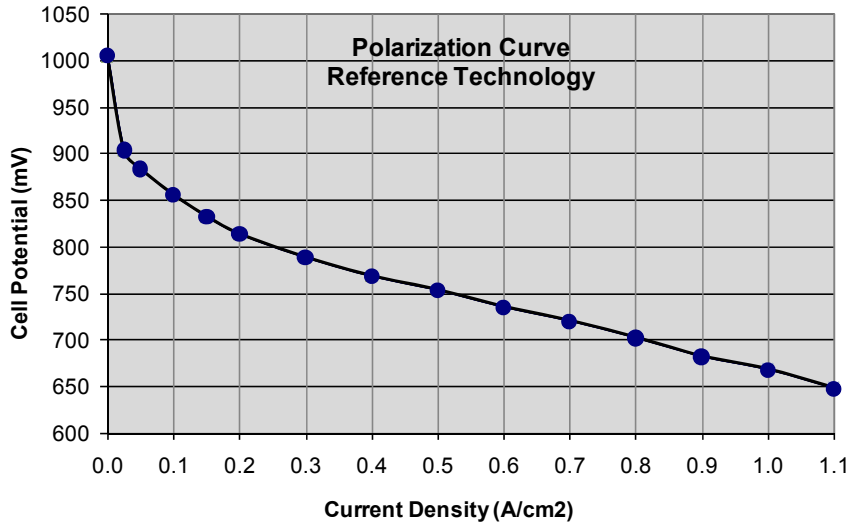
**Cell stability through -20C start was acceptable -- depression of end cell voltages is evident**

# Energy Accounting

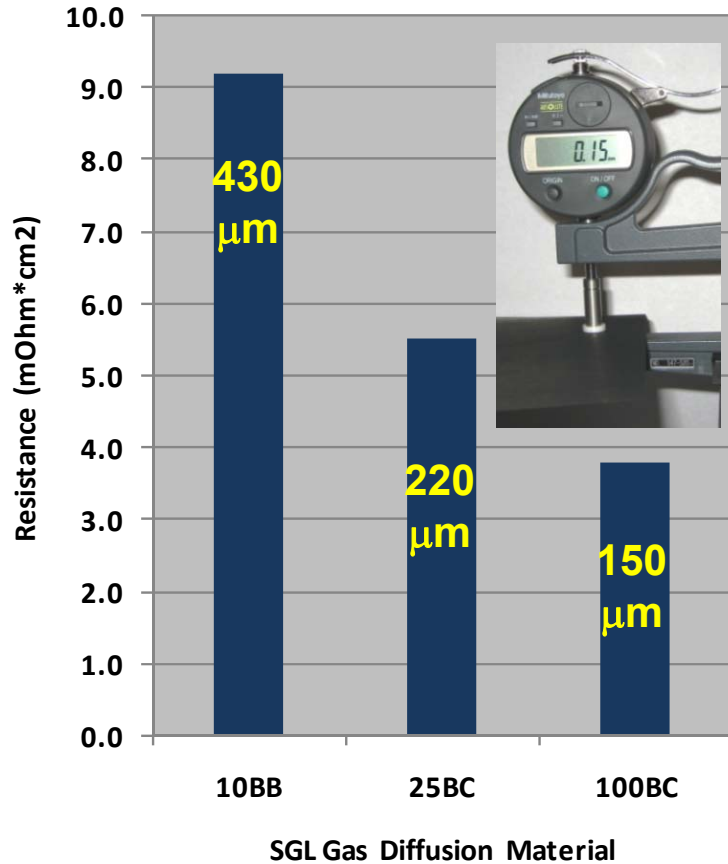


**Estimated energy use over complete start/shutdown cycle  
 = 5.6 MJ approaching DOE target (previously 26 MJ)**

# Materials Development

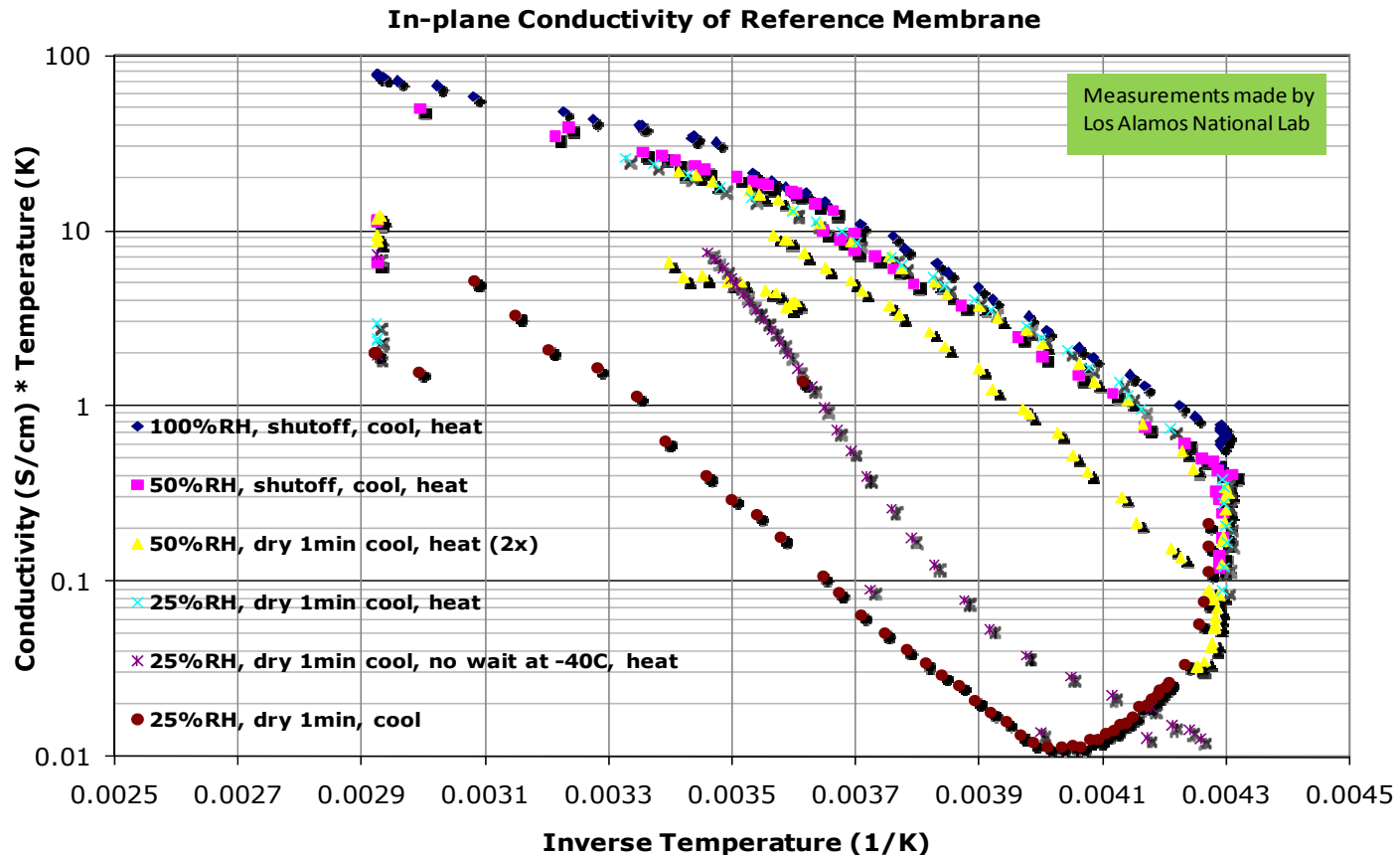


Reference MEA



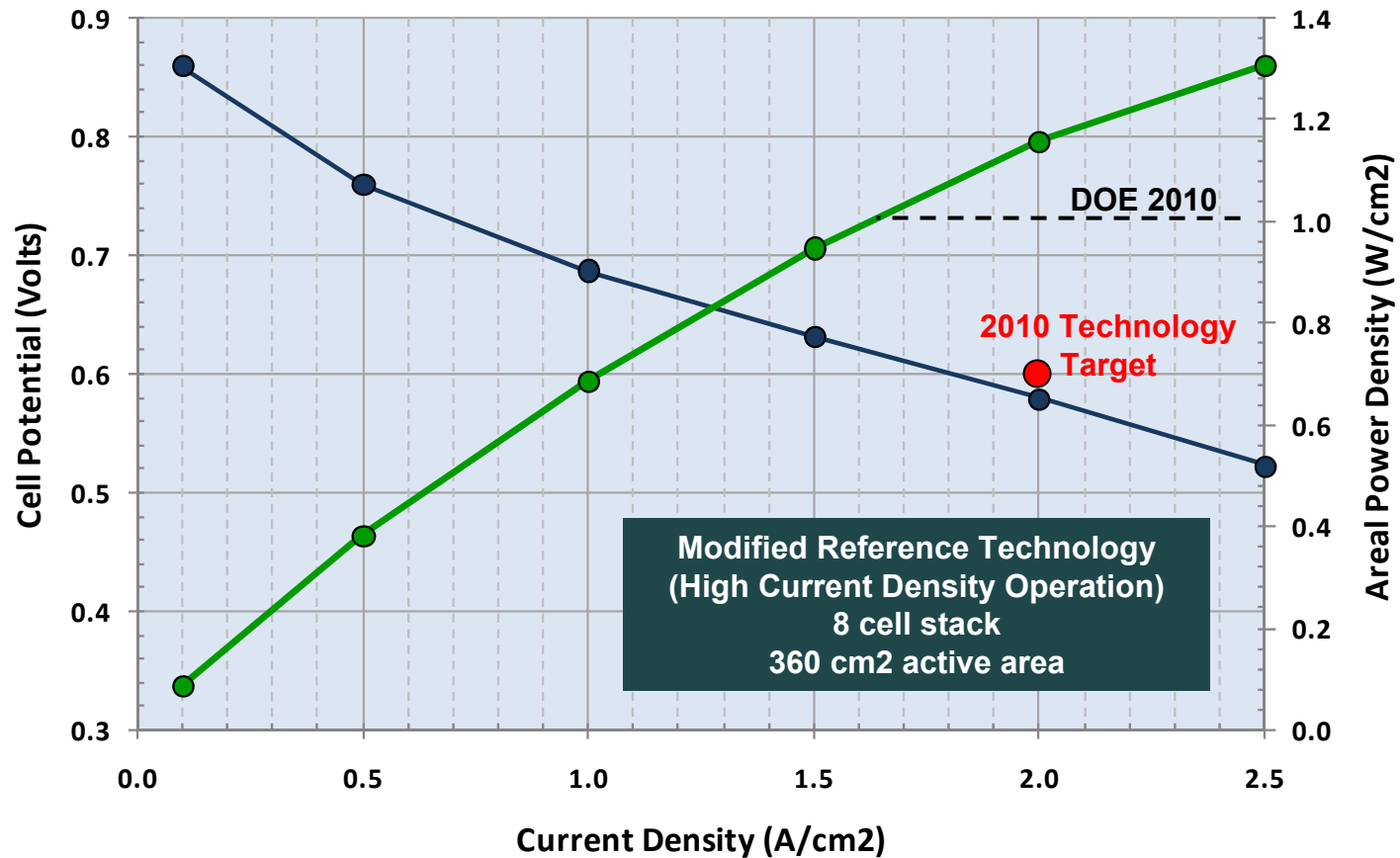
**Program targeting higher durability MEAs & thinner diffusion layers**

# Materials Testing



**Temperature dependence of Reference MEA conductivity under various shutdown approaches has been measured**

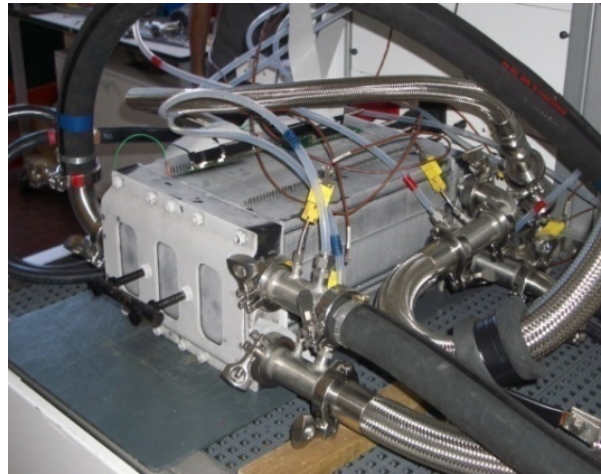
# 2010 Technology Preview



**Key target for 2010 stack technology will be a Rating Current Density (RCD) of 2.0 A/cm<sup>2</sup>**

# Future Work

- **Install and commission environmental chamber**
- **Develop 2d model to afford startup procedure optimization**
- **Analyze post-test material sets to understand decay modes**
- **Improve material sets (MEA durability, GDM thickness)**
- **Measure MEA stresses and refine process constraints**
- **Develop & validate 2010 Stack Technology**





# Summary

- **2010 startup goal of 50% rated power in 30 seconds has been achieved (32 cell, full format Reference Technology stack)**
- **Energy budget target of 5 MJ currently exceeded by 12%, will be met with further optimization**
- **Next generation 2010 material sets are in active development, to be informed by forthcoming post-test analyses**
- **2010 Technology, on account of higher performance and reduced thermal mass, will meet targets from start temperatures < -20C**

<b>Technical Targets: 80-kWe (net) Transportation Fuel Cell Stacks Operating on Direct Hydrogen</b>			
<b>Characteristic</b>	<b>Units</b>	<b>Status 2005 (DOE)</b>	<b>Status CIRRUS FY08</b>
Cold start-up time to 50% of rated power	seconds	20	30
Startup and shutdown energy (from -20C ambient)	MJ	7.5	5.6
Unassisted start from low temperature	C	-20	-25