# AURORA Program

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


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Nuvera Fuel Cells


June 9, 2010

Project ID #
**FC028**

# Program Overview

## Timeline

- Actual start: 9/30/2009
- Planned end: 9/30/2012
- 15% complete

## Barriers

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

## Budget

- Total project funding
  - $4.460 MM (DOE)
  - $1.570 MM (Cost Share)
- FY09 funding: $ 0.125 MM
- FY10 funding: $ 1.871 MM

## Partners

- Johnson Matthey Fuel Cells
- Penn State University
- Lawrence Berkeley Lab

# Program Objectives

The **objective** of this program is to investigate transport limitations at high current densities in order to optimize the efficiency of a stack technology meeting DOE 2015 cost targets.

**Table 3.4.3 Technical Targets: 80-$kW_e$ (net) Transportation Fuel Cell Stacks Operating on Direct Hydrogen [a]**

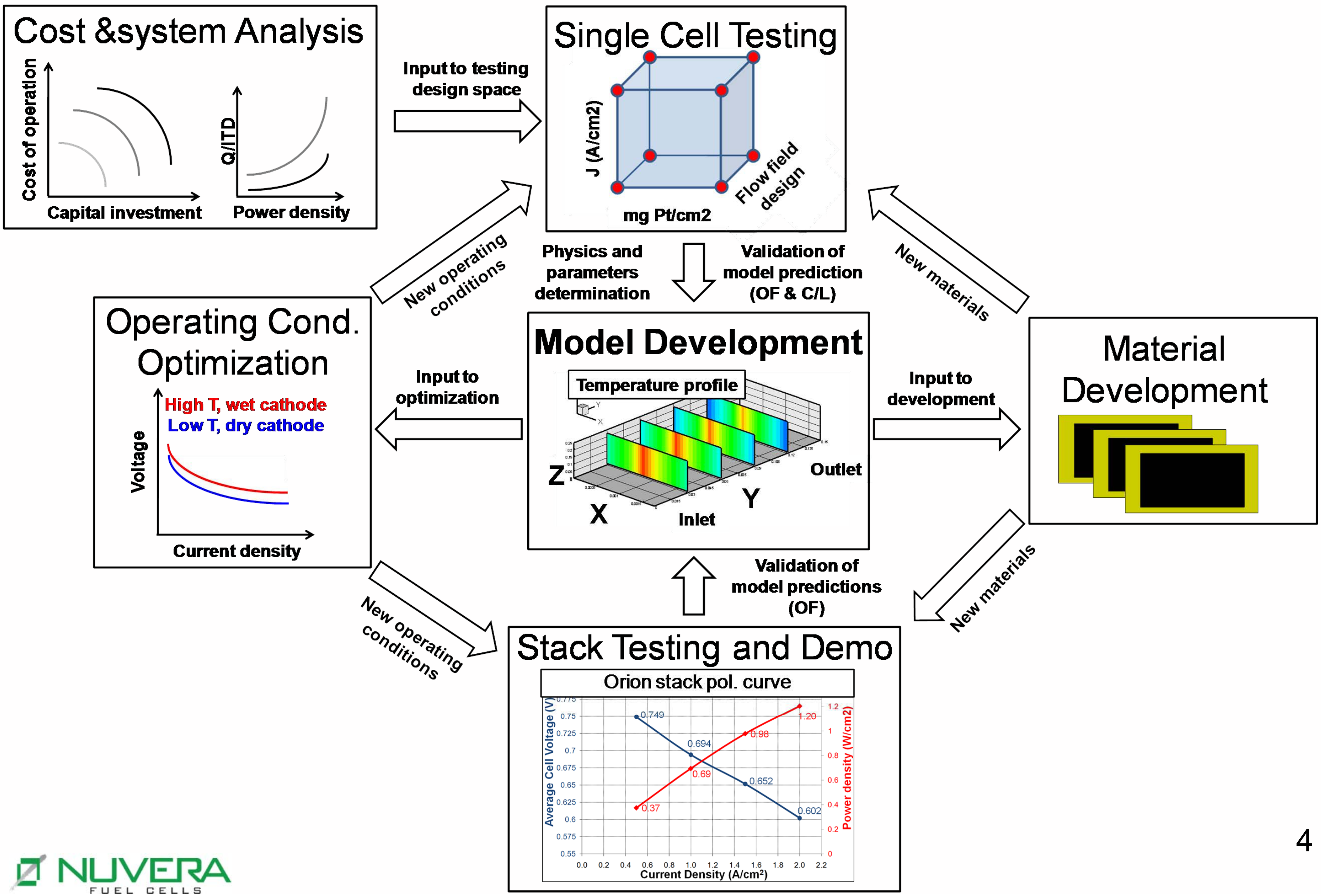
| Characteristic | Units | 2003 Status | 2005 Status | 2010 | 2015 |
|---|---|---|---|---|---|
| Stack power density [b] | W / L | 1,330 | 1,500 [c] | 2,000 | 2,000 |
| Stack specific power | W / kg | 1,260 | 1,400 [c] | 2,000 | 2,000 |
| Stack efficiency [d] @ 25% of rated power | % | 65 | 65 | 65 | 65 |
| Stack efficiency [d] @ rated power | % | 55 | 55 | 55 | 55 |
| Cost[e] | $ / $kW_e$ | 200 | 70 [f] | 25 | 15 |
| Durability with cycling | hours | N/A | 2,000 [g] | 5,000 [h] | 5,000 [h] |

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

| FY2010 Goals | Status |
|---|---|
| Stack demonstrating 1W/cm2 with 0.2 mg Pt/cm2 | In progress |
| Implementation of predictive model for high power density (Ver 1.0) | In progress |

# Program Approach

A detailed predictive model is at the center of the program.

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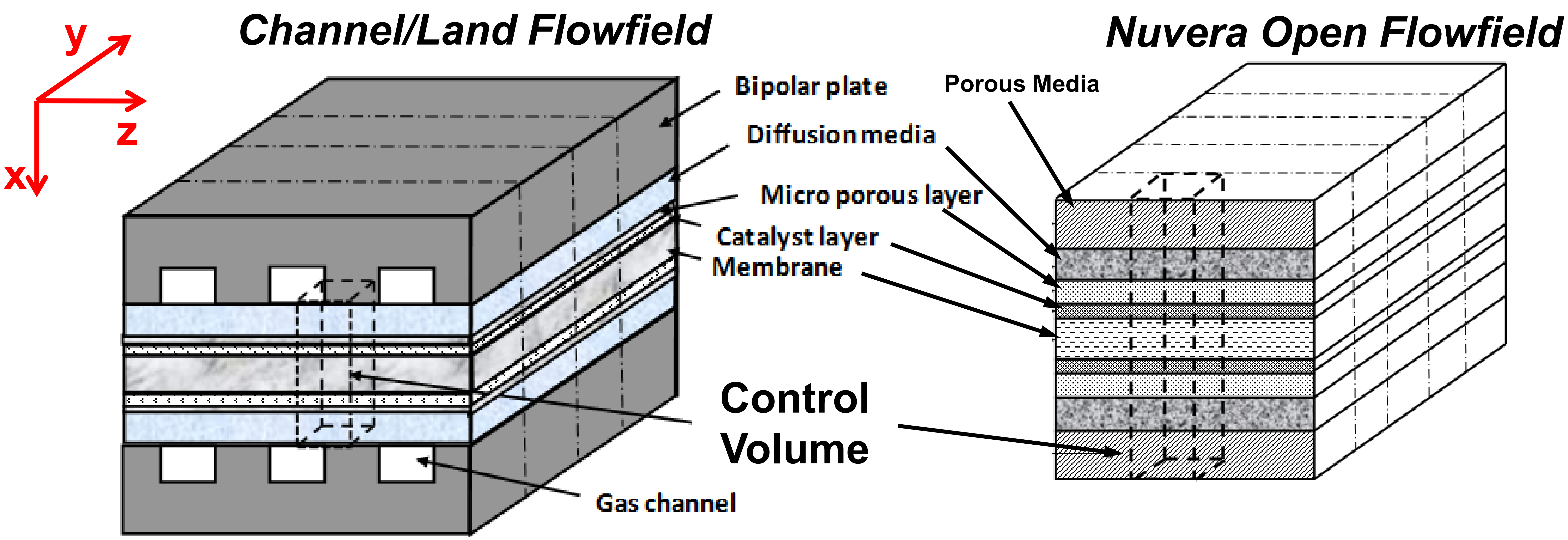
# FC Modeling -- Approach

The physics of the quasi-3D, multi-architecture model will be 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.

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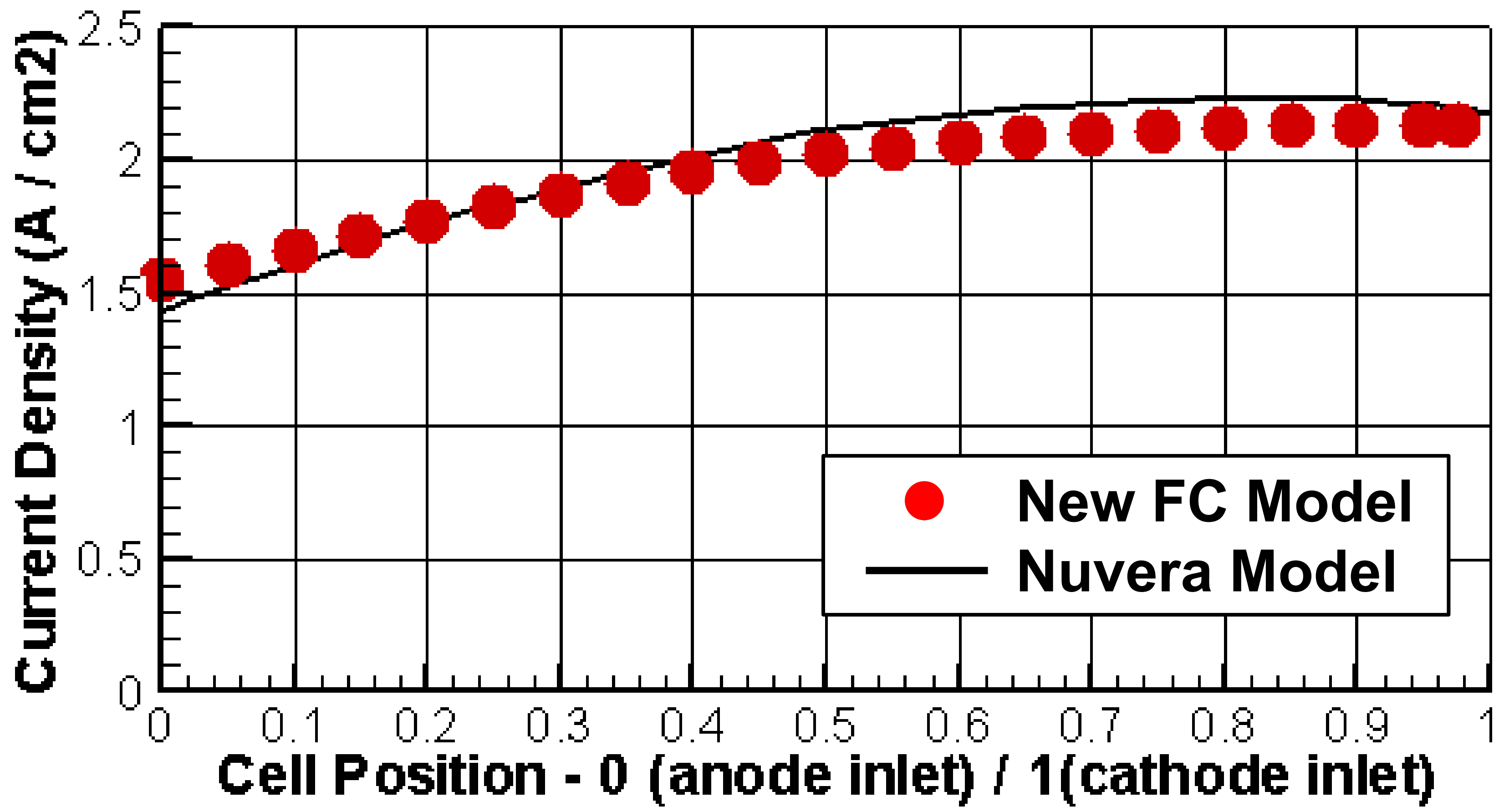
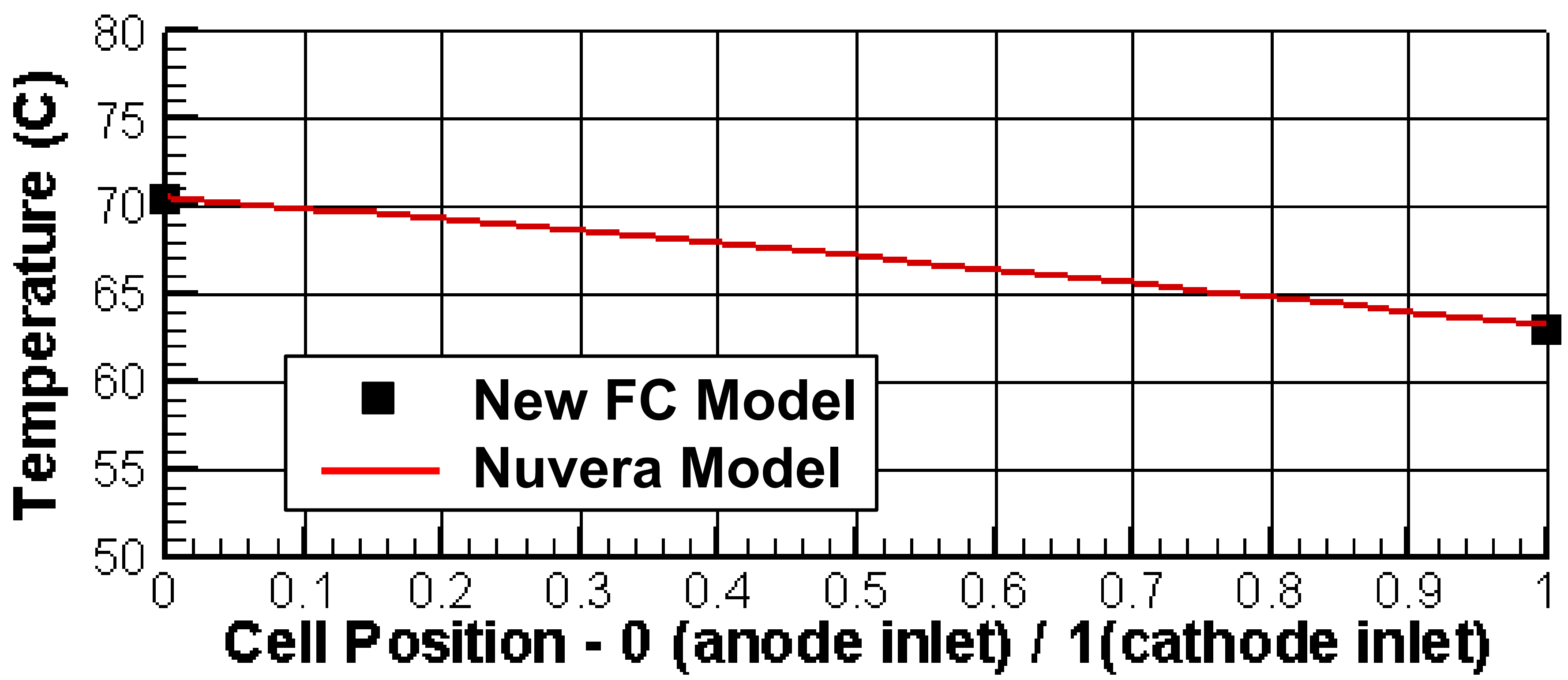
# FC Modeling - Status

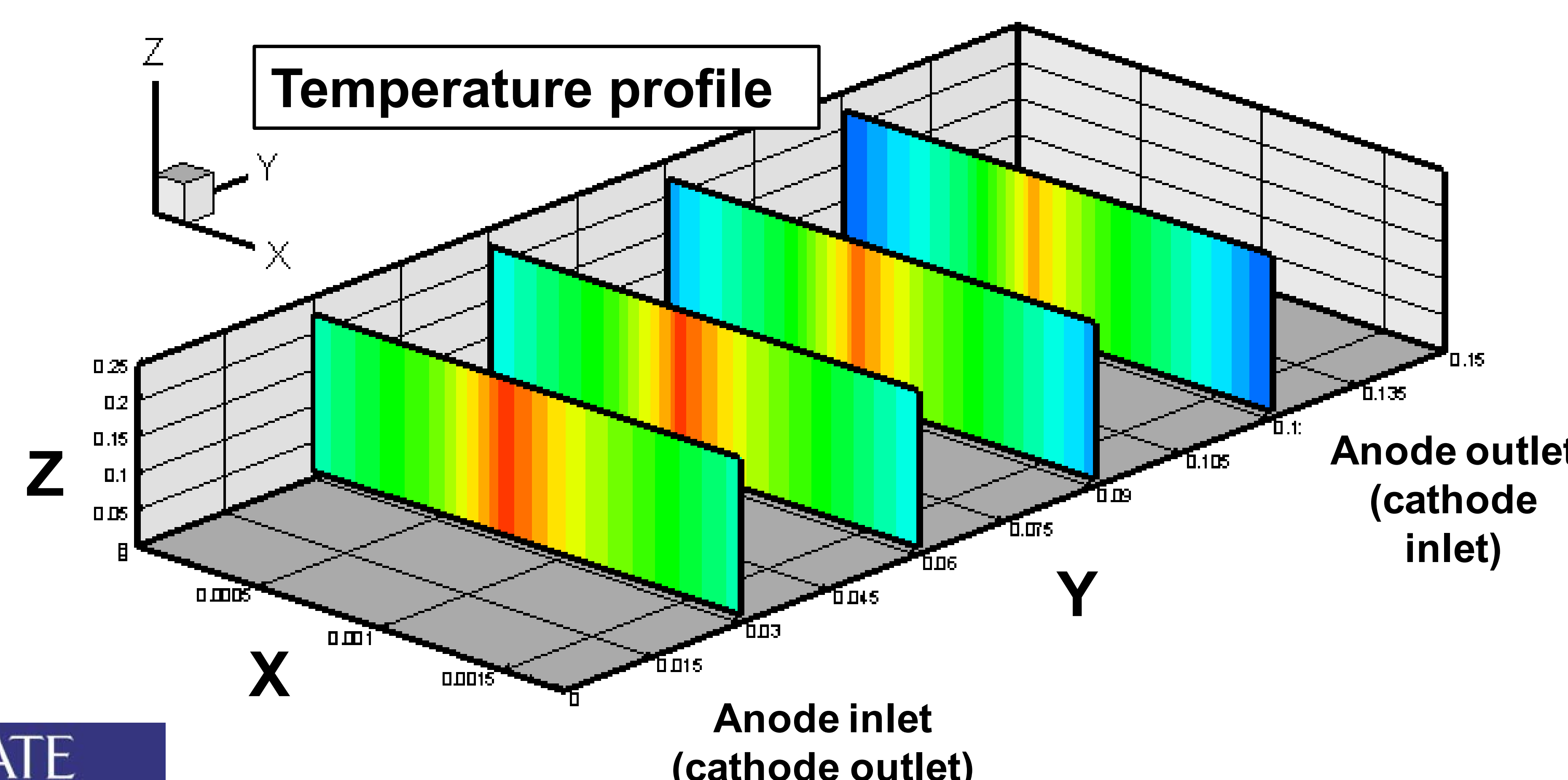
Predictions obtained using two independent models (Nuvera & PSU) are producing similar results.

**Model approach tested**

- PSU existing 2D model modified to represent Open Flow field
- Species concs & T variation in Y direction has been implemented.
- Model run in counter-flow, and benchmarked against Nuvera model

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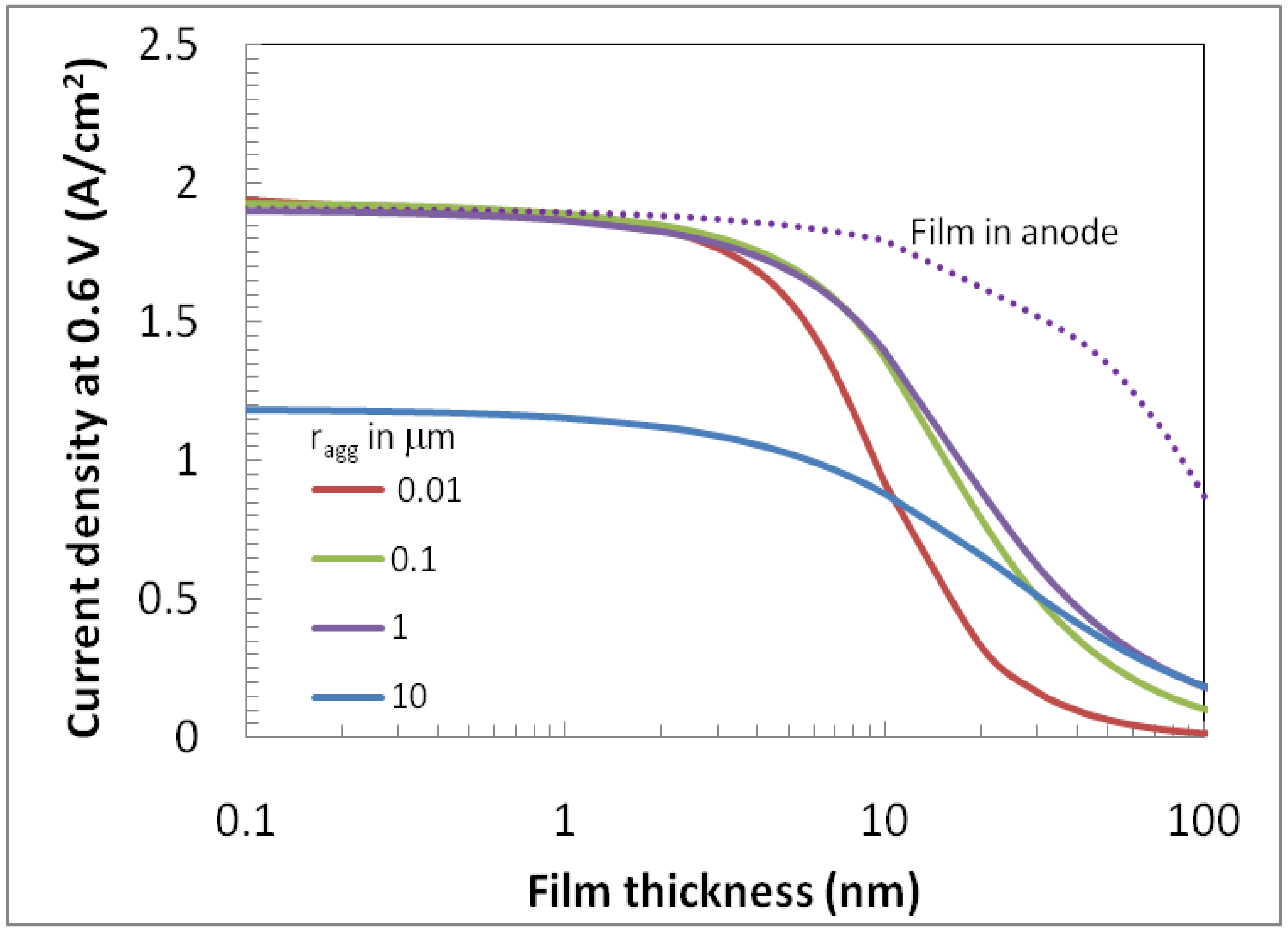
# FC Modeling – MEA physics

A detailed submodel is being developed to capture the physics prevailing inside the MEA under high current density operation.

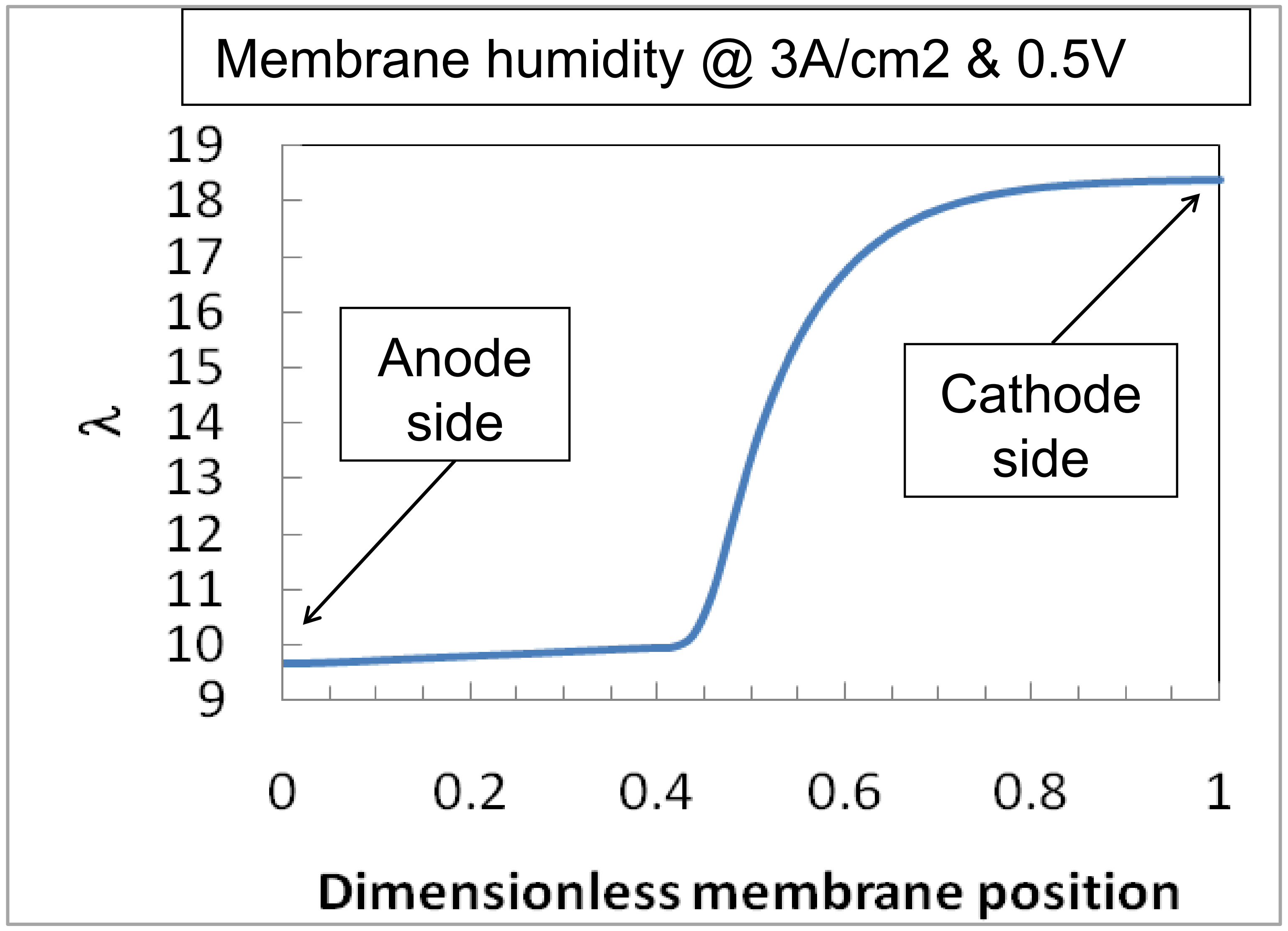
**Catalyst layer modeling**

- Evaluate film thickness effect
- Relate thicknesses & sizes to loadings
- Understand impact at the agglomerate scale with varying properties




**Membrane modeling**

- At high CD some membrane dehydration can occur even with fully humidified gases
- Caused by electro-osmotic flow, large gas fluxes, & phase-change-induced flow
- Thermal management is critical

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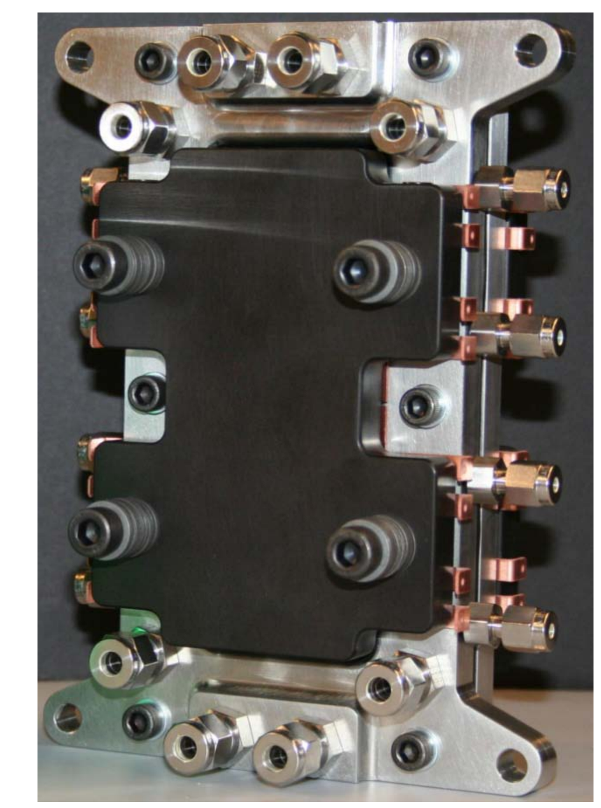
# Single Cell Testing

Preliminary testing has confirmed the need for the new test fixture to study cell performances at high current density.

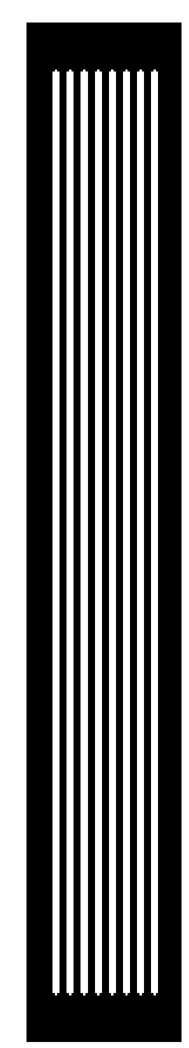
## Nuvera

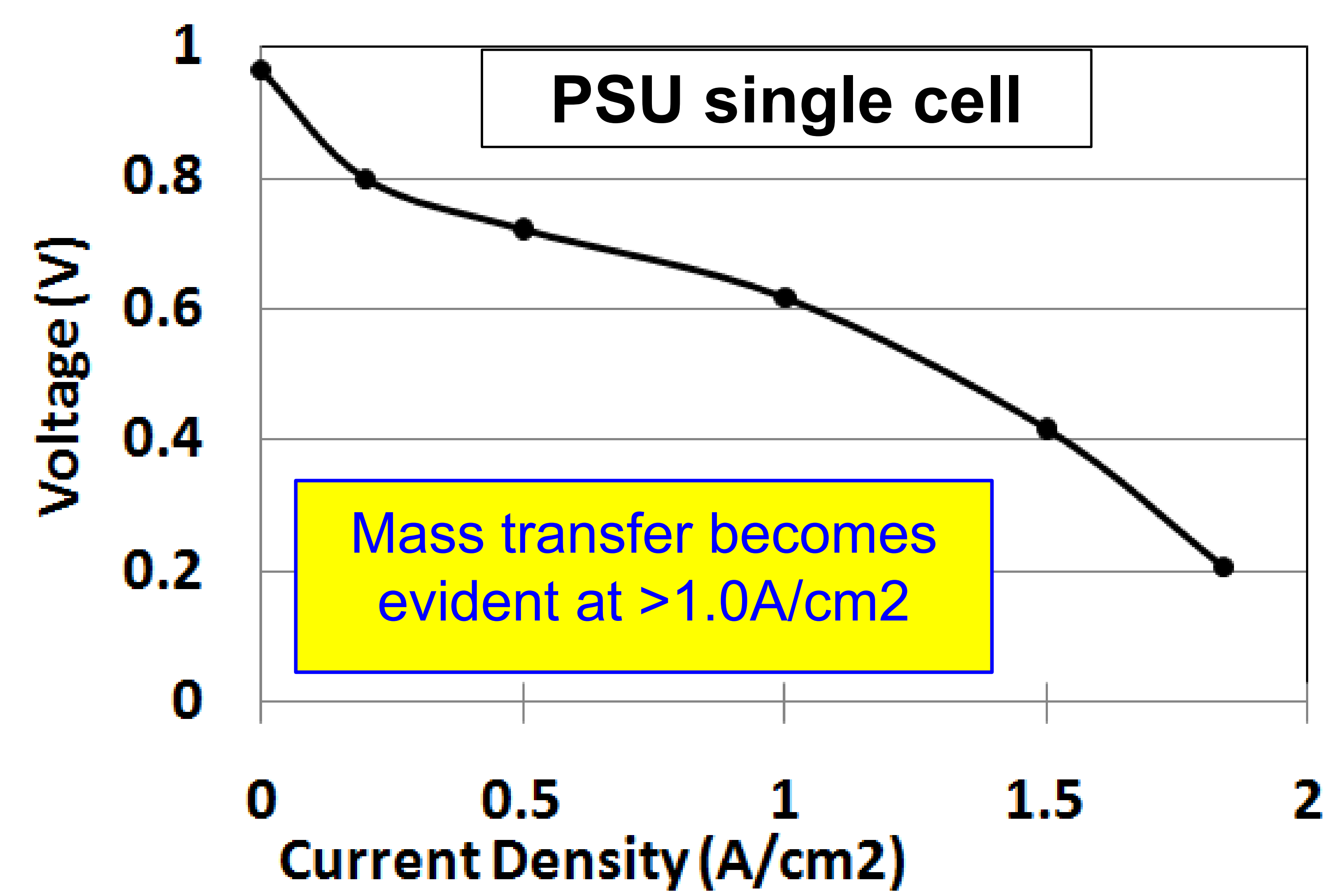
- TesSol test stand dedicated to program.
- Nuvera single cell fixture developed in SPIRE available in AURORA for high current density studies.



## Penn State University

- Initial tests ongoing on PSU Cell.
- AA=14.6 cm2, Channel/Land, same flow length of Nuvera single cell.
- Nuvera single cell will be tested at PSU





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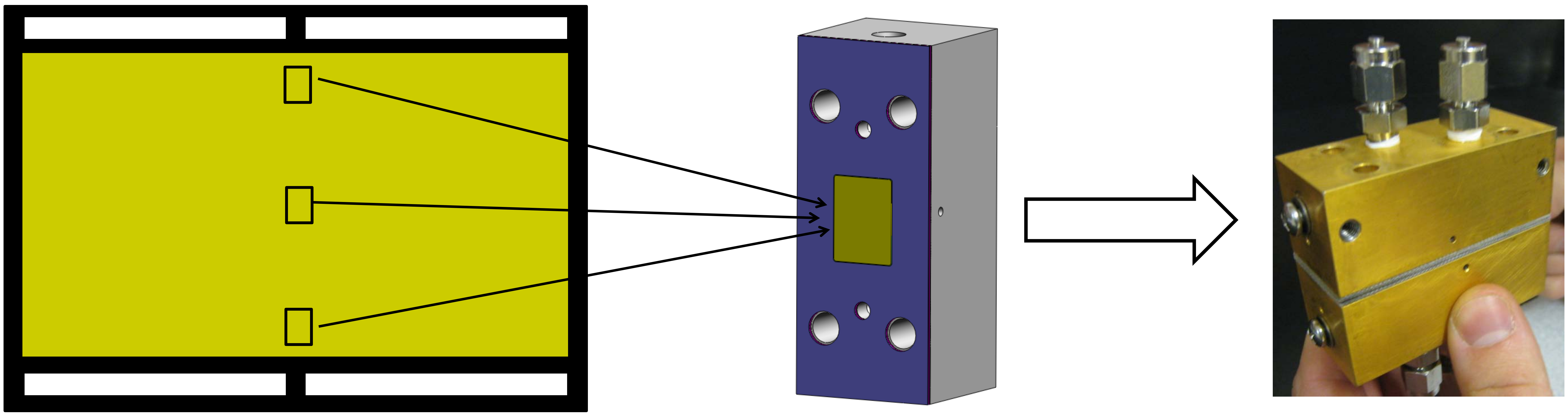
# Transport Studies at NIST

A small (1.9cm$^2$ active area) test fixture has been used to study local conditions predicted inside a full active area stack.



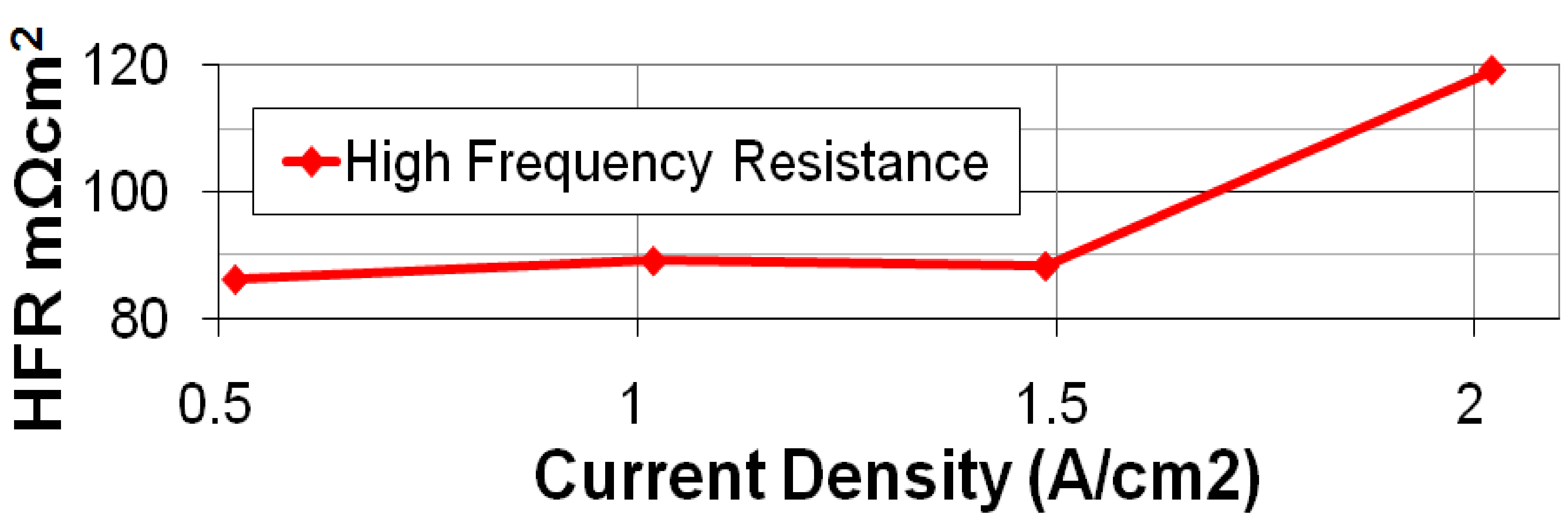
- Original cell design provided by LANL was modified to host Nuvera Open Flowfield

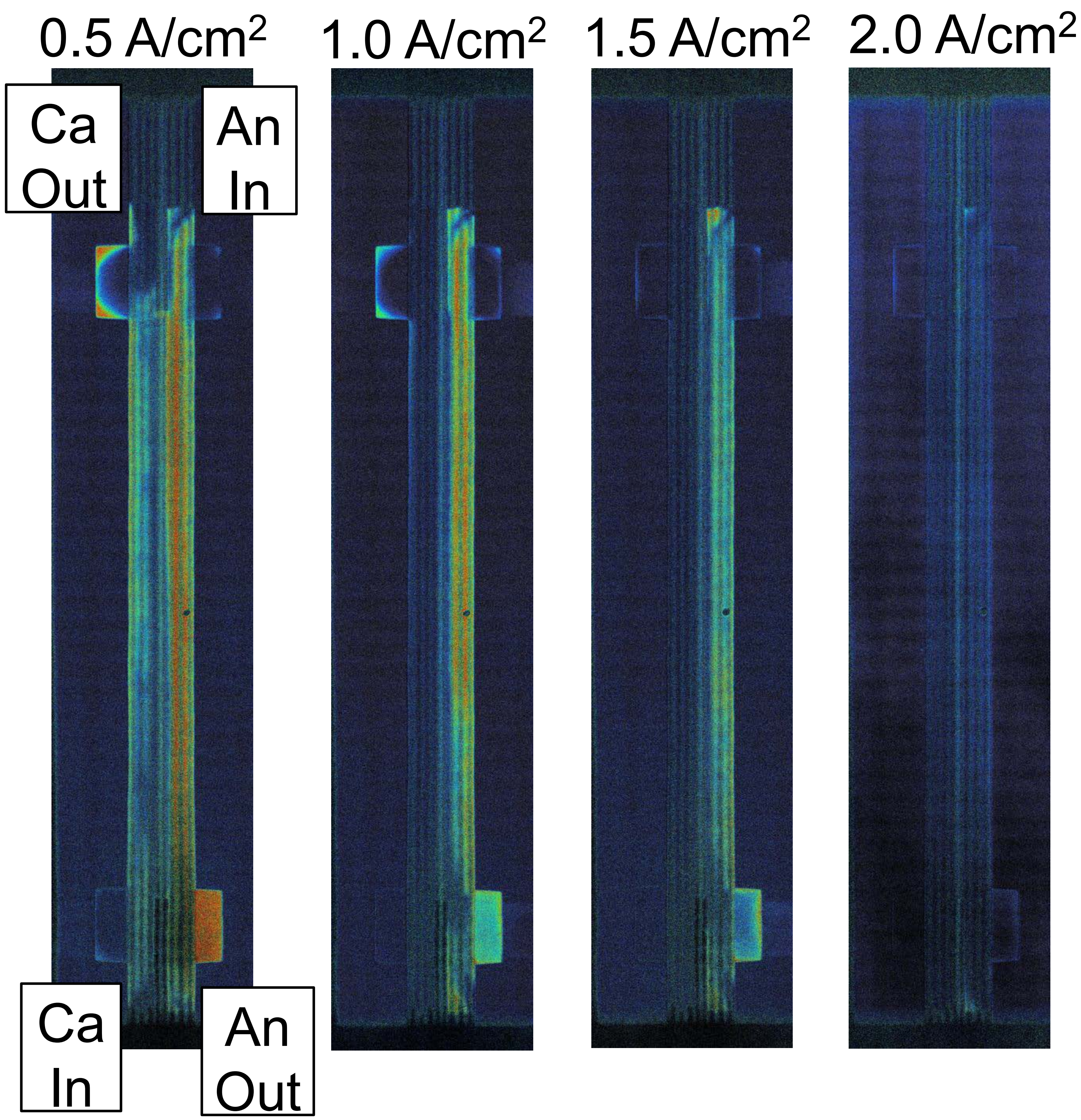
- Water transport through-the-plane has been explored via high-resolution neutron radiography

# Transport Studies at NIST

Neutron imaging proved very effective in visualizing changes in water distribution with changes in current density.

- Anode & cathode stoichiometries kept constant as current density increases.
- Water present in cell decreases with increasing current density.
- At 2.0 A/cm$^2$ both cell voltage and HFR are affected by low membrane hydration.




Cell represents conditions in the center of the full size cell

**Thanks to LANL & NIST for all the help provided**

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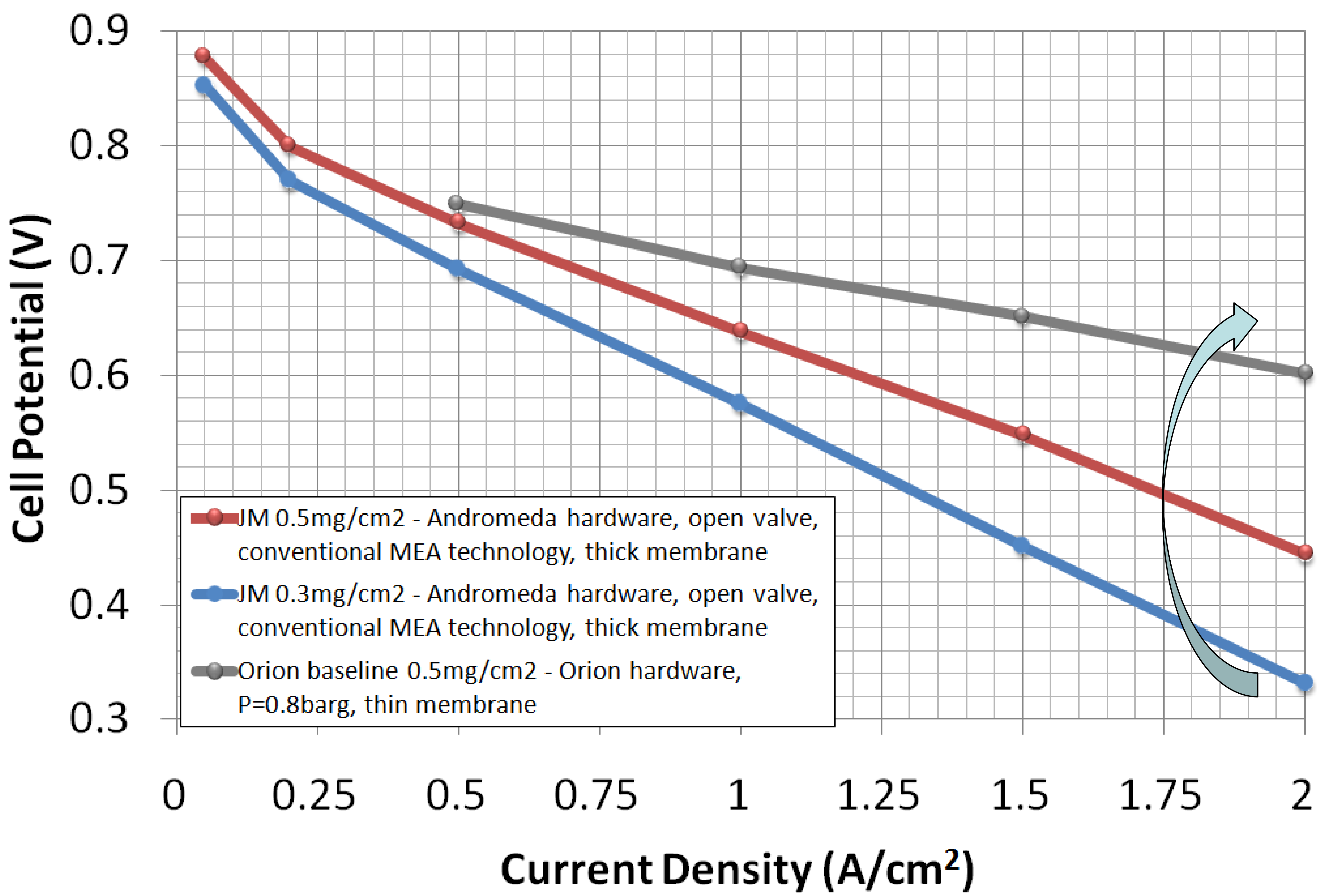
# Initial Material Screening

The first comparative results of different cathode Pt loadings running at elevated current density have been obtained.




**MEA**

- Gradient loadings
- Thinner membrane
- New ionomer chemistry
- Process optimization
- GDM selection/tuning

**STACK**

- Orion hardware
- Resistance reduction
- Operating conditions optimization/modeling

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JM Johnson Matthey Fuel Cells *the power within*

# Stack Testing with 3M NSTF

While stack assembly and process optimizations are needed, use of 3M's NSTF in Nuvera's open flowfield has produced encouraging results.

**Testing at 3M:**

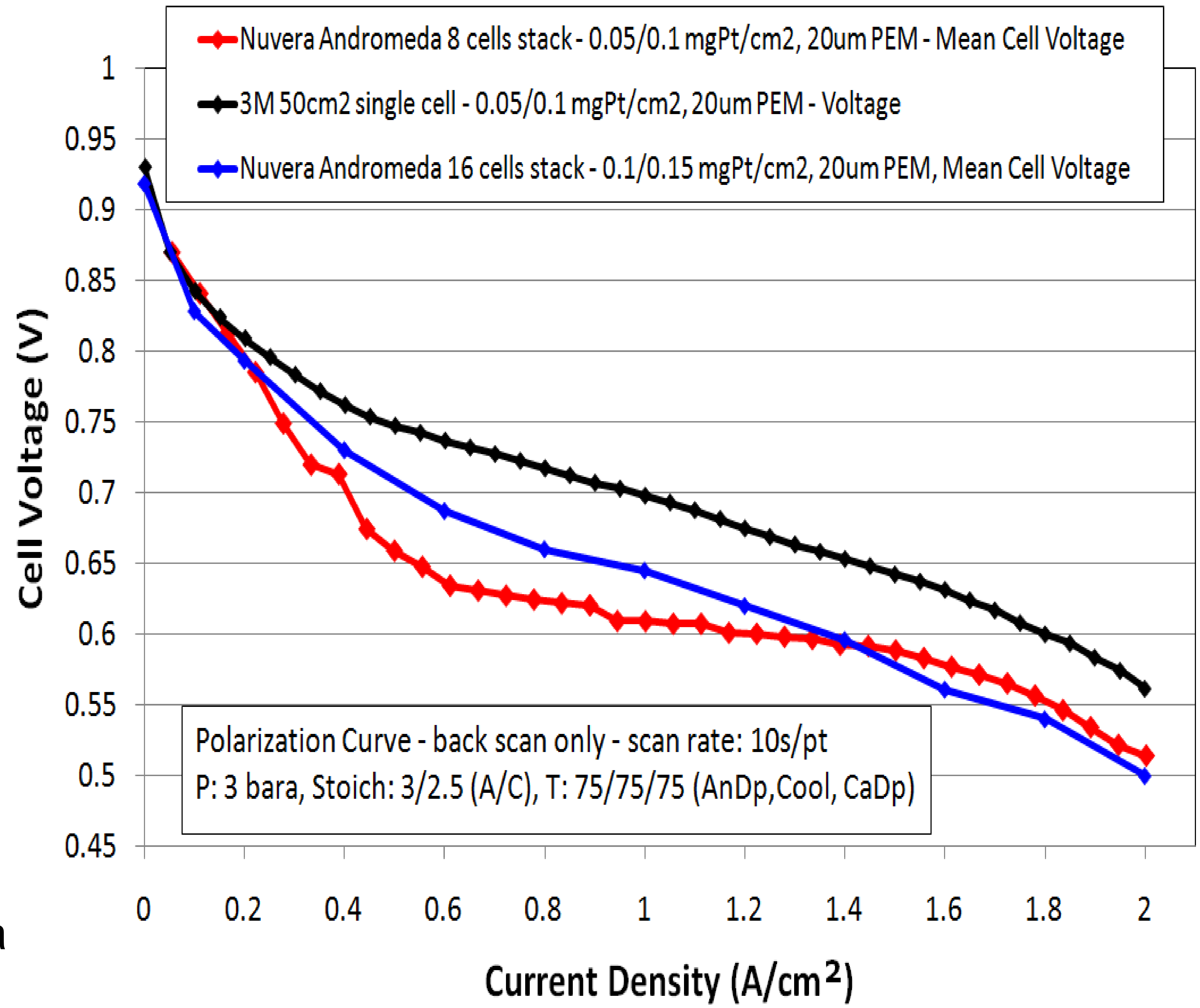
**16 cells Andromeda**

- 0.1/0.15 mgPt/cm2, 20μm membrane
- Worked "out of the box"
- No contamination after 3000 hrs shelf time &150 hrs operation.

**Testing at Nuvera:**

**8 cells Andromeda**

- 0.05/0.1 mgPt/cm2, 20μm membrane; ~20 hrs operation.
- Conditions tuning expected to control flooding in mid CD range.
- Improvements in ohmic resistance expected to close gap with SC data



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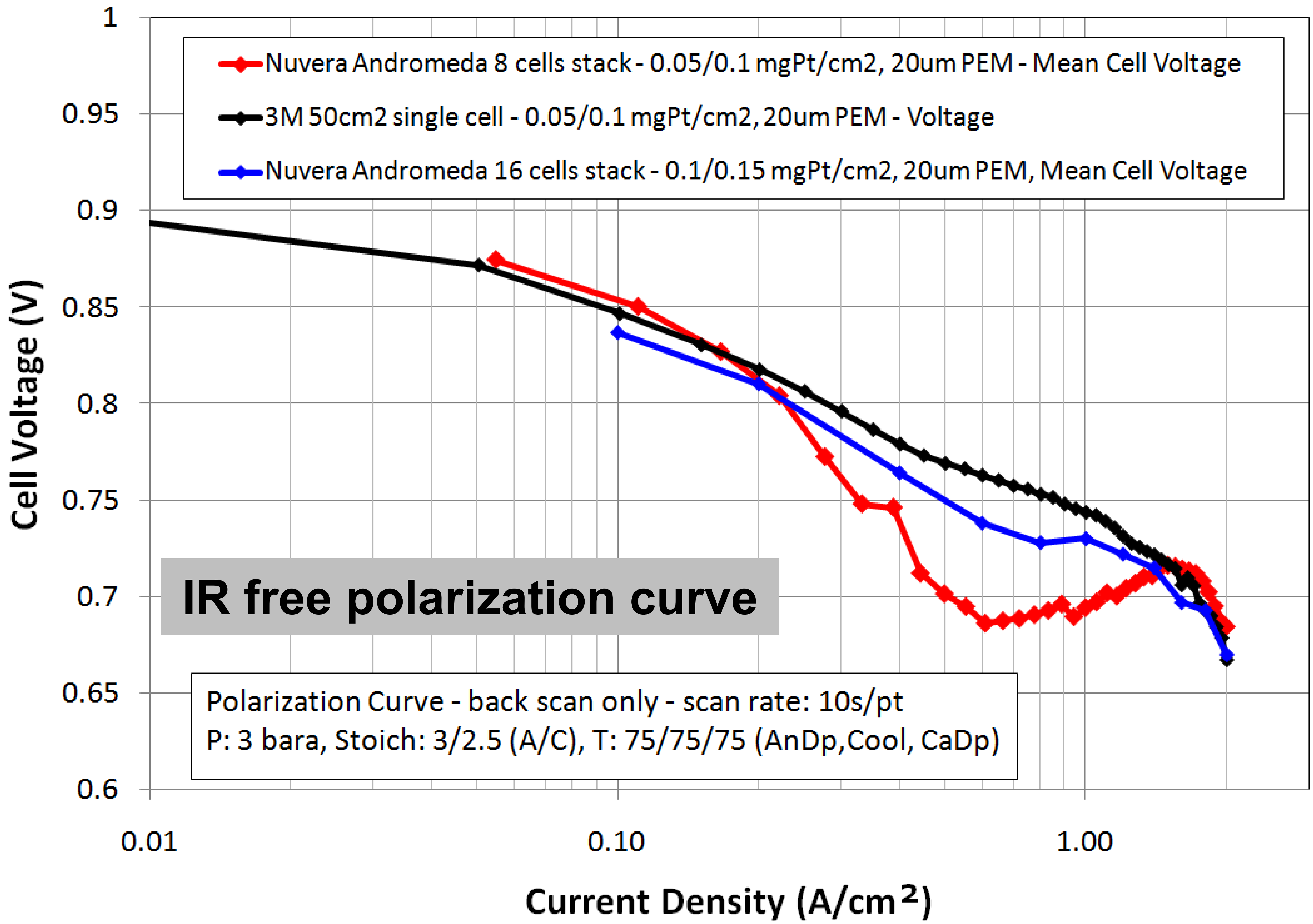
# Stack Testing with 3M NSTF

Applying IR correction to the polarization data indicates that performance differences can be addressed by reducing contact resistances.



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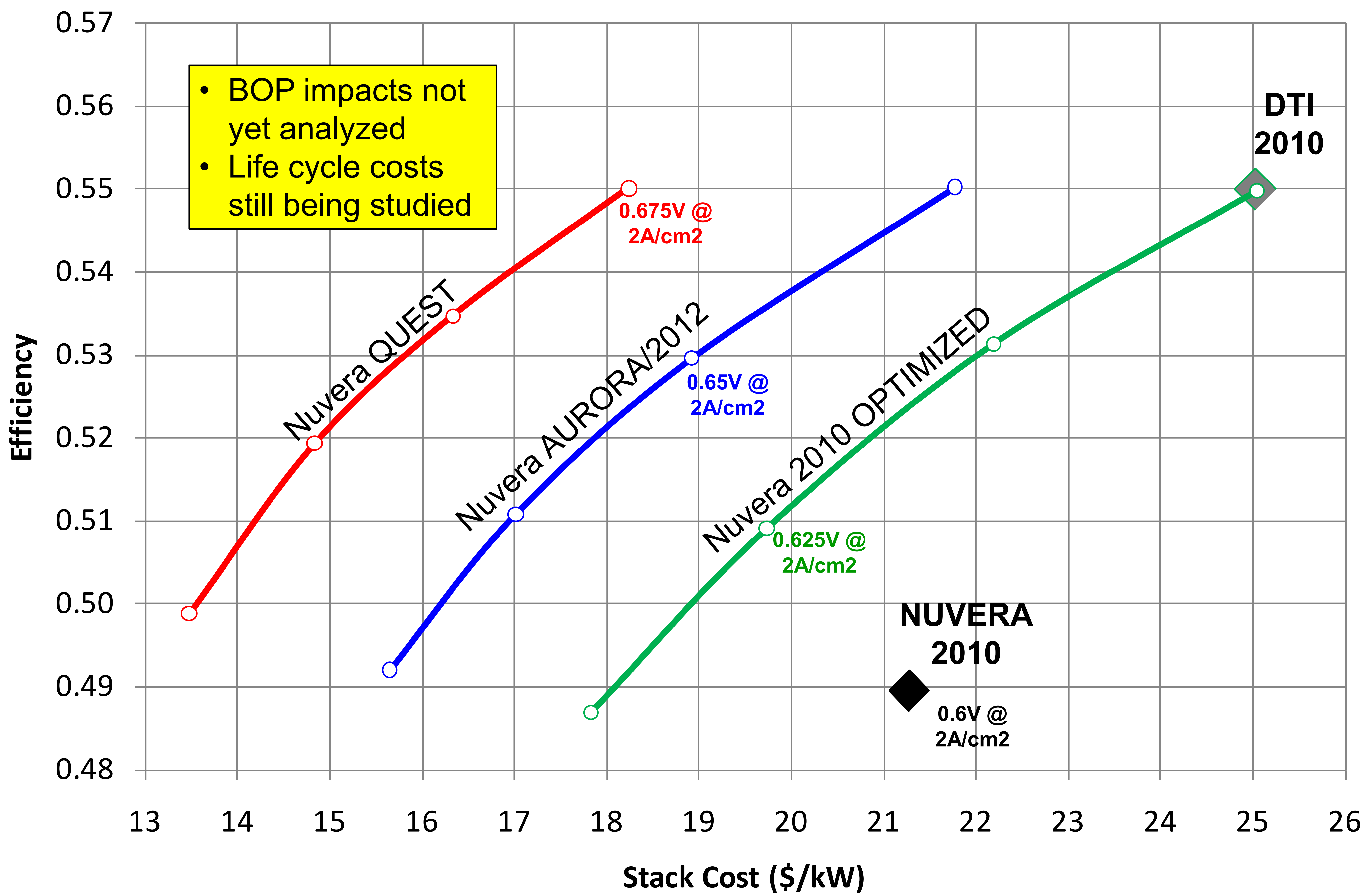
# Stack Cost Analysis

(supported by DTI)

With reference to 2010 technology, AURORA targets correspond to stack cost savings of $300-$840/vehicle.



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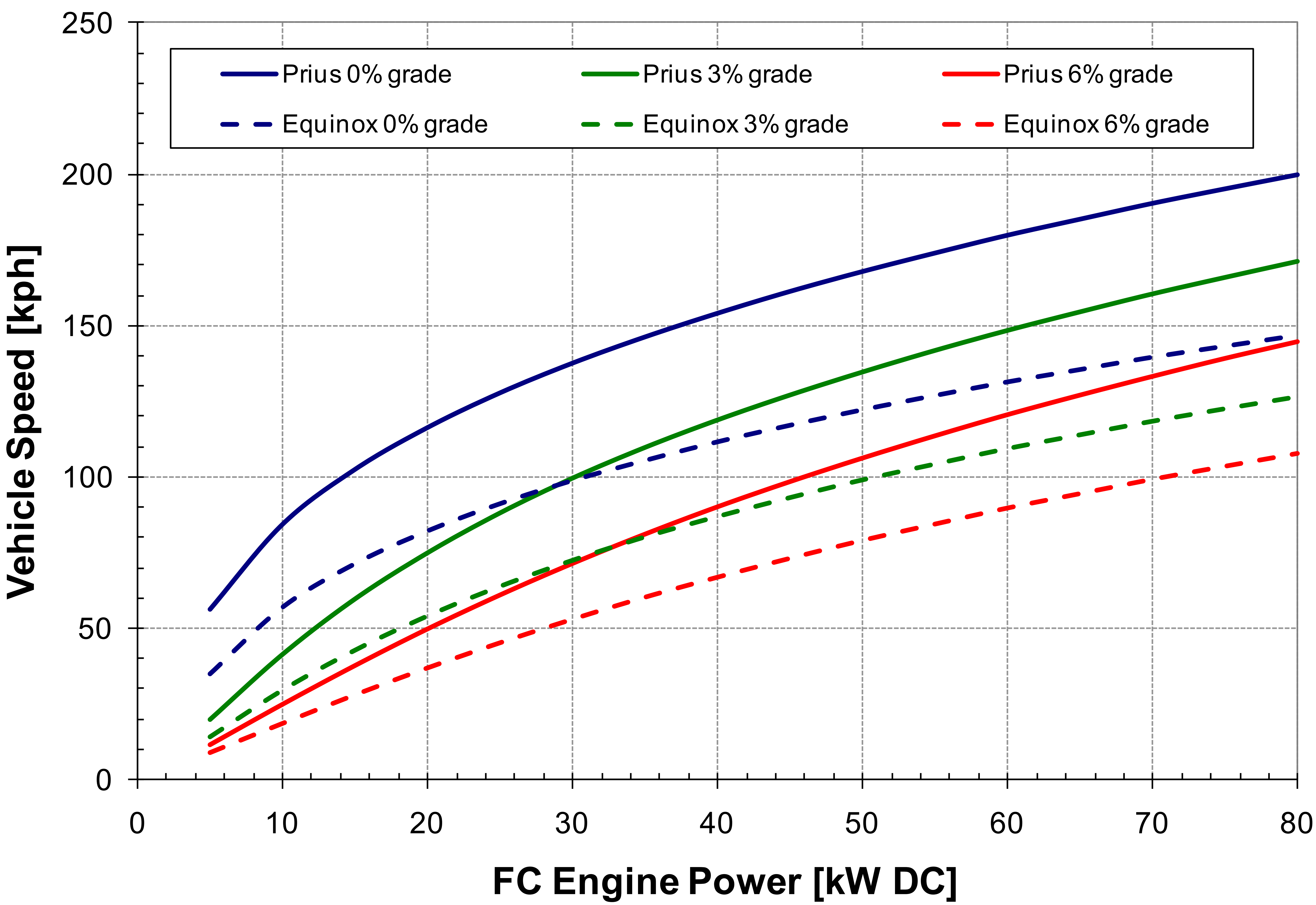
# Systems Analysis

A detailed vehicle model was exercised to understand fuel cell power requirements as a function of speed and grade.



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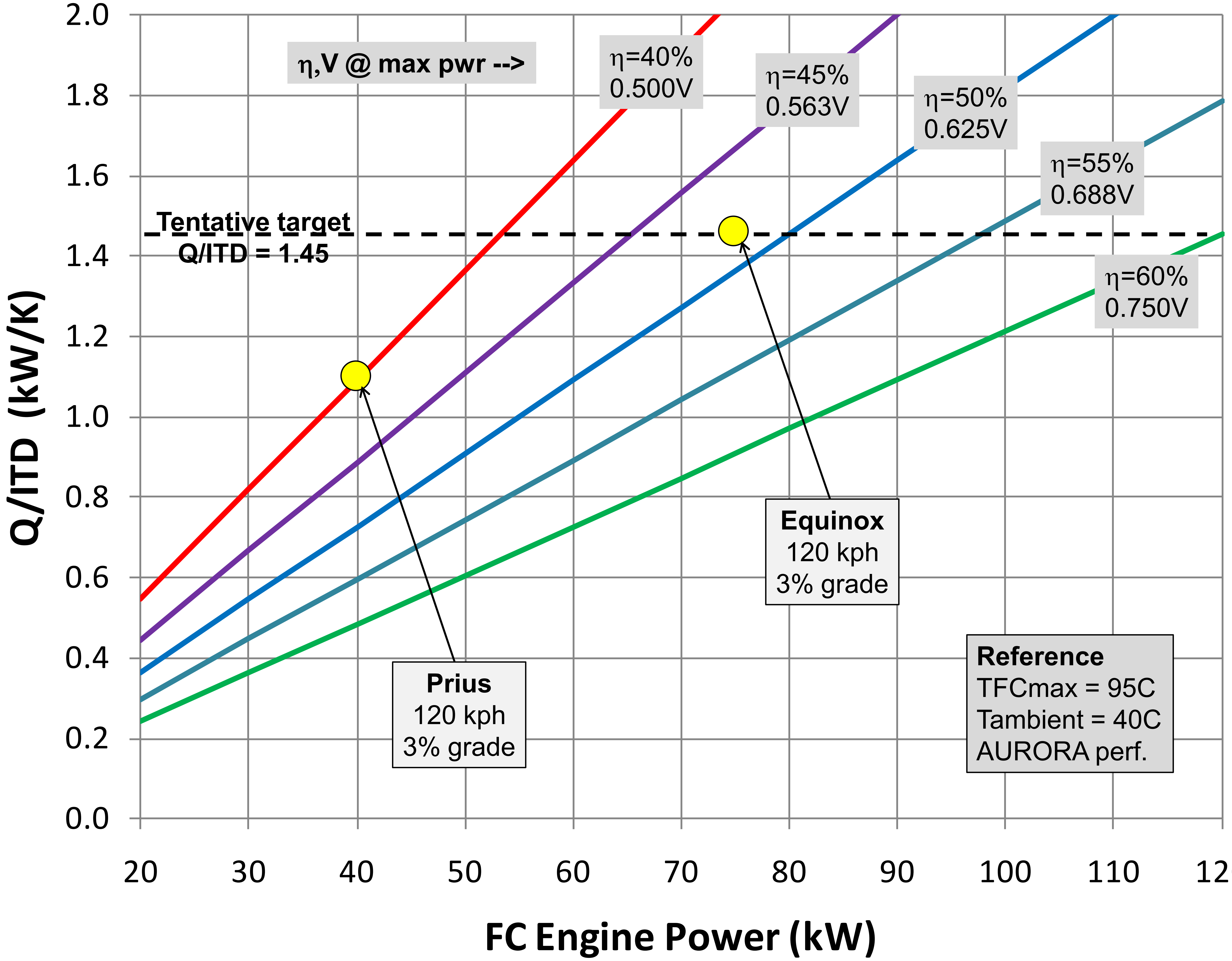
# Systems Analysis

Heat rejection constraints dictate vehicle-dependent performance limitations (speed vs. grade) at elevated ambient temperatures.



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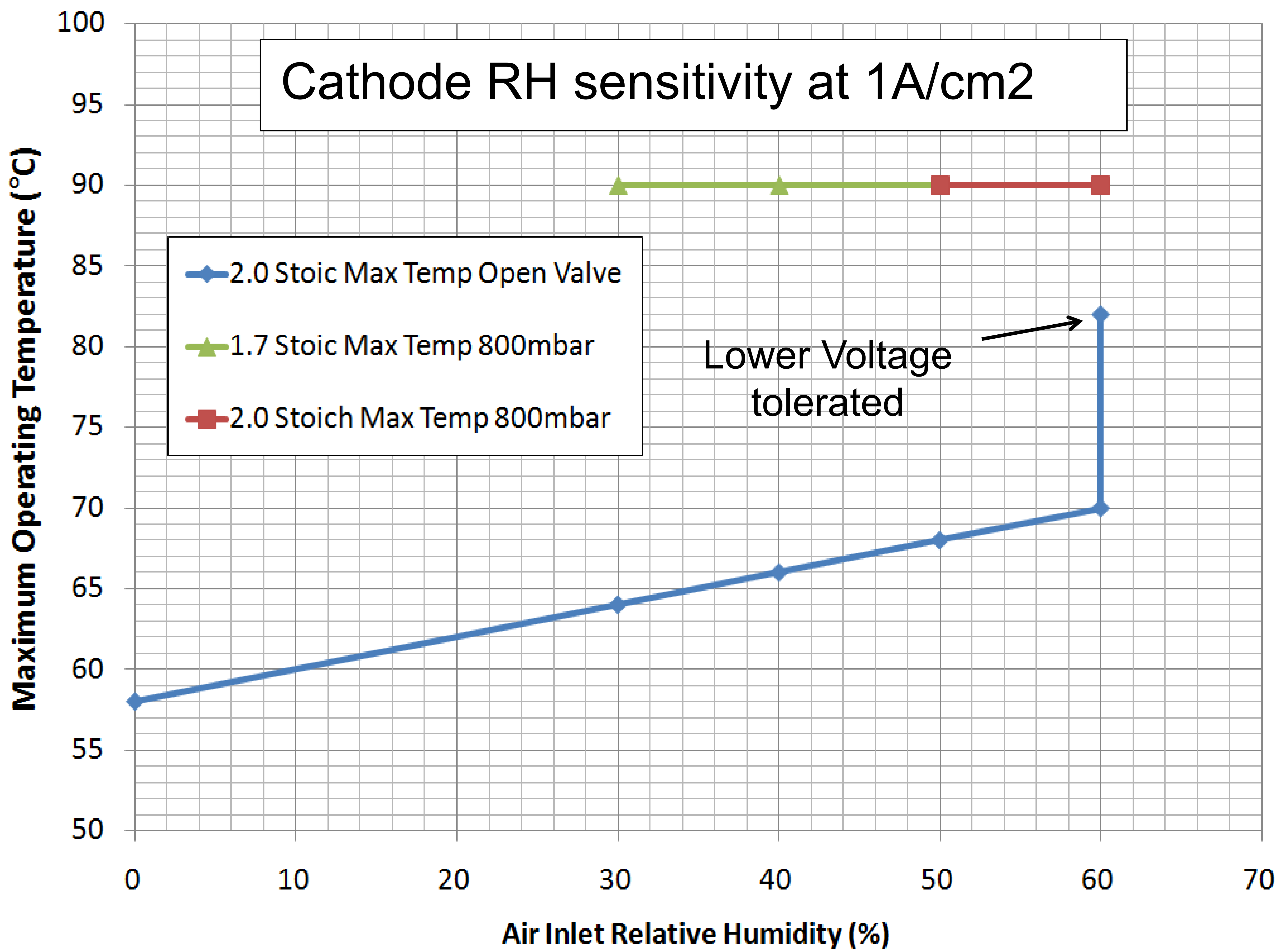
# Humidified Cathode

Historically Nuvera focused exclusively on unhumidified air -- testing has been started to assess air humidification/temperature tradeoffs.

**Initial testing takeaways**

- Testing at 1A/cm2 shows humidified cathode enables operation at higher T.
- Temperature capability reduced at higher current, even fully saturated.
- Elevated inlet pressure enables higher temperature and reduced humidification.
- Voltage decay can be traded off to increase maximum operating temperature



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# Future Work

## Single cell testing

- New tests on PSU hardware: C/L operated at high current density
- New campaign at NIST: screening of materials with different Pt loading and ionic conductivities.
- Tests on Nuvera's new single cell at both Nuvera and PSU.

## Model development

- Converge Nuvera Model and AURORA FC Model predictions.
- Develop LBL MEA Model (inferred by JMFC MEA properties)
- Integrate LBL MEA Model into AURORA FC Model

## Material development

- MEAs with increased ionic conductivity will be tested in 2010
- MEAs with loadings approaching 0.2mgPt/cm2 will be tested in 2010

# Summary

- Nuvera is working in AURORA to optimize the efficiency of a stack consistent with DOE cost targets:
  - Cost goal = 7.5 W/mgPt
  - Performance goal = 0.6V at >1.0 W/cm2
- A Model capable of predicting high current density operation in different architectures is the central deliverable of the program. The model structure has been defined, and predictive benchmarking is underway.
- Material development aimed at reducing Pt loading and membrane resistivity is key to the success of the program. The first results of testing low Pt ECPs have been obtained, and the roadmap is set.
- Tests on single cell and full active area stacks will be used to screen new materials, define inputs to the model and validate it. Infrastructure is being prepared (Nuvera) and exercised (PSU), and the new single cell test fixture is undergoing commissioning.