Advances in Materials for PEM Fuel Cells and Electrolyzers for Exploration System Missions

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H_2/O_2 Primary and Regenerative Fuel Cells

- Primary Fuel Cell ($H_2/O_2 \rightarrow$ electricity)
- Electrolyzer (electricity $\rightarrow H_2/O_2$)
- Applications
  - Mobile Power sources
    - Automobiles, Lunar Rovers, Lunar Landers, Unmanned Aircraft
  - Large scale energy storage
    - Renewable Energy Storage, Lunar Surface Systems
  - "Back-up" Power and Battery Recharging
    - Remote Cell Phone Towers, Materials Handling Equipment

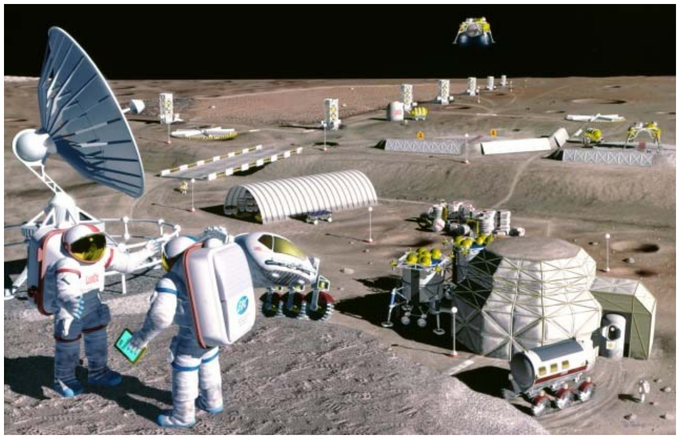
Challenges

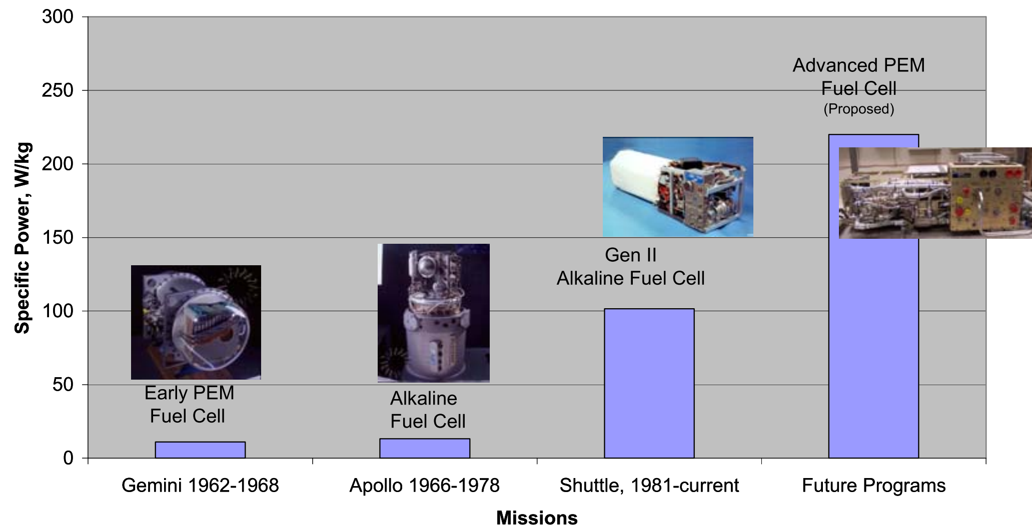
Application	Barriers
Automobiles	Materials Cost and Durability
Lunar Systems	Efficiency and Durability and technology maturity
Unmanned Aircraft	Fuel Storage, specific Energy
Renewable Energy Storage	Cost, efficiency, and storage logistics
Back up Power	Cost and durability

Specific Technology Focus at JPL

Application	Technical Focus
Automobiles	• Reducing precious metal loading to 0.2 mg/cm^2 • Increasing the durability of catalysts to 5000 hours
Lunar Systems	• Improving Efficiency PEM H_2/O_2 fuel cell • Advanced Oxygen Evolution Catalysts for PEM water electrolysis • Electrolysis Stacks capable of balanced pressure operation 2000 psi

PEM Fuel Cell for Lunar Lander (Altair), Lunar Surface Mobility systems, and Lunar Habitats.





- **Advantages of PEM fuel cells over state-of-art alkaline fuel cells include :**
    - **lower mass and volume**
    - **enhanced safety**
    - **longer life, > 5000 hours**
    - **increased flexibility for load handling**
    - **improved reliability**

Approach

- Fabrication of Nafion-Based MEAs
  - JPL in-house methods
  - Procured from two other Vendors
  - Evaluate membranes of various thicknesses and EW

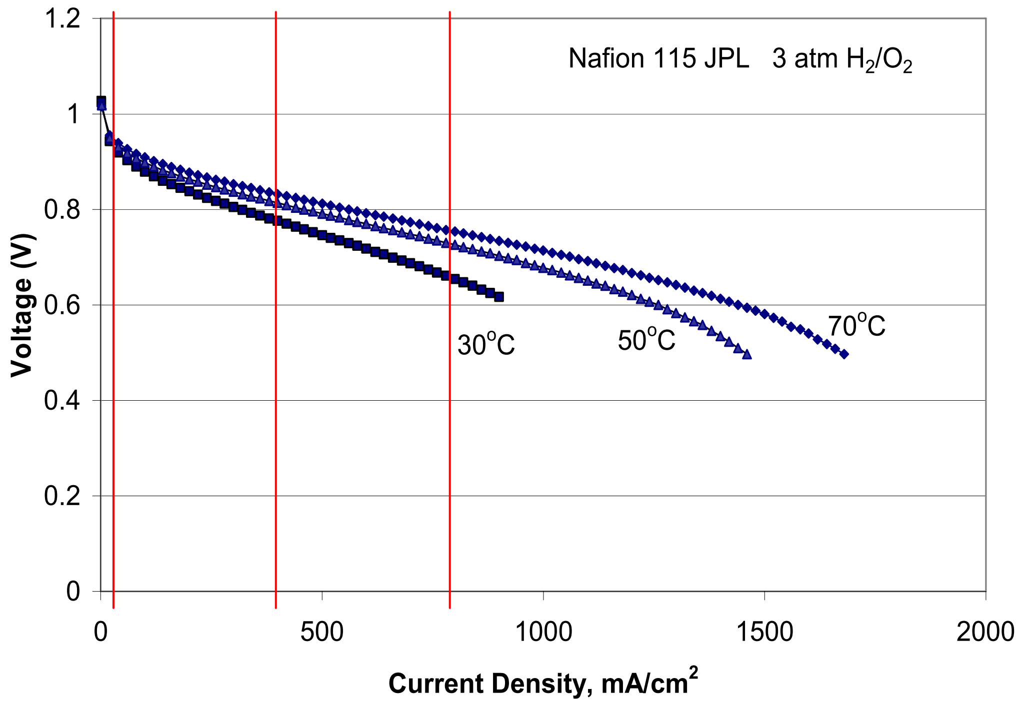
MEA performance characterization

- Operating conditions
- Membrane types and thicknesses
- Backing papers
- Catalyst loading

JPL MEA scale up results

JPL and vendor MEA comparison

JPL MEA Performance Characterization
Effect of Temperature

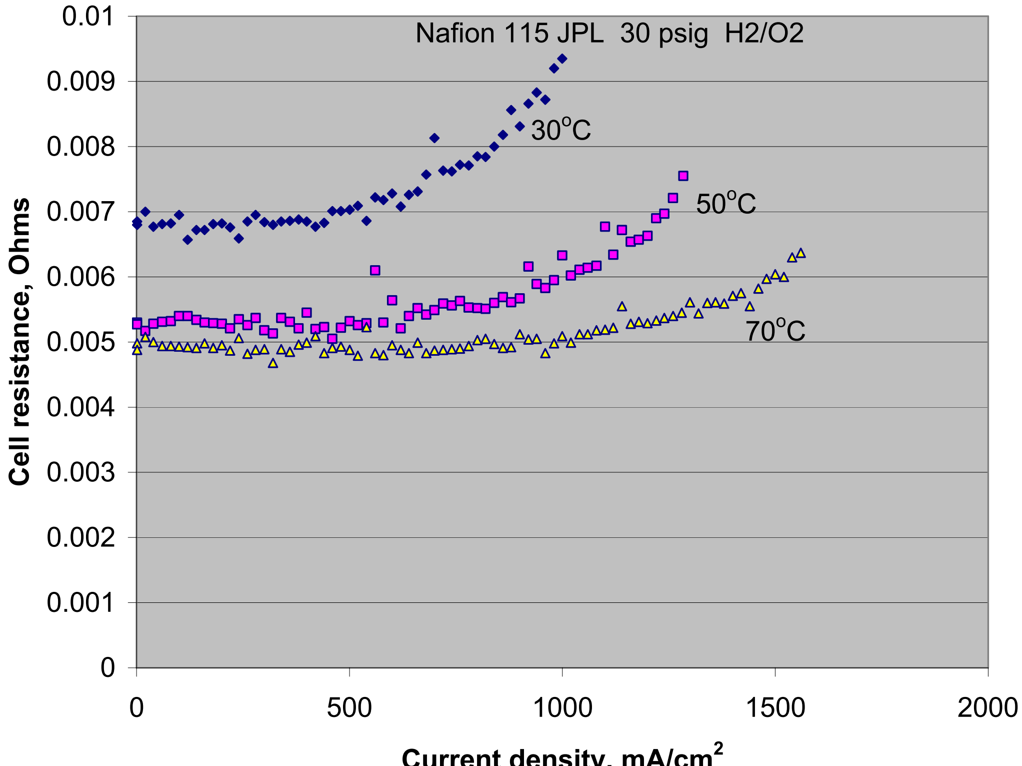


30 – 70 °C

C.D. mA/cm²	Δ V mV
40	25
400	54
800	77

- Performance increase of 20 , 54 and 77 mV at 40, 400 , and 800 mA/cm²
- Improvement largely due to ionic resistance of membrane

Internal Resistance
Effect of Temperature



400 mA/cm²

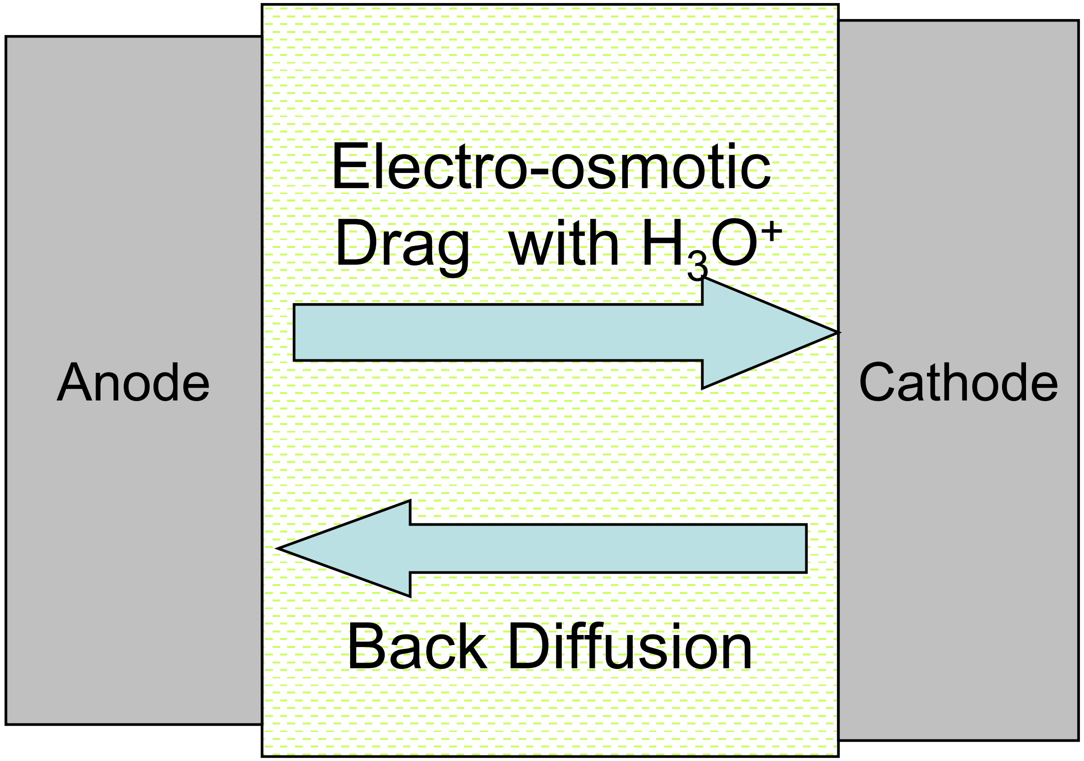
°C	HFR mOhm
30	7
50/70	4.5

1200 mA/cm²

°C	HFR mOhm
30	-
50	5.8
70	5

- HFR decreases with temperature
  - Nafion conductivity increases with temperature
- HFR increases with current density
  - point of increase pushed to higher current density with increase in temperature

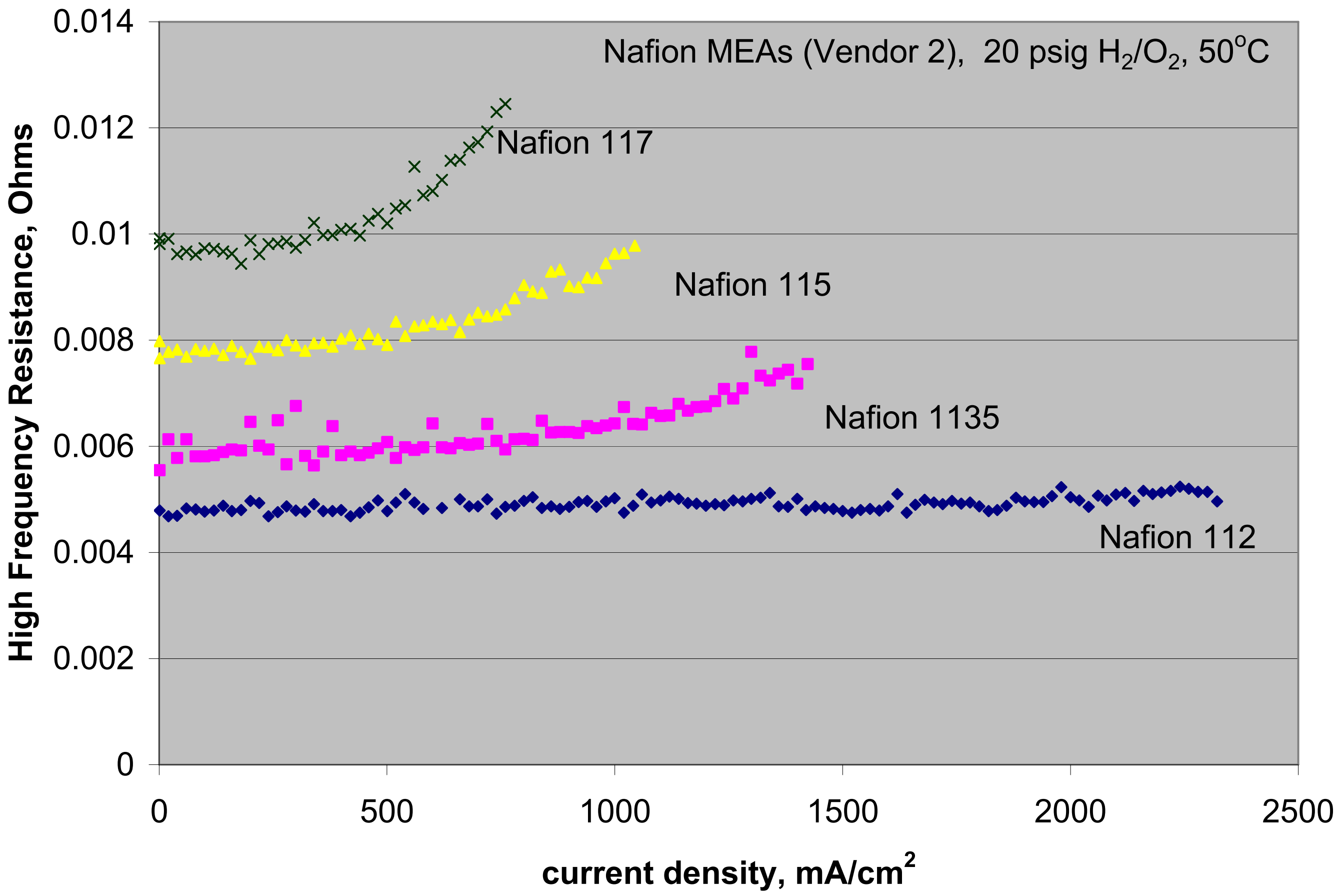
Water Transport Processes in an MEA



Felix Buchi and Gunther Scherer, *J. Electrochem. Soc.*,**148** A183 (2001).

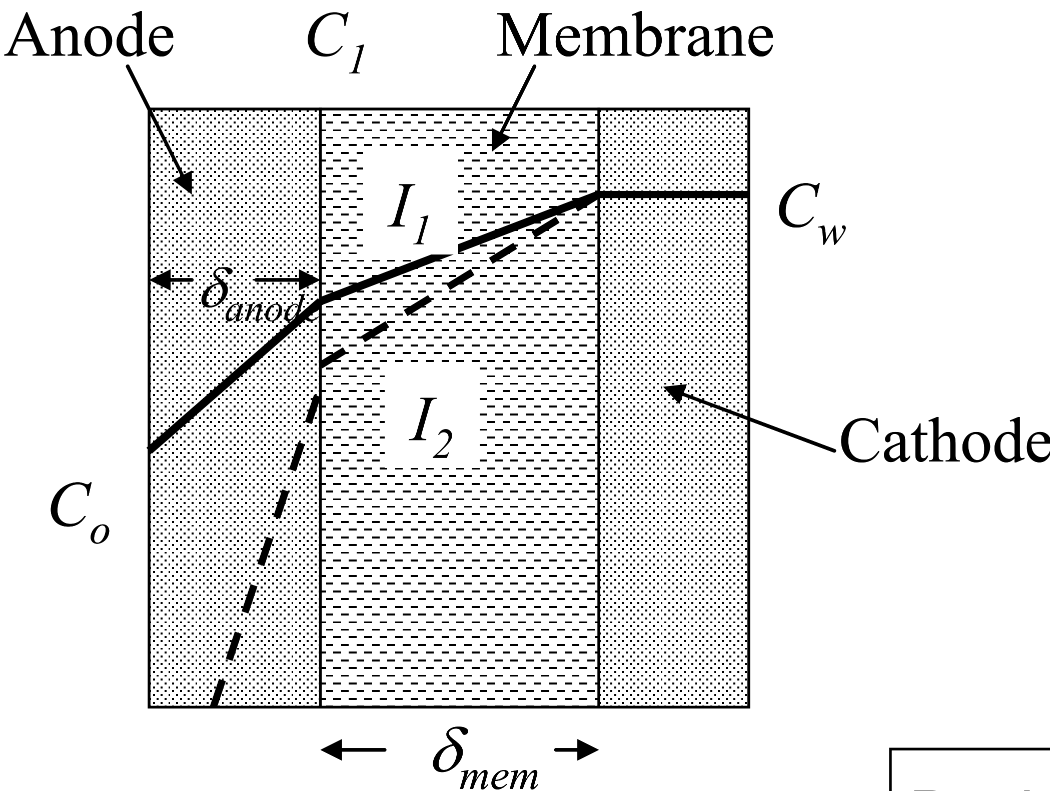
M. Eikerling, Yu. I. Kharkats, A.A. Kornysheve and Yu. M. Volfkovich, *J. Electrochem.Soc.*, **145** 2684 (1998).

Membrane Thickness and Resistance



•Thinner membranes exhibit low constant resistance over wide range of current density

One-Dimensional Analysis of Water Transport



$$\frac{\gamma . I}{F} = \frac{k^o D_w \{C_w(I) - C_1(I)\}}{\delta_{mem}(I)}$$

γ is the electrosmotic coefficient,

I_{bdl} is the current density,

F is the Faraday constant,

Dw is the diffusion coefficient of water

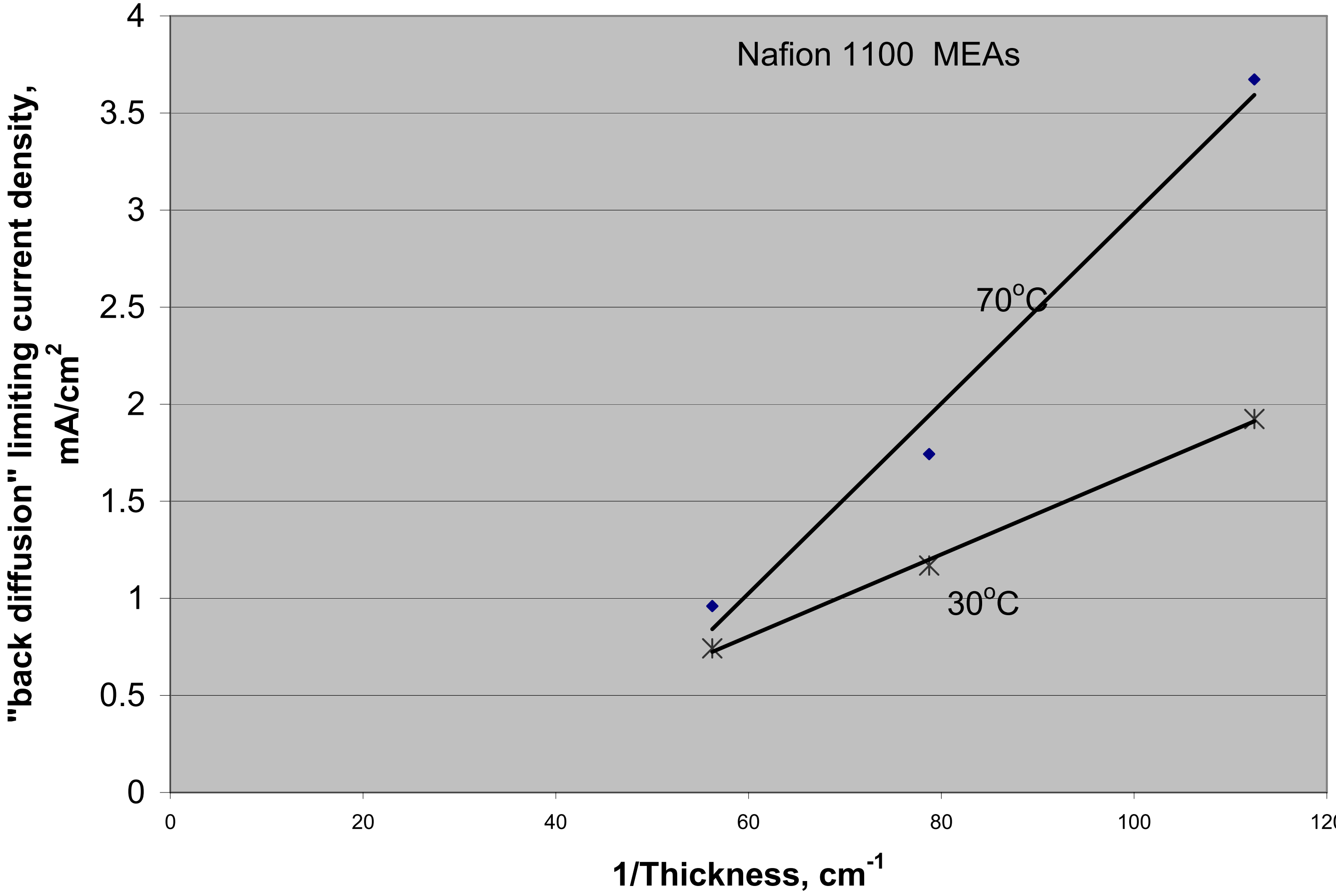
Cw is the concentration at the cathode end of the membrane

δ_{mem} is the thickness of the membrane electrolyte. ,

Back-diffusion Limited current

$$I_{bdl} = \frac{D_w C_w F}{\gamma . \delta_{mem}}$$

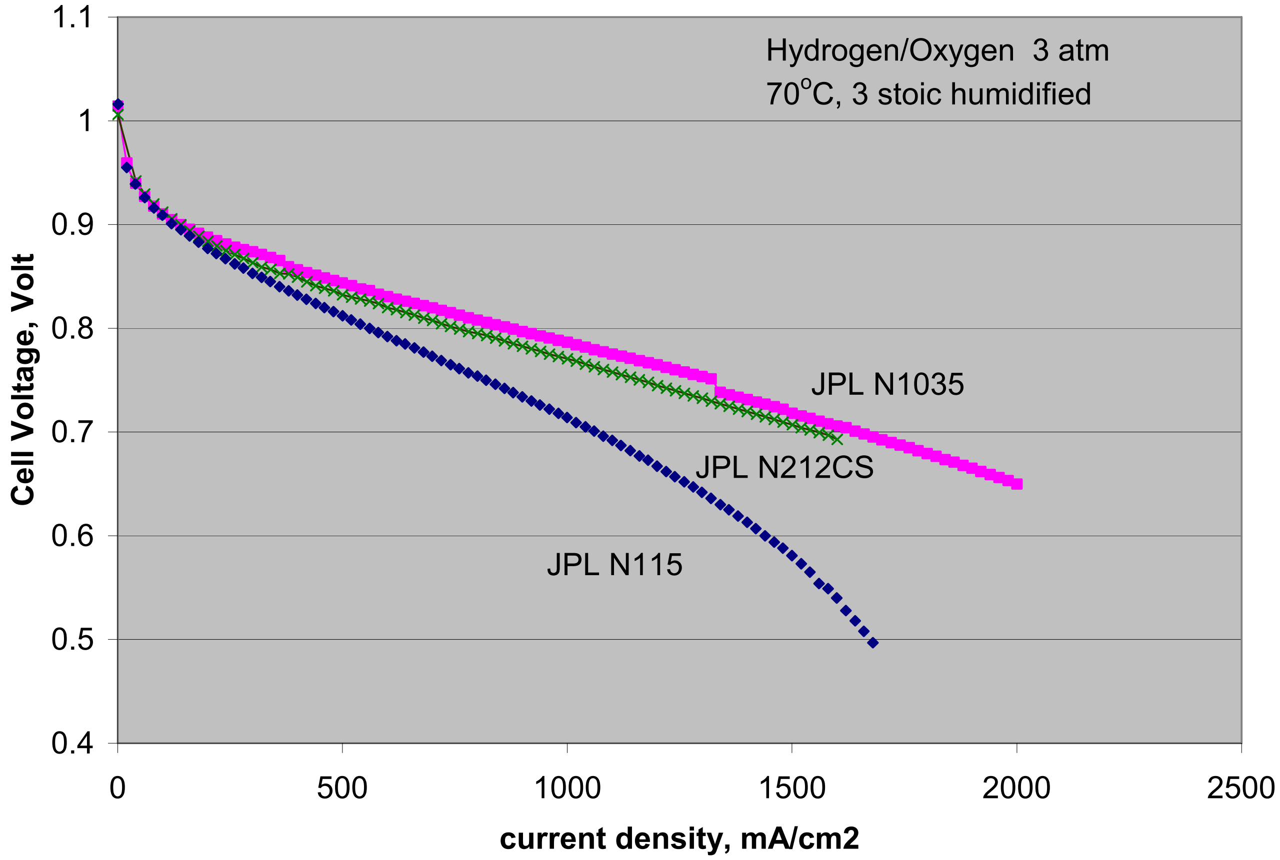
Verification of Analysis



D_w determined to be 2x 10^{-5} cm^2 s^{-1} at 30°C ; consistent with literature data*

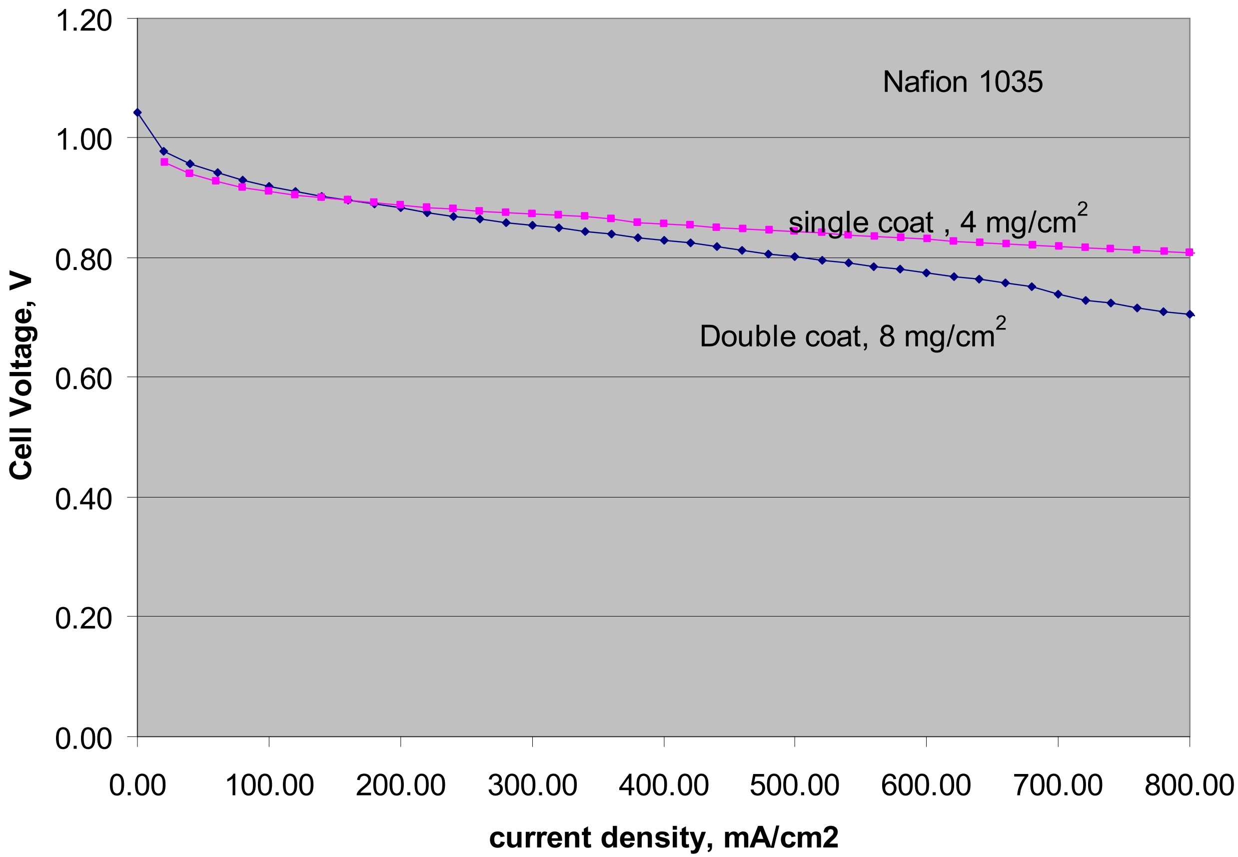
*Thomas A. Zawodzinski, Jr., Thomas E. Springer, John Davey, Roger Jestel, Cruz Lopez, Judith Valeria, and Shimshon Gottesfeld, *J. Electrochem. Soc.,* Vol. 140,1993 p.1981.

JPL MEA Performance Characterization Nafion 1035, 212CS & 115 JPL MEAs



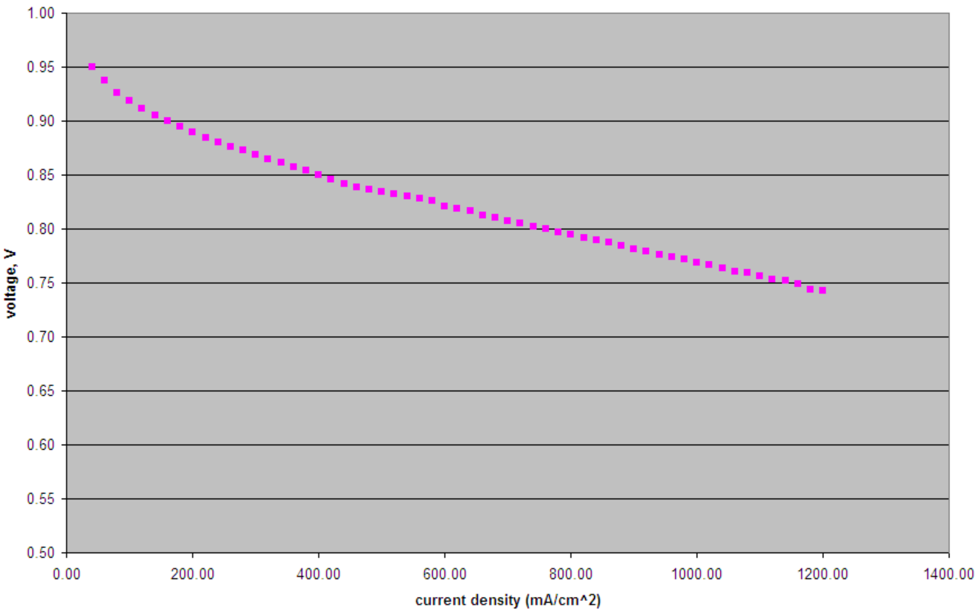
- Performance increases as membrane thickness decreases
- Performance increases as equivalent weight decreases

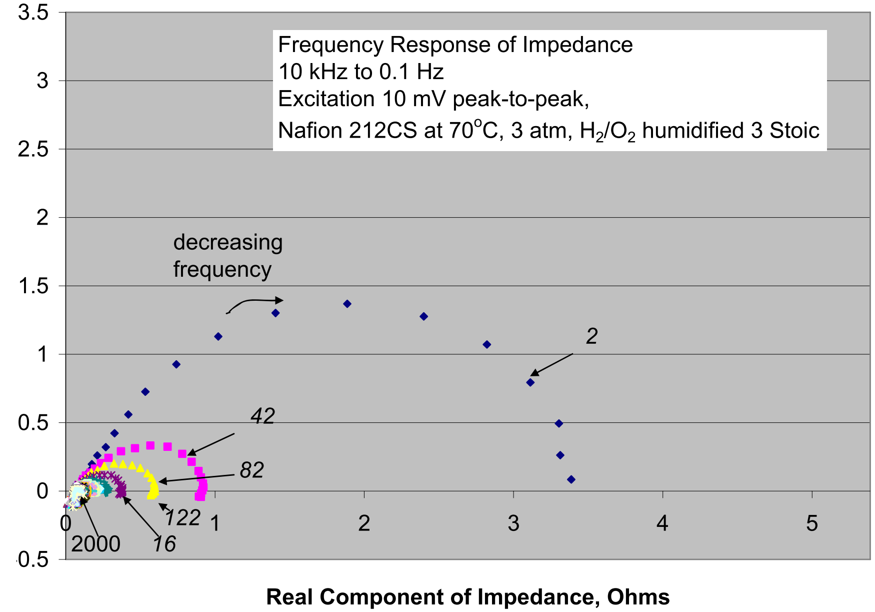
Nafion 1035 JPL
Comparison of 4 mg/cm^2 and 8 mg/cm^2



Double coat (8 mg/cm^2) shows slightly better performance over single coat(4 mg/cm^2) at low current densities. The higher loading does seem to reduce performance at higher current densities.

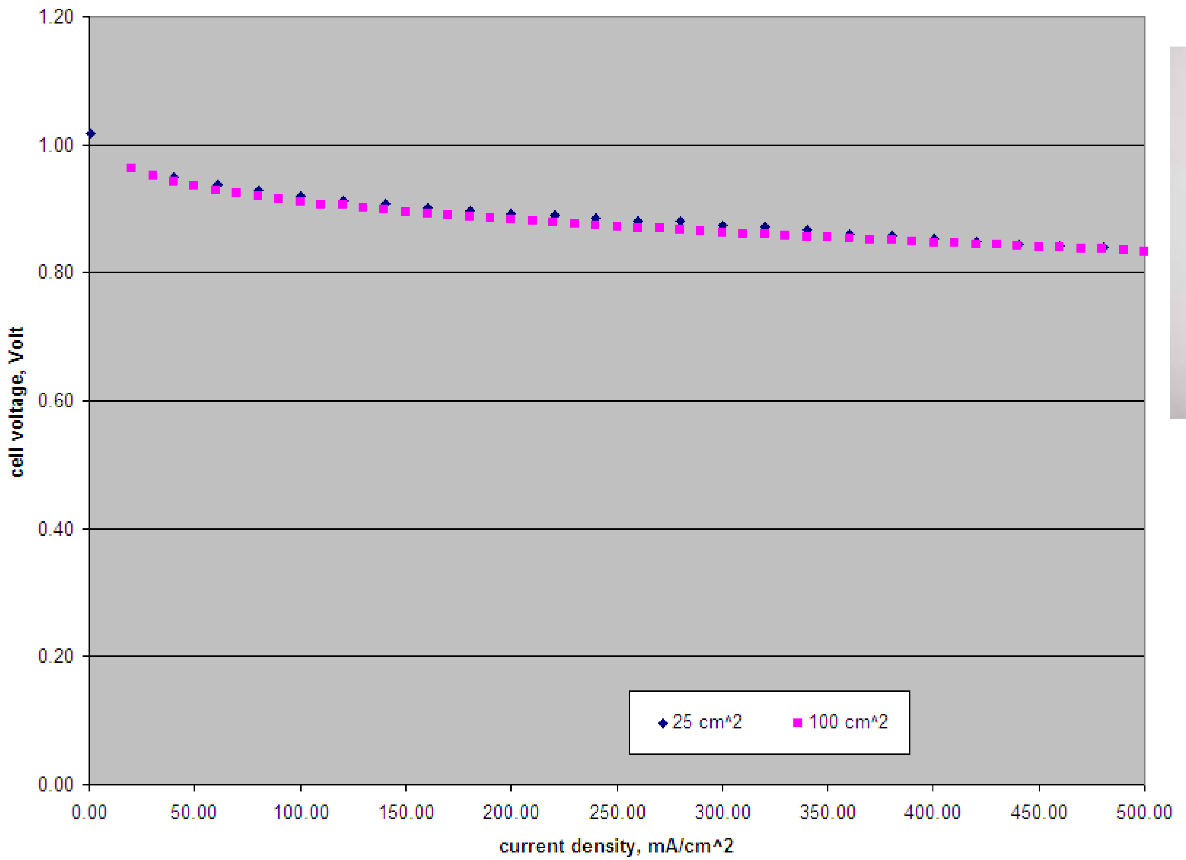
Polarization Characteristics of - 212CS JPL MEA

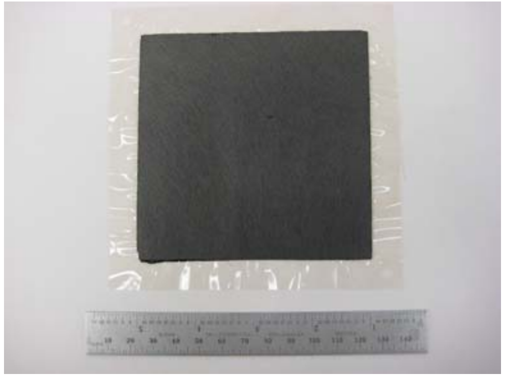




- Mass transfer effects not seen at high current densities
- Thinner membrane allows faster back-diffusion to anode

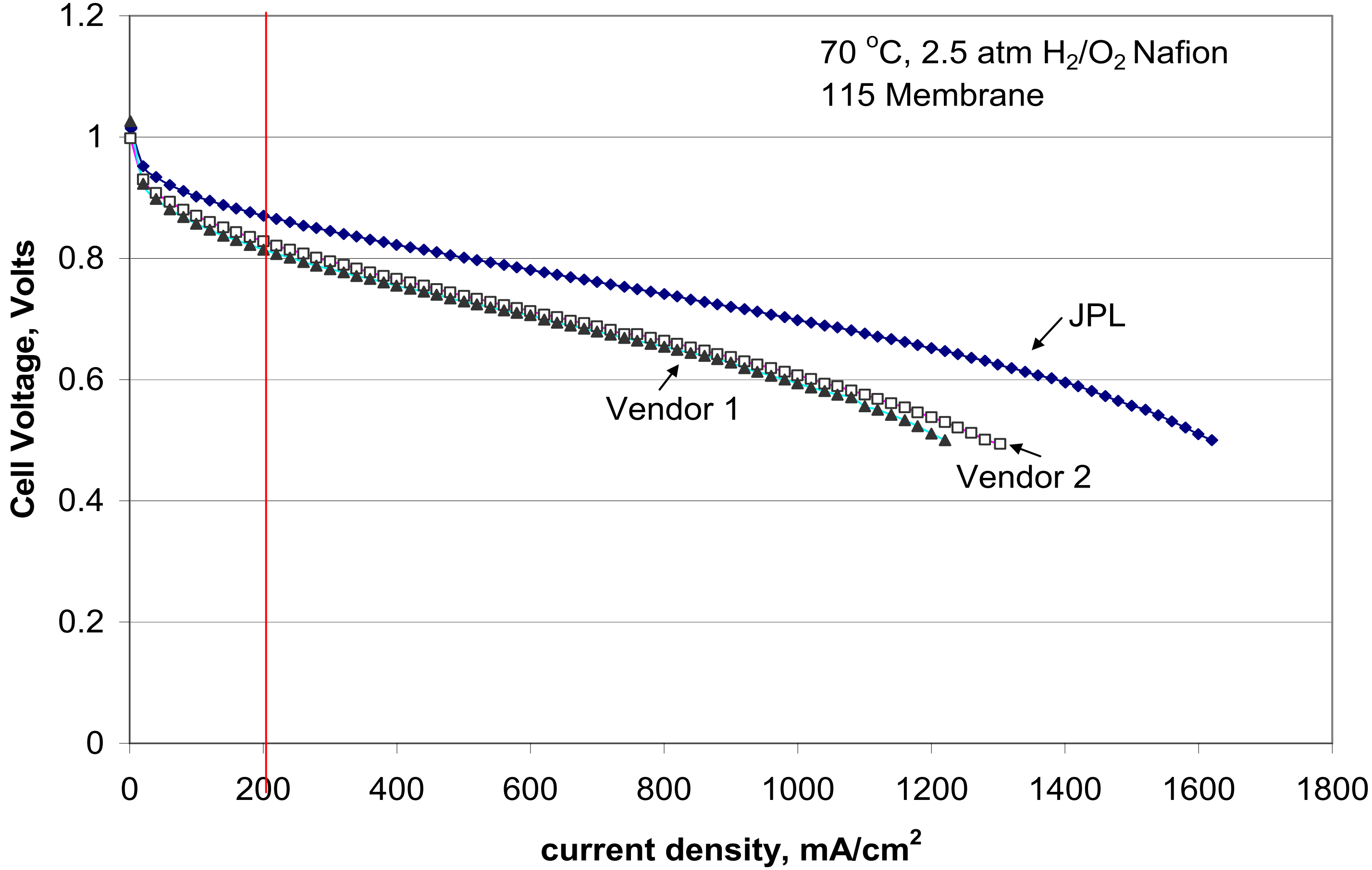
Nafion 212CS based MEA Scale-up Experiments





- Results on 25 cm^2 and 100 cm^2 active area demonstrates scalability of MEA manufacturing process loss in performance

JPL and Vendor MEA Performance Comparison



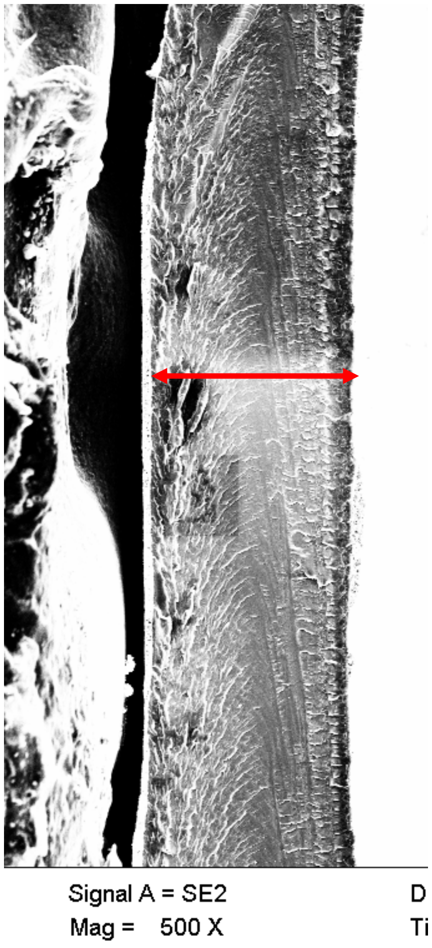
- JPL MEA ~ .88 V at 200 mA/cm^2
- Vendor MEAs ~ .82-.84 at 200 mA/cm2

JPL and Vendor MEA Performance Comparison

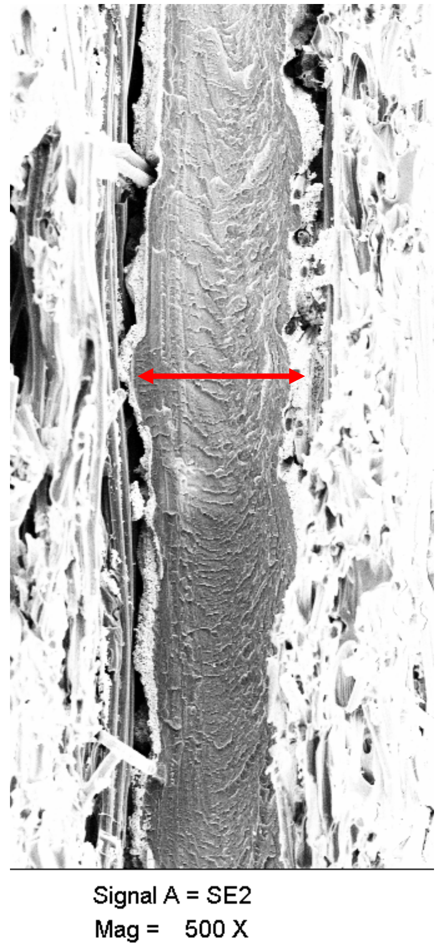
MEA Type	Processing	Gas Diffusion Layer
N115 JPL	Paint / Hot Press	Catalyst coated Toray 060 / Hot Pressed and bonded
N115 Vendor 1	Screen Print / Cold Press ?	Uncatalyzed carbon cloth / Felt; not bonded
N115 Vendor 2	Transfer / Hot Press?	Carbon coated Toray 060; Non-bonded

SEM cross-sections of JPL & Vendor MEAs

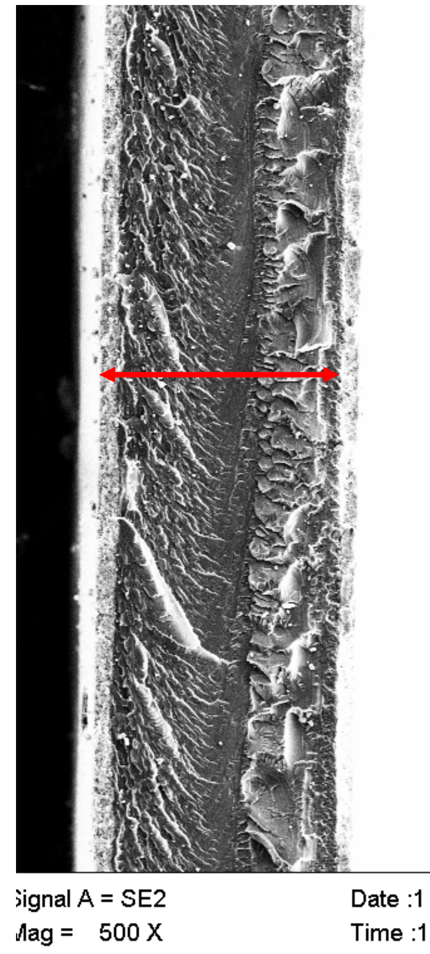
Vendor 1



JPL

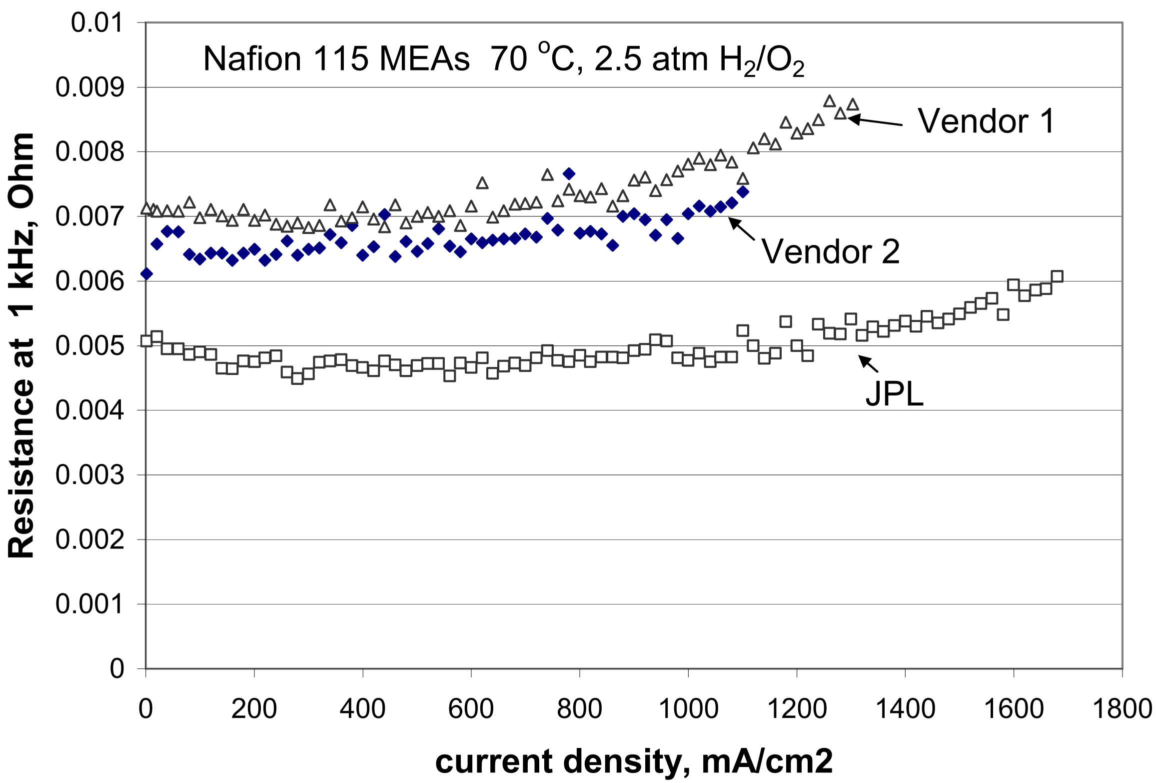


Vendor 2



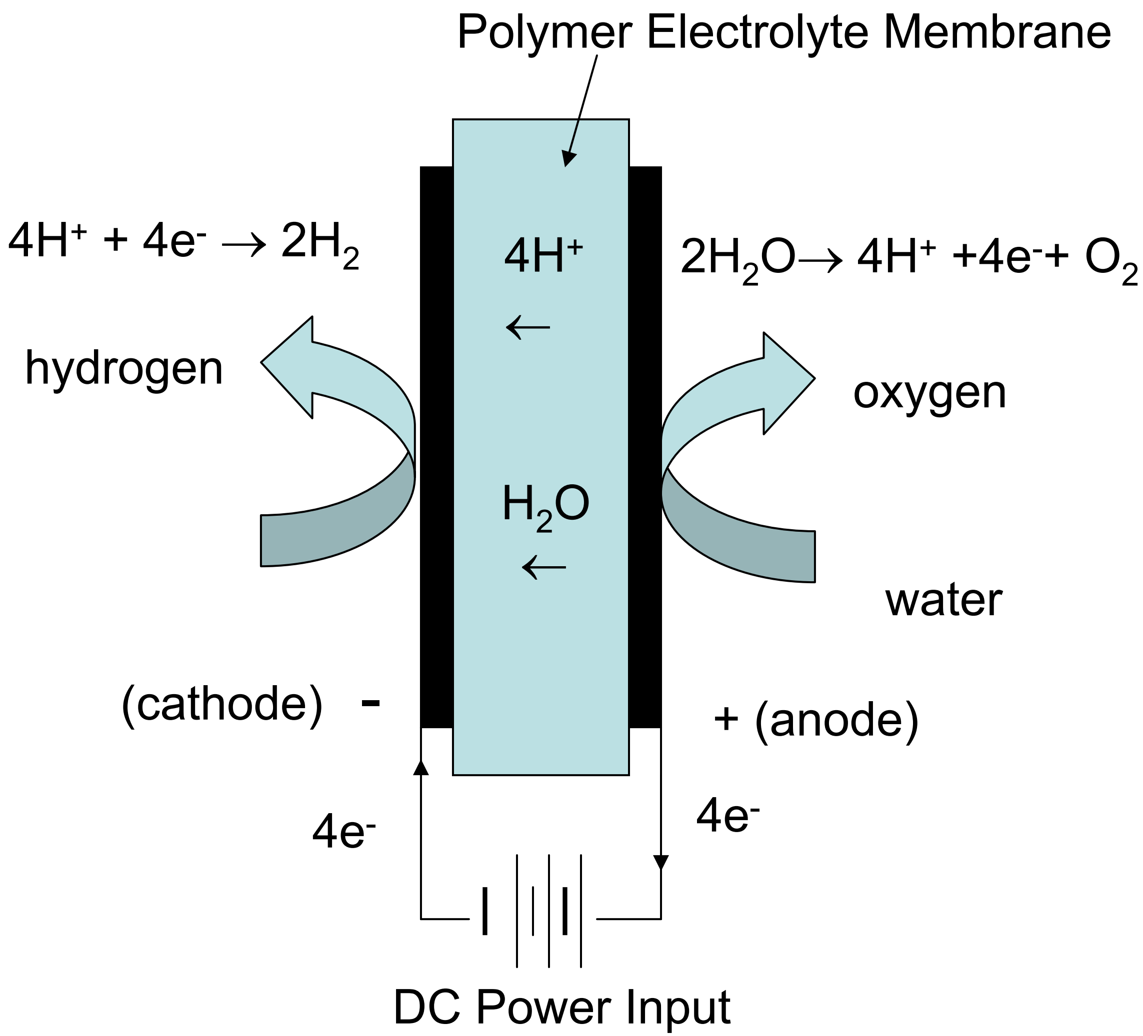
JPL process results in about 10-15% reduction in membrane thickness

JPL and Vendor MEA Performance Comparison

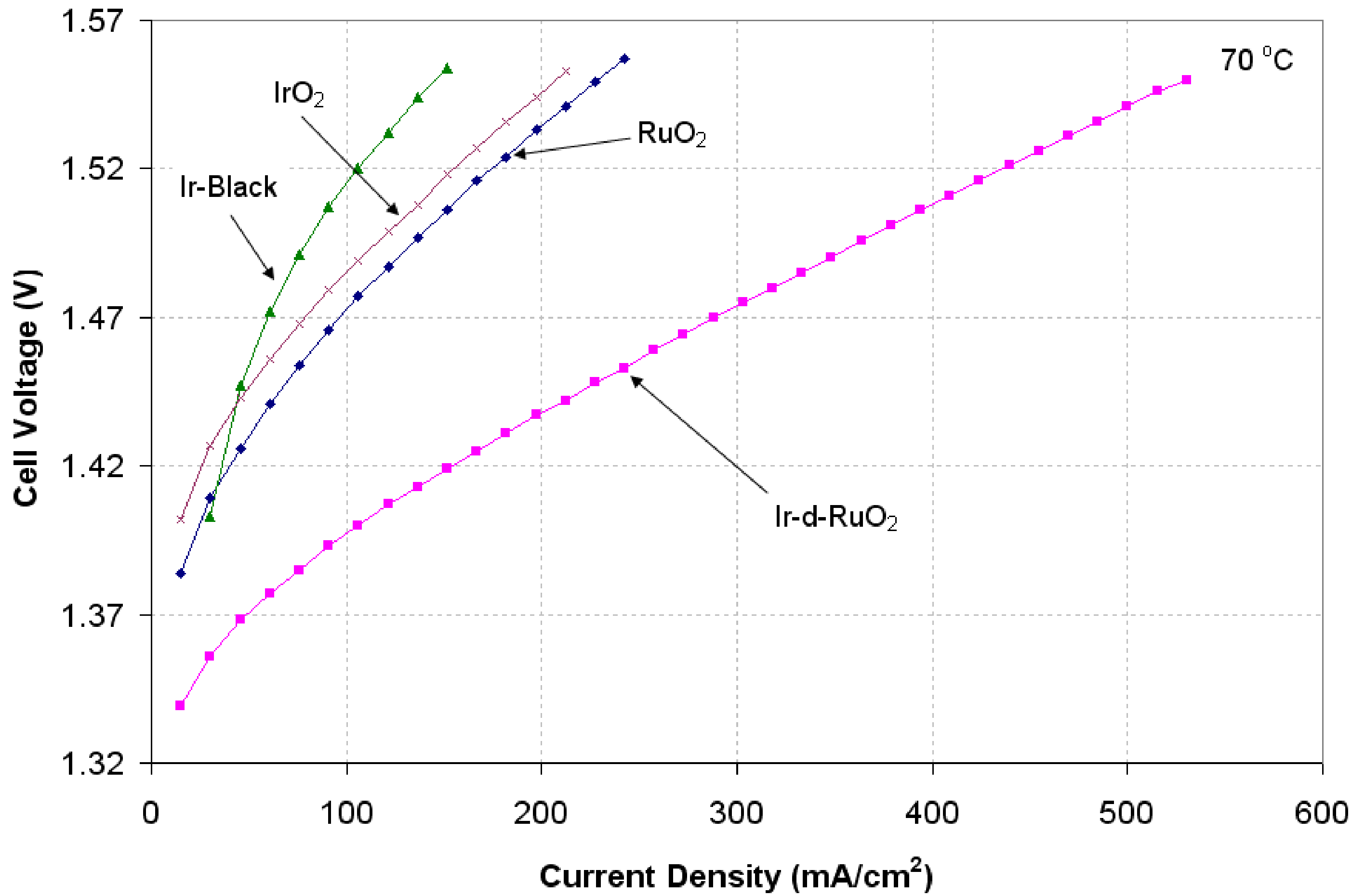


- JPL MEA ~ 5 milliohms,
- Vendor 1 ~6.5 milliohms,
- Vendor 2 ~ 7 milliohms

Schematic of Water Electrolysis

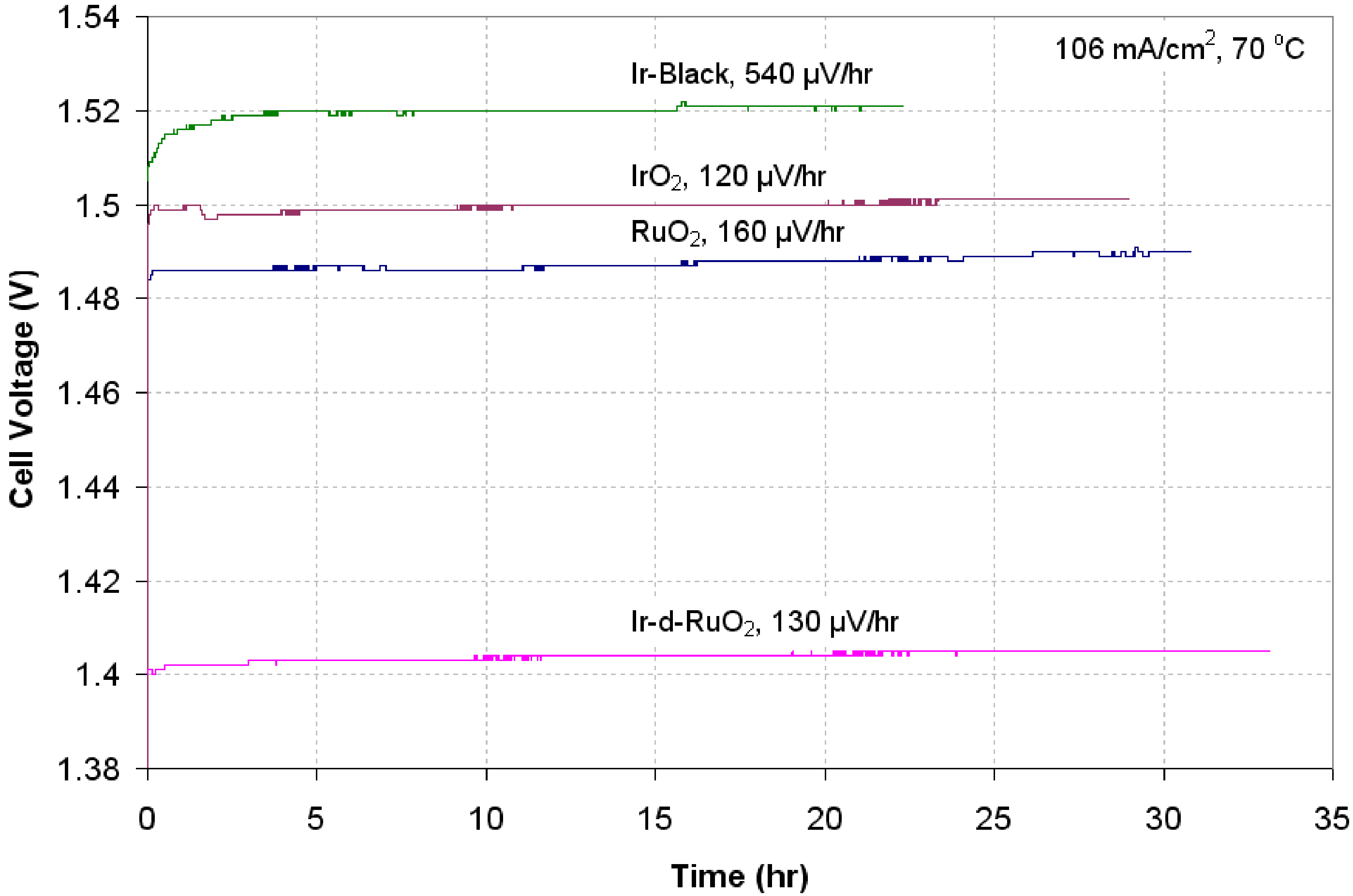


Iridium-doped Ruthenium Oxide Catalyst Performance Versus Commercially Available Materials



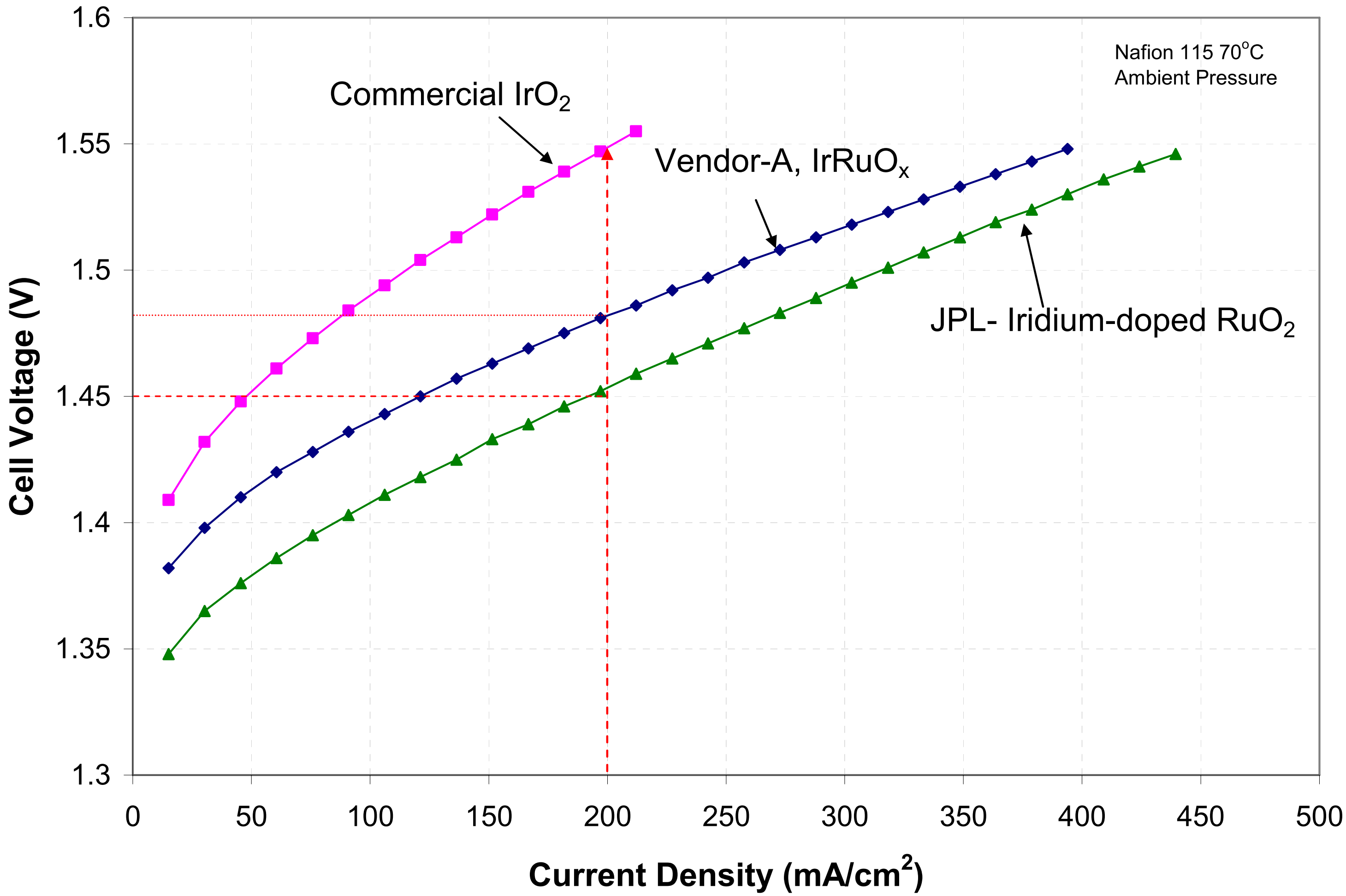
- The iridium-doped ruthenium oxide catalyst performed better than the individual constituents

Short-Term Durability Tests



- Stability testing exhibit the same performance trends as polarization experiments
- Ir-doped ruthenium oxide catalyst as stable as iridium oxide

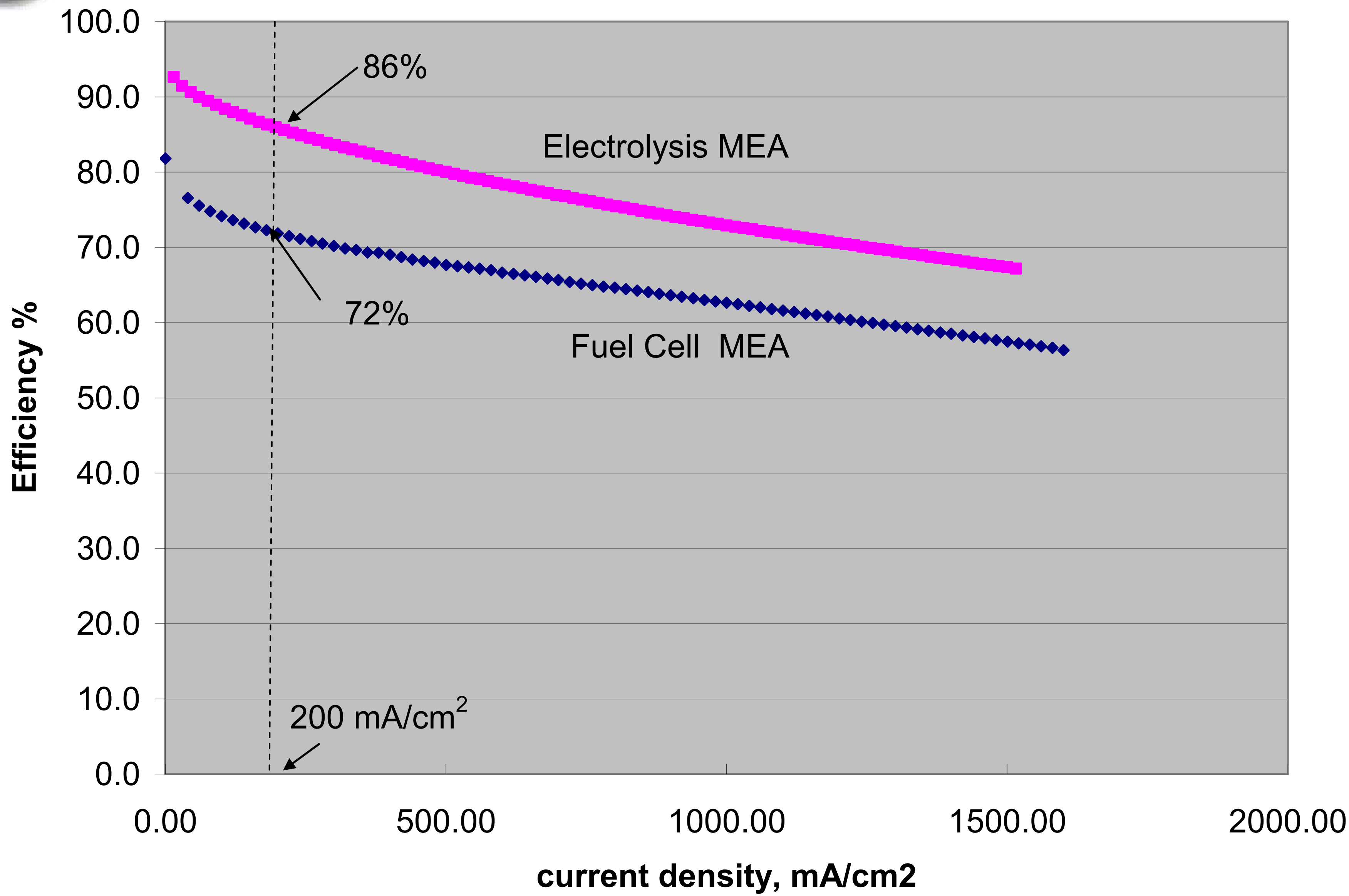
Advances in Electrolysis MEAs at JPL



•JPL's Iridium-doped Ruthenium oxide catalyst exhibits higher performance compared to commercial and vendor-supplied materials.

•With the performance of 1.45V at 200 mA/cm^2 these JPL MEAs have the potential of meeting the full success criteria

Status of the Performance of Advanced MEAs from JPL



Demonstrated Performance exceeds minimum success criteria for MEAs

Acknowledgement

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