AURORA Program

Transport Studies Enabling Efficiency Optimization of Cost-Competitive Fuel Cell Stacks

Presenter: Robert Dross (PM)

Principal Investigator: Amedeo Conti

Nuvera Fuel Cells

May 17, 2012

Project ID # **FC028**

Program Overview

Timeline

- Actual start: 9/1/2009
- Planned end: 8/31/2012
- 90% complete

Barriers

- Barriers addressed
  - (B) Cost
  - (C) Performance
  - (E) System thermal & water management

Budget

- Total project funding
  - $4.46 M (DOE, includes $375K to LBNL)
  - $1.57 M (Cost Share)
- FY'11 Actual Funding: $1.195 M
- Planned FY'12 Funding: $0.876 M

Partners

- Johnson Matthey Fuel Cells
- Penn State University / University of Tennessee
- Lawrence Berkeley Lab

Relevance

*The **objective** of this program is to optimize the efficiency of a stack technology meeting DOE 2015 cost targets.*

Table 3.4.4 Technical Targets: 80-kW$_e$ (net) Transportation Fuel Cell Stacks Operating on Direct Hydrogen[a]				
Characteristic	**Units**	**2011 Status**	**2017 Targets**	**2020 Targets**
Stack power density[b]	W / L	2,200[c]	2,250	2,500
Stack specific power	W / kg	1,200[c]	2,000	2,000
Stack efficiency[d] @ 25% of rated power	%	65	65	65
Cost[e]	$ / kW$_e$	22[f]	15	15
Durability with cycling	hours	2,500[g]	5,000[h]	5,000[h]
$Q/\Delta T_i$[i]	kW/ºC	–	1.45	1.45

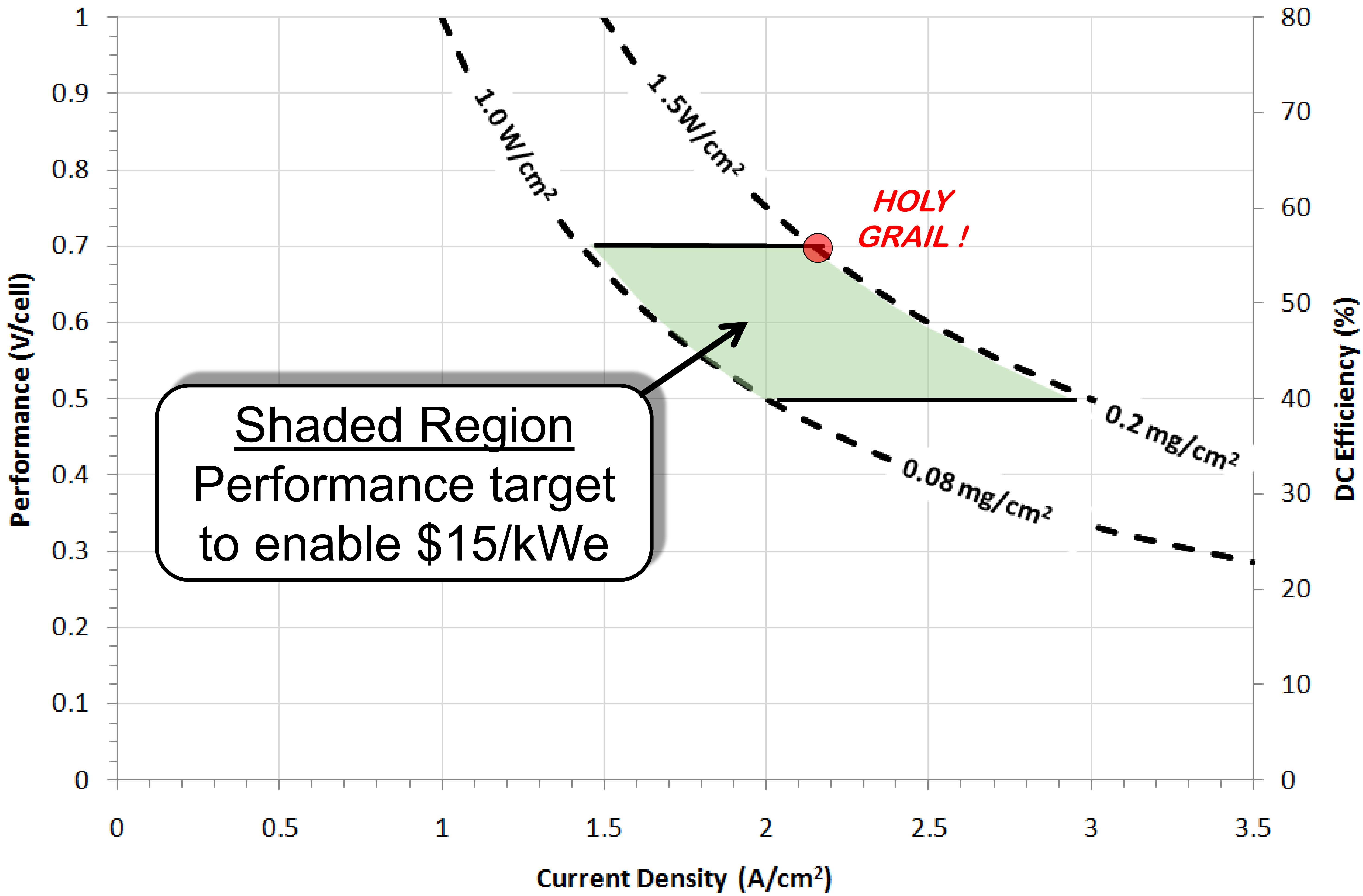
[e] Based on 2002 dollars and cost projected to high-volume production (500,000 stacks per year).

<u>Program is on schedule and the 2010 Go/No-Go milestone has been met</u>

NUVERA FUEL CELLS

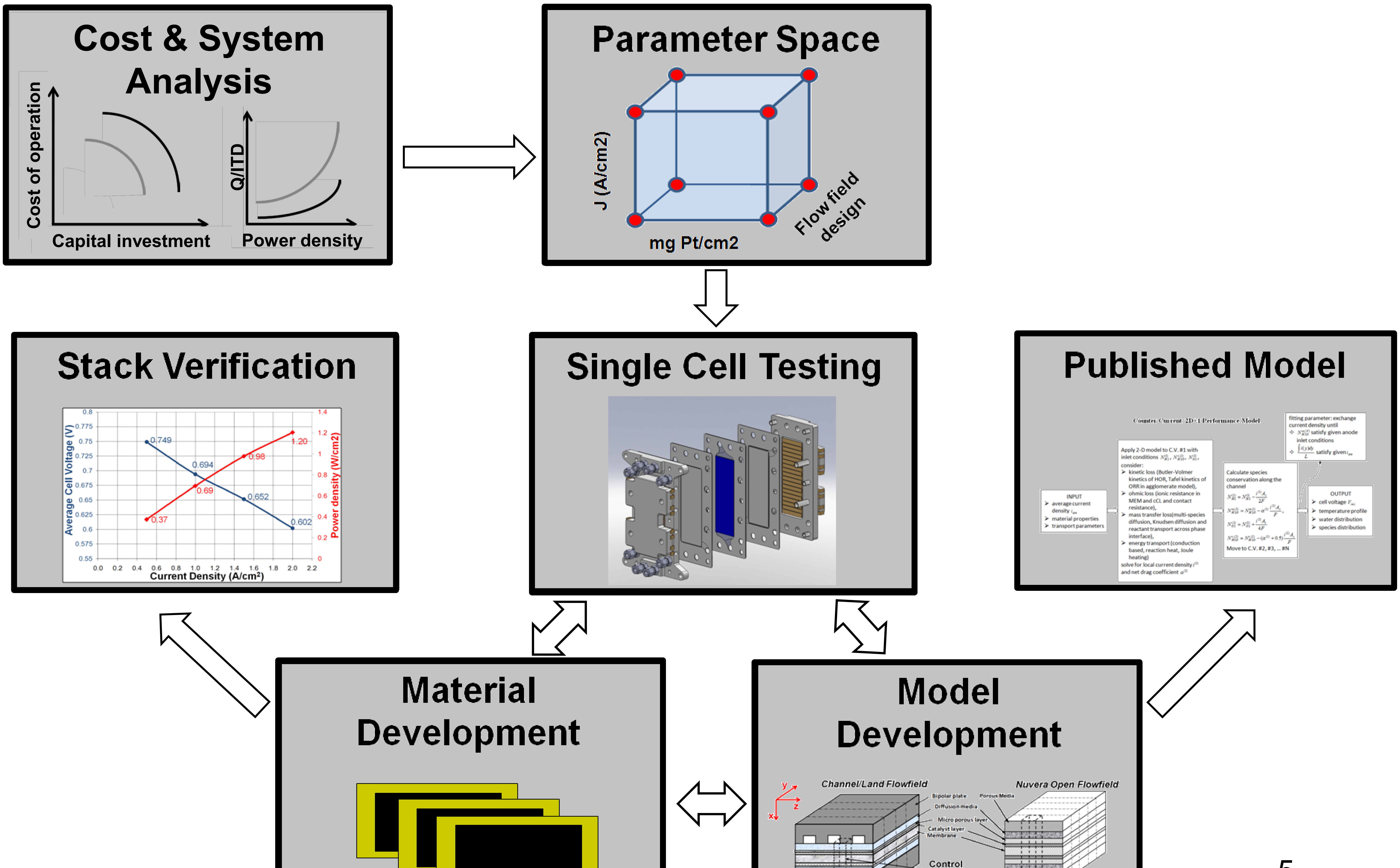
Technical Target - Approach

Target: *Demonstrate stable and repeatable high power performance on a full format fuel cell stack: 7.5 W/mg-Pt @ 500mV.*



NUVERA FUEL CELLS

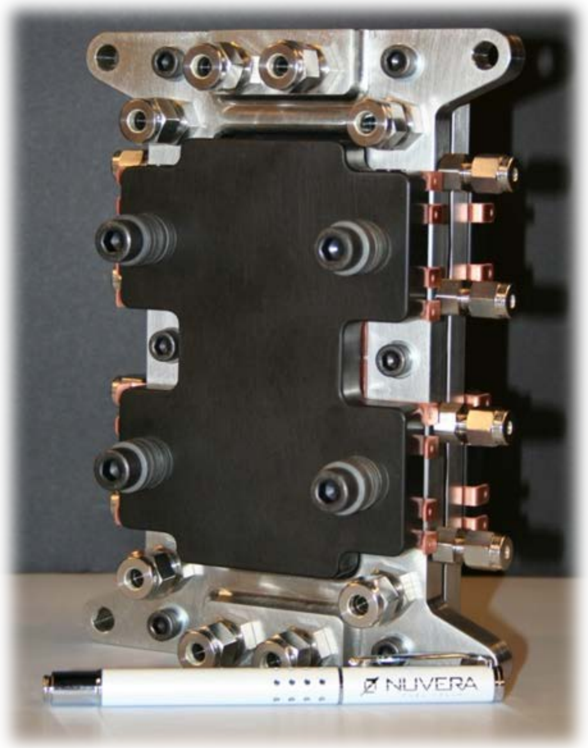
Program Approach

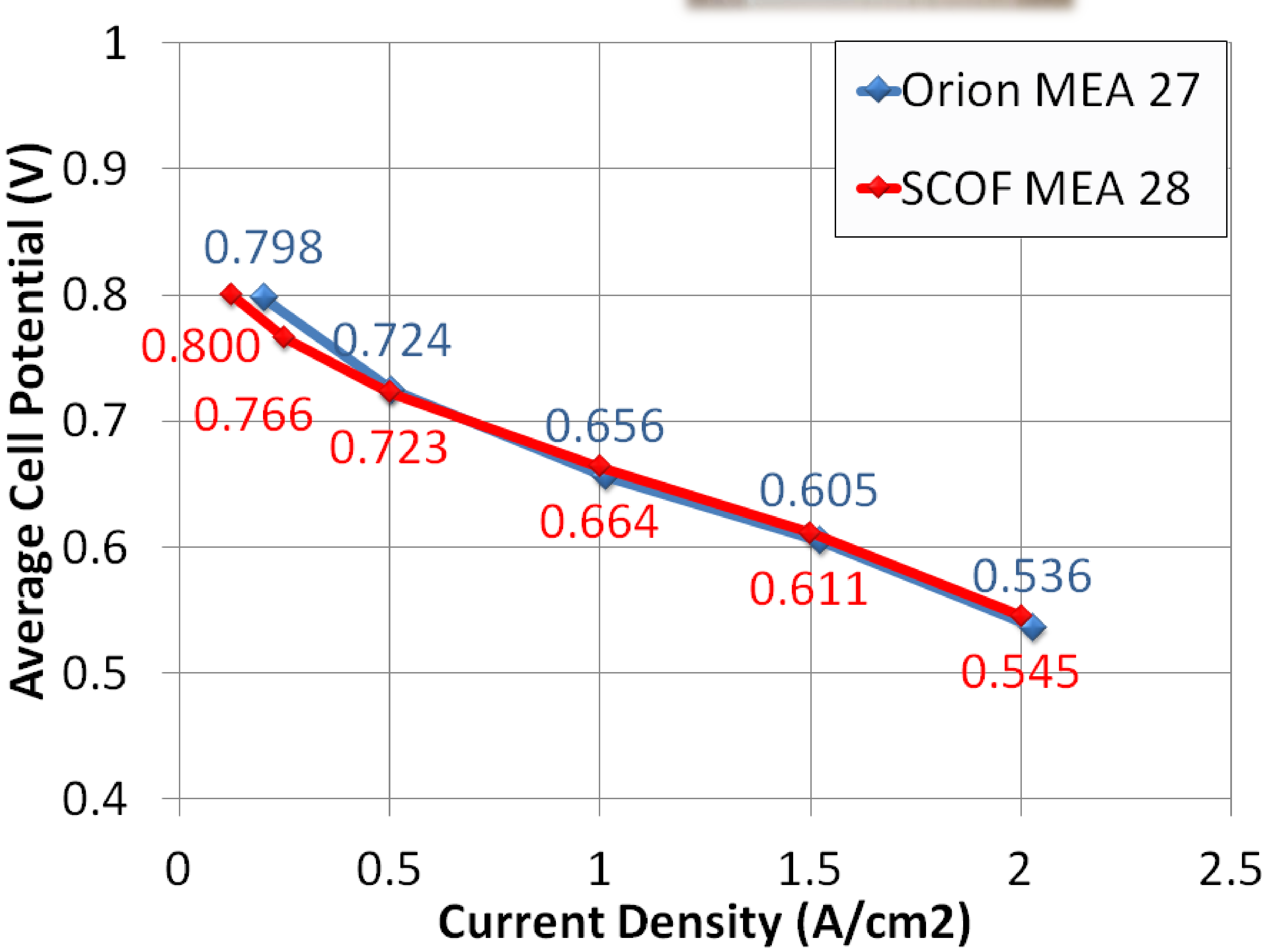


Single Cell Development

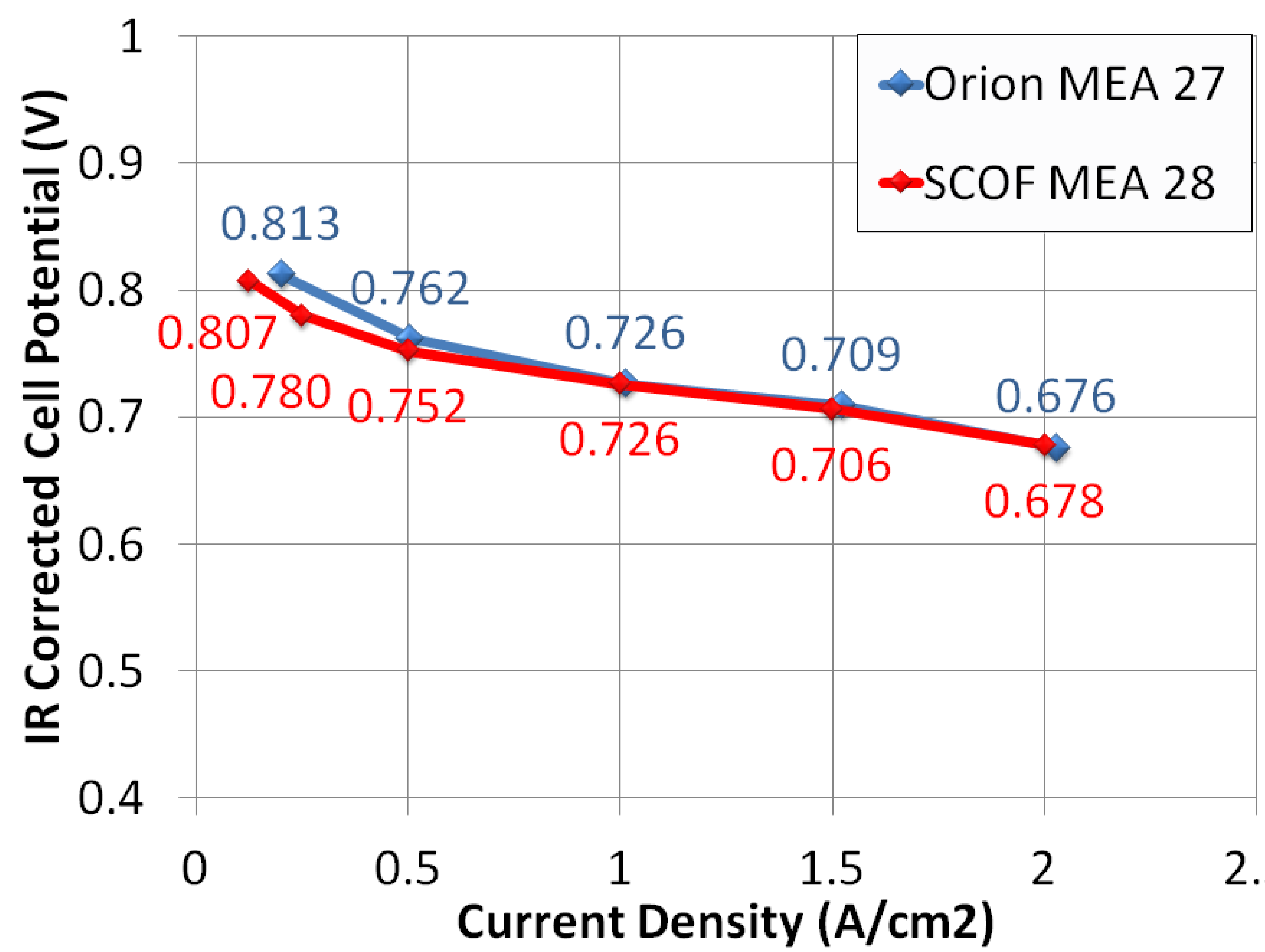
Performance of SCOF compared to full format Orion stack.

Single Cell
Open Flowfield
(SCOF) Hardware





Similar performance obtained between single cell and full format stack.



T_{cell}= 60 °C, An 50% RH, Ca 0% RH, Press ~1.1 to 1.8 bara

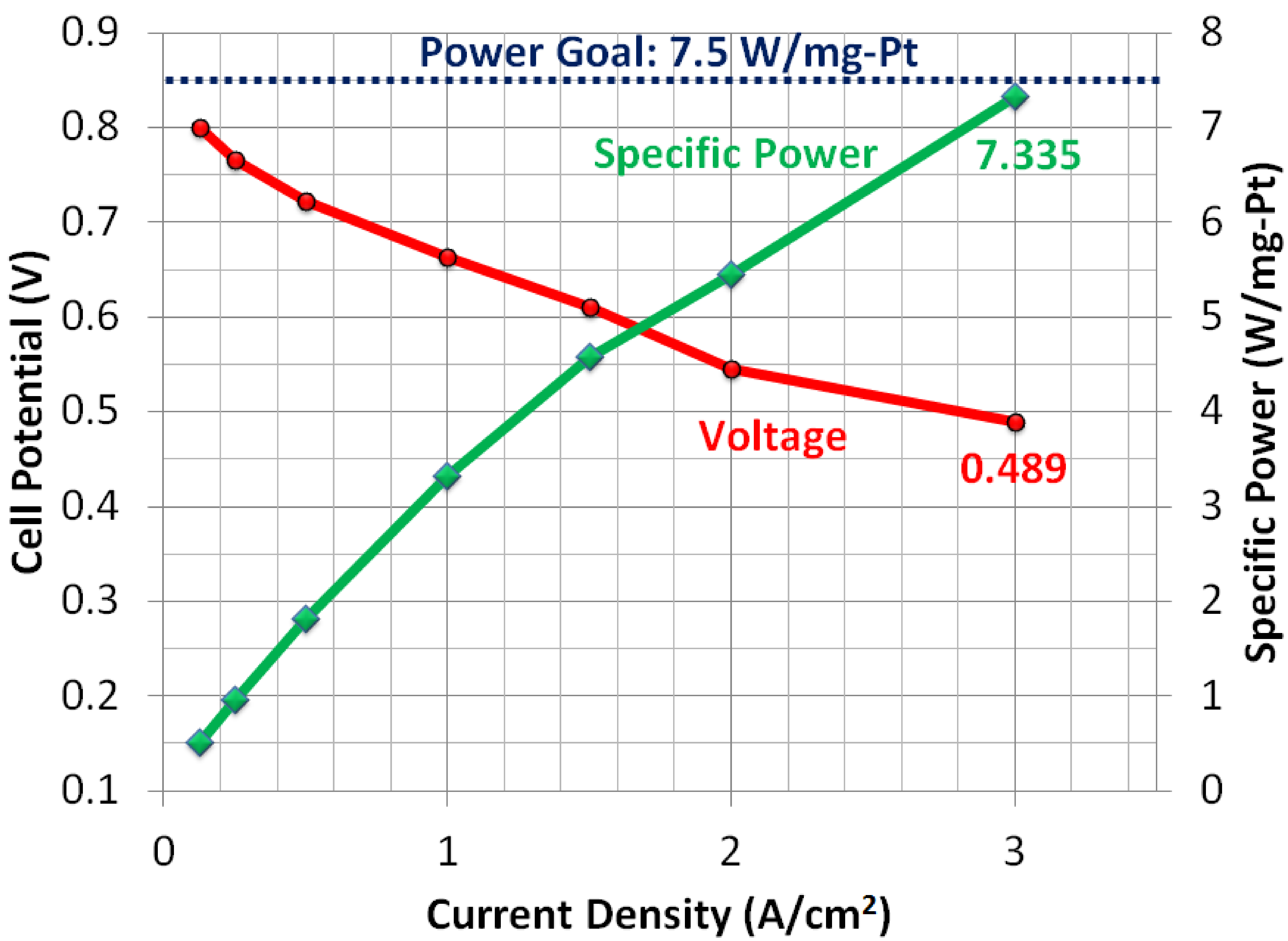
MEA27 : JM MEA27, 0.05 mg Pt/cm² An, 0.15 mg Pt/cm² Ca GDL: SGL 25BC

MEA28 : JM MEA28, 0.05 mg Pt/cm² An, 0.15 mg Pt/cm² Ca GDL: SGL 25BC

NUVERA FUEL CELLS

Single Cell Testing

Low Pt loading (0.2 mg-Pt/cm²) MEAs from JM tested on SCOF hardware

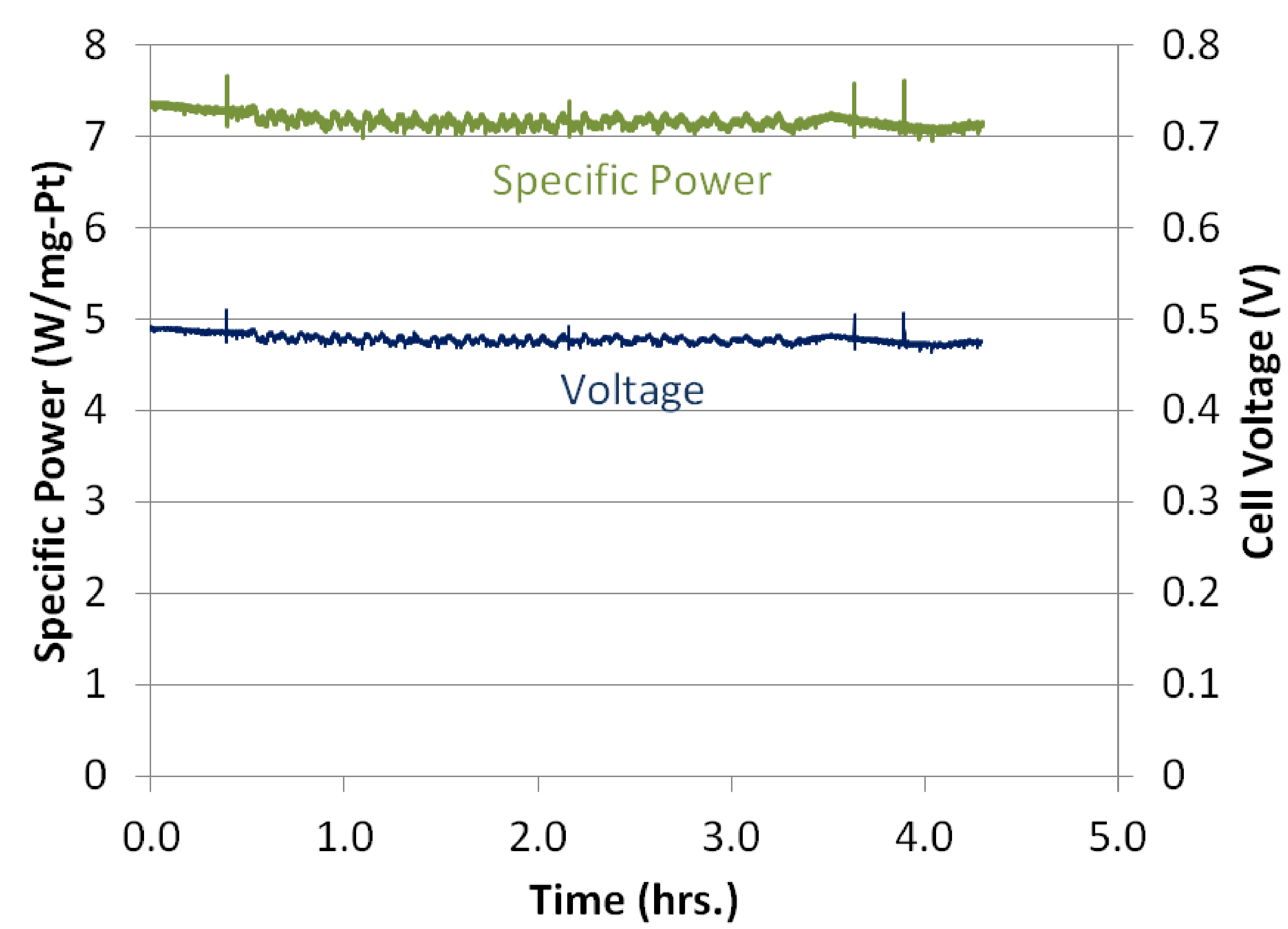


T_{cell}= 60 °C, An 50% RH, Ca 0% RH, Press ~1.1 to 2.4 bara

MEA28 : JM MEA28, 0.05 mg Pt/cm² An, 0.15 mg Pt/cm² Ca GDL: SGL 25BC

Specific Power of 7.3 W/mg-Pt Achieved on single cell

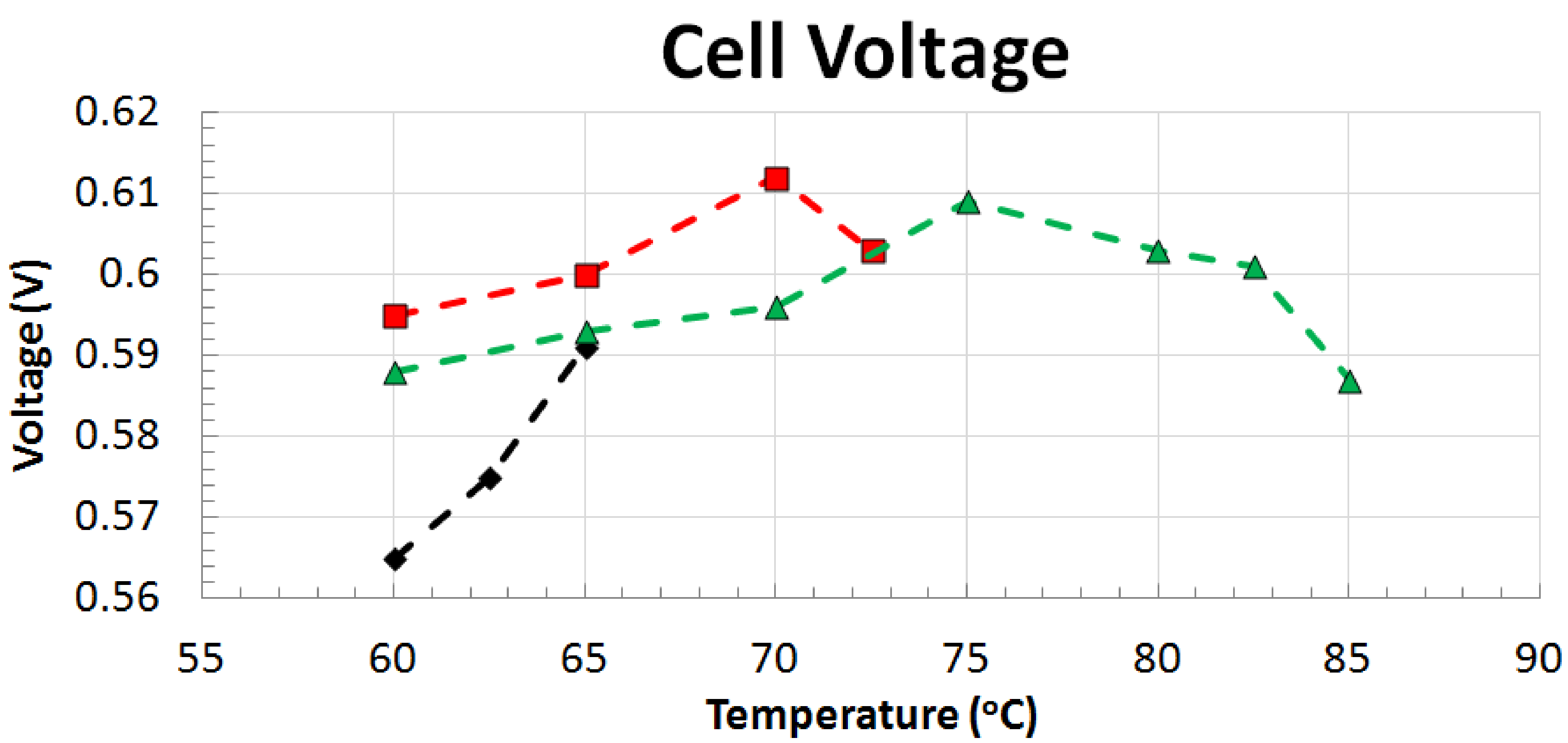
- Stability demonstrated at high current density point



NUVERA FUEL CELLS

Single Cell Testing

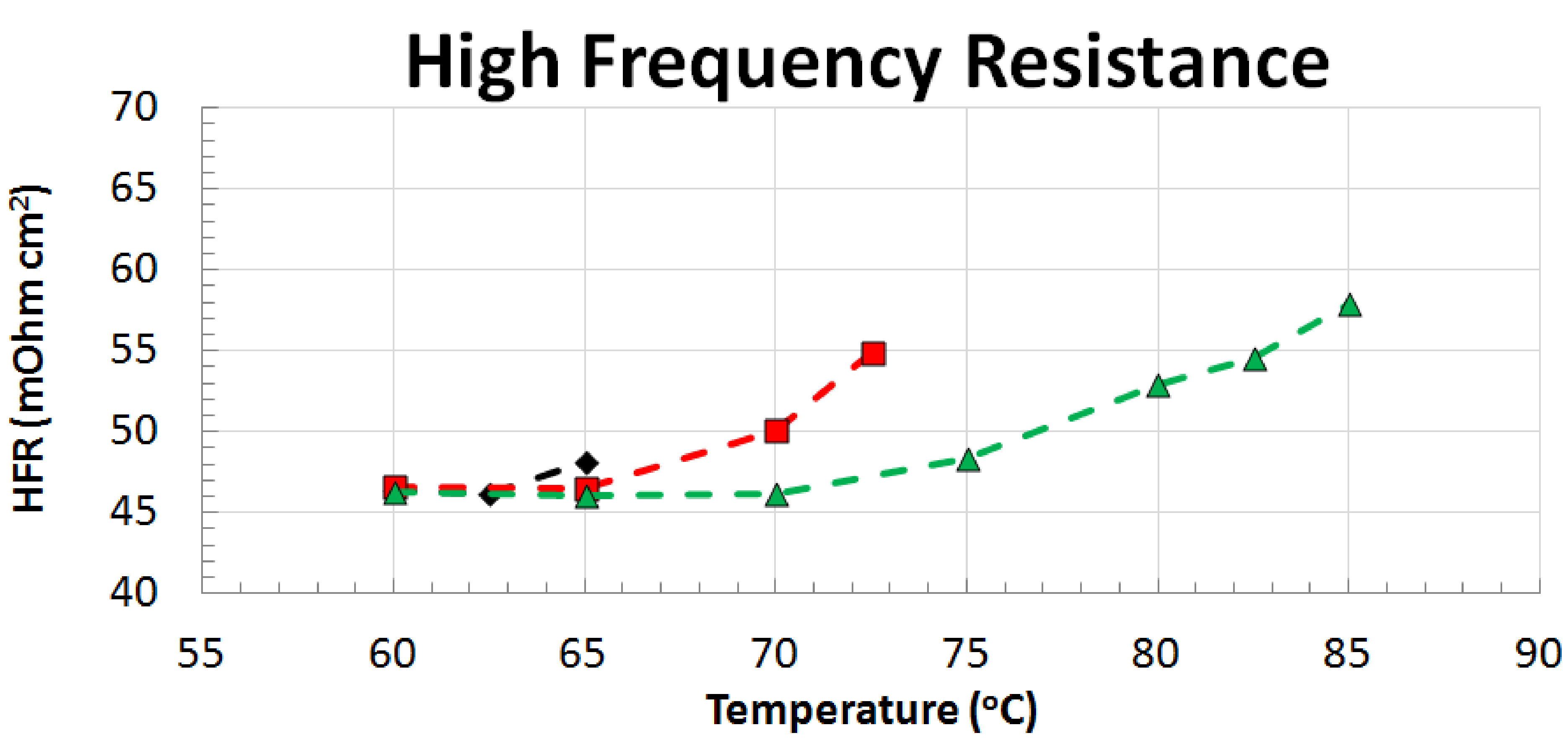
Temperature sensitivity study conducted at 2 A/cm^2 on standard Pt loading (0.55 mg-Pt/cm^2) materials

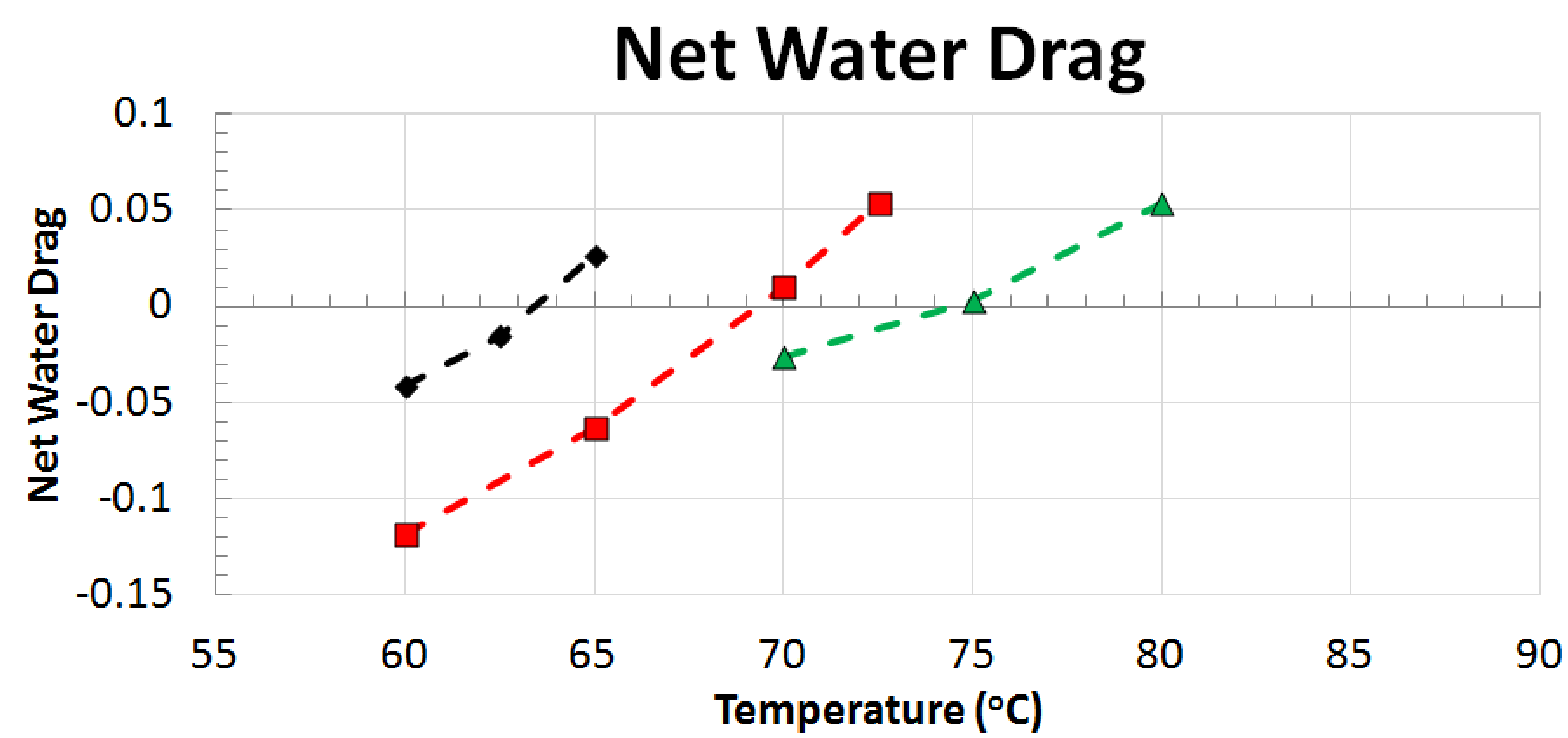


RH (%) An / Ca	Press (bar) An/Ca
53 / 0	1.8 / 1.8
53 / 0	1.8 / 2.4
53 / 53	1.8 / 2.4

Critical parameters to cell hydration were studied and results used to inform the model

- Concerns about heat rejection capability were addressed by increasing operation temperature.

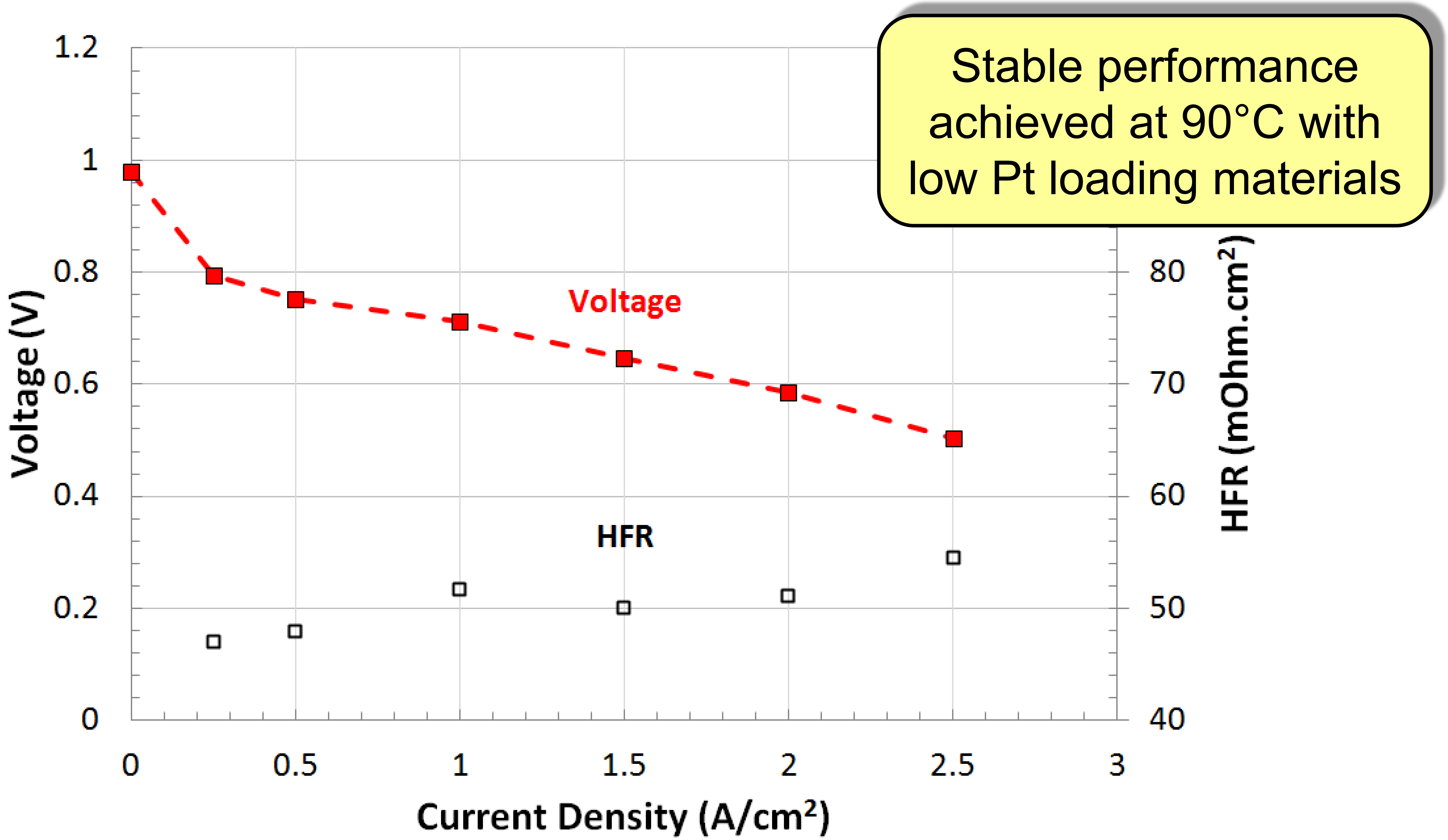




MEA: Gore 5730, 0.15 mg Pt/cm^2 An, 0.4 mg Pt/cm^2 Ca
GDL: SGL 25BC

Single Cell Testing

Stable performance demonstrated at elevated temperature with low Pt loading materials (0.2 mg-Pt/cm^2)



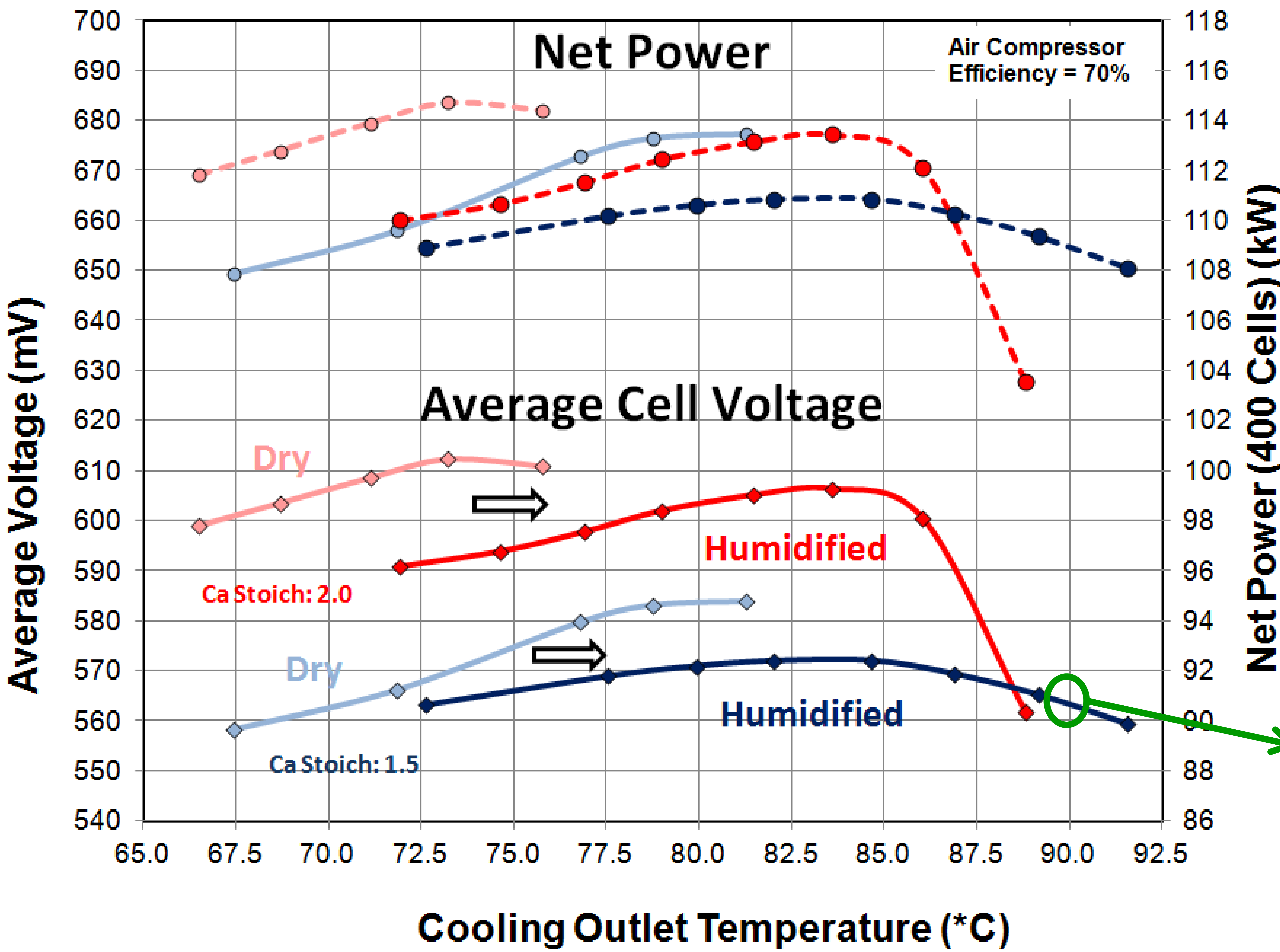
T_{cell}= 90 °C, An 53% RH, Ca 75% RH, Press 2.4 bara

SCOF cell, JM MEA28: 0.05 mg Pt/cm^2 An, 0.15 mg Pt/cm^2 Ca, GDL: SGL 25BC

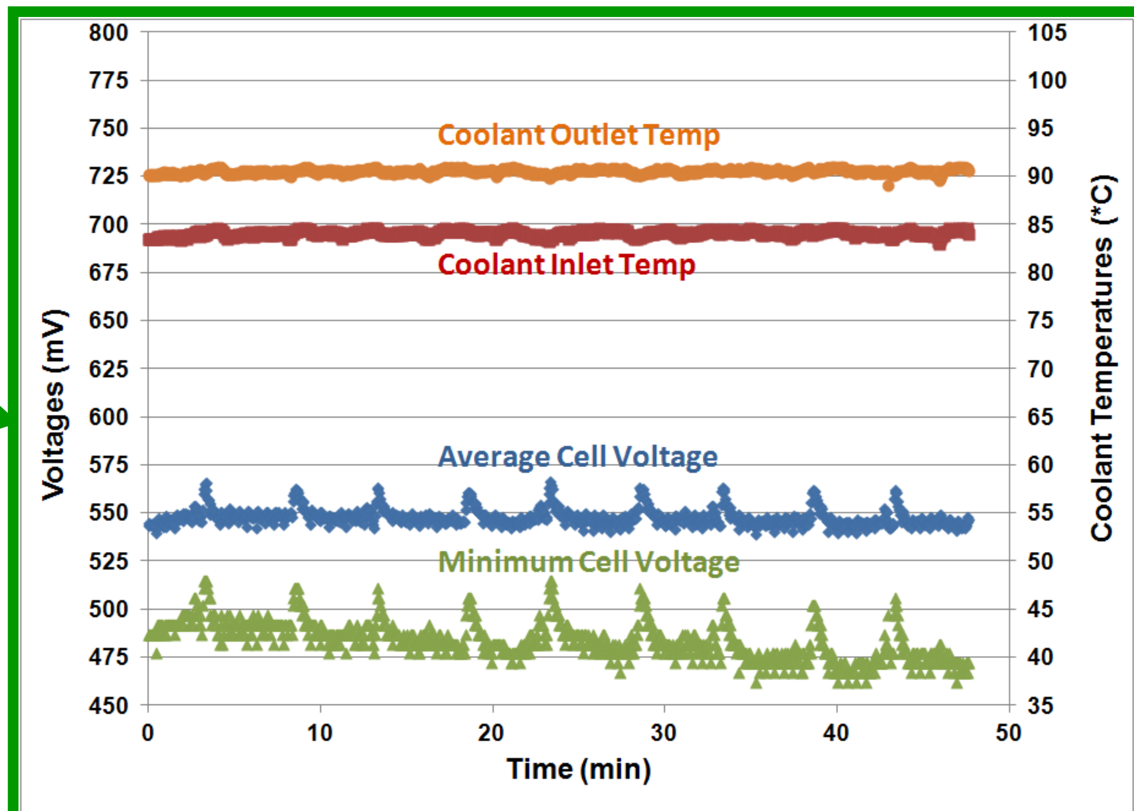
NUVERA FUEL CELLS PENNSTATE THE UNIVERSITY of TENNESSEE

Stack Testing

Stable performance at elevated temperature
on full format, 64 cell stack using a cathode humidifier.



System simulation testing confirms stability at high temperatures



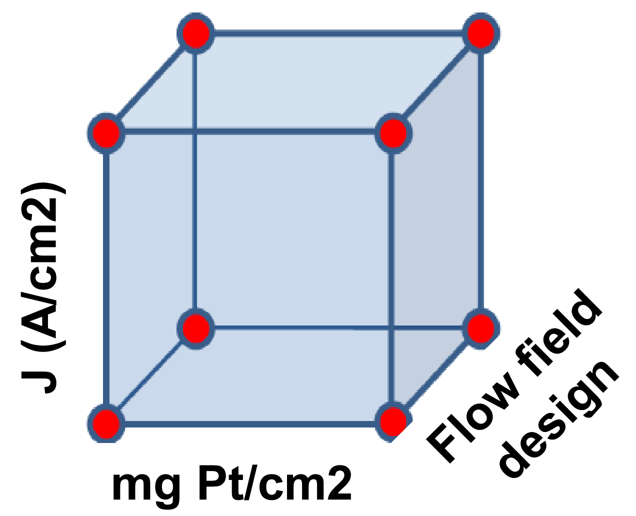
Current Density = 2.20 A/cm^2, Inlet Pressure = 1.40 barg
Anode Stoich = 2.00, Anode RH = 50%

NUVERA FUEL CELLS

Model Roadmap

A model capable of predicting high current density operation in different architectures is the central deliverable of the program

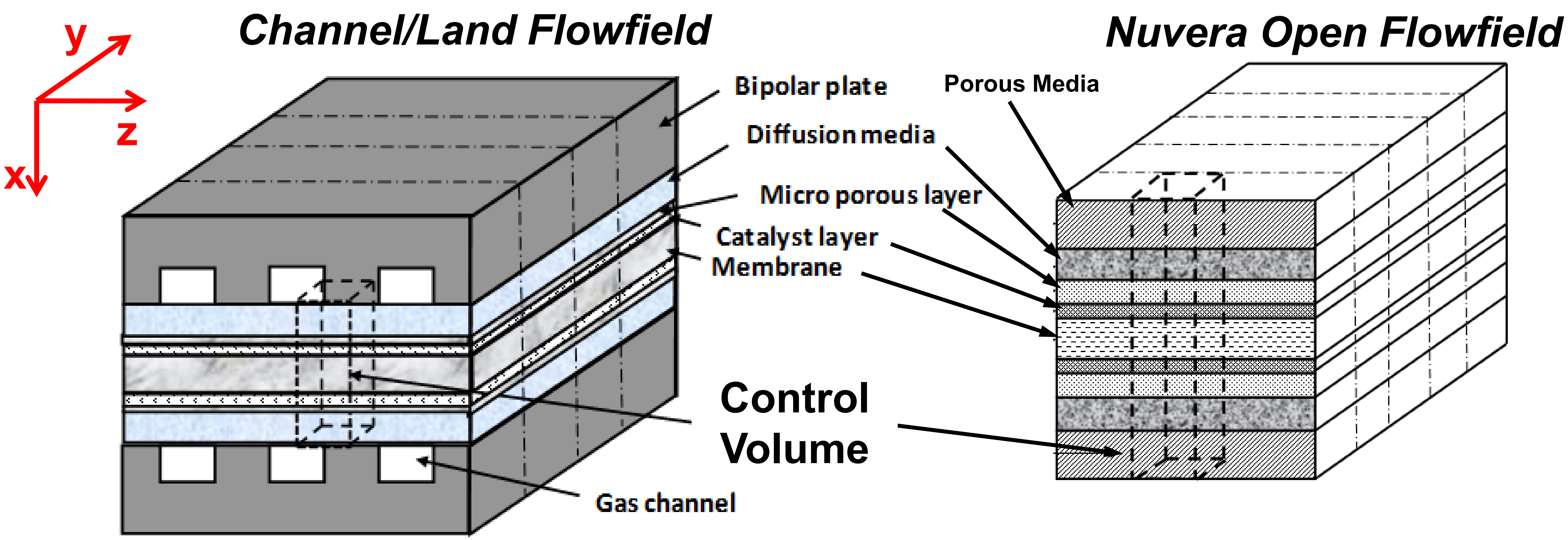
- **Single phase model generation** from PSU 2D channel/land model – **Q2 2010** Completed
  - 2D +1, counter flow reactants, compatible with multiple architectures
- **Initial validation with empirical Nuvera model – Q3 2010** Completed
- **Initial performance verification** – **Q4 2010** Completed
- **Multi-phase physics implementation** – **Q1 2011** Completed
  - Verification with empirical Nuvera model
  - Initial performance verification
- **Agglomerate electrode model implementation (LBNL)** – **Q1 2011** Completed
- **Tune model parameters and collect dataset – Q3 2011** Completed
- **Model Validation**: Demonstrate predictive capability – **Q4 2011** Completed
- **Additional Model Validation– Q3 2012** On Track
  - Validate: High Temperature, Channel Land Architecture, Low Pt Loading
- **Model Publication** – **Q3 2012** On Track



NUVERA FUEL CELLS | BERKELEY LAB | PENNSTATE 1855 | THE UNIVERSITY of TENNESSEE UT

FC Modeling -- Approach

The physics of the quasi-3D, multi-architecture model is as similar as possible between channel/land and open flowfields.

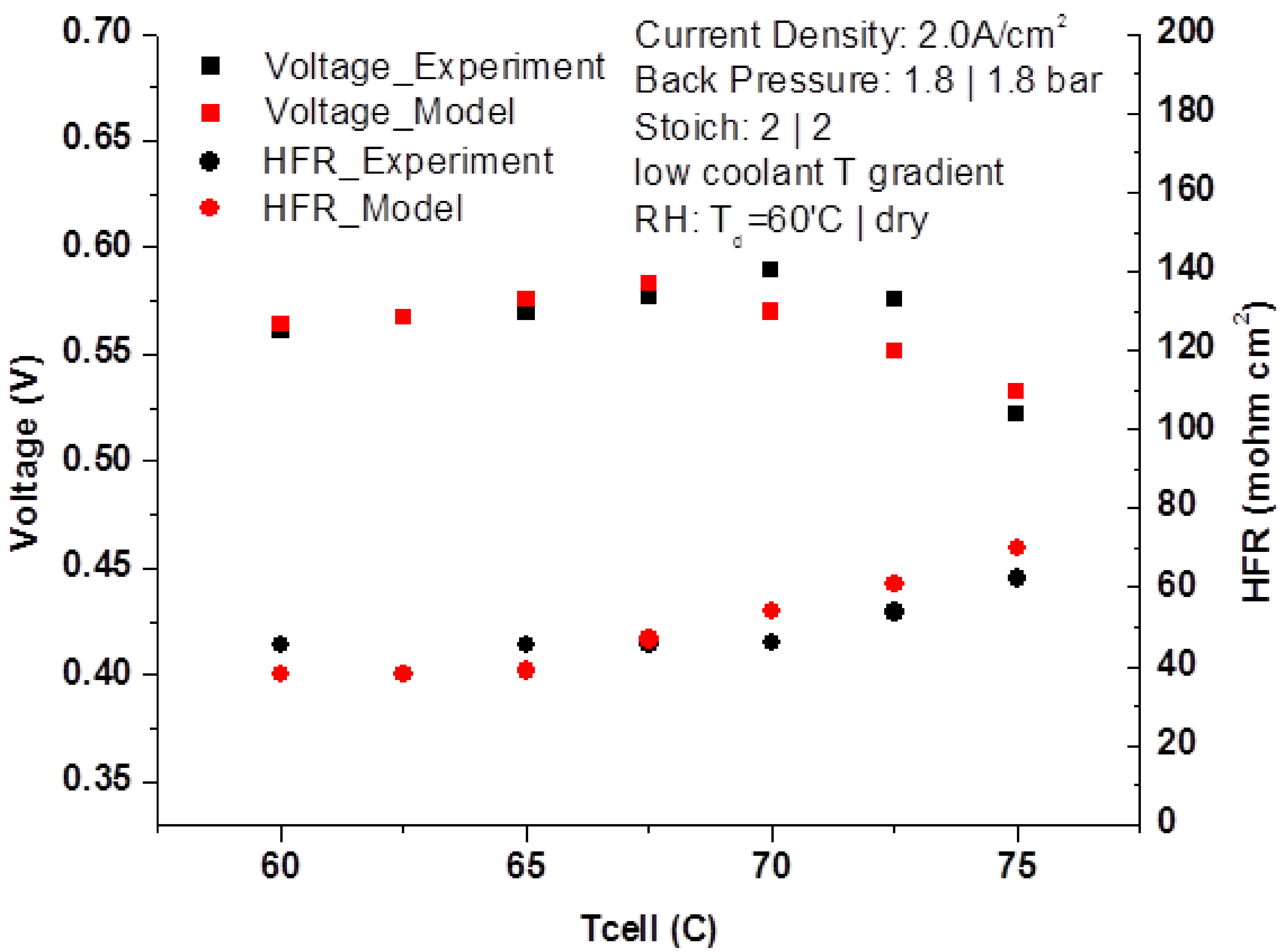


2D+1 model reduces computational efforts

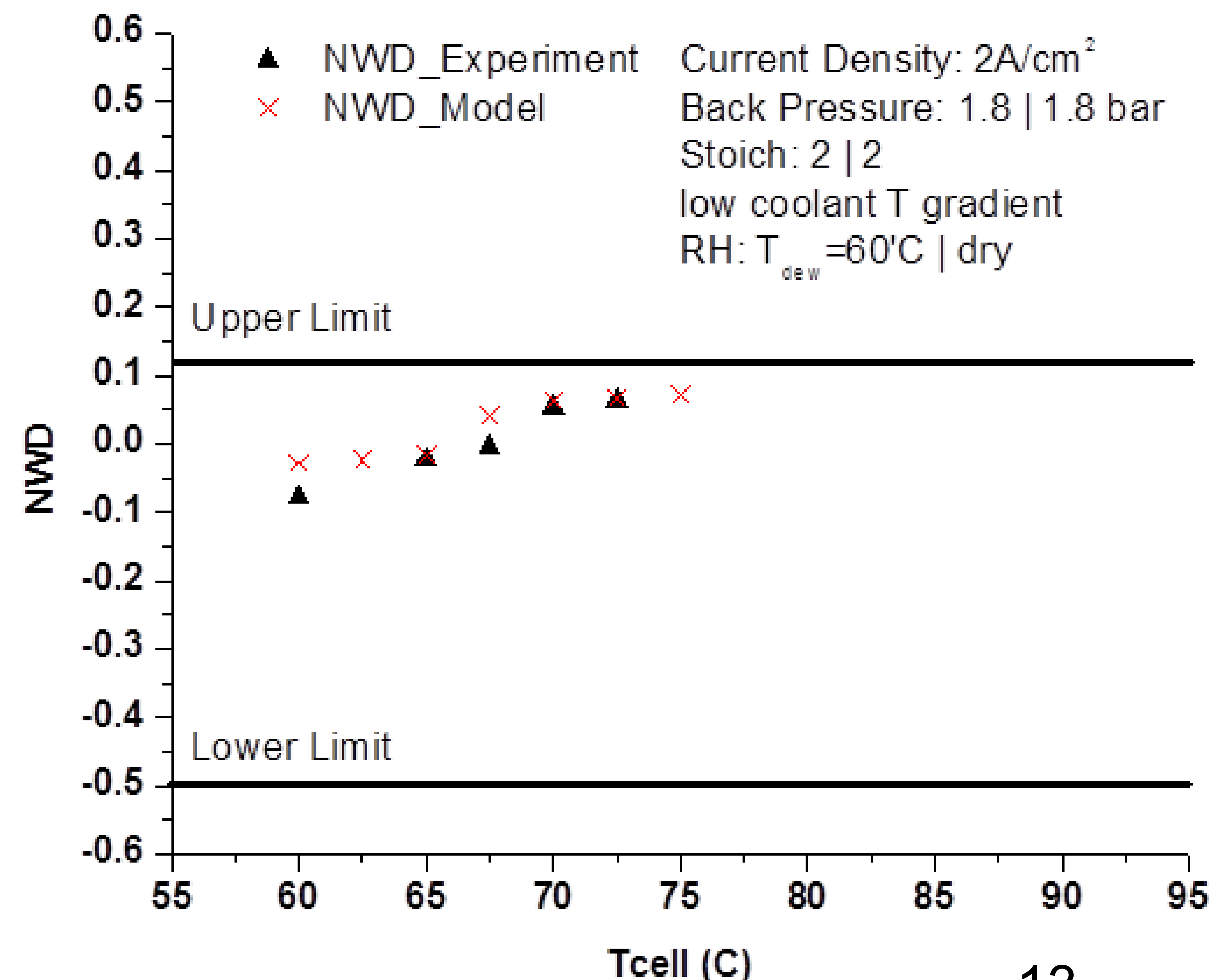
- No parameters vary in Y direction <u>inside</u> control volume.
- Species concentrations and T vary in Y direction along different control volumes.
- 2D model (XZ) is inferred by variations along Y and uses a fine mesh to predict local conditions accurately.

FC Modeling - Status

Model validation at high temperatures



- Net water drag measurements were used for accurate water transport model validation



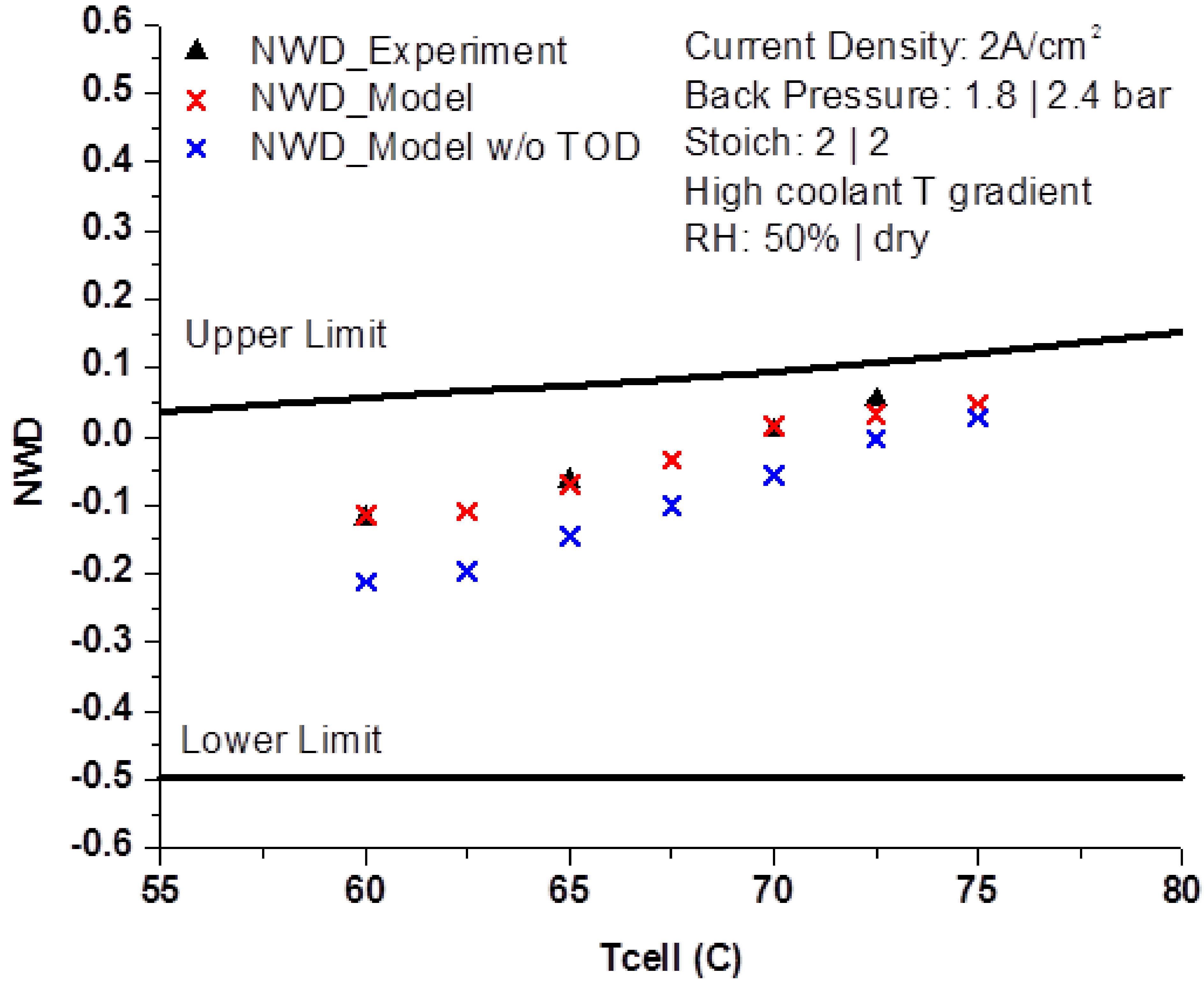
Model was successfully validated through a range of temperatures

NUVERA FUEL CELLS PENNSTATE THE UNIVERSITY of TENNESSEE UT

FC Modeling - Status

Thermo-osmosis in the membrane is the mode of temperature-driven water transport. Water flux was proportional to temperature difference and increases with average membrane temperature with the direction from cold to hot side. [1]

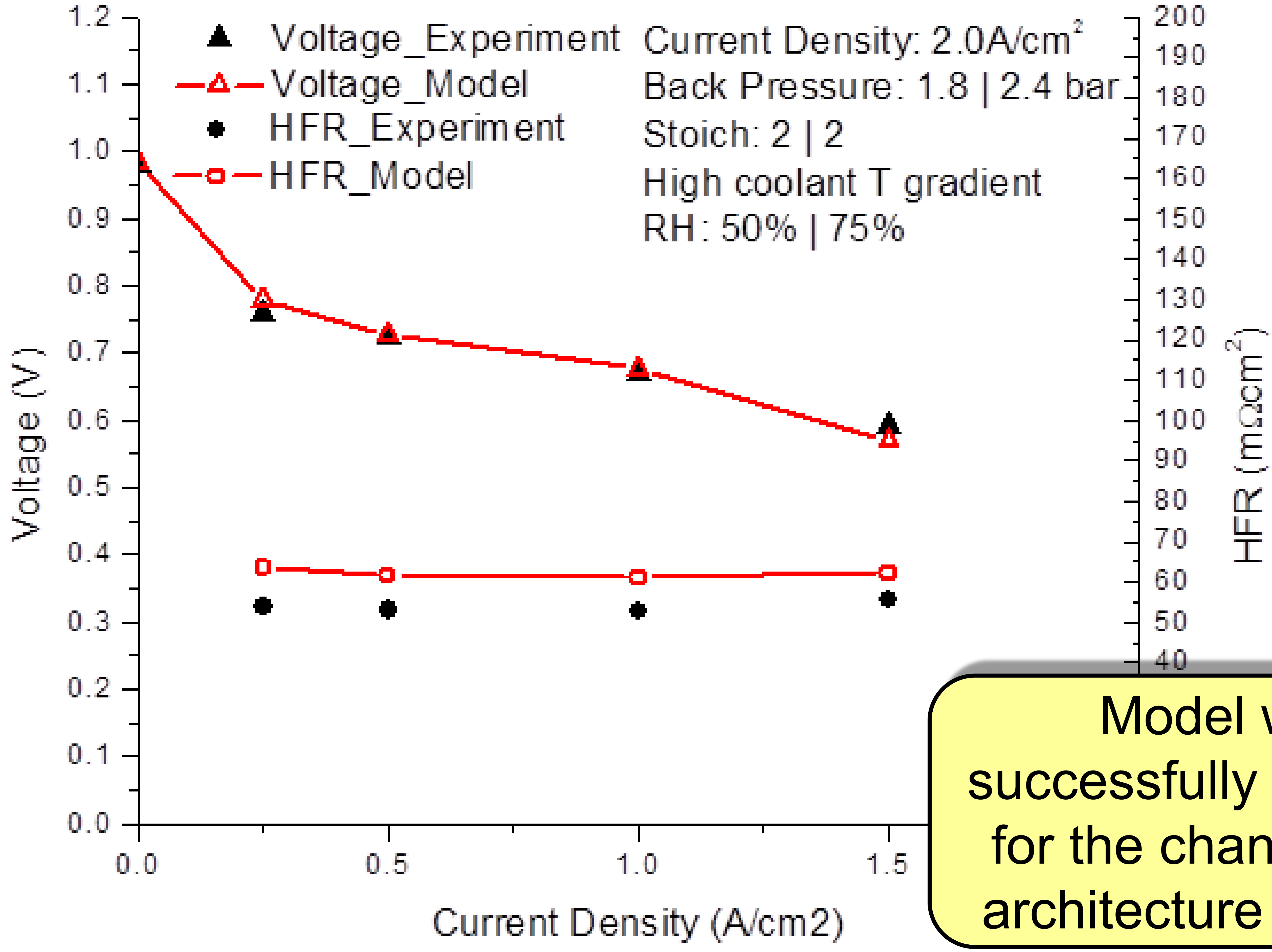
$$\vec{N}_{TOD} = -D_T \nabla T \quad mol/m^2 \cdot s \quad \text{where} \quad D_T = -\frac{1.66\times10^{-5}}{18\times10^{-3}} \exp\left(-\frac{2297}{T}\right) \frac{mol}{m\cdot s\cdot K}$$



1. Kim, S.; Mench, M. M., Investigation of temperature-driven water transport in polymer electrolyte fuel cell: Thermo-osmosis in membranes. *J Membrane Sci* **2009,** *328* (1-2), 113-120.

FC Modeling - Status

Model validation of channel/land architecture

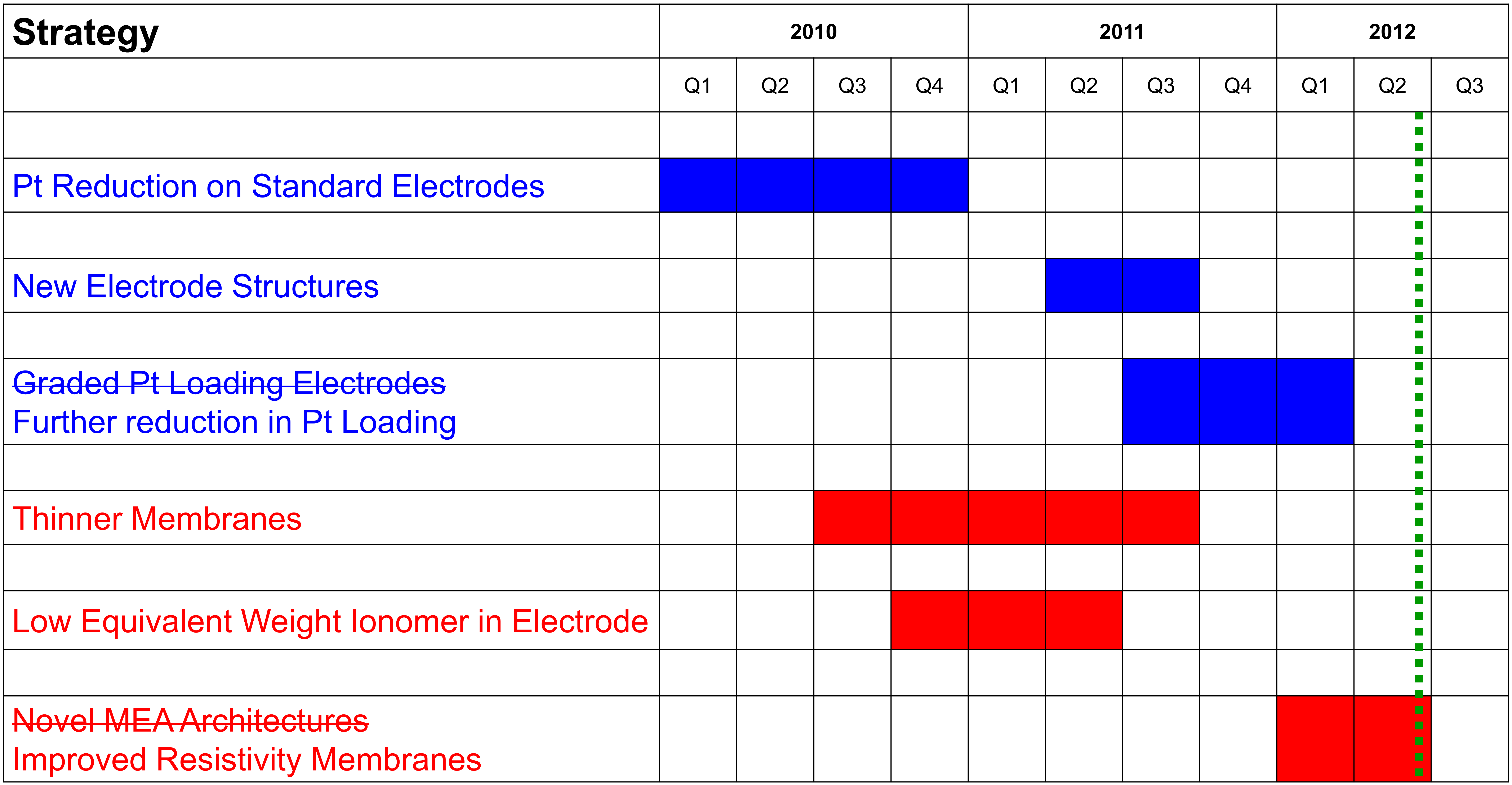


Model was successfully validated for the channel/land architecture at 90°C

NUVERA FUEL CELLS | PENNSTATE | THE UNIVERSITY of TENNESSEE

Materials Roadmap

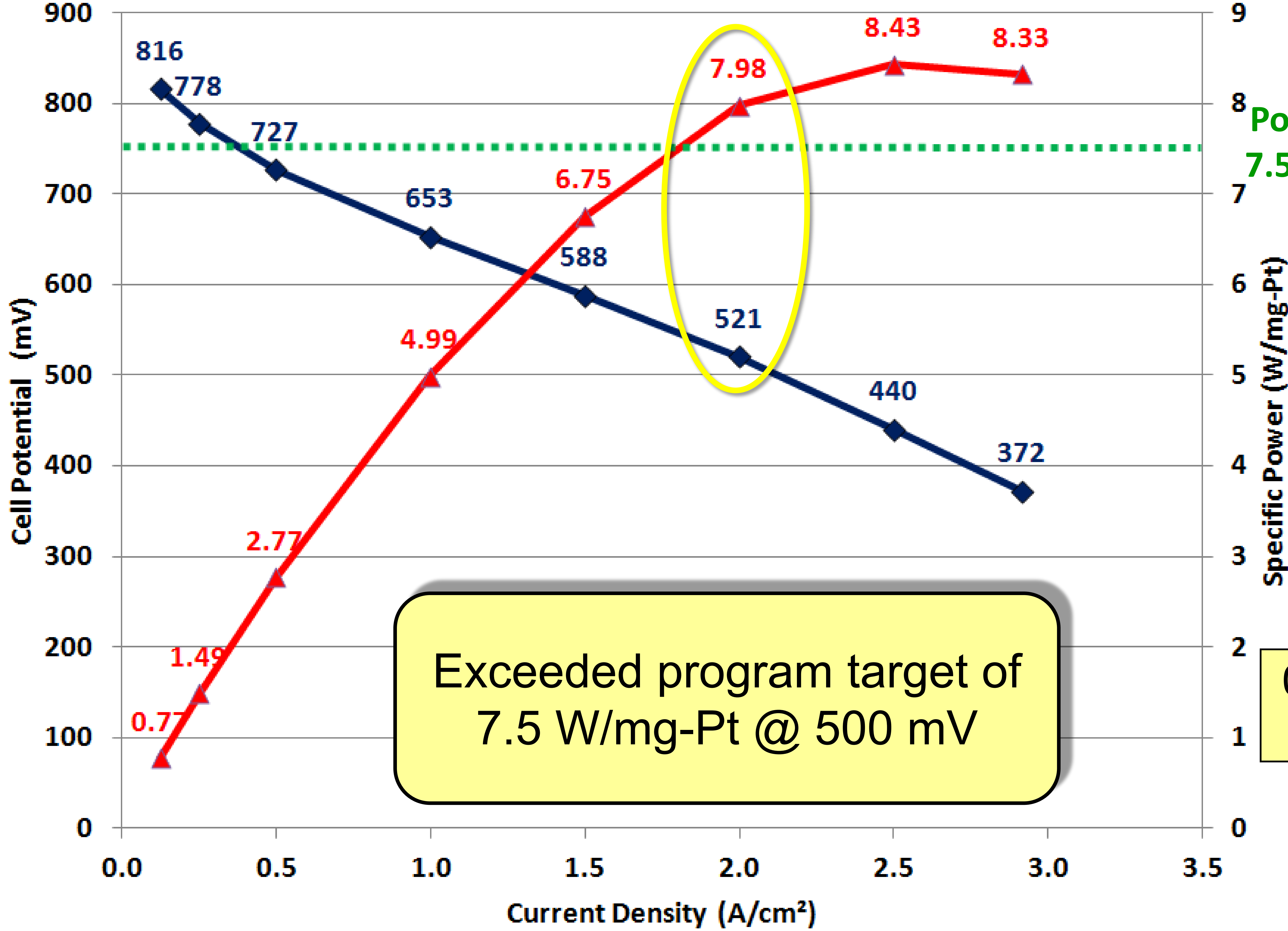
Material development aimed at reducing Pt loading and optimizing performance at high current densities is key to the success of the program



NUVERA FUEL CELLS JM Johnson Matthey Fuel Cells the power within

Materials Development Status

Demonstrated 7.98 W/mg-Pt at 521 mV on a 4 Cell Orion Stack



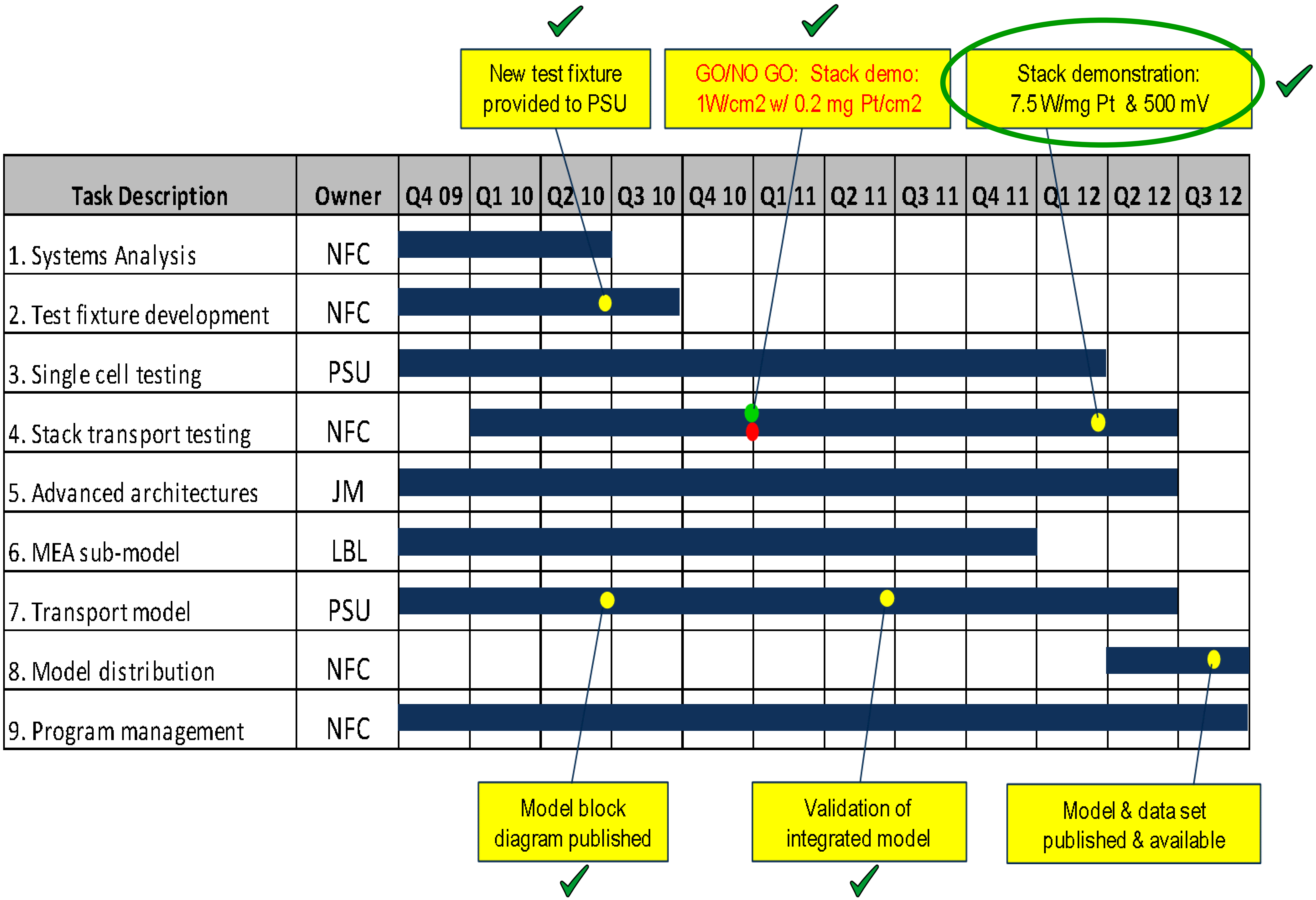
0.13 mg-Pt/cm2
Total Loading

T_{cell}= 60 °C, An 50% RH, Ca 0% RH, Press ~1.1 to 2.4 bara
MEA29 : JM MEA29, 0.025 mg Pt/cm² An, 0.106 mg Pt/cm² Ca
GDL: SGL 25BC

NUVERA FUEL CELLS
Johnson Matthey Fuel Cells
the power within

Plan and Milestones - Approach

The program is on schedule and the Go/No-Go milestone has been met



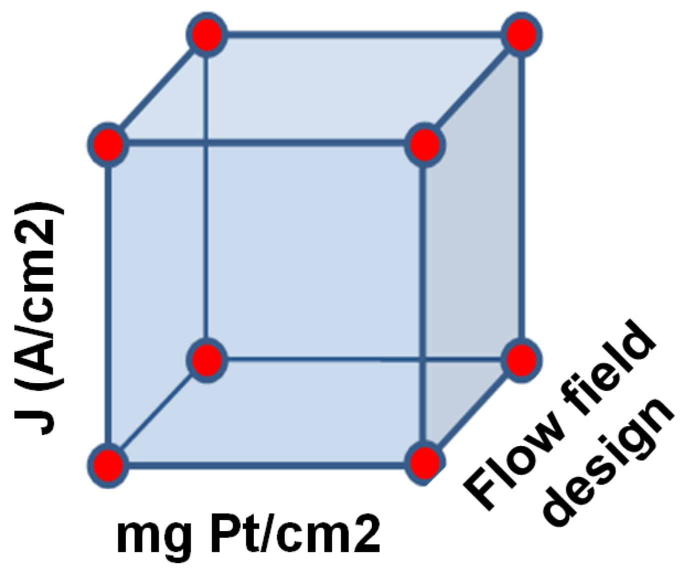
Future Work

Single cell testing

- Test new MEAs to support ongoing materials development
- Perform parametric studies to support model tuning and validation

Model development

- Tune and validate model for:
  - High Temperature Operation
  - Channel/Land architectures
  - Low Pt Loading MEA
- Publish Model and Dataset



Material development

- MEAs with improved resistivity will be produced and tested in 2012

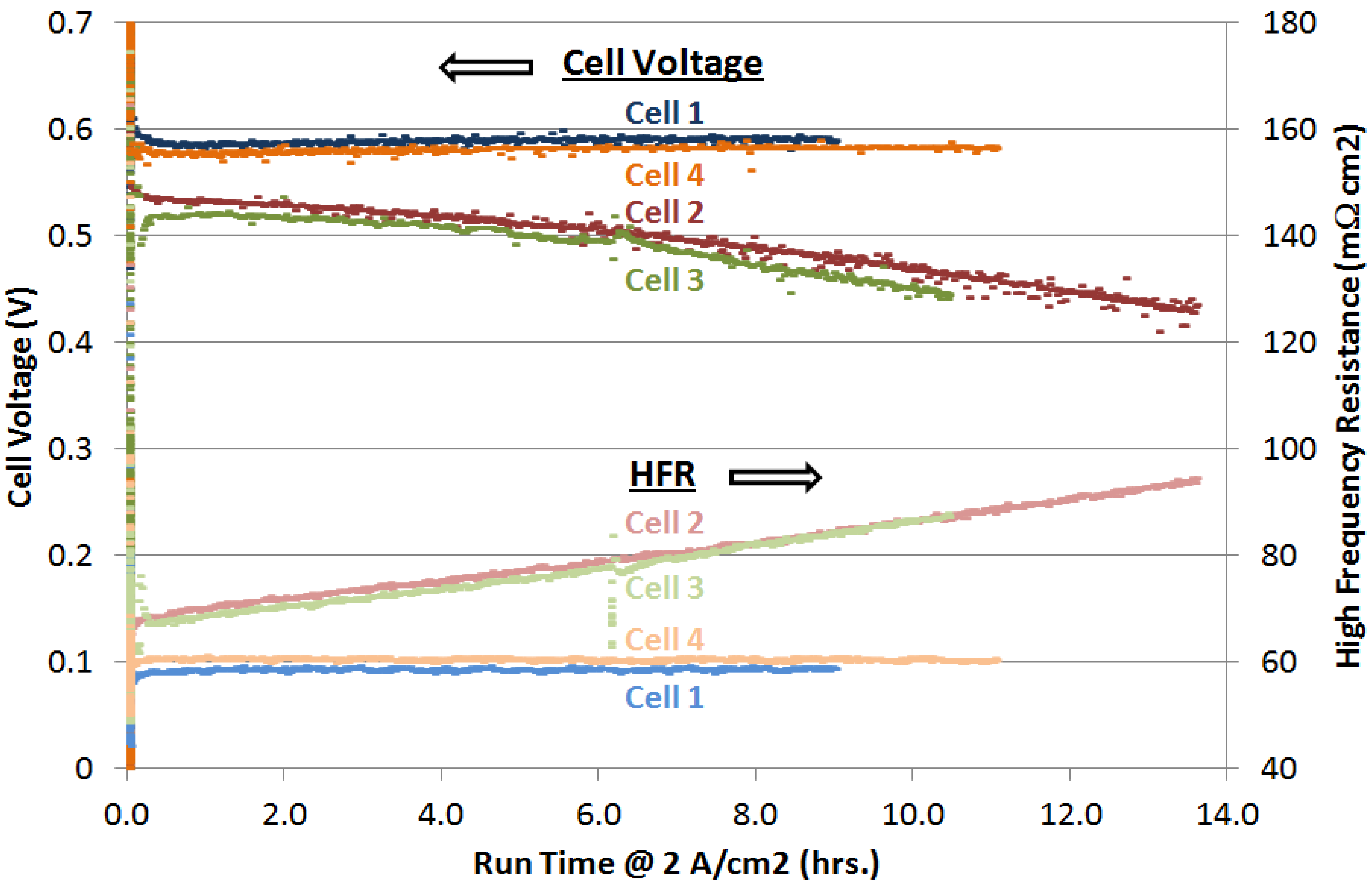
Summary

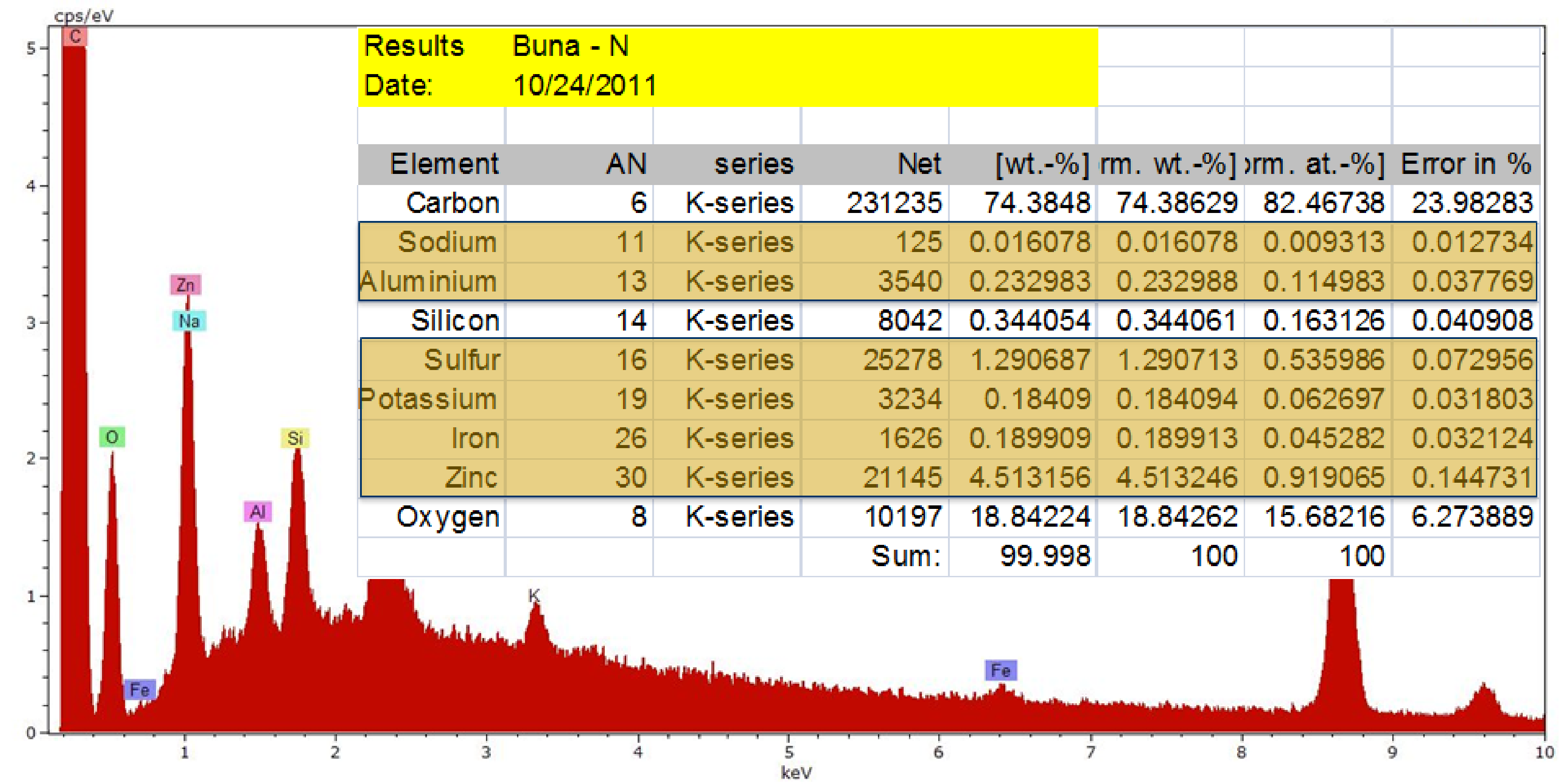
- The AURORA program plans to achieve DOE cost targets by using a combination of high current density with low Pt loadings.
  - 7.5 W/mgPt => $15/kW
- A model capable of predicting high current density operation in different architectures is the central deliverable of the program.
  - Model predictions have been used to drive materials development
  - Verification at high temperature is underway
- Material development aimed at reducing Pt loading and optimizing performance at high current densities is key to the success of the program.
  - 7.98 W/mg-Pt was demonstrated on a full format 4 Cell Orion Stack
- High temperature operation has been explored in both single cell and full format stack testing to address $Q/\Delta T_i$ requirements
  - Stable operation up to 90°C was demonstrated on a 64 cell stack using a cathode humidifier.

Technical Back-Up Slides

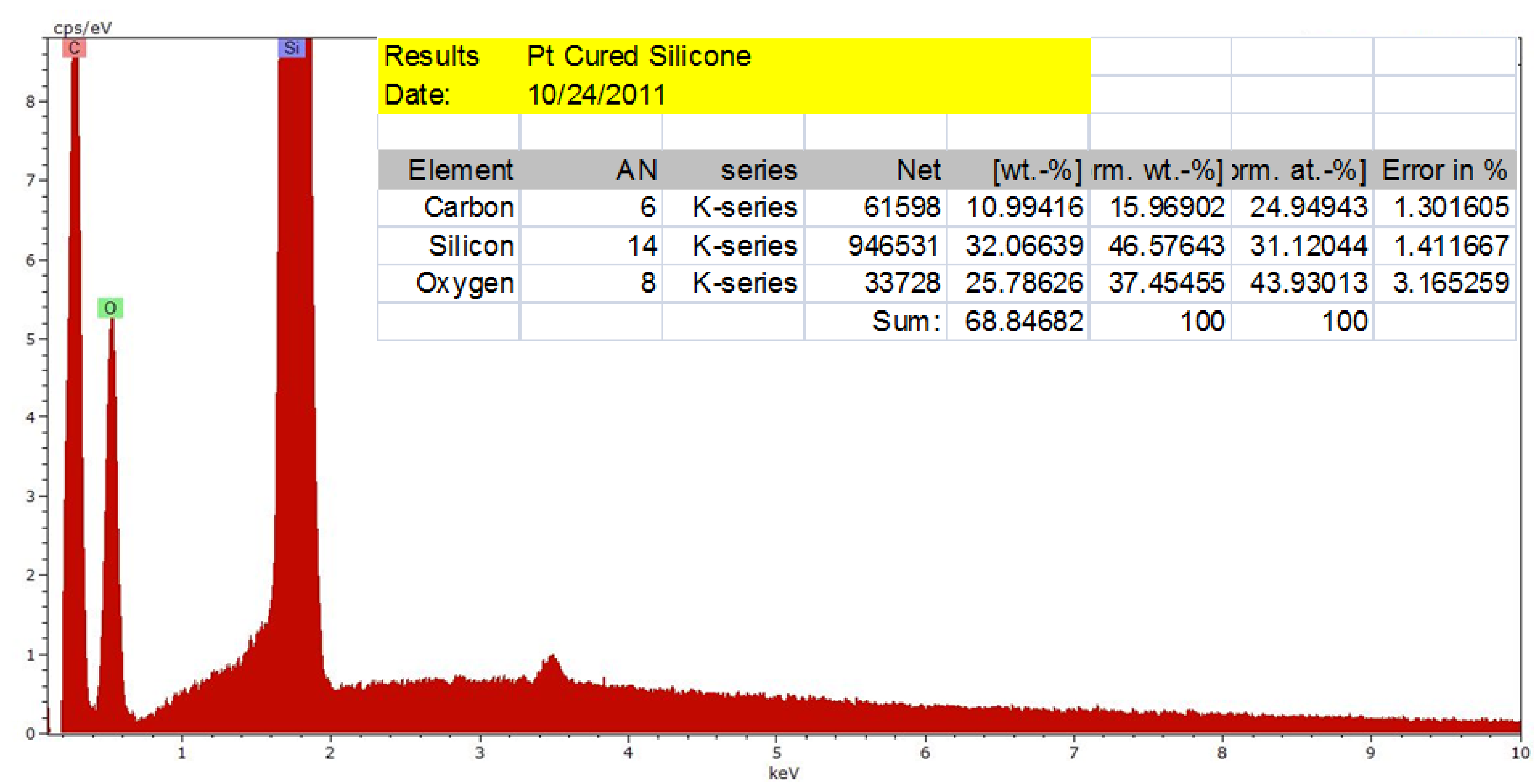
Single Cell Development

Gasket contamination problem was identified and solved.





Results	Buna - N						
Date:	10/24/2011						
Element	AN	series	Net	[wt.-%]	rm. wt.-%]	ɔrm. at.-%]	Error in %
Carbon	6	K-series	231235	74.3848	74.38629	82.46738	23.98283
Sodium	11	K-series	125	0.016078	0.016078	0.009313	0.012734
Aluminium	13	K-series	3540	0.232983	0.232988	0.114983	0.037769
Silicon	14	K-series	8042	0.344054	0.344061	0.163126	0.040908
Sulfur	16	K-series	25278	1.290687	1.290713	0.535986	0.072956
Potassium	19	K-series	3234	0.18409	0.184094	0.062697	0.031803
Iron	26	K-series	1626	0.189909	0.189913	0.045282	0.032124
Zinc	30	K-series	21145	4.513156	4.513246	0.919065	0.144731
Oxygen	8	K-series	10197	18.84224	18.84262	15.68216	6.273889
			Sum:	99.998	100	100	



Results	Pt Cured Silicone						
Date:	10/24/2011						
Element	AN	series	Net	[wt.-%]	rm. wt.-%]	ɔrm. at.-%]	Error in %
Carbon	6	K-series	61598	10.99416	15.96902	24.94943	1.301605
Silicon	14	K-series	946531	32.06639	46.57643	31.12044	1.411667
Oxygen	8	K-series	33728	25.78626	37.45455	43.93013	3.165259
			Sum:	68.84682	100	100	

- Zn contamination from the gasket caused excessive degradation.
- Problem was solved by changing gasket material.

NUVERA FUEL CELLS

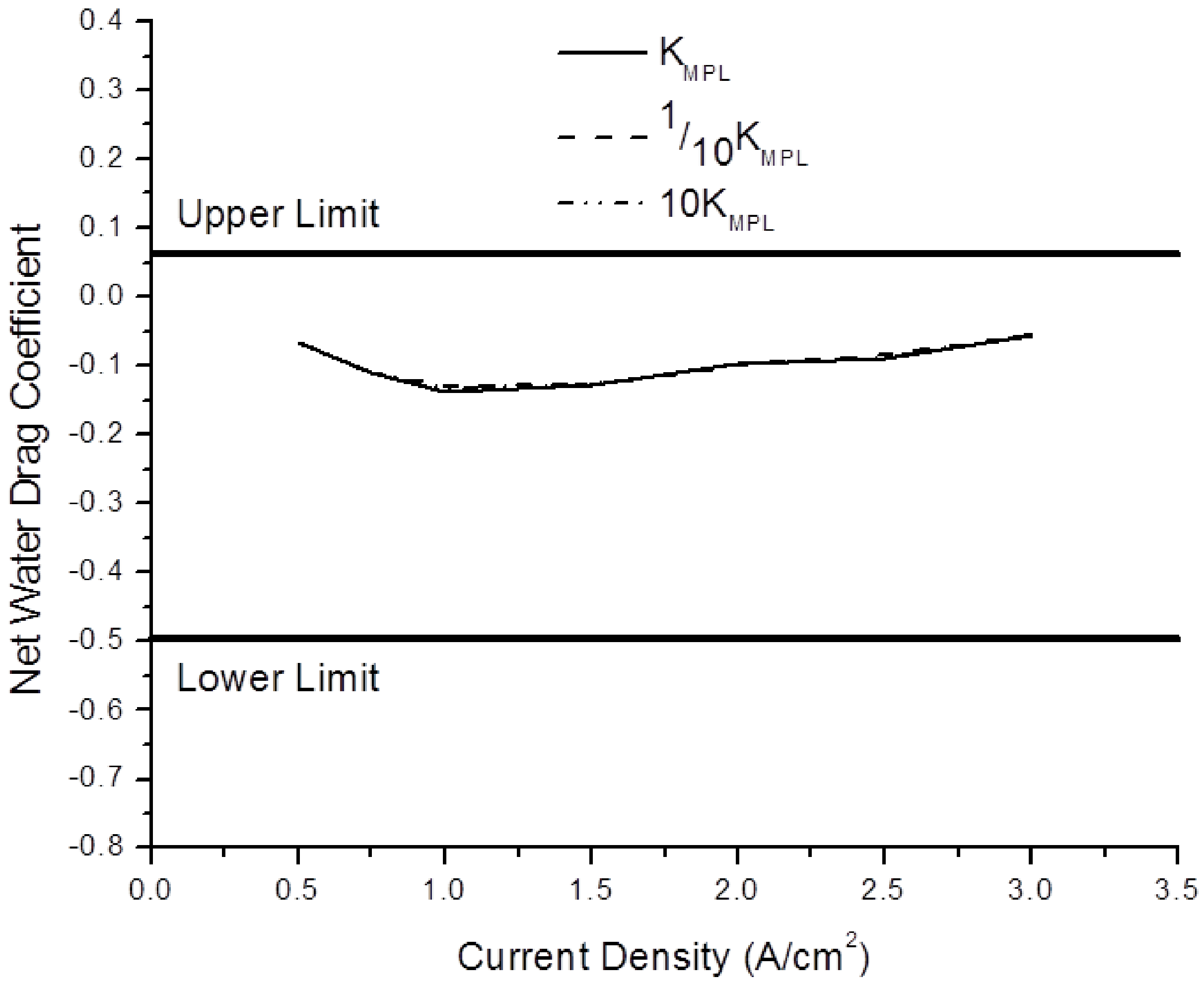
FC Modeling - Status

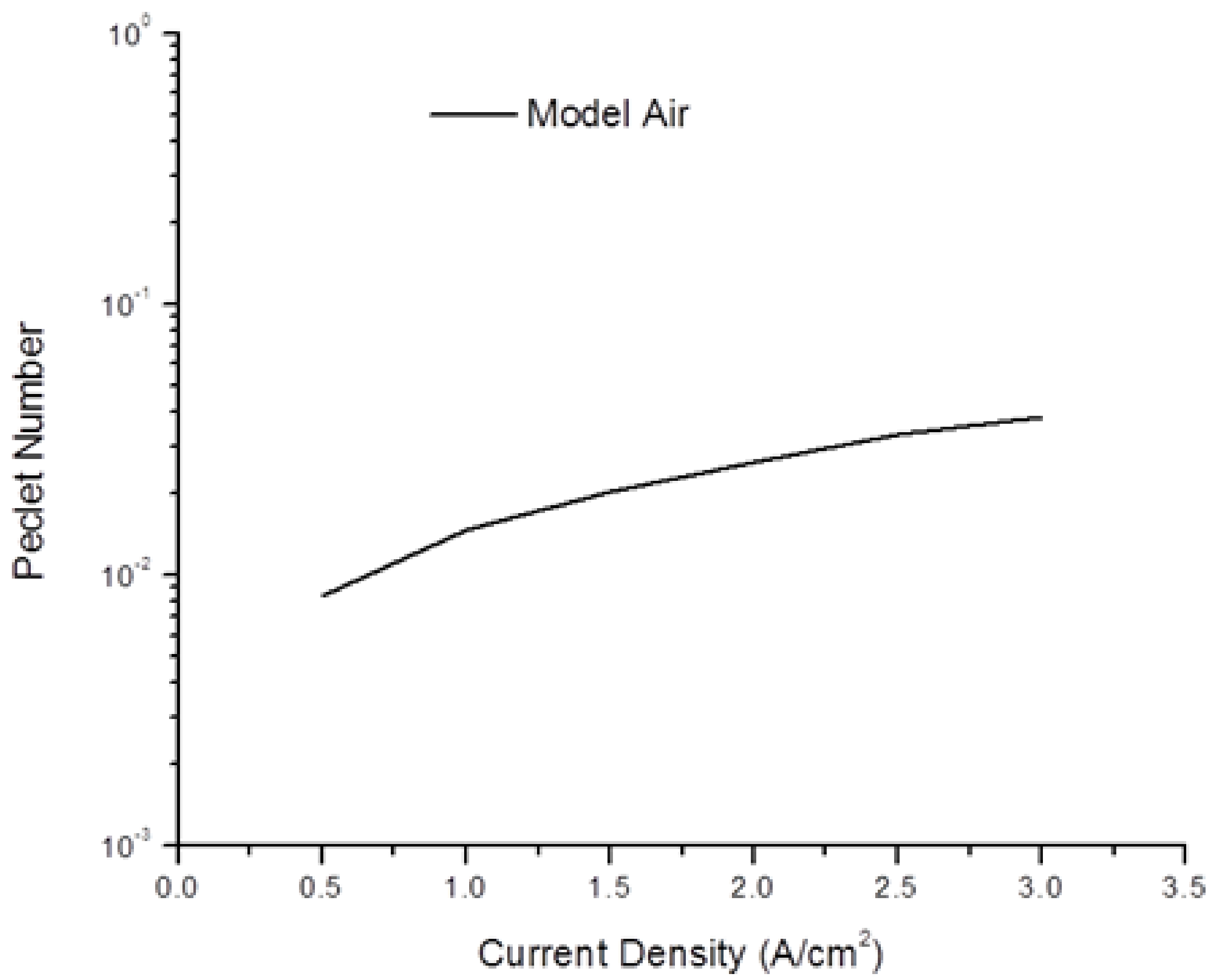
Study to determine the dominant water transport mechanism.

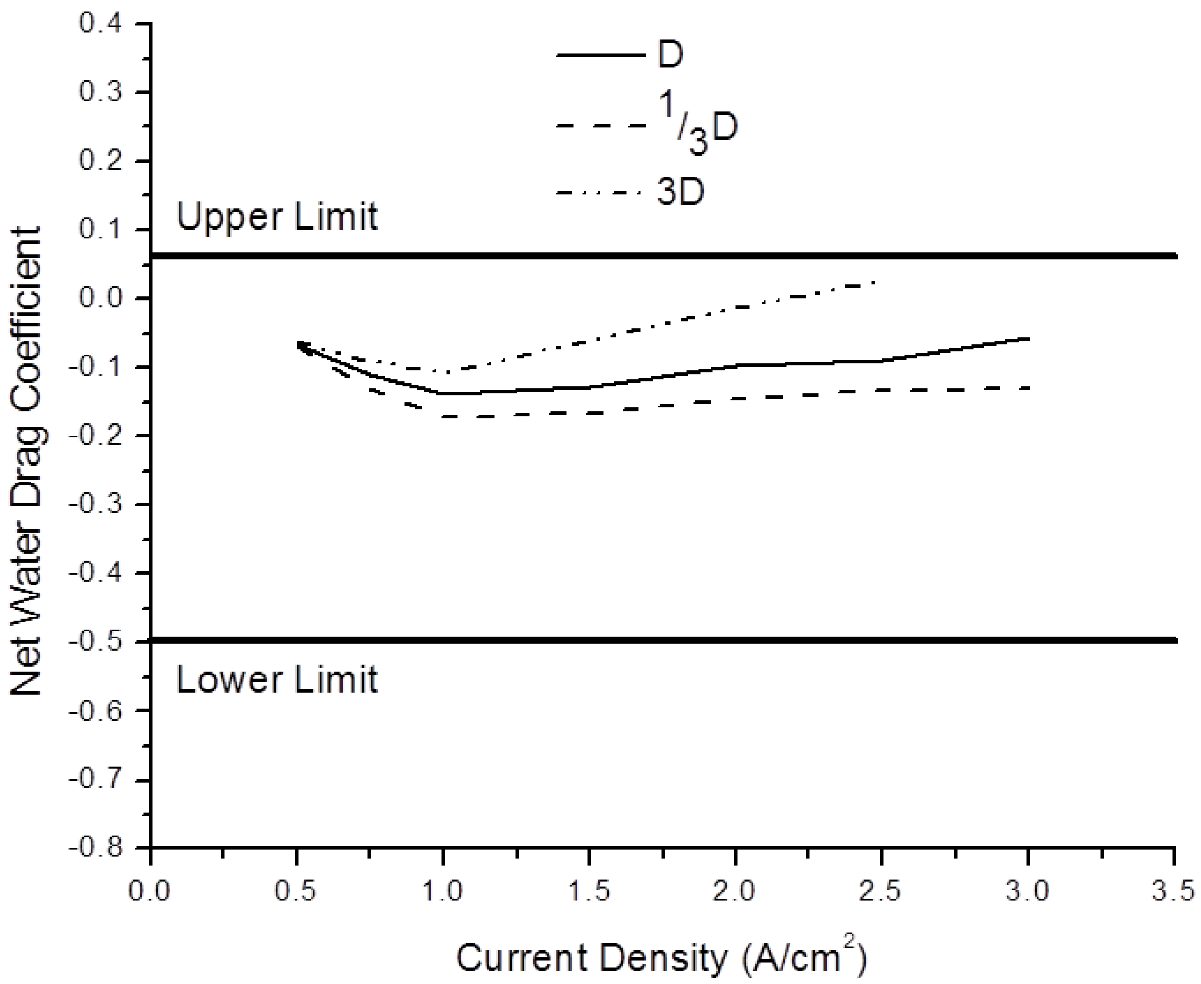
Since MPL is the most restrictive component for liquid water, the parametric study on MPL permeability is conducted to determine whether capillary flow is dominating. As observed, the order of magnitude change in MPL permeability has minimal impact on net water transport, therefore the capillary flow is considered insignificant compared to gas phase transport.

The non-dimensional Peclet Number is used to measure the relative importance of convective to diffusive flow. Even though Pe increases with current density, it is orders of magnitude lower than unity, indicating convective flux is insignificant compared to diffusive flux.

Net water balance is very sensitive to changes in water vapor diffusion coefficient, confirming the dominating role of diffusive flow in water transport in porous media.







Diffusive flow was found to be the dominating water transport mechanism

NUVERA FUEL CELLS PENNSTATE THE UNIVERSITY of TENNESSEE

FC Modeling - Status

High temperature modeling approach

In order to meet system requirement

3

RH=50% constant
high ΔT
BP 1.8 | 1.8
dry cathode

In order to reach stable performance at higher temperature

2

RH=50% constant
low ΔT
BP 1.8 | 1.8
dry cathode

4

RH=50% constant
high ΔT
BP 1.8 | 2.4
dry cathode

1

T_{dew}=60°C constant
low ΔT
BP 1.8 | 1.8
dry cathode

<u>Summary of Experimentally-Observed Limiting Temperature</u>

1. Dry cathode, Anode T_d=60°C , low ΔT, BP 1.8 | 1.8: up to 72.5°C
2. Dry cathode, Anode RH=53%, low ΔT, BP 1.8 | 1.8 : up to 75°C
3. Dry cathode, Anode RH=53%, high ΔT, BP 1.8 | 1.8: up to 65°C
4. Dry cathode, Anode RH=53%, high ΔT, BP 1.8 | 2.4 : up to 75°C
5. RH_{cath}=53%, Anode RH=53%, high ΔT, BP 1.8 | 2.4: up to 87.5°C

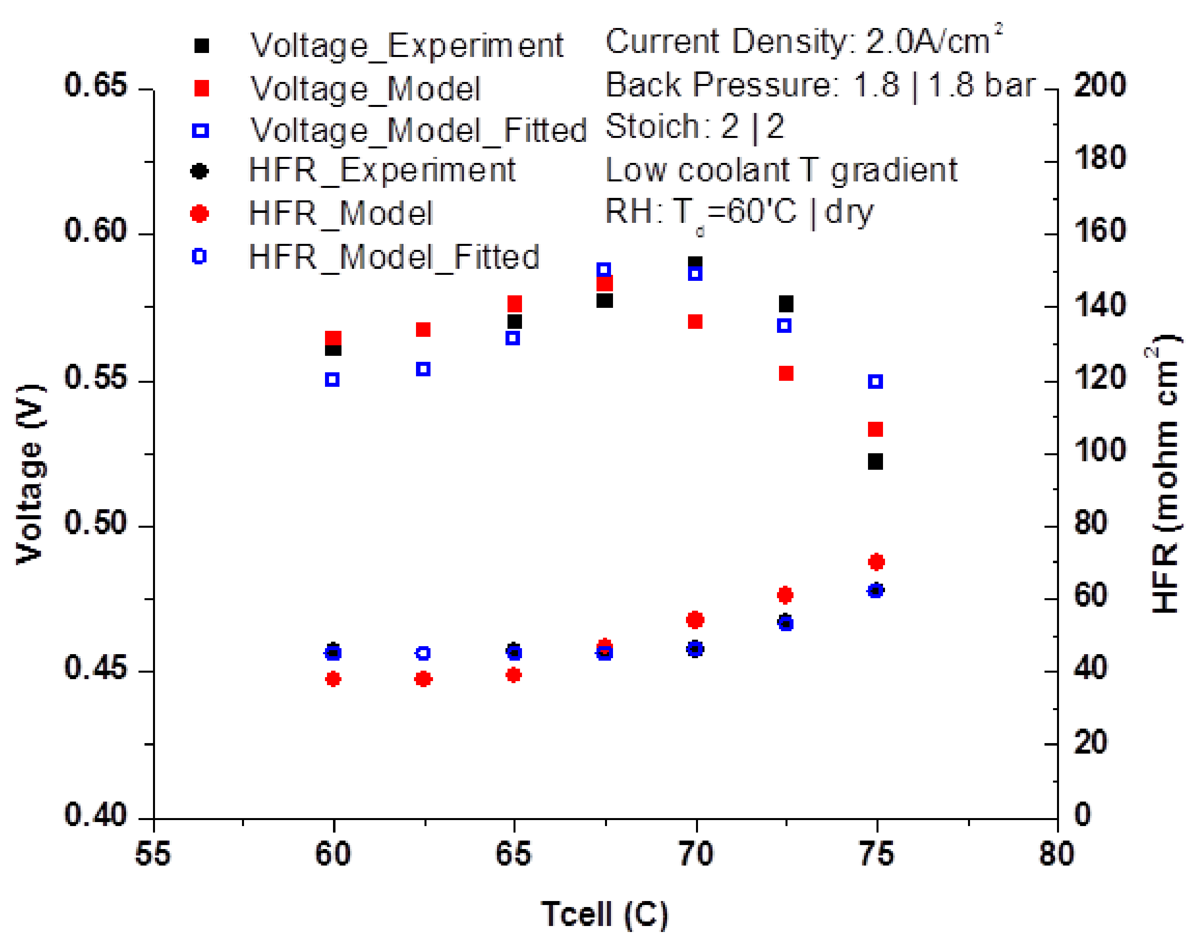
5

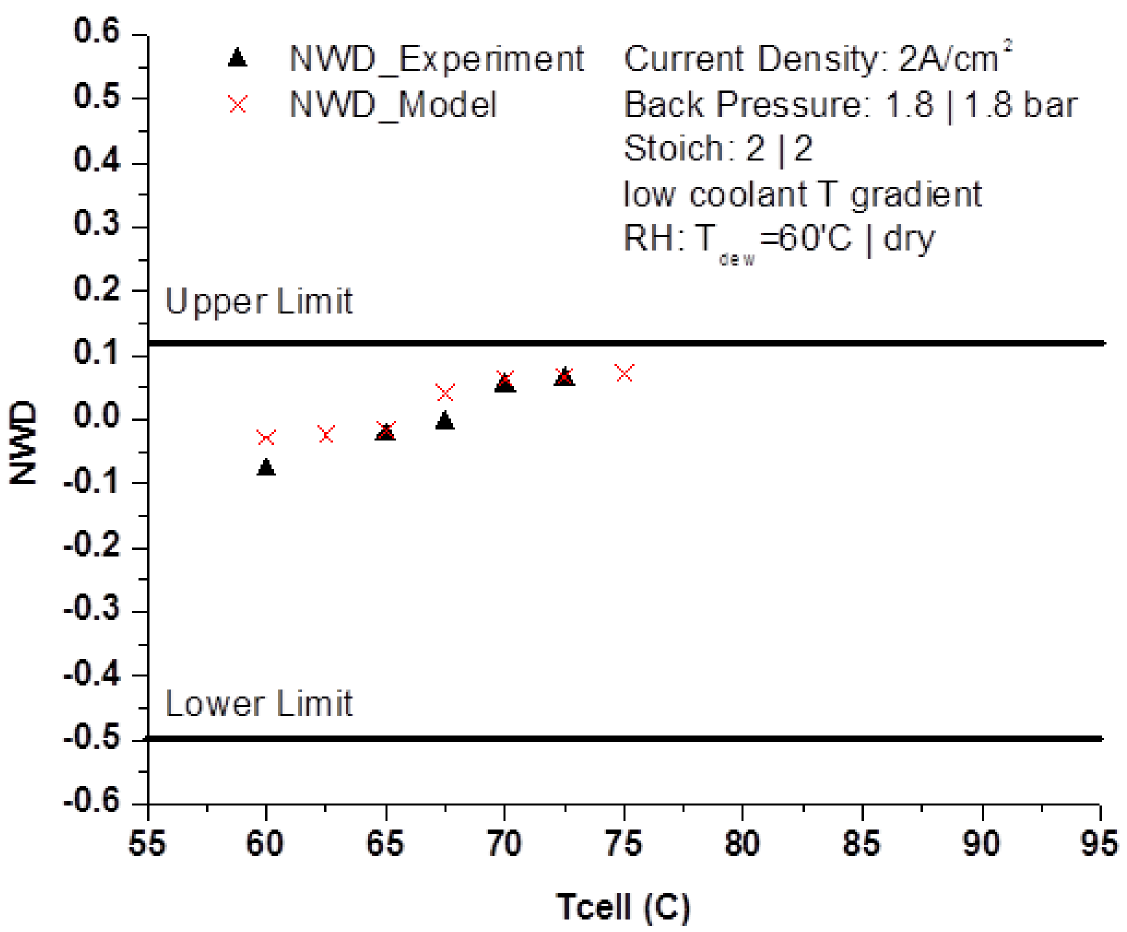
RH=50% constant
high ΔT
BP 1.8 | 2.4
cathode RH=50%

FC Modeling - Status

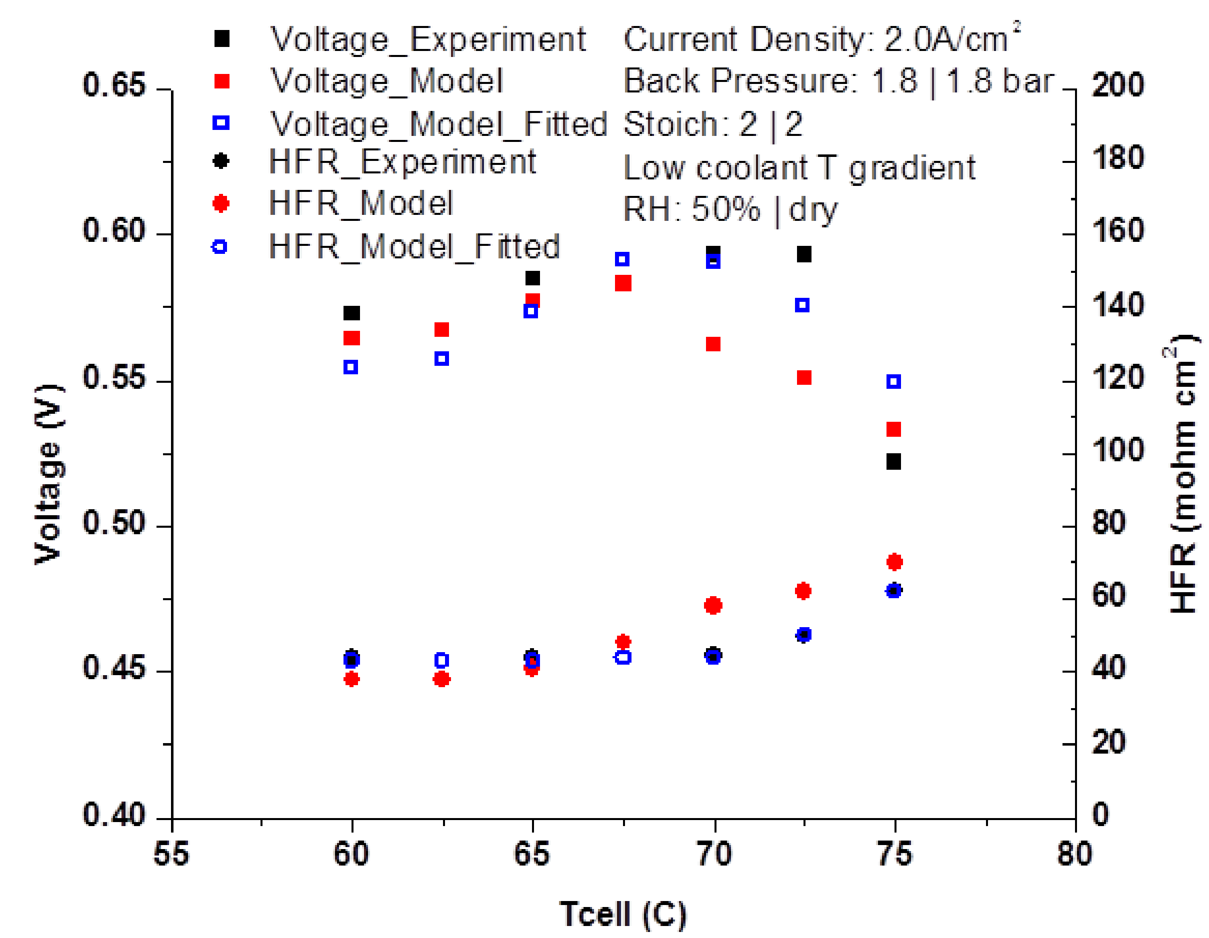
High temperature model tuning and validation preliminary results

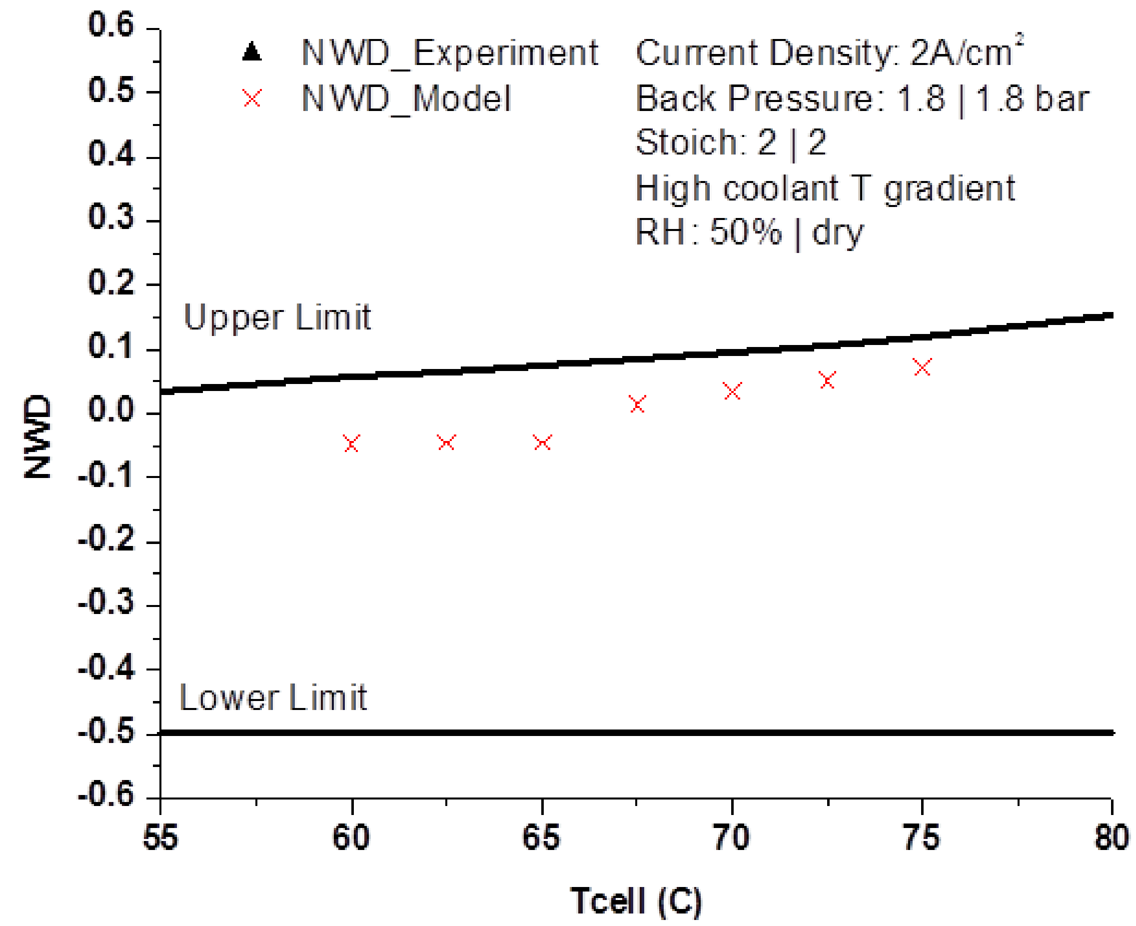
Condition 1:



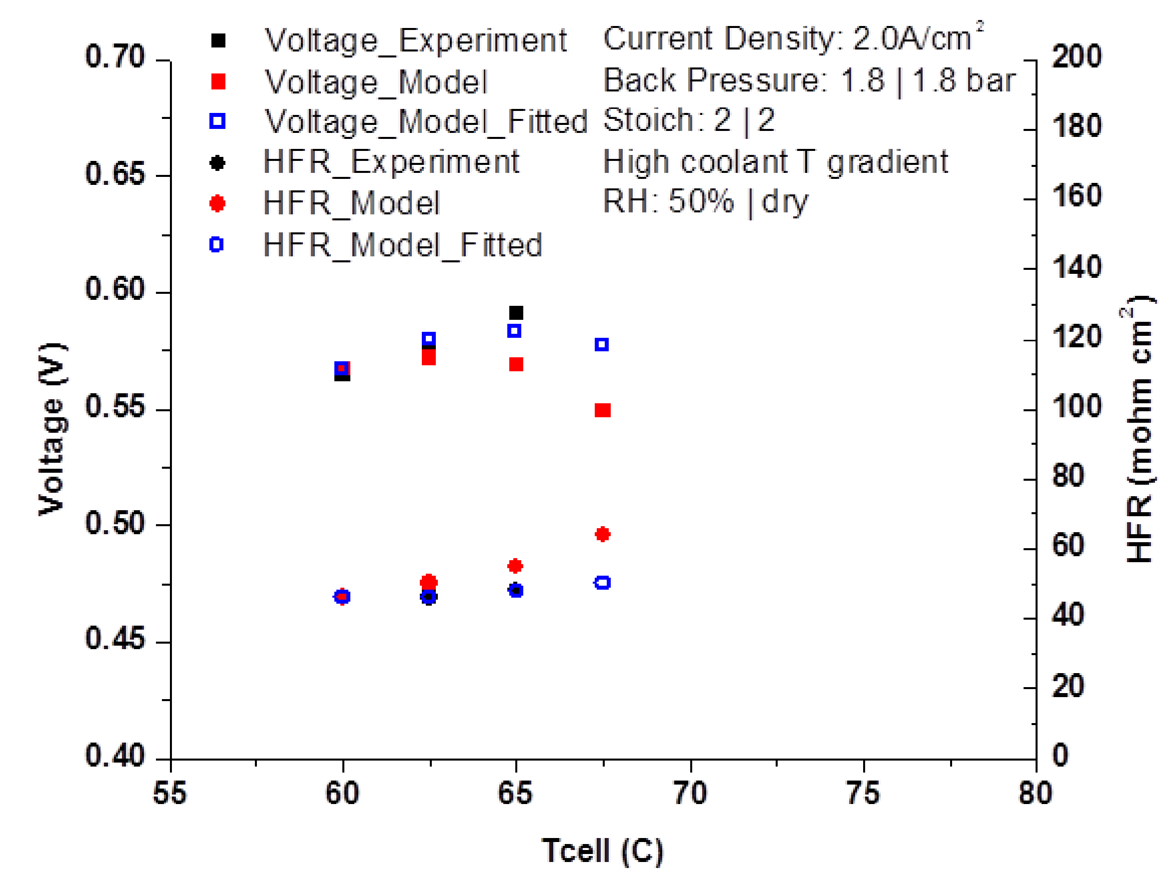


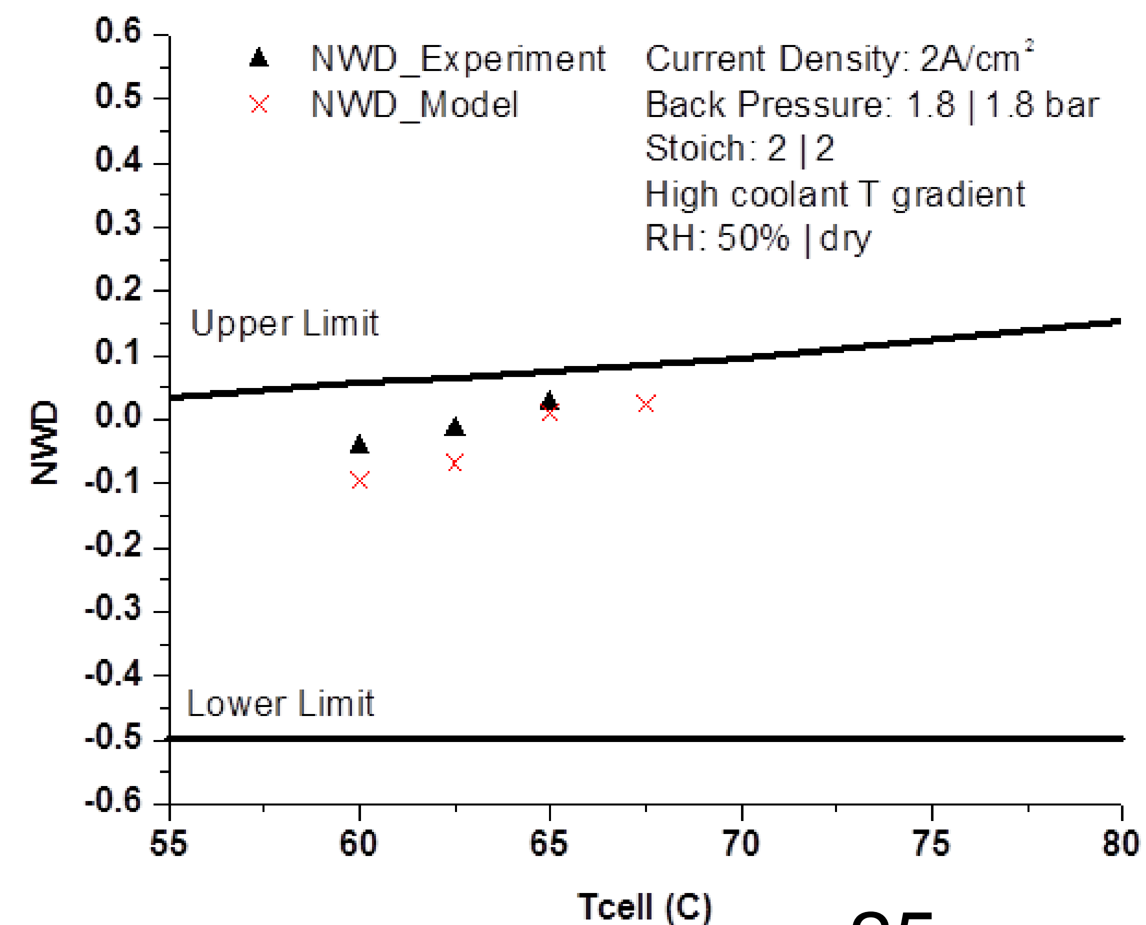
Condition 2:





Condition 3:

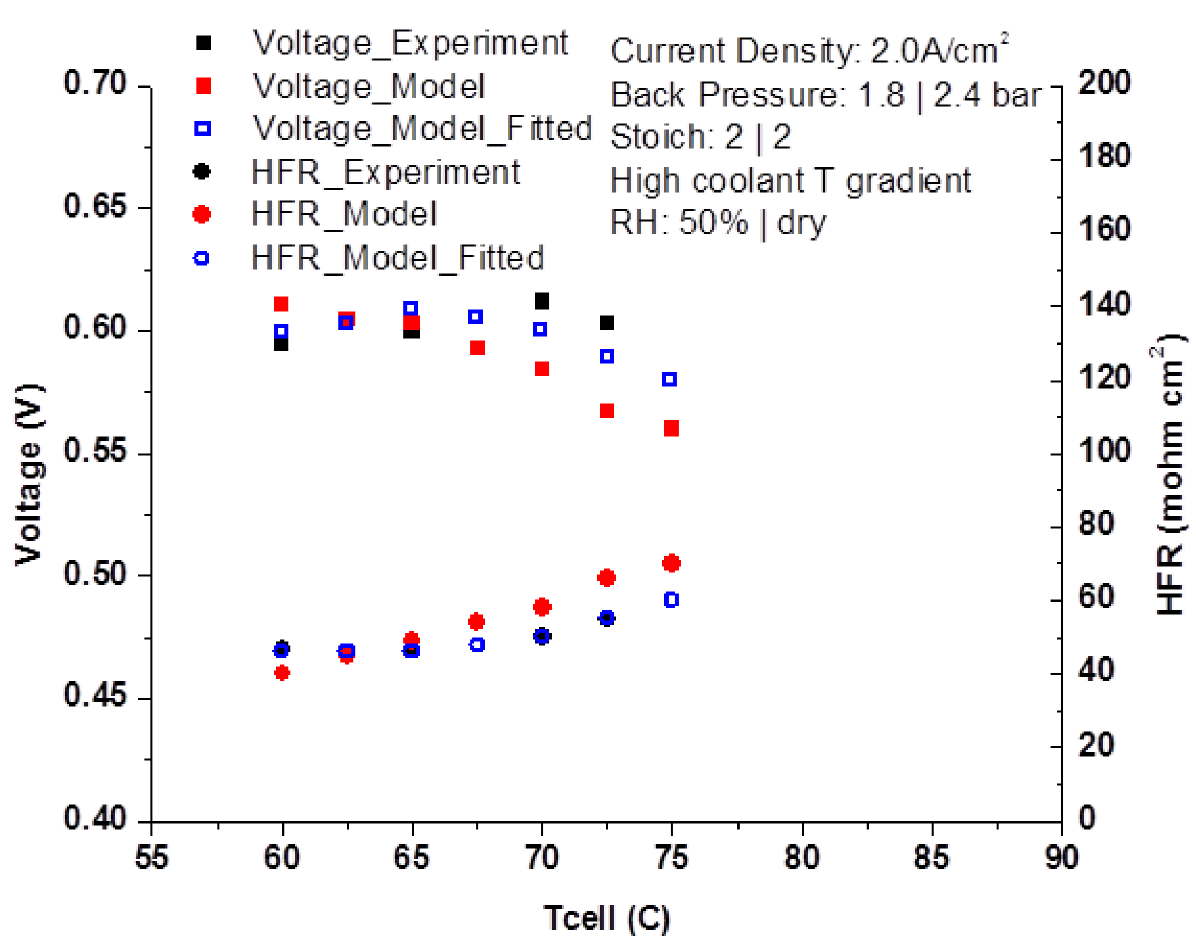


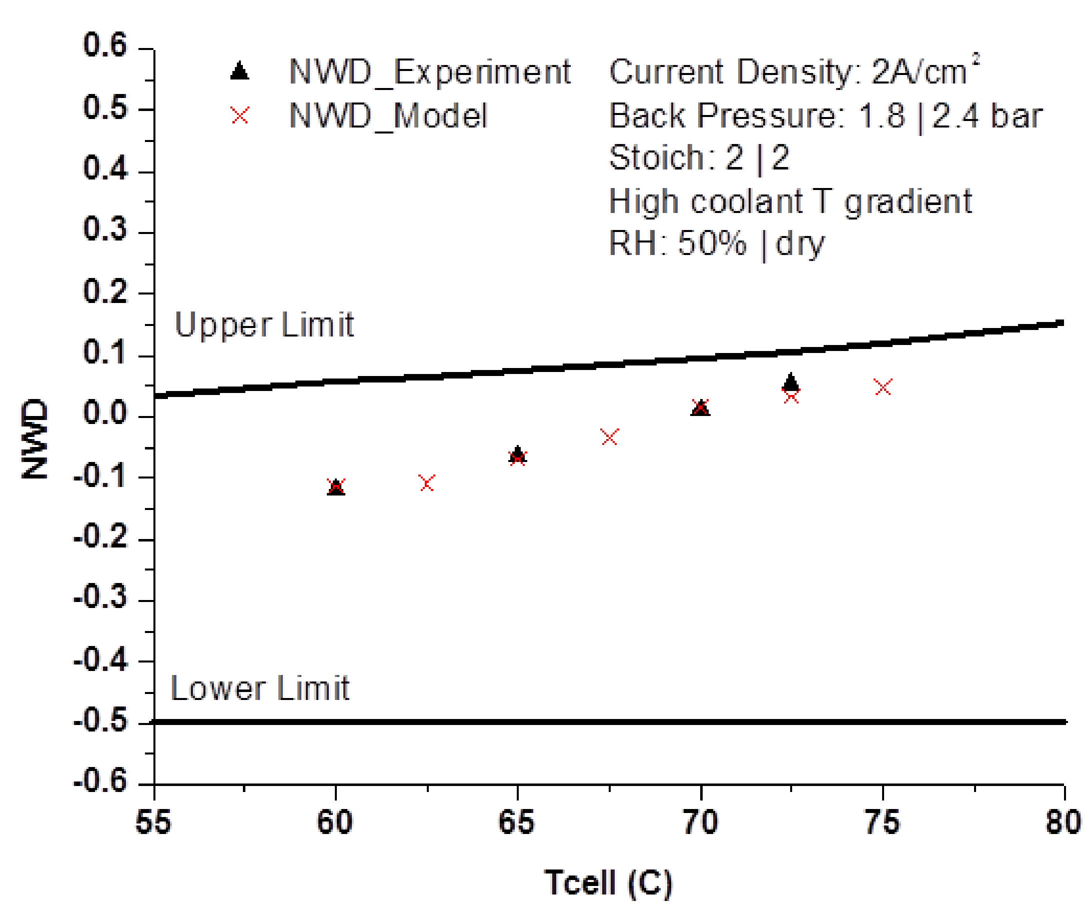


FC Modeling - Status

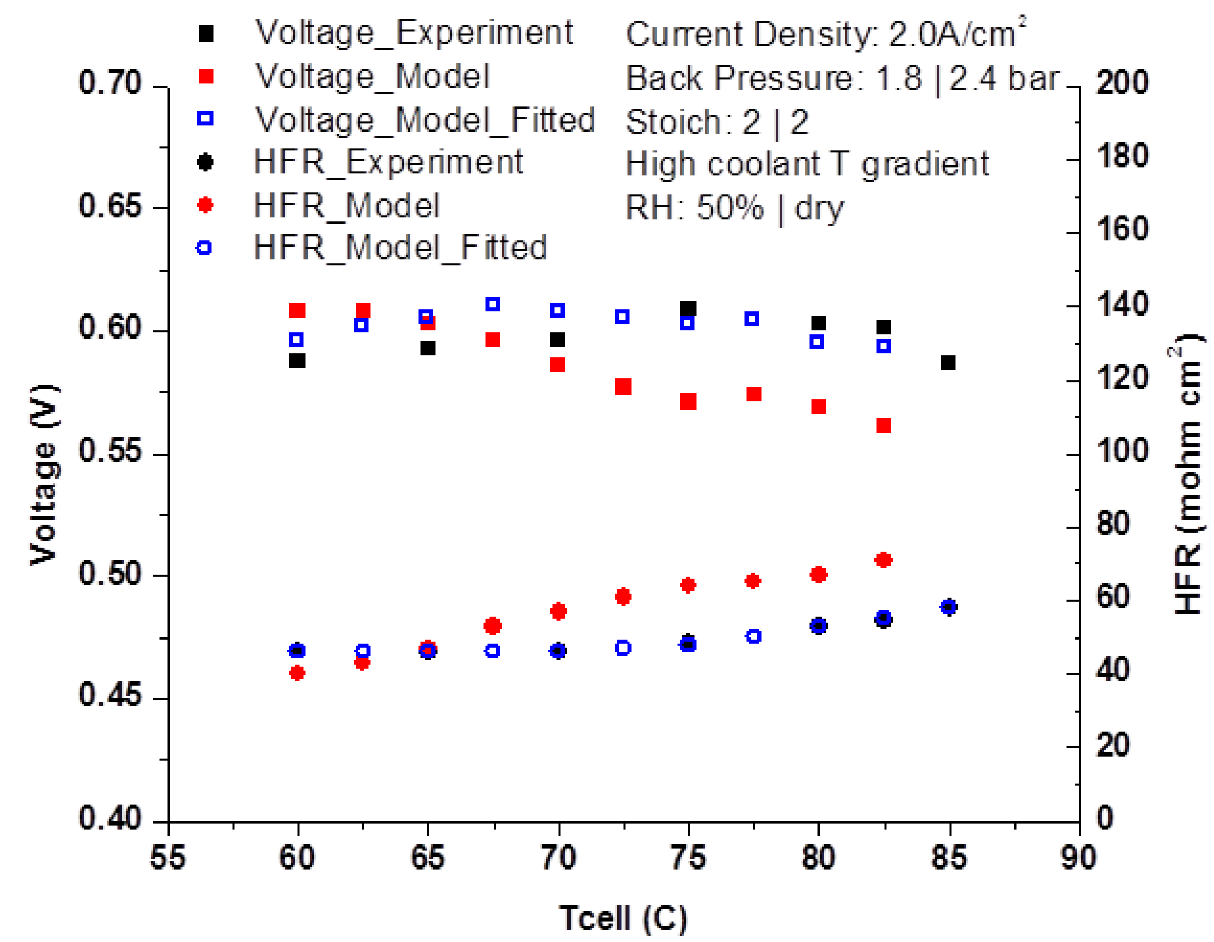
High temperature model tuning and validation preliminary results

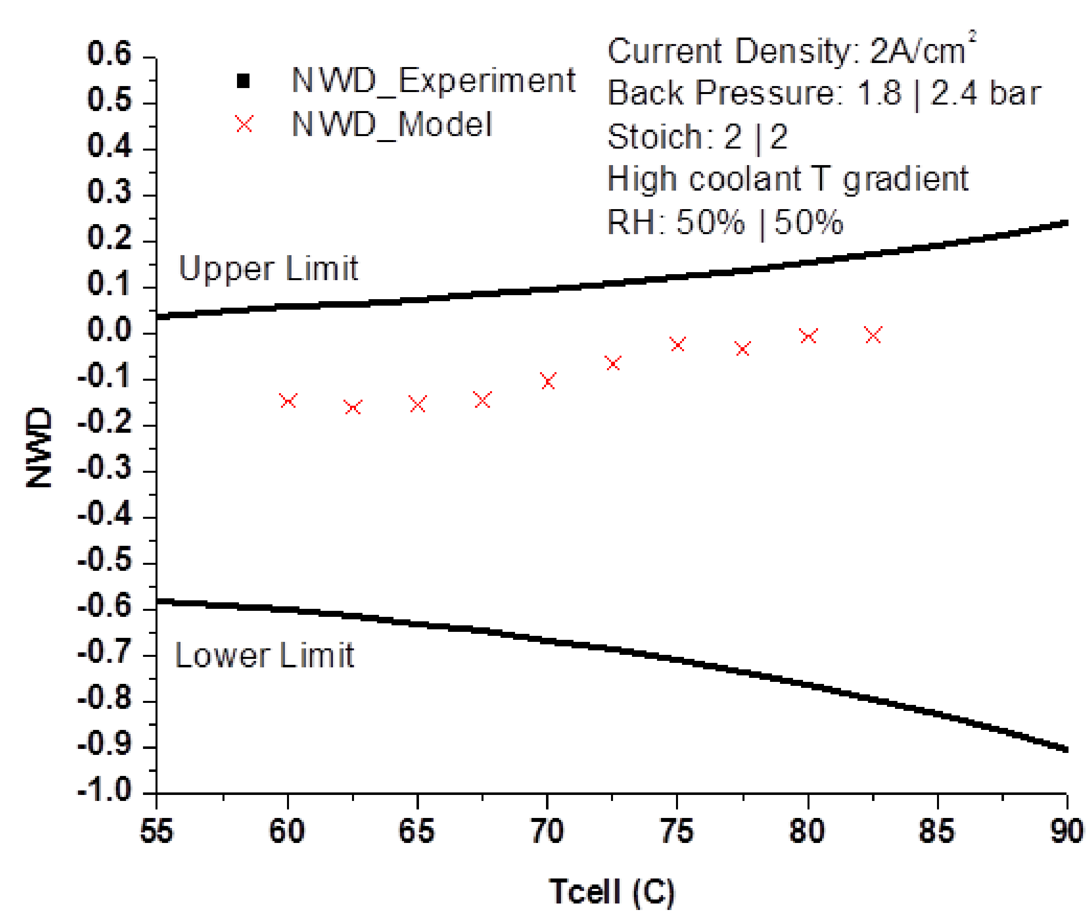
Condition 4:





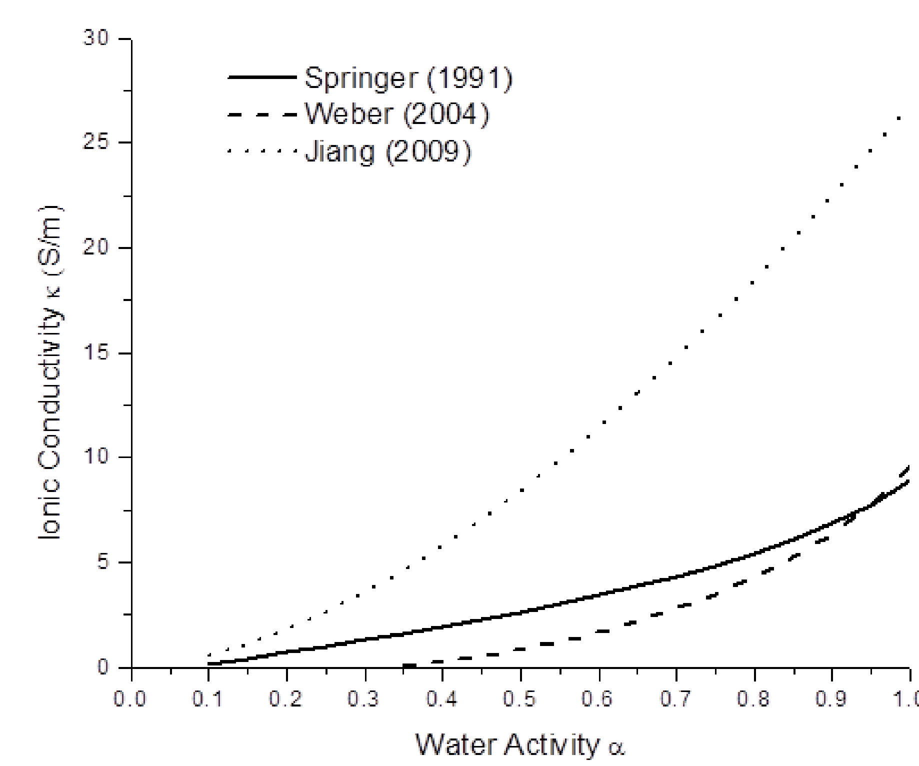
Condition 5:





Discrepancies between the model and experimental data (HFR and performance) is believed to be caused by the ionic conductivity correlation. Several common correlations have been tried but none of them are consistent with the experimental results.

	Mathematical Description
Springer	$\kappa = (0.5139\lambda - 0.326)\exp\left[\frac{10500}{R}\left(\frac{1}{303} - \frac{1}{T}\right)\right]$
Weber	$\kappa = 50(f - 0.06)^{1.5}\exp\left[\frac{15000}{R}\left(\frac{1}{303} - \frac{1}{T}\right)\right]$ where $f = \frac{\lambda \bar{V}_0}{\bar{V}_m + \lambda \bar{V}_0}$
Jiang (GM)	$\kappa = 24 \times RH^{1.67}\exp\left[\frac{12000}{R}\left(\frac{1}{353} - \frac{1}{T}\right)\right]$



Springer, T. E.; Zawodzinski, T. A.; Gottesfeld, S., Polymer electrolyte fuel cell model. *J Electrochem Soc* **1991,** *138*, 2334.

Weber, A. Z.; Newman, J., Transport in polymer-electrolyte membranes-II. Mathematical model. *J Electrochem Soc* **2004**, *151* (2), A311-A325.

Jiang, R.; Mittelsteadt, C. K.; Gittleman, C. S., Through-plane proton transport resistance of membrane and ohmic resistance distribution in fuel cells. *J Electrochem Soc* **2009**, *156*, B1440.

NUVERA FUEL CELLS | PENNSTATE | THE UNIVERSITY of TENNESSEE