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Gore's Development Path to a Commercial Automotive Membrane Electrode Assembly

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W. L. Gore & Associates

A company with an unrelenting commitment to fitness-for-use of our products and a culture that drives continuous innovation to deliver products that make a difference in peoples' lives.

"Our products will do what we say they will do".

Bob Gore
former CEO, current Chairman of the Board

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Creative Technologies Worldwide

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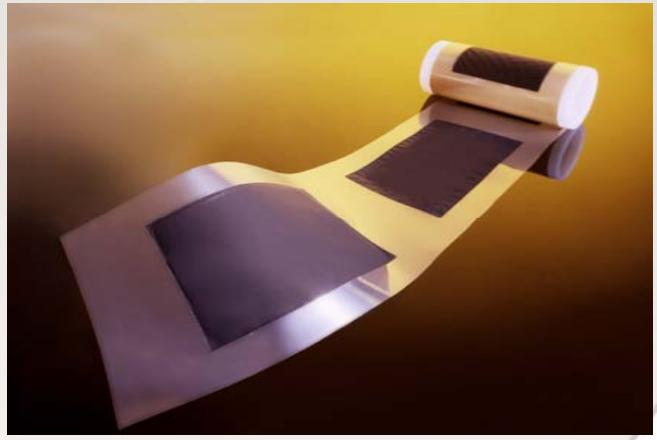
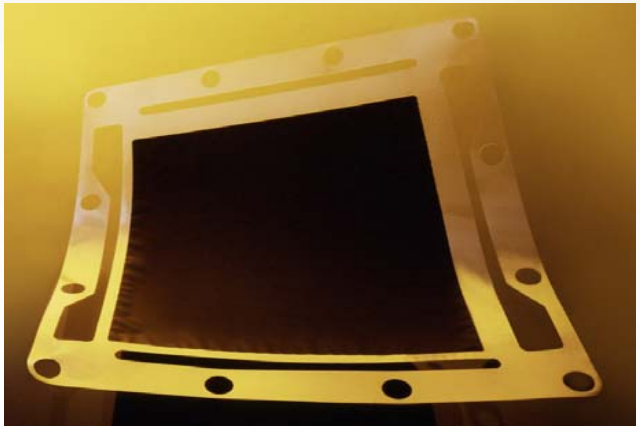
Gore Fuel Cell Technologies

- Supplying advanced MEA products to the industry since 1995
  - Technology Leadership
  - Strong Partnerships
  - Broad Experience





- Committed to enabling commercialization of fuel cells
  - Application-specific MEA products

Global Gore Fuel Cell Team

GORE CONFIDENTIAL

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Internal Combustion Engine

Zero emissions (environmental)

More efficient (fuel savings)

Fuel Flexible (energy security)

Less moving parts (reliability)

Quieter, lower heat signal (military uses)

Fuel Cells

Lower weight/volume

Rapid "recharging"

Environmental benefits

Lower lifecycle costs

Batteries

Distributed generation (Reliability, cost)

Low emissions (environmental)

High efficiency (fuel savings)

Electric Grid

$$\left(\frac{\$}{\text{kW-hr}}\right)_{\text{system}}$$

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Electric Grid

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Automotive sets the standard

- Most demanding technically
- Most cost-sensitive
- Highest quality expectations
- Highest volume potential

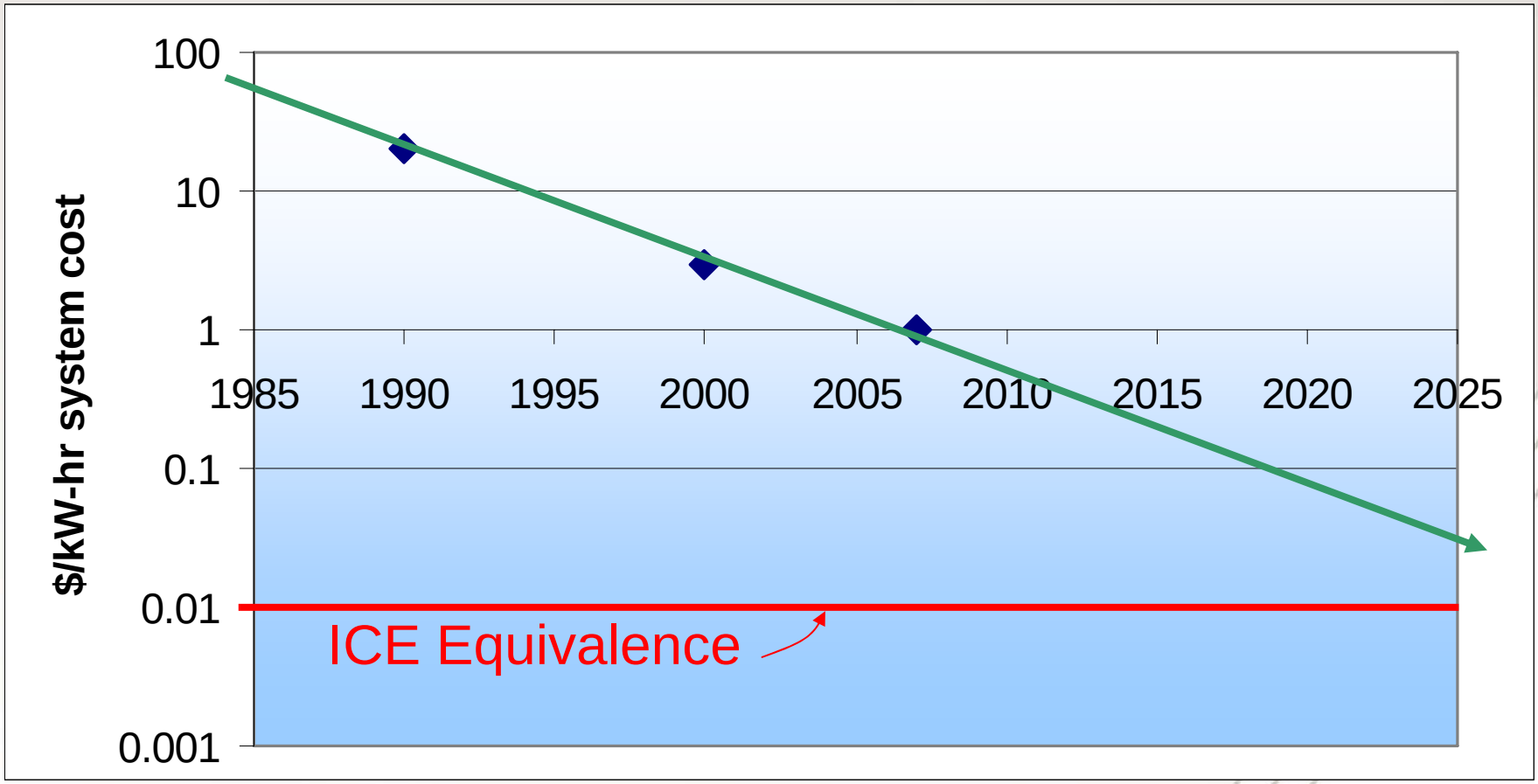
Cold Start
Freeze Survivability

High Power
Operation

Rapid Power
Transients

Stop / Start

$/kW-hr system cost



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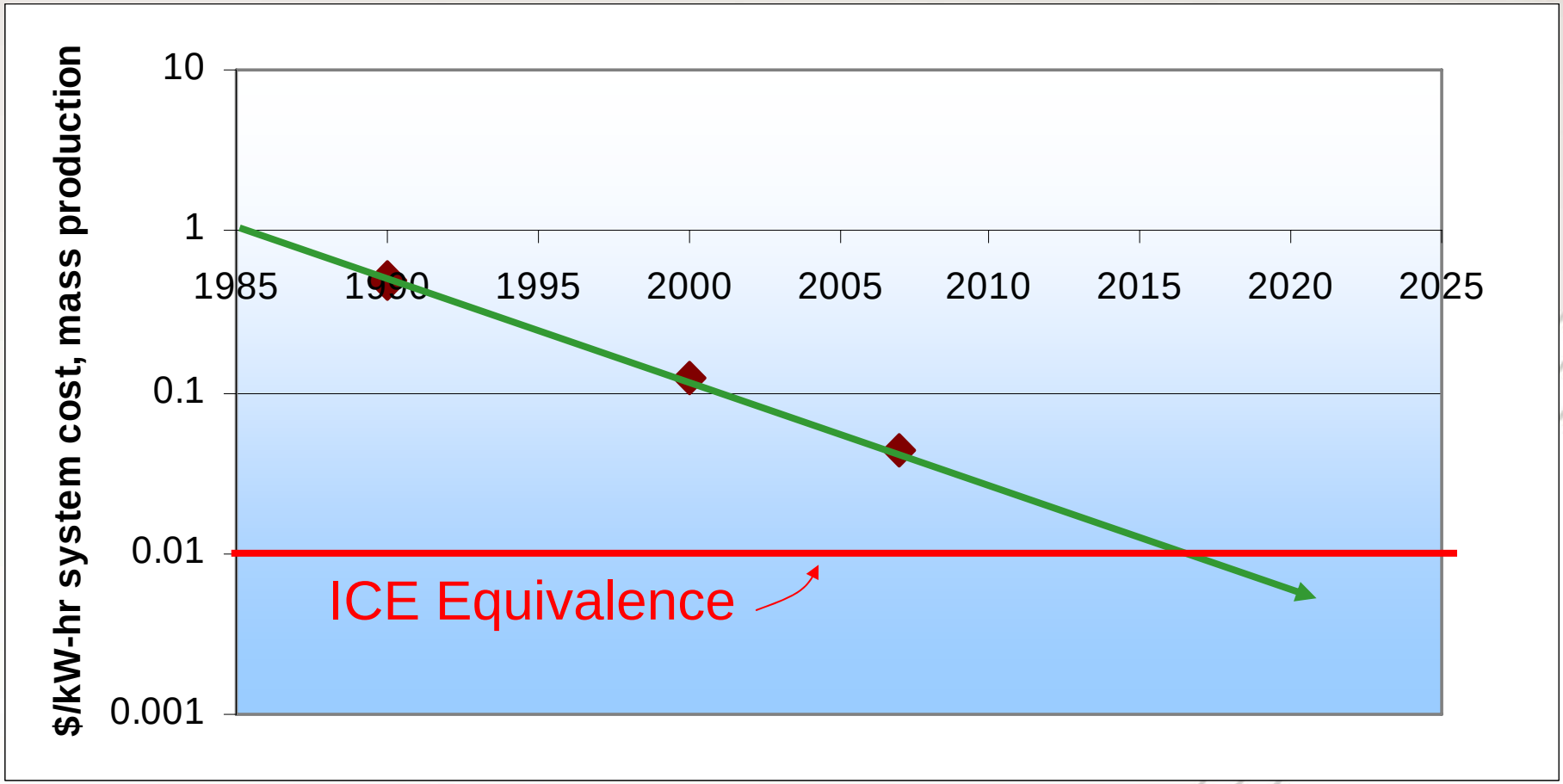
Projected $/kW-hr system cost, assuming mass production



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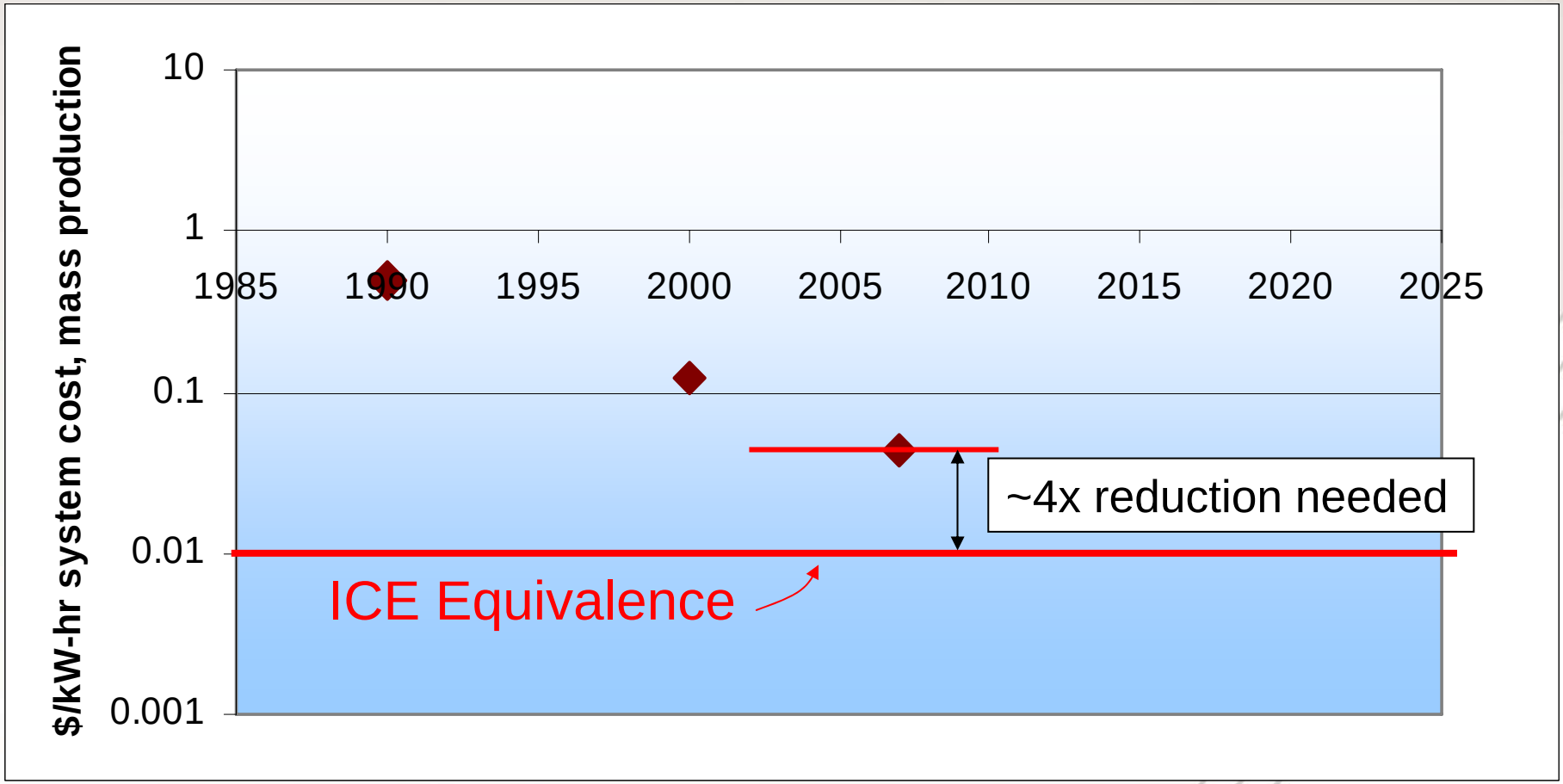

How can we close this gap? *….from an MEA supplier's perspective…*

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$$\left(\frac{\$}{\text{kW-hr}}\right)_{\text{system}}$$

Variable Cost

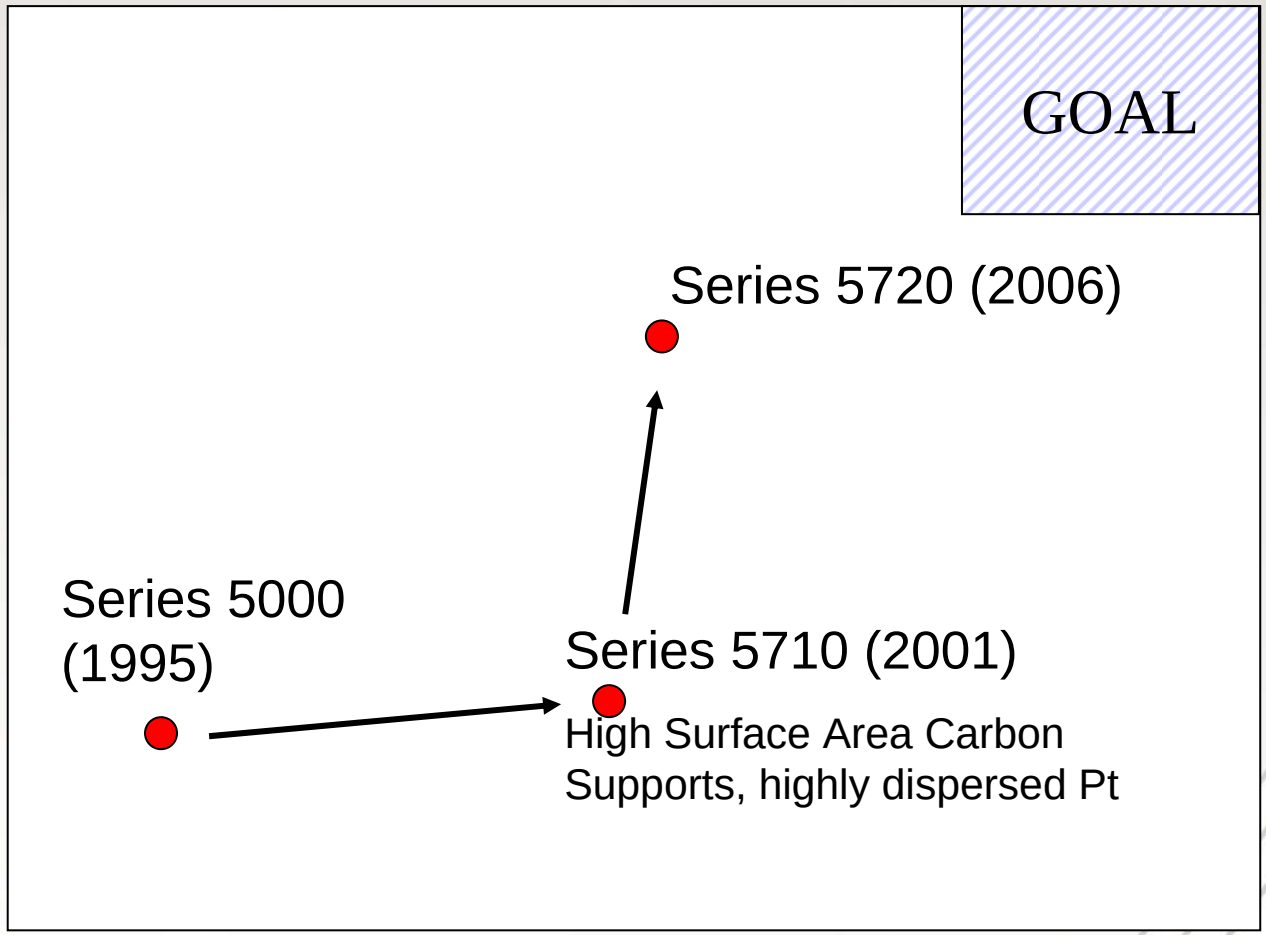
Fixed Cost

Variable Cost Reduction

- Membrane costs are projected to meet the most aggressive automotive cost targets in volume
  - Perfluorinated membranes (Mathias, et al. ECS Interface, Fall 2005)
- Largest MEA Variable Cost: Catalyst
  - Today's typical loadings are ~2-5x the long-term targets
  - Need to improve *durability* and *reduce loadings*
  - Largest remaining "materials" challenge

Electrode Development Trends

Electrode Development Trends



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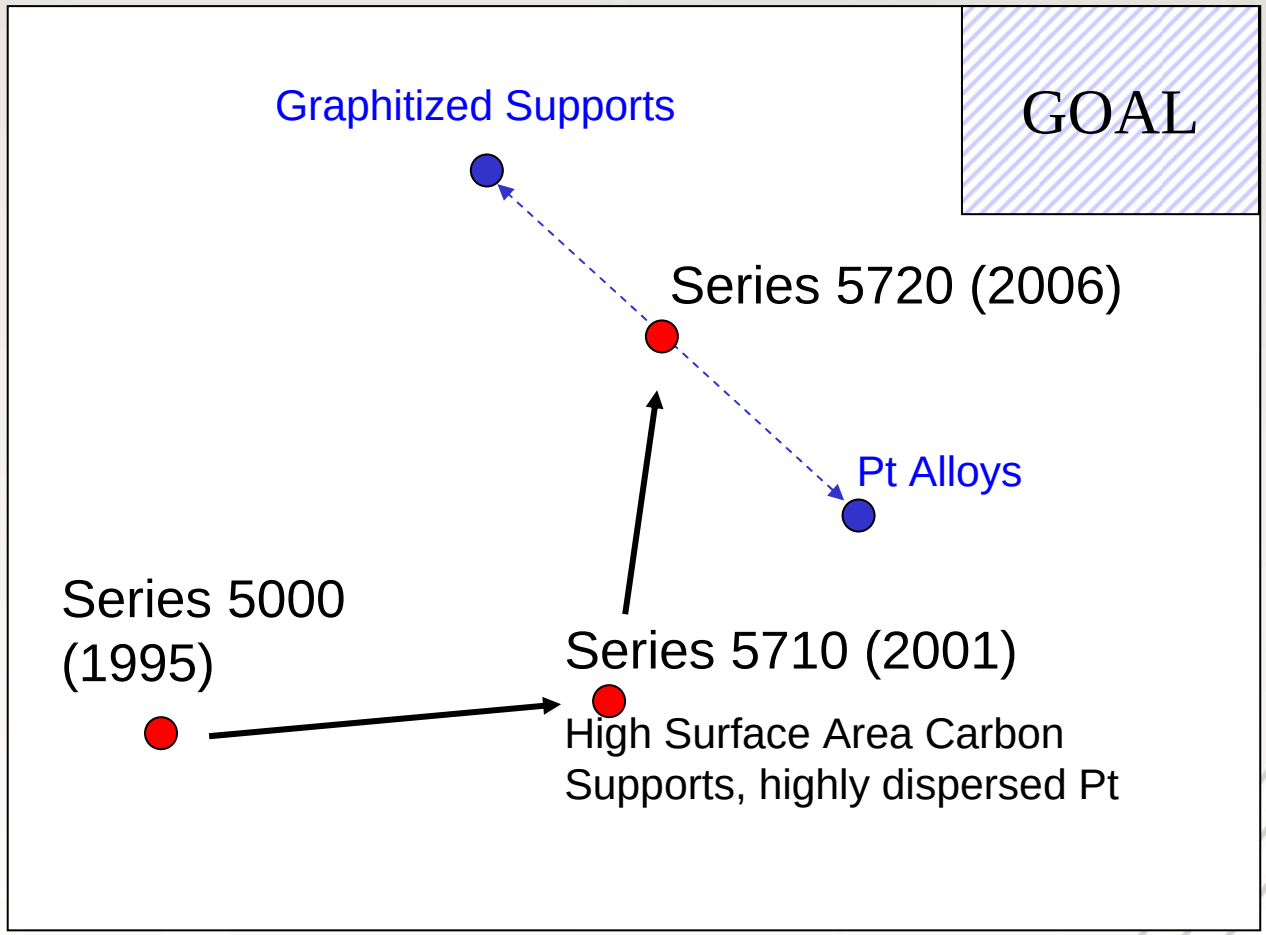
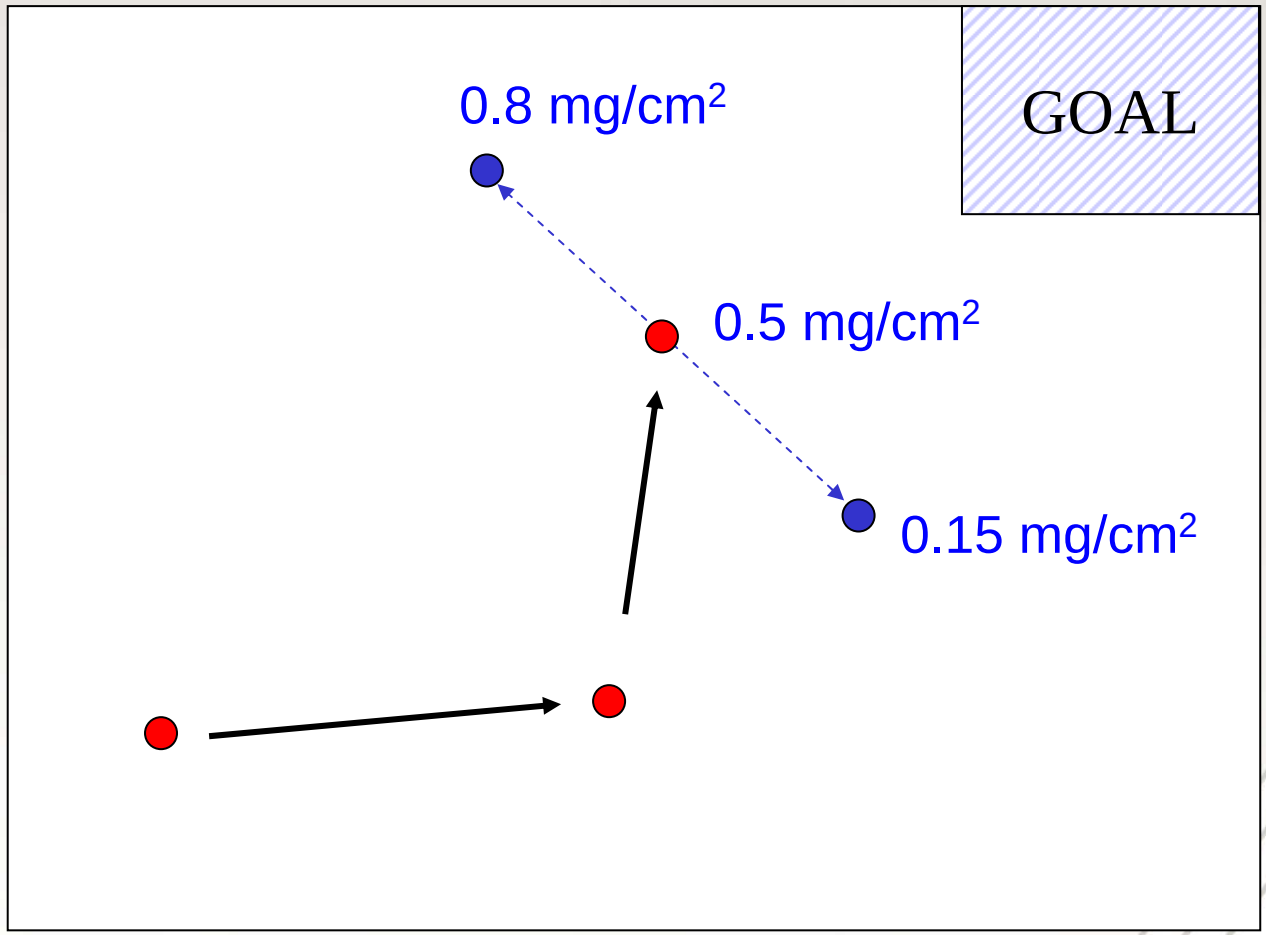
Electrode Development Trends



Electrode Development Trends



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$$\left(\frac{\$}{\text{kW-hr}}\right)_{\text{system}}$$

Higher Power Density

Higher Power Density

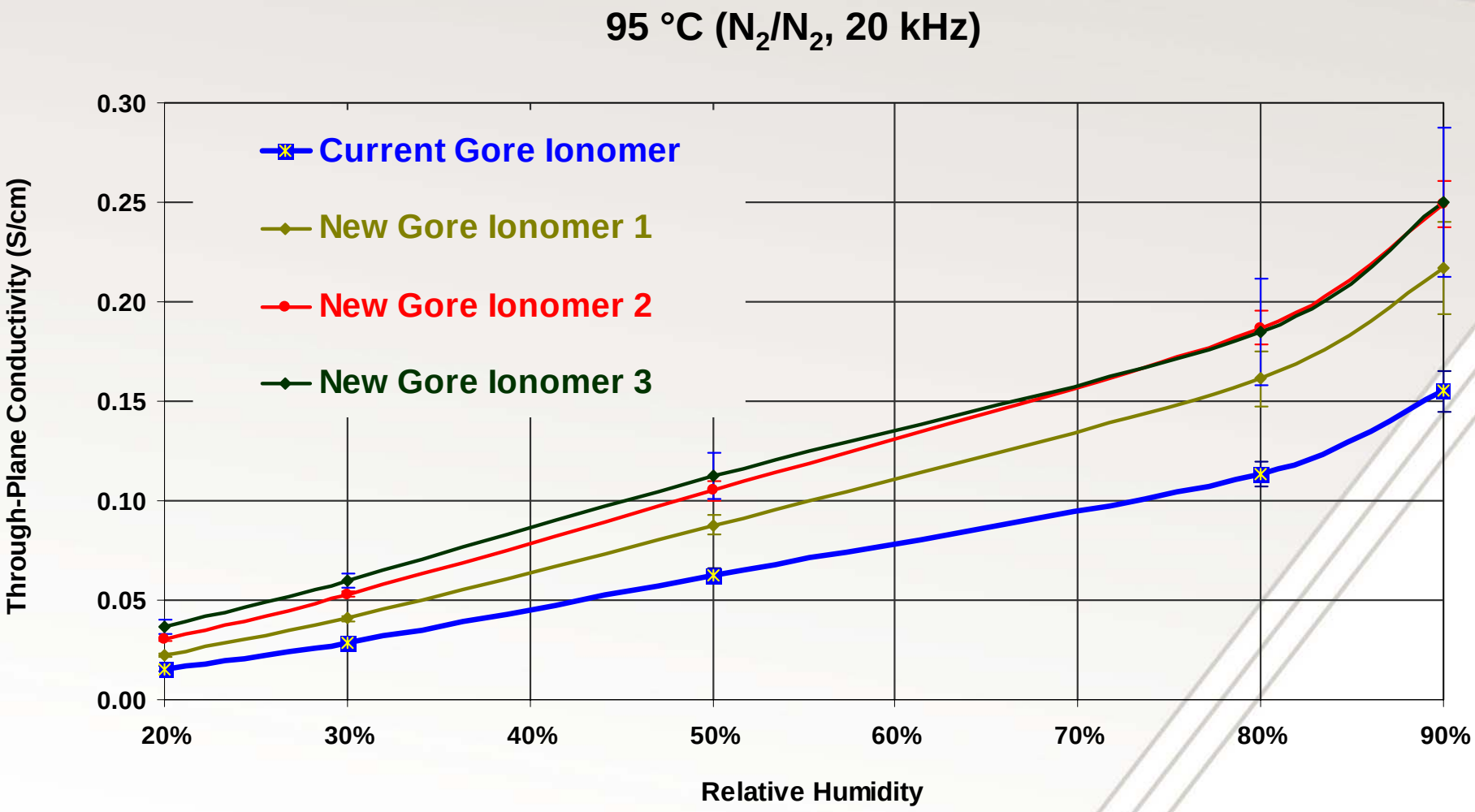
- Designing stacks to run at higher rated current density can result in significant cost savings / stack
  - Lower number of cells
  - Smaller cells, less MEA / stack
- Typically, this results in an efficiency tradeoff, as lower voltages are reached at higher current density

How much of a tradeoff is this for automotive applications?

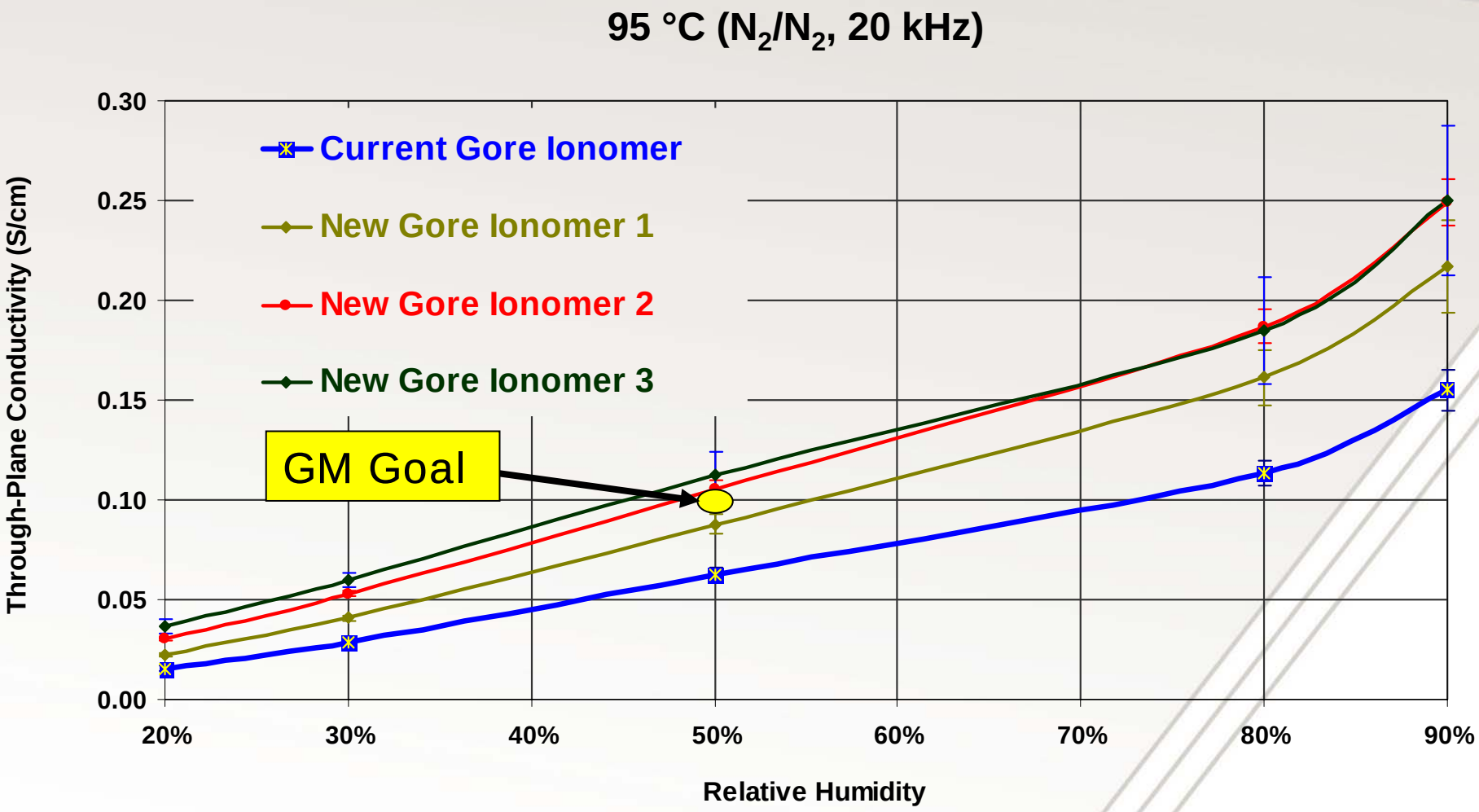
Calculations provided by Nuvera

- Demonstration of large impact of cell count reduction from higher current density operation, and relatively small efficiency impact on actual driving cycle
- Upon request by Nuvera, these calculations are not included for broad dissemination.
- To request a copy, contact James Cross at Nuvera

Gore Ionomer Development



Gore Ionomer Development



System
Simplification

system

Longer Lifetime

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System Simplification / Durability

Reduce / Eliminate Humidification Reduce Radiator Size (Higher T)	Membrane Dehydration Accelerate Chemical Attack
Simplify Start-up / Shut-down Simplify Voltage Controls	Carbon Corrosion Platinum Dissolution
Lower Fuel Purity Requirements Lower Air Purity Requirements	Anode Catalyst Poisoning Cathode Catalyst Poisoning

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System Simplification / Durability

Reduce / Eliminate Humidification Reduce Radiator Size (Higher T)	Membrane Dehydration Accelerate Chemical Attack

Can the MEA ***Operate*** in Hot, Dry Conditions?

Can the MEA ***Survive*** in Hot, Dry Conditions?

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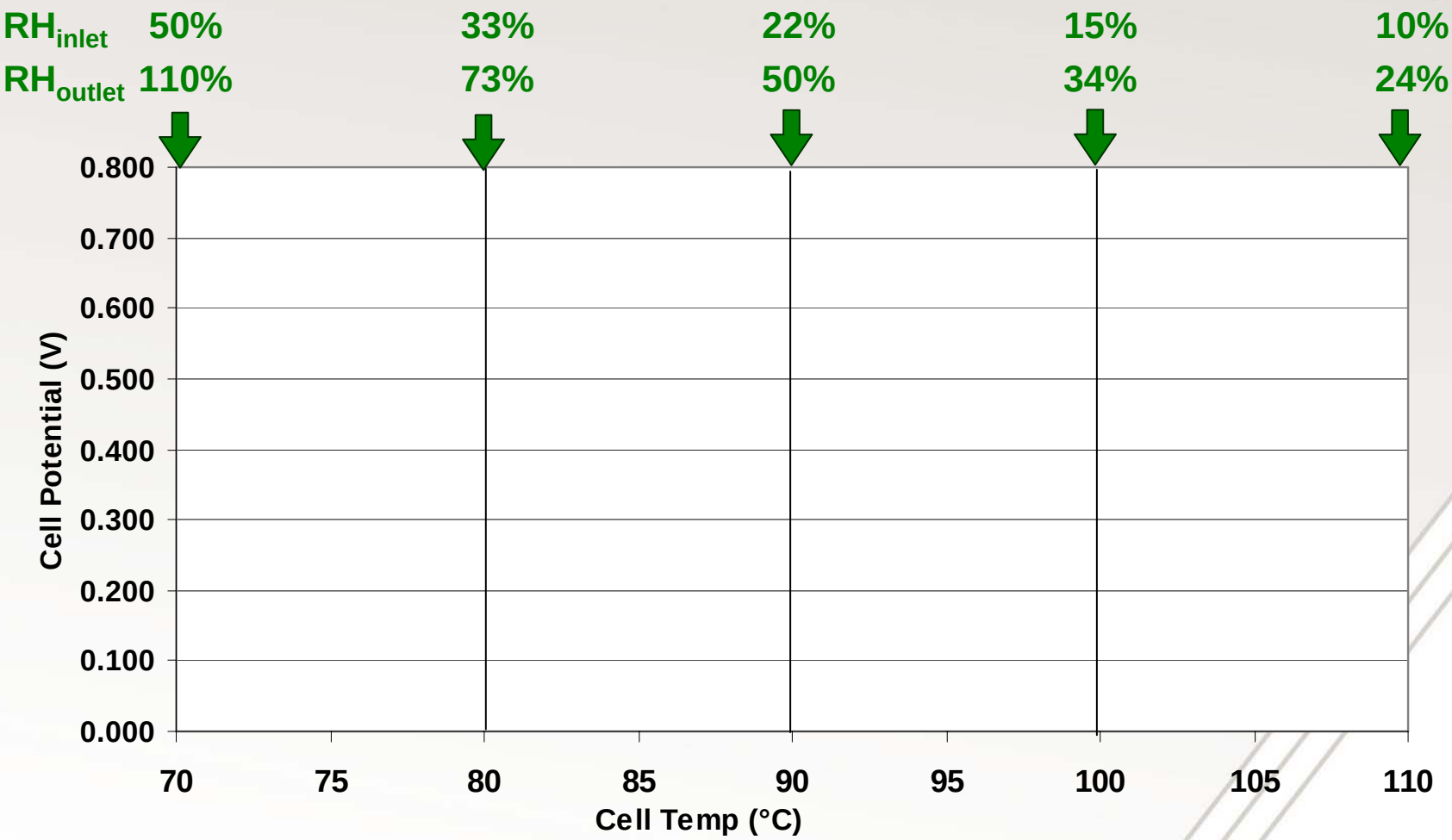
RH sensitivity at 1200 mA/cm^2



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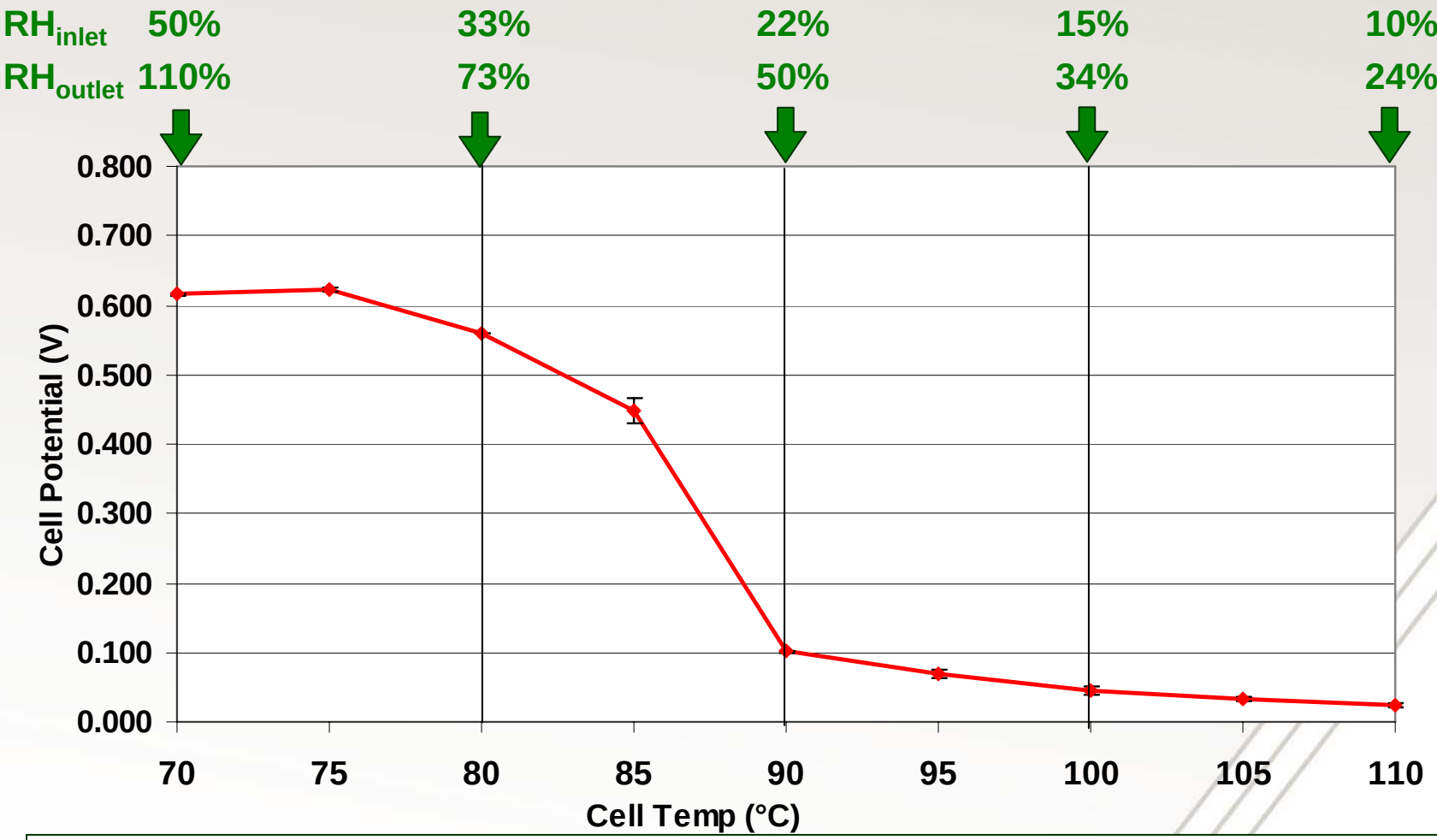

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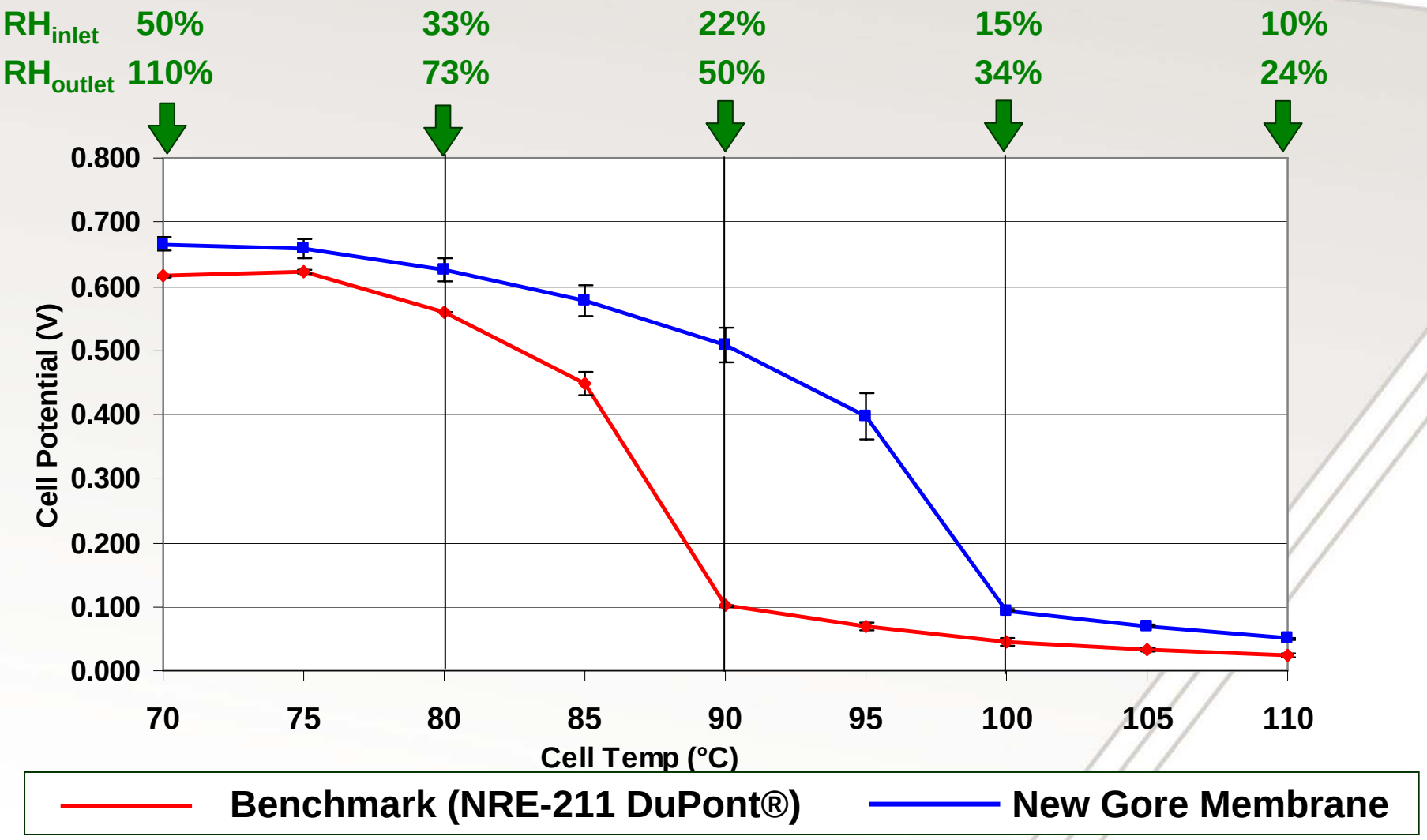

110°C Cell Temperature

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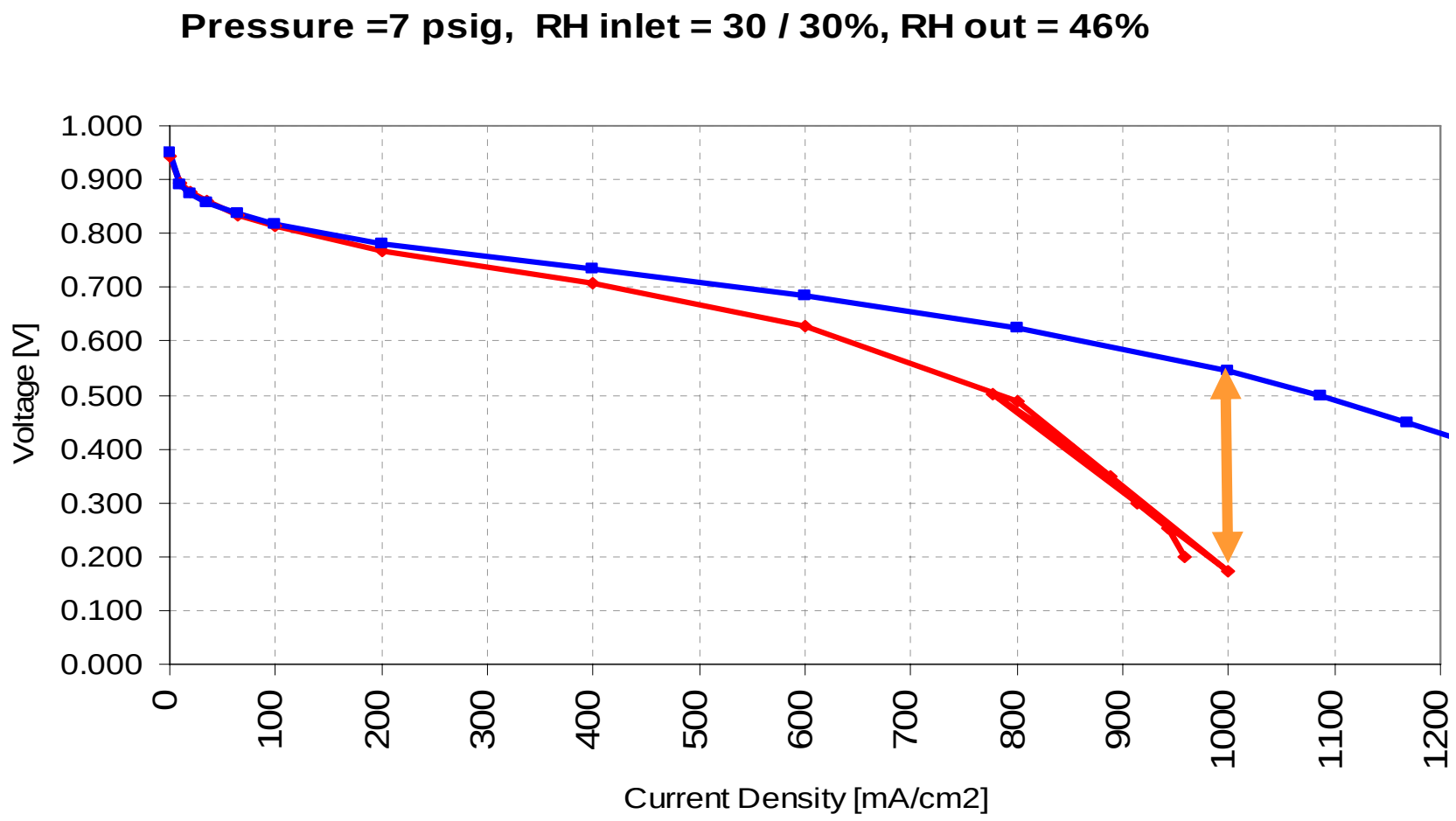

Benchmark (NRE-211 DuPont®)

New Gore Membrane

Can it Survive?

- Two key aspects to membrane durability:
  - Mechanical durability
    - RH Cycling
  - Chemical durability
    - OCV Hold testing

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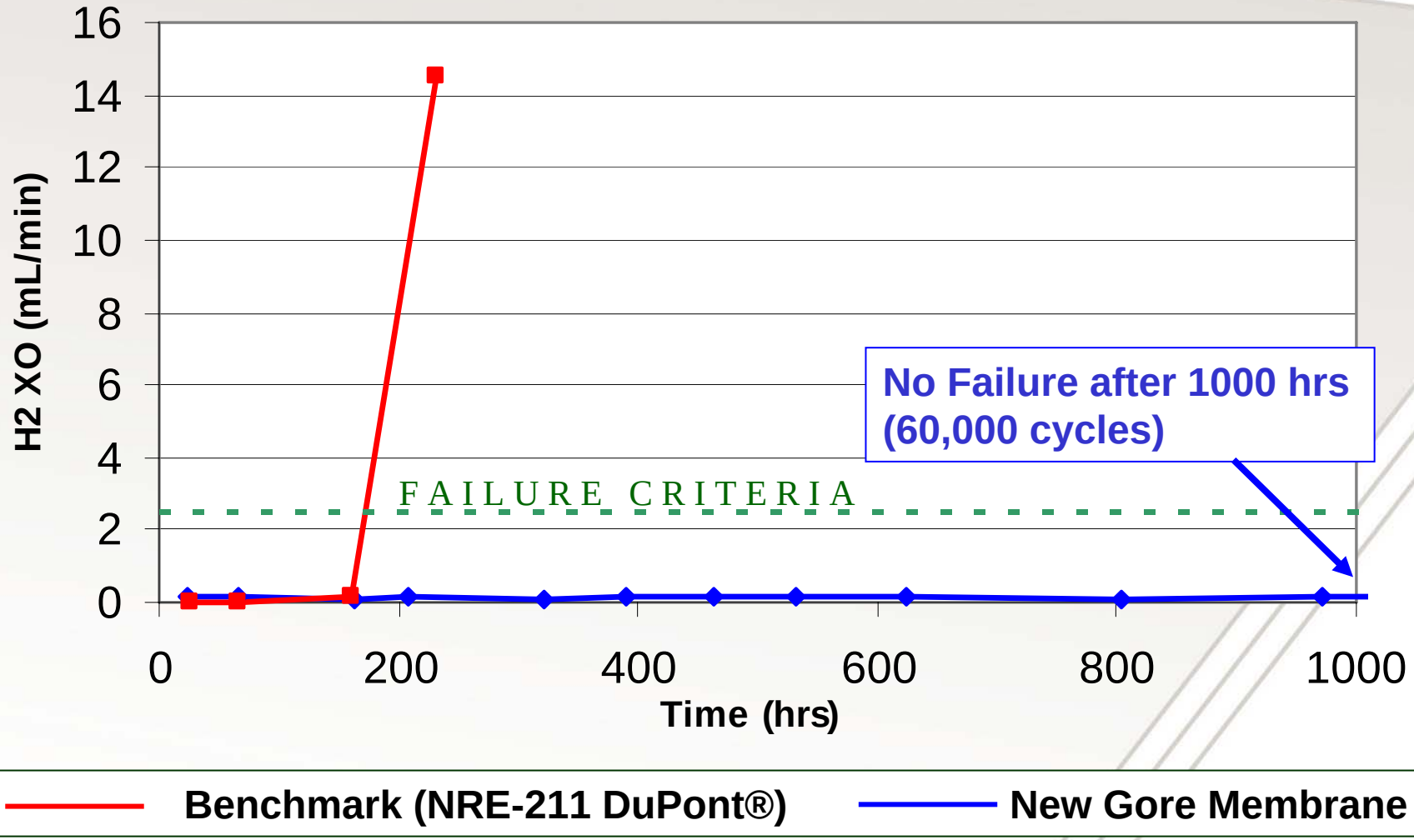
Relative Humidity Cycling (N_2)



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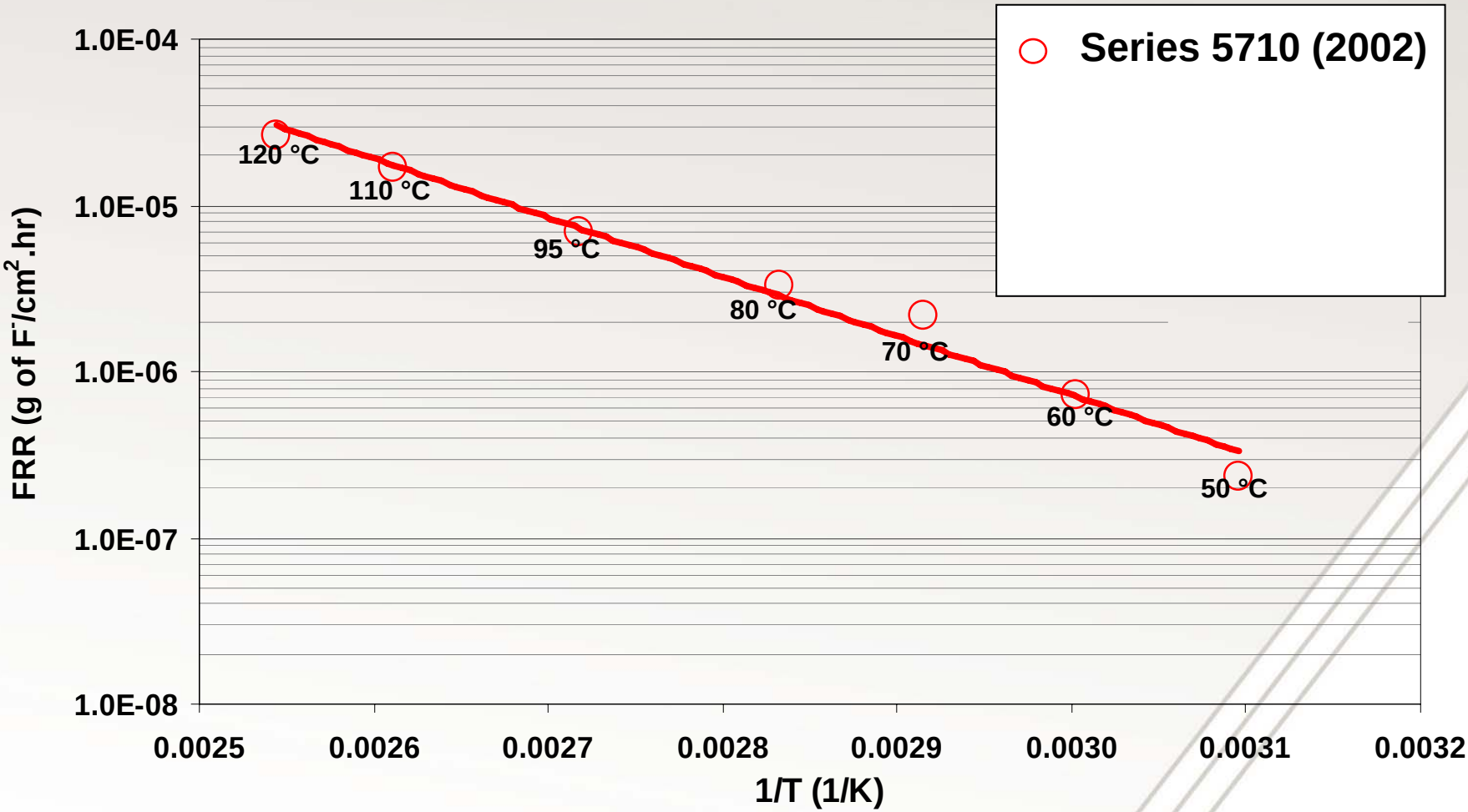
Rate of Chemical Degradation
(OCV Hold Test)



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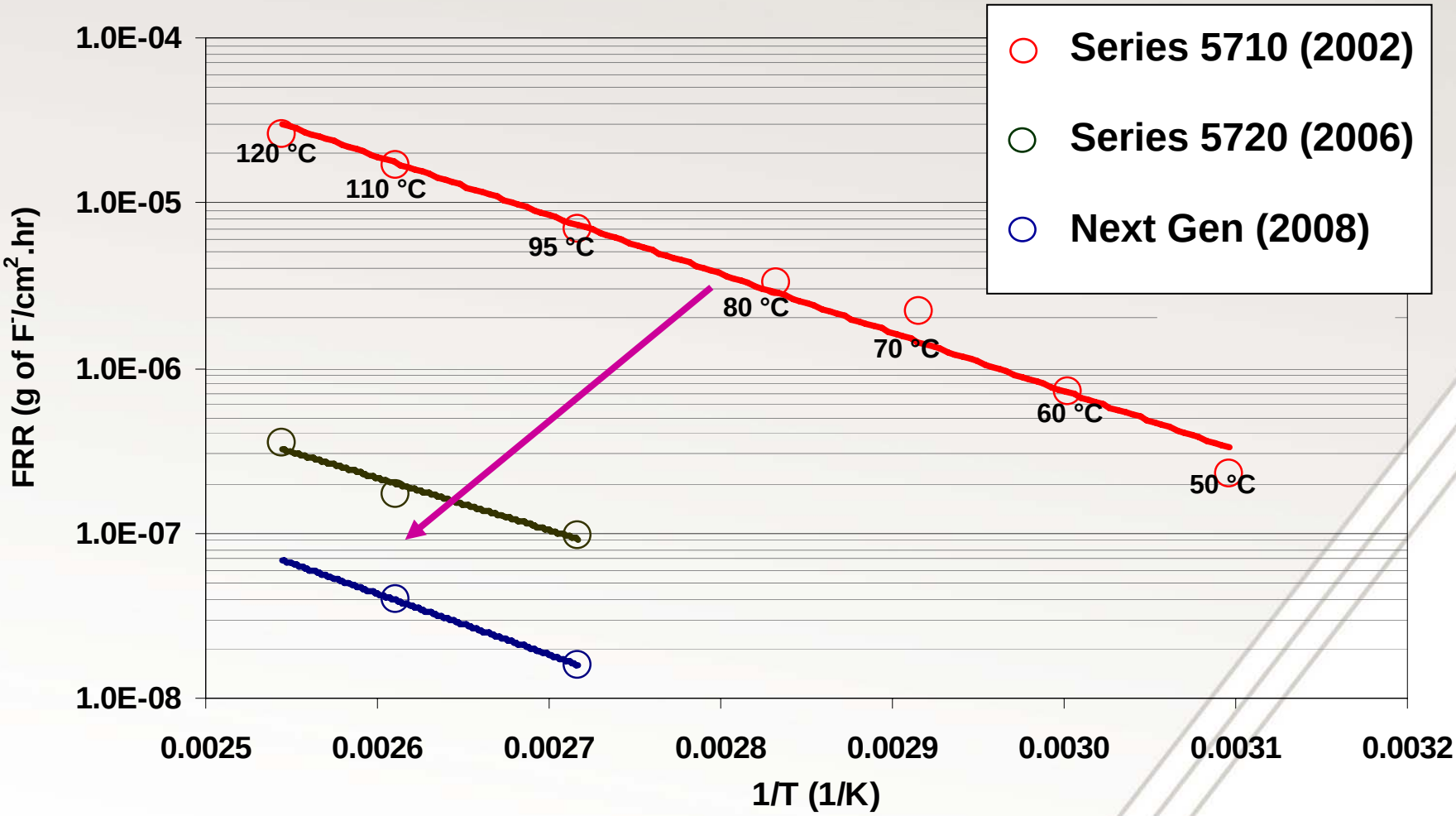
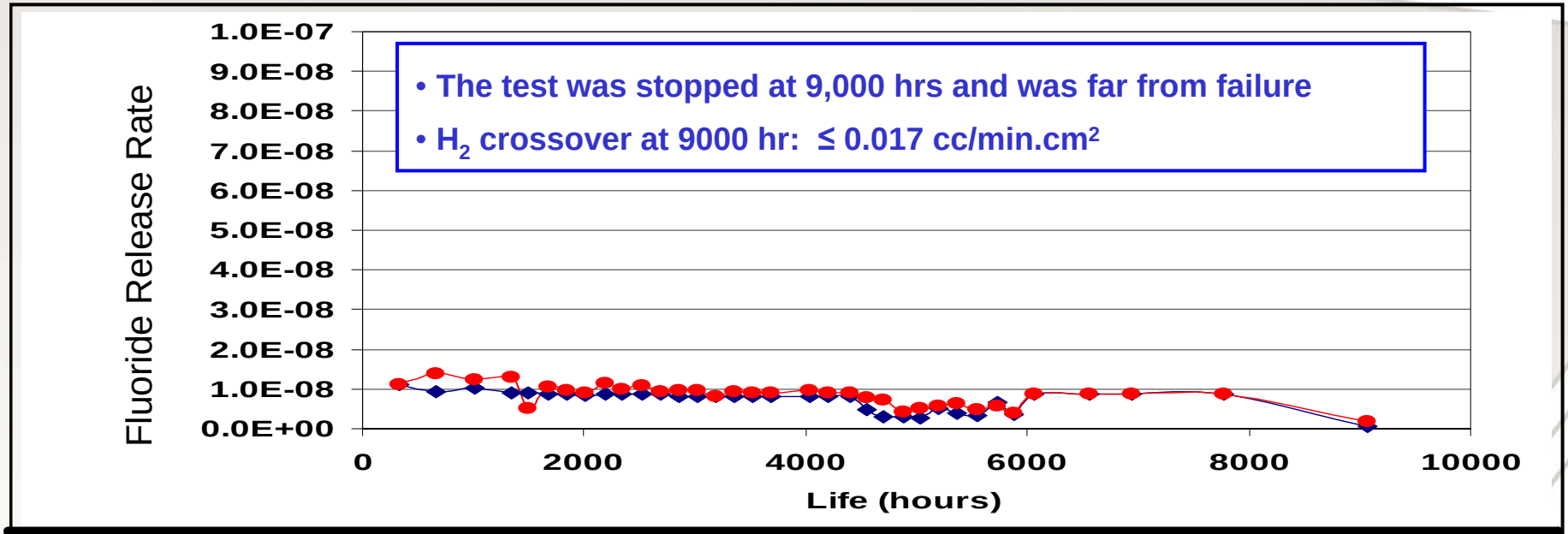


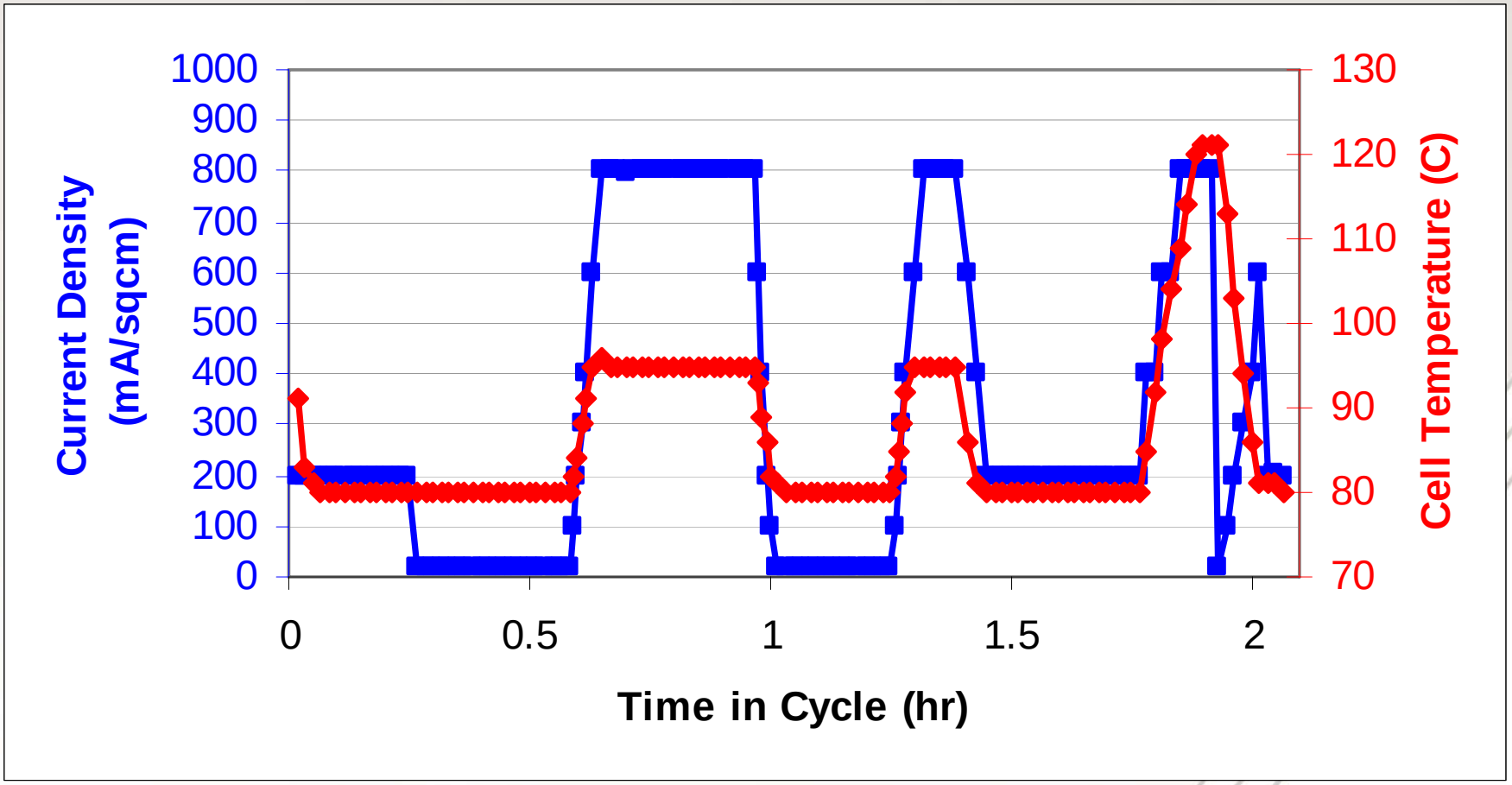
Membrane Durability: 80°C Duty Cycle



T_{Cell} (°C)	Load (mA/cm²)	Stoic (A and C)	Pressure (kPa)	Inlet RH (%)	Exit RH (%)
80	20-1000	10-1.7	170	50	60-120

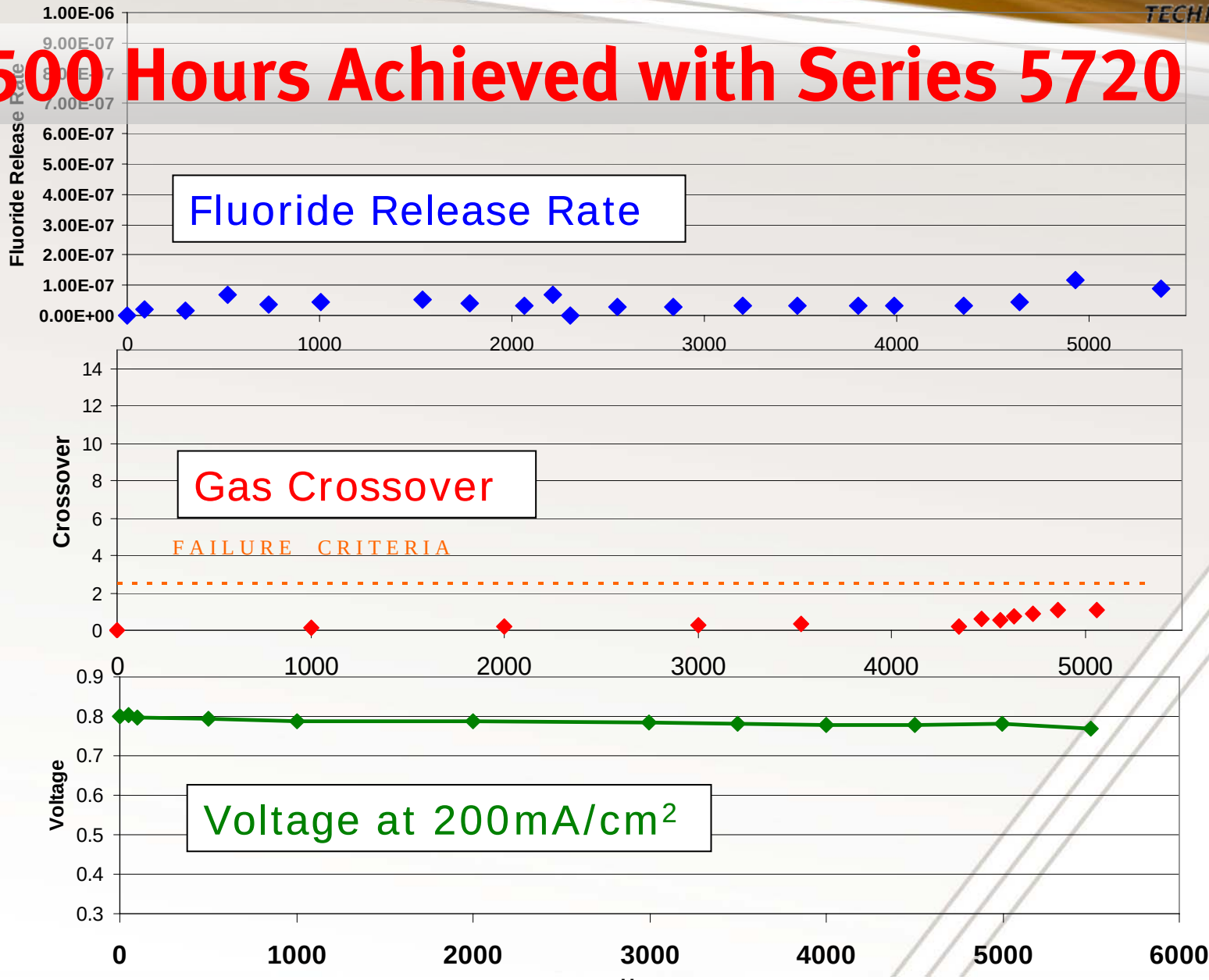
Very little change in membrane thickness after 9,000 hrs on test

New Duty Cycle with Variable Cell Temperature



Includes RH cycles (RH_{exit} 26% - 158%), Cell Temp. 80-120°C

5500 Hours Achieved with Series 5720

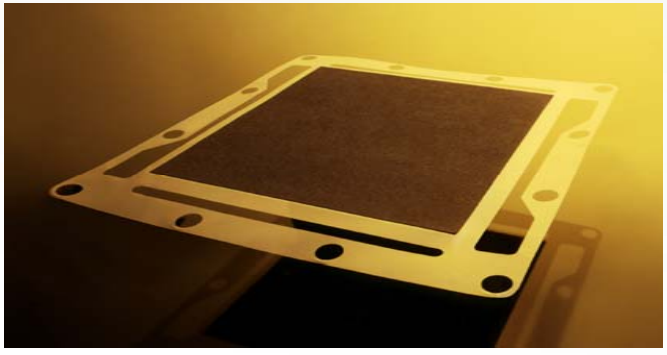


Leveraging Automotive Technology

- MEA technologies developed for automotive applications provide significant value in non-automotive applications
- Forklifts, stationary, back-up power, bus, etc.
  - Longer life
  - Higher power density
  - System Simplification

...the Final Piece of the Puzzle...

- Commitment
  - Gore remains highly committed to the success of this industry
  - Experience: Supplying MEAs to the fuel cell industry for 12 years



  - Long-standing partnerships with leading fuel cell developers

Thank You!

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