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# **Low-Noble-Metal-Content Catalysts/Electrodes for Hydrogen Production by Water Electrolysis**

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Organization: Proton OnSite

Date: May 15, 2013

Project ID: PD098

# Overview

## Timeline

- Project Start: 28 June 2012
- Project End: 27 Mar 2013
- Percent complete: 100%

## Budget

- Total project funding
  - DOE share: \$150,000

## Barriers

- Barriers addressed
  - G: Capital Cost

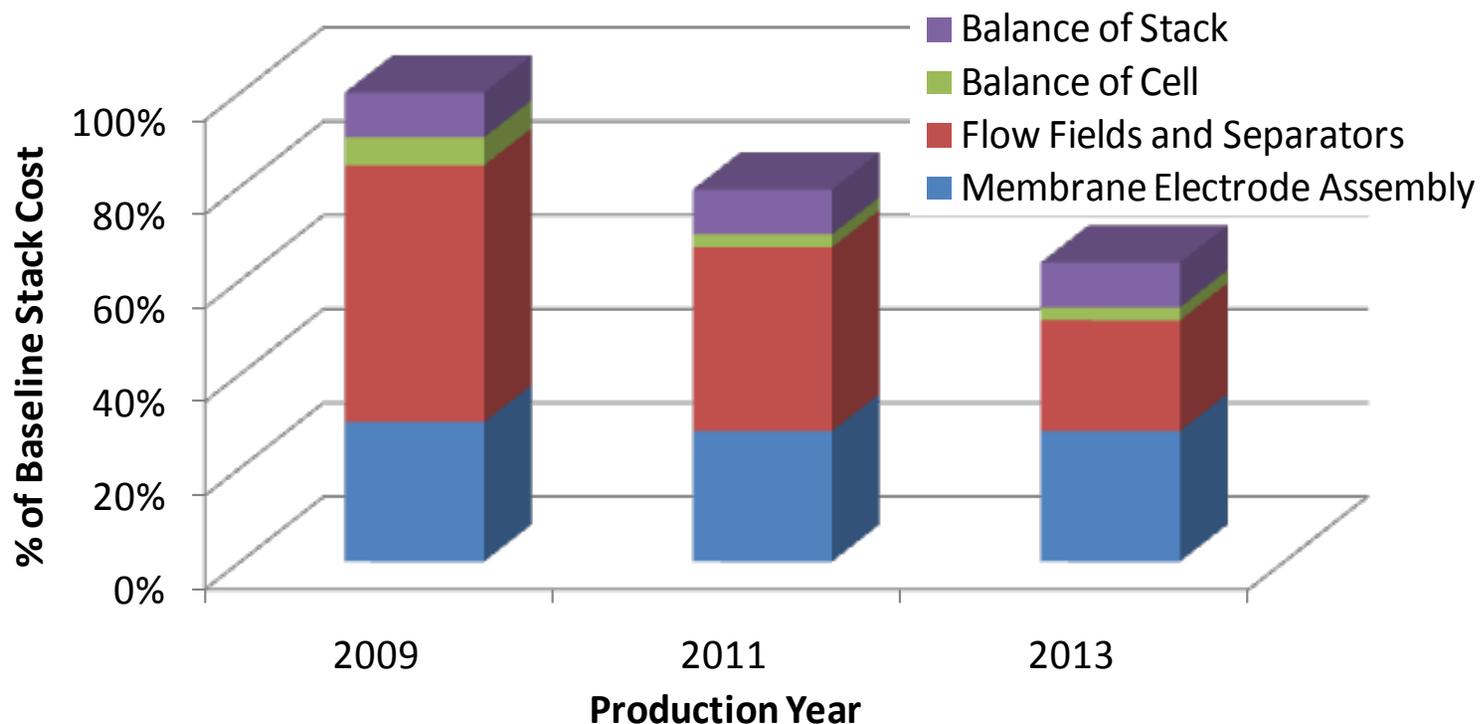
Characteristics	Units	2011	2015	2020
		Status <sup>c</sup>	Target <sup>d</sup>	Target <sup>e</sup>
Hydrogen Levelized Cost (Plant Gate) <sup>f</sup>	\$/kg H <sub>2</sub>	4.10	3.00	2.00
Total Capital Investment <sup>b</sup>	\$M	68	51	40
System Energy Efficiency <sup>g</sup>	%	67	73	75
	kWh/kg H <sub>2</sub>	50	46	44.7
Stack Energy Efficiency <sup>h</sup>	%	74	76	78
	kWh/kg H <sub>2</sub>	45	44	43
Electricity Price <sup>i</sup>	\$/kWh	From AEO '09	\$0.049	\$0.031

## Partners

- Brookhaven National Lab

# Relevance: Problem to be Addressed

- MEA becoming larger fraction of cost
  - Other component costs continue to decrease with technology advances
- PGM content contributes 50% of material cost
  - Also sensitive to PGM price volatility
- Labor cost in catalyst application also a major cost
- Need new manufacturing methods and ultra-low PGM loading



# Relevance: Hydrogen Energy Storage

- Easily scalable; can independently scale charge, discharge, and storage capacity
- Reduction of noble metal content breaks significant cost barriers in system capital cost enabling market entry in:
  - Transportation
  - Biogas
  - High value chemical streams
  - Green production of fertilizer
  - Capture of stranded renewable energy

# Relevance: Project Objectives

- Optimize composition and microstructure of cathode catalysts on carbon-based substrates
- Demonstrate equivalent cathode performance to baseline with ultra-low catalyst loading
- Screen promising candidates for core-shell anode catalysts and non-carbon catalyst supports
- Demonstrate feasibility of reduced anode catalyst loadings
- Estimate the impact of noble metal reduction on the cost of hydrogen from water.

# Approach

## Task Breakdown

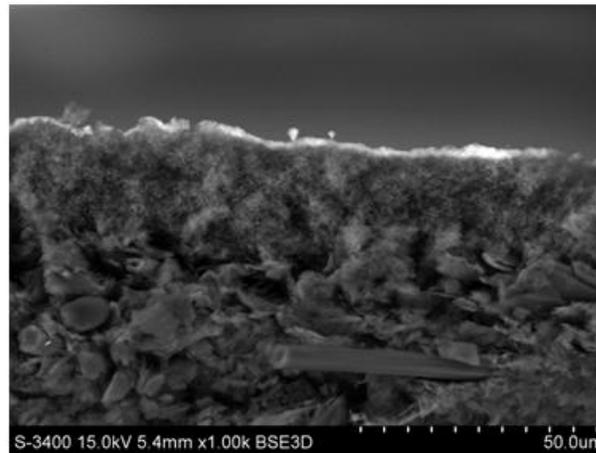
- Task 1.0 Cathode
  - Subtask 1.1 Catalyst synthesis and characterization
  - Subtask 1.2 Optimization of GDE fabrication
  - Subtask 1.3 500 hours durability test
- Task 2.0 Anode
  - Subtask 2.1 Catalyst screening and synthesis
  - Subtask 2.2 Studying support and GDL materials
  - Subtask 2.3 Initial MEA tests of GDE samples
- Task 3.0 Preliminary Cost Analysis
  - Use H2A model to quantify impact of changes to electrode composition and structure on \$/kg H<sub>2</sub>

# Approach: Low Catalyst Loading Concept

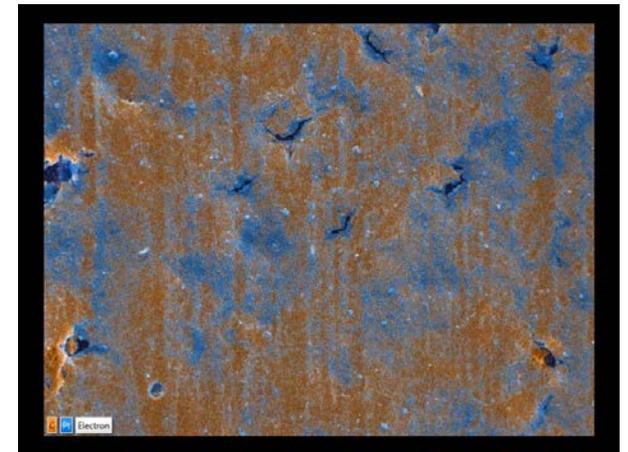
- Increase the Pt specific surface area by synthesizing sized-controlled, core-shell nanocatalysts
- Better utilization achieved with a more effective GDE structure
- Translates into a 98% reduction of Pt.



GDE



Microporous layer minimizes surface roughness. Catalyst layer is 1-3  $\mu\text{m}$  thick.



Pt (blue) and Carbon (yellow) by EDS.

# Technical Accomplishments

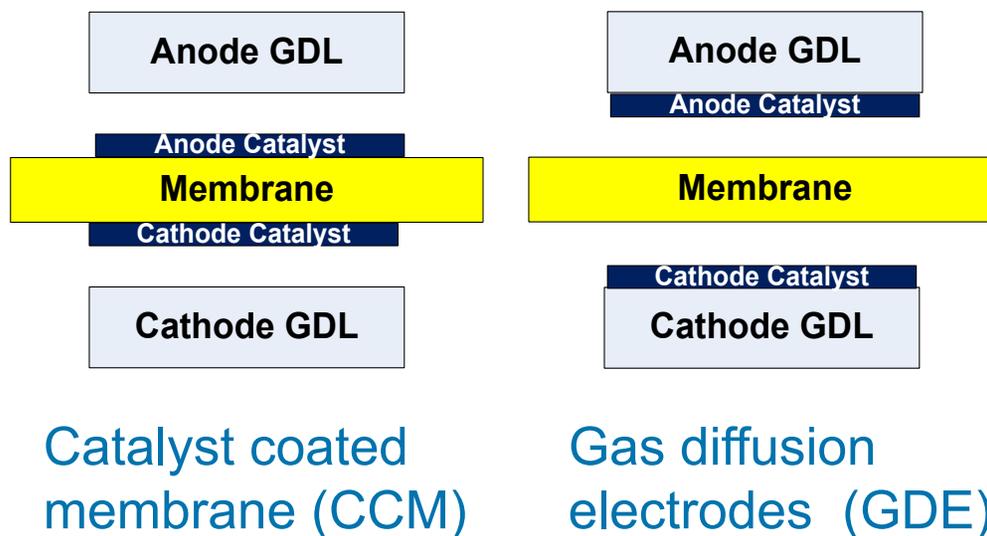
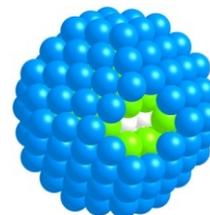
Task	Task description and significant achievements	Completion
1.1	Ru <sub>1</sub> Pt <sub>1</sub> core-shell nanoparticles were synthesized via green chemistry and their uniform 2-monolayer-thick Pt shells were characterized using STEM and XRD.	100%
1.2	Cathode GDE samples with different GDLs, carbon supports, and ionomer contents were tested. Baseline performance is achieved or exceeded slightly.	100%
1.3	500-hours durability tests on two GDE samples showed equal or better performance versus the Proton baseline	100%
2.1	Synthesized and tested various nanocatalysts containing Ru, Ir, and Pt. Found RuIr core-shell nanocatalysts highly active and durable.	100%
2.2	Studied TiO <sub>2</sub> nanoparticles as the catalyst support and carbon-based GDLs.	50%
2.3	Tested one carbon-based GDE and four Ti-based GDEs	100%
3.0	H <sub>2</sub> A Analysis	100%
	Final Reporting and Phase 2 proposal	3/27/2013

# Technical Accomplishments

- Task 1: Cathode
  - Successfully synthesized and characterized catalysts for use on the cathode coated GDEs
  - Successfully fabricated catalyst coated GDEs for operational testing
  - Durability target of 500 hours met and continues to operate
- Task 2: Anode
  - Successfully synthesized and screened catalysts for OER use.
  - Surveyed anode support and GDL materials
  - Conducted operational tests, demonstrating feasibility of the anode GDE approach

# Technical Accomplishments: Gas diffusion electrodes made of core-shell nanocatalysts

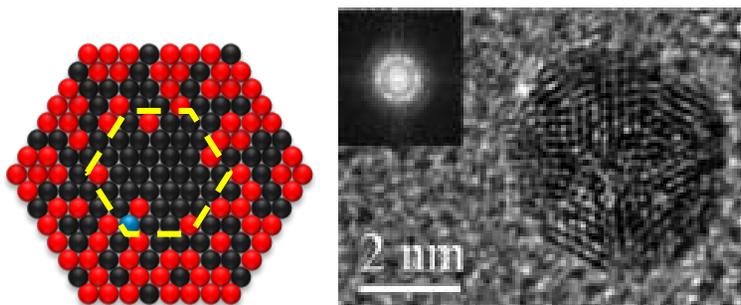
- Synthesizing well-defined core-shell nanocatalysts to optimize surface properties for high performance with ultra-low precious metal loadings.
  - Ru@Pt for HER at the cathode
  - Ru@Ir for OER at the anode
- Fabricating effective gas diffusion electrode (GDE)



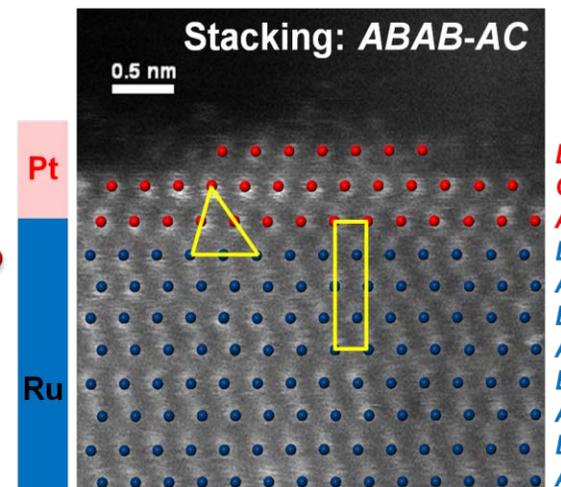
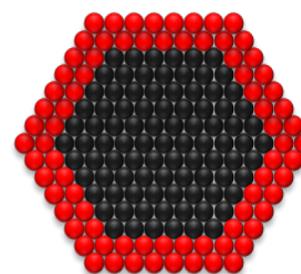
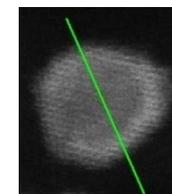
# Technical Accomplishments

- Task 1.1 Cathode catalyst, Ru@Pt-bilayer core-shell nanoparticles

Previous methods produced Ru-rich core and Pt-rich shell

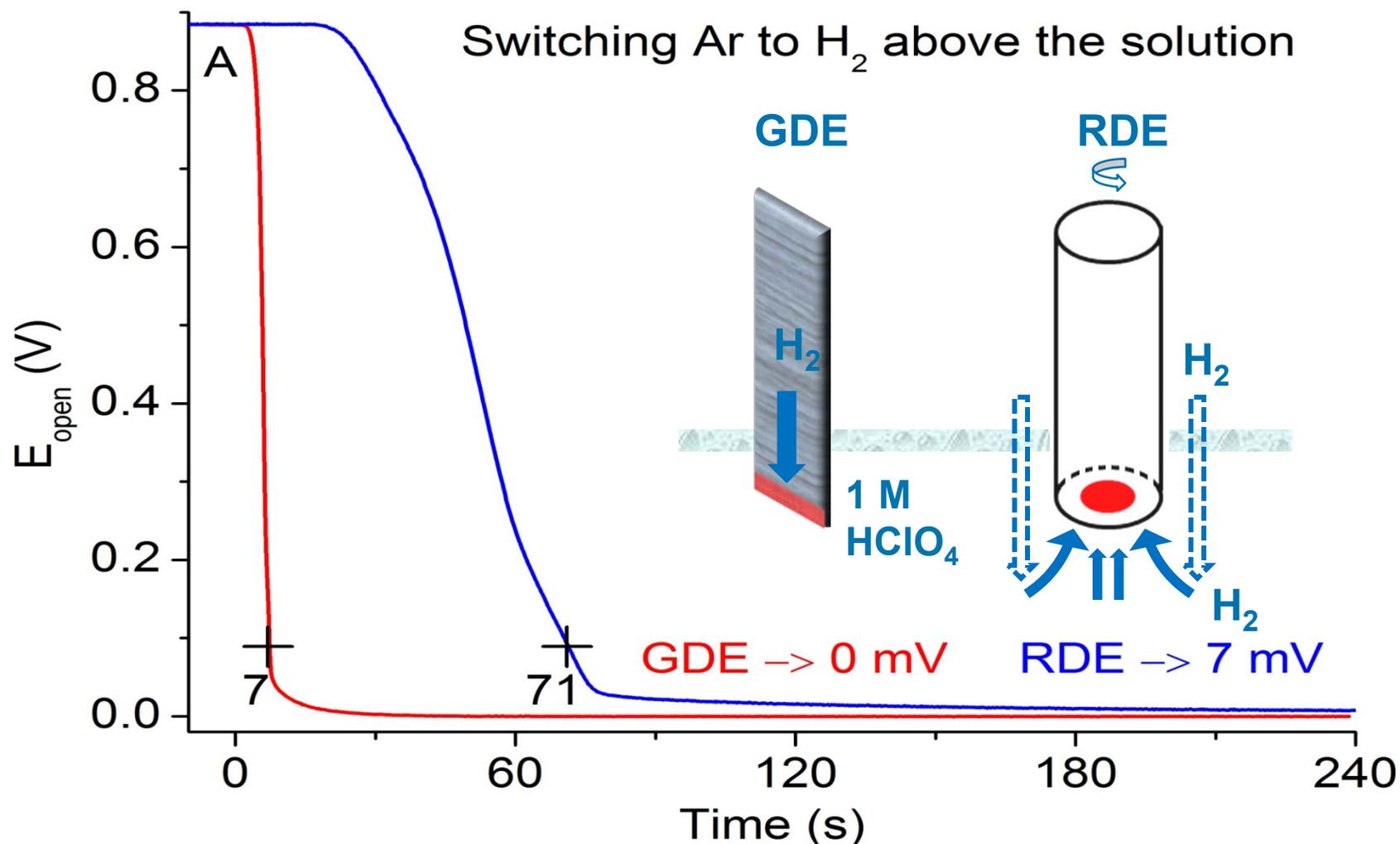


Defect-induced partial alloying eliminated.



Atomic-level perfection was achieved in synthesizing core-shell electrocatalysts via green chemistry – ethanol as the solvent and reductant without capping agents and templates.

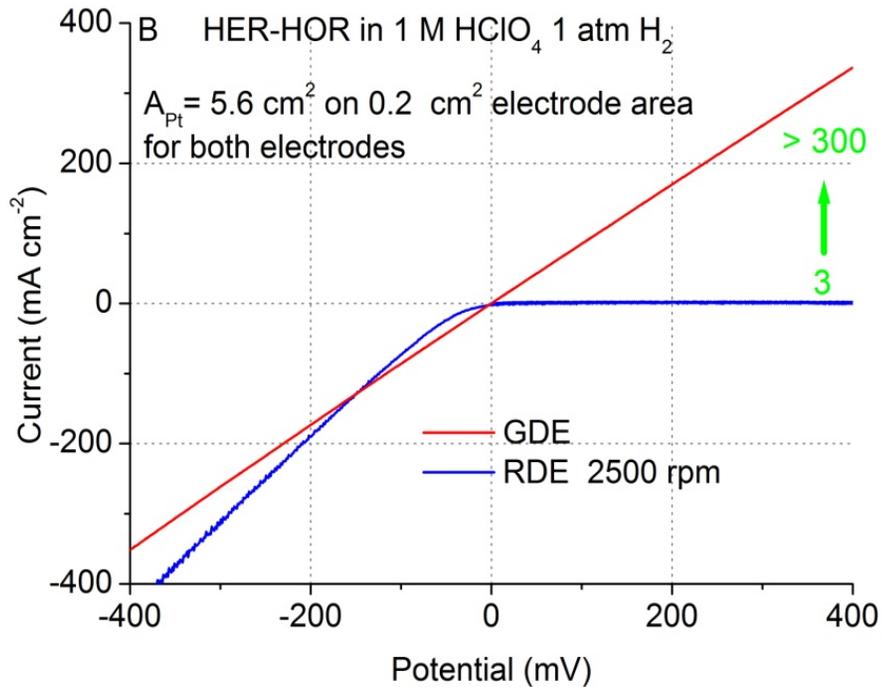
# Technical Accomplishments: GDE hanging-strip measurement



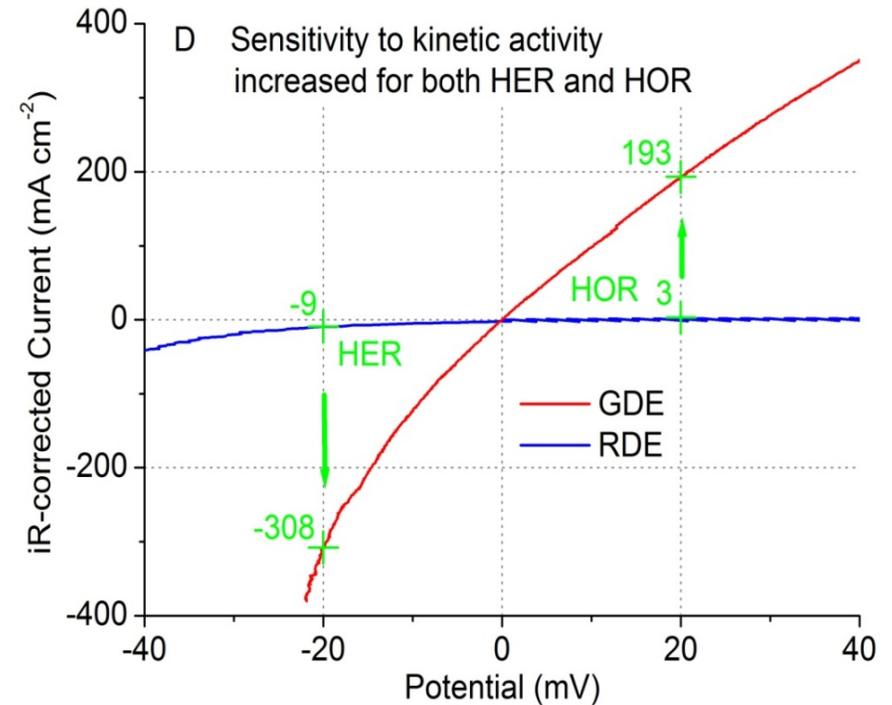
Provides a fast and sensitive test method for  
selecting catalysts and optimizing GDE fabrication.

# Technical Accomplishments

## Current Voltage Analysis



The mass transport current for HOR is increased more than 100 times.

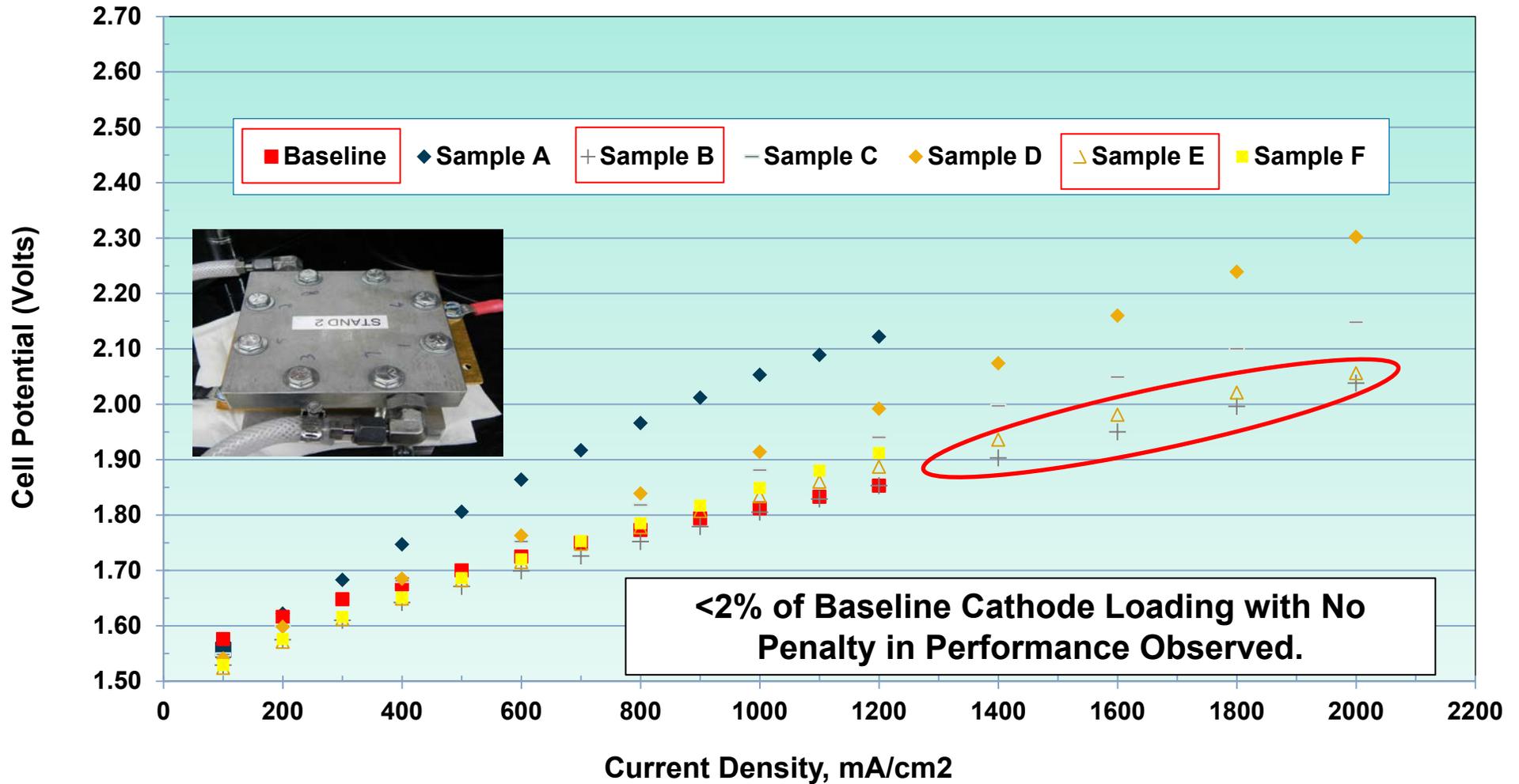


iR-corrected current is 10 to 100 times higher than that on RDE for HER and HOR, respectively.

# Technical Accomplishments

## Cathode GDE Performance Screening

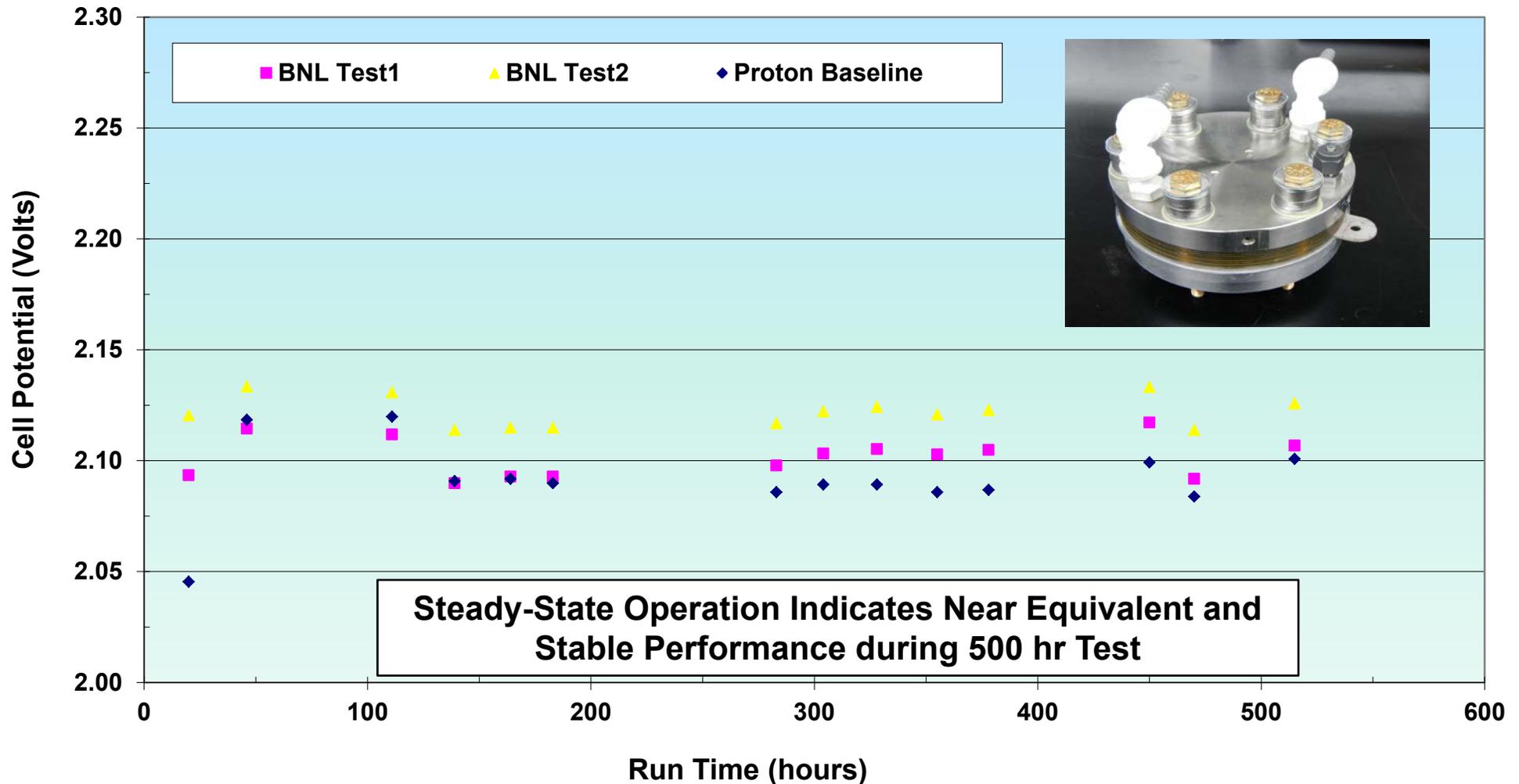
### Brookhaven Cathode GDE vs. Proton Baseline MEA



# Technical Accomplishments

## Cathode GDE Durability Testing

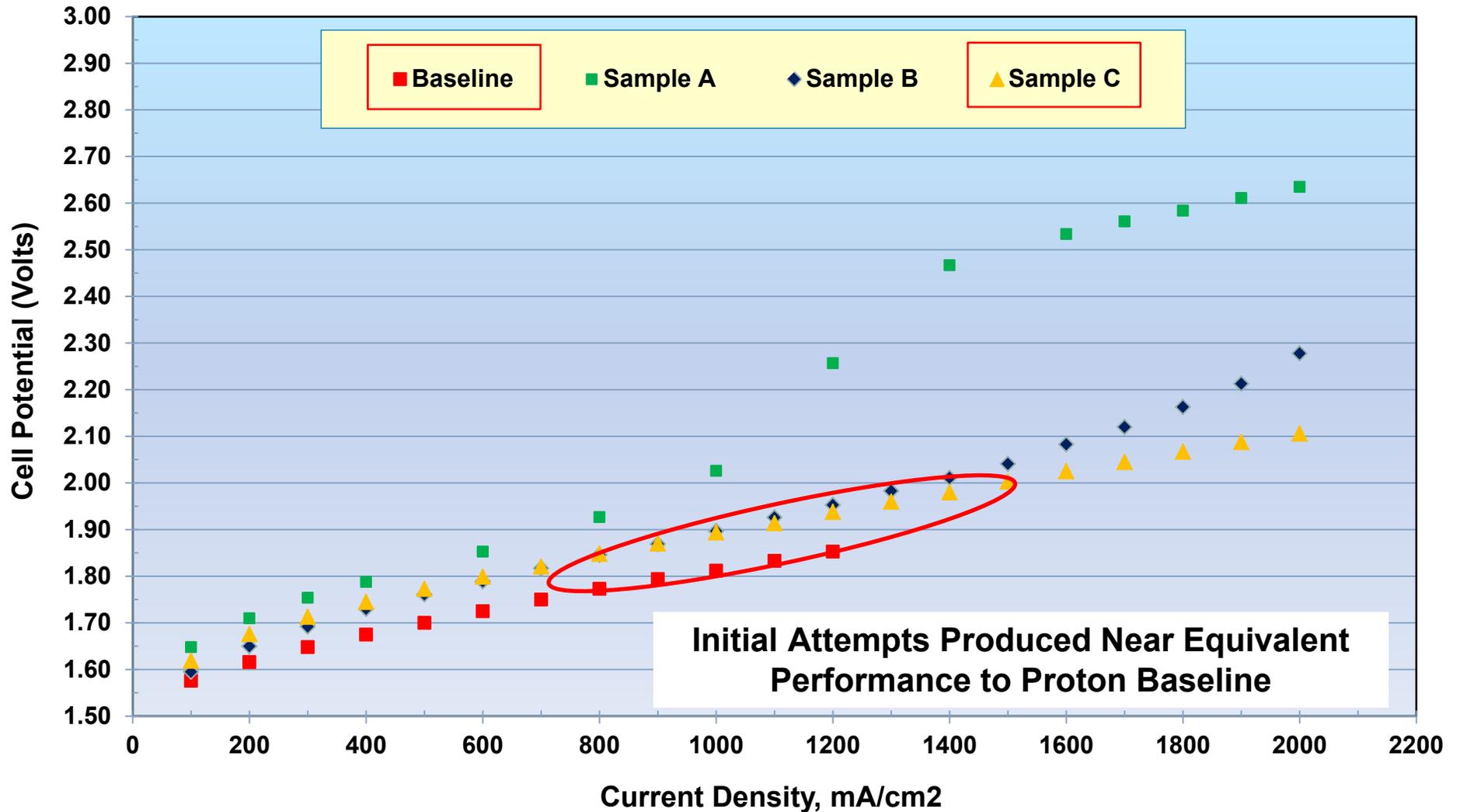
### Brookhaven Cathode GDE Durability Test



# Technical Accomplishments

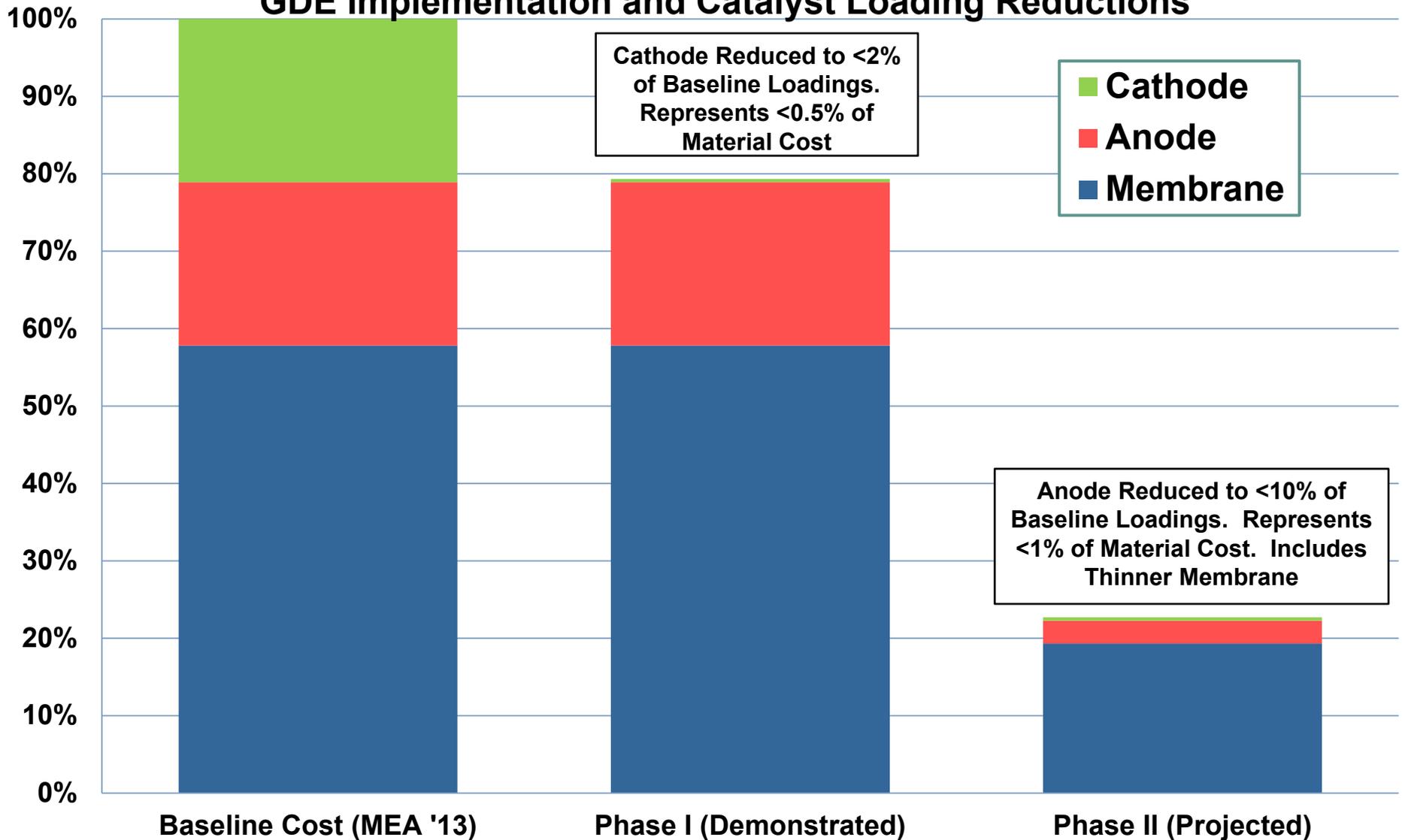
## Anode GDE Feasibility Testing

### Brookhaven Anode GDE vs. Proton Baseline MEA



# Technical Accomplishments

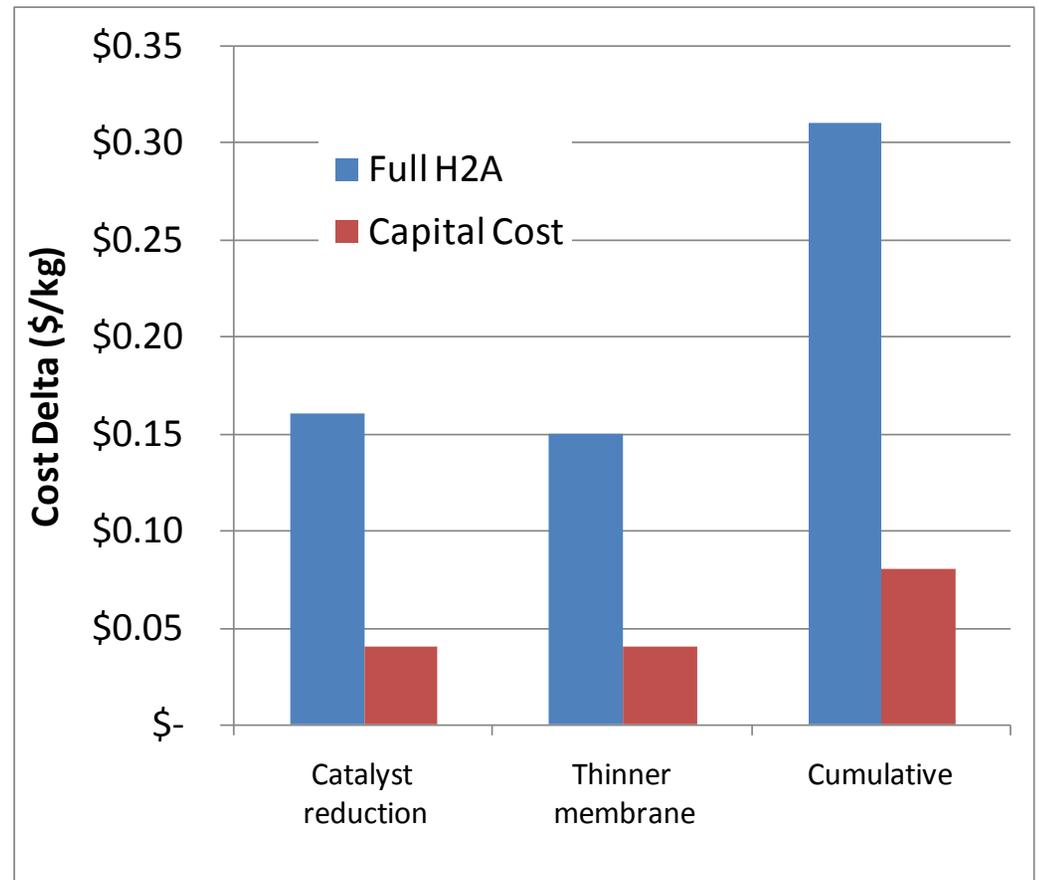
## MEA Material Cost Reductions Through GDE Implementation and Catalyst Loading Reductions



# Technical Accomplishments

## Cost Analysis

- Phase 1 Approach:
  - H2A Analysis shows \$.30/kg reduction in overall H<sub>2</sub> cost
  - Represents capital cost savings of ~\$165K/MW installation



# Future Work: Proton

- **Proposed work for Phase II:**
  - Refinement of cathode to exceed baseline performance with loadings demonstrated in Phase I
  - Optimize anode GDE for durability testing and efficiency improvements
  
- **Scale-up Testing and Cell Stack Development**
  - Increase GDE size to demonstrate in 86 cm<sup>2</sup> cell design
  - Modify cell embodiment to better match GDE component
  - Conduct multi-cell operational test to simulate pilot run and assess GDE fabrication reproducibility.

# Summary

- **Relevance:** Demonstrates technology pathway to reducing cell stack capital cost to enable energy market penetration
- **Approach:** Optimize catalyst utilization and activity for (2) orders of magnitude loading reduction
- **Technical Accomplishments:**
  - 500 hour durability test successfully completed for cathode GDE
  - Parts fabricated were tested successfully in commercial cell stack hardware
  - Anode feasibility demonstrated in 25 cm<sup>2</sup> test cell
  - GDE fabrication process decreases steps in existing manufacturing process, reducing MEA cost through labor reduction.
- **Collaborations:**
  - Brookhaven National Labs: Screening and fabrication of GDE
- **Proposed Future Work:**
  - Optimize cathode and anode GDEs to increase cell efficiency, while maintaining ultra-low catalyst loadings
  - Electrode and stack scale up
  - Manufacturing cost reduction study and refined H<sub>2</sub>A model \$/kg cost analysis