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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

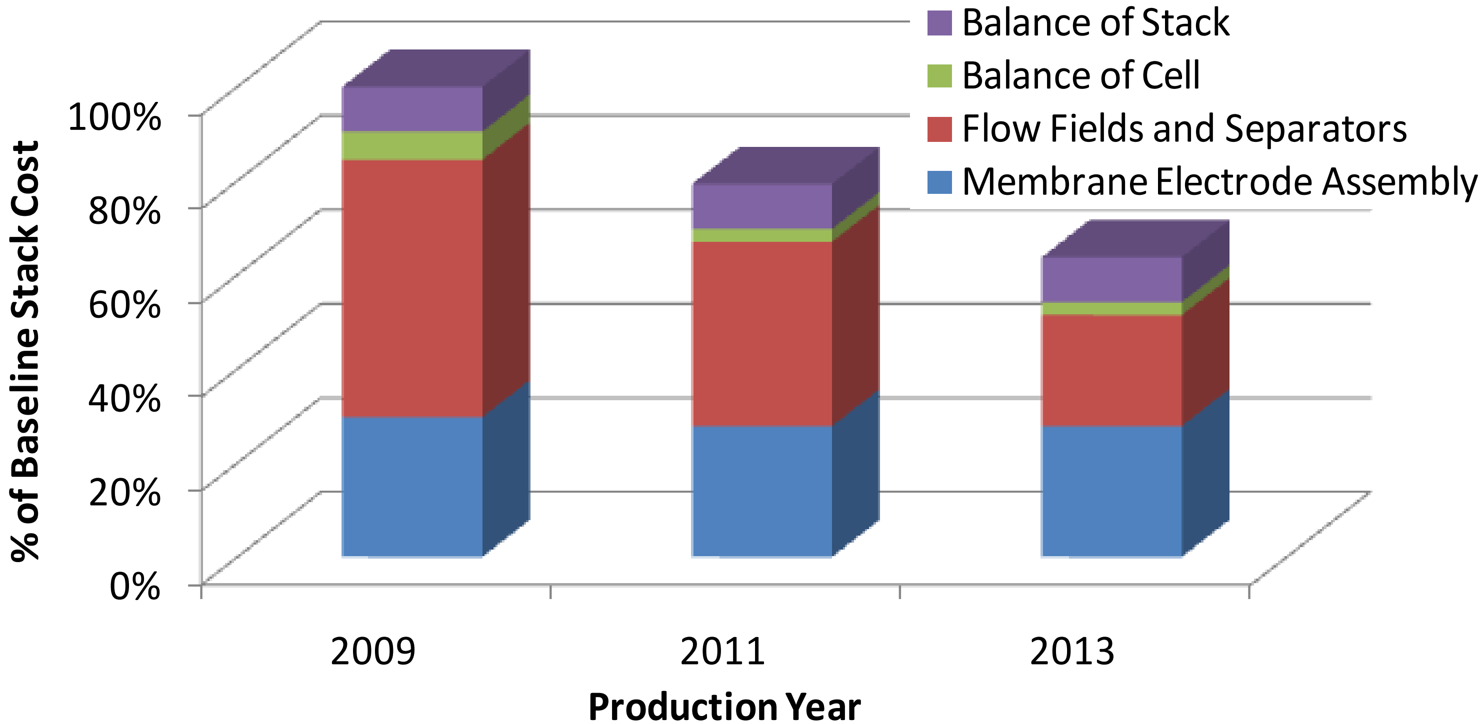
Table 3.1.5 Technical Targets: Central Water Electrolysis Using Green Electricity [a,b]				
Characteristics	Units	2011 Status [c]	2015 Target [d]	2020 Target [e]
Hydrogen Levelized Cost (Plant Gate) [f]	$/kg H_2	4.10	3.00	2.00
Total Capital Investment [b]	$M	68	51	40
System Energy Efficiency [g]	%	67	73	75
	kWh/kg H_2	50	46	44.7
Stack Energy Efficiency [h]	%	74	76	78
	kWh/kg H_2	45	44	43
Electricity Price [i]	$/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

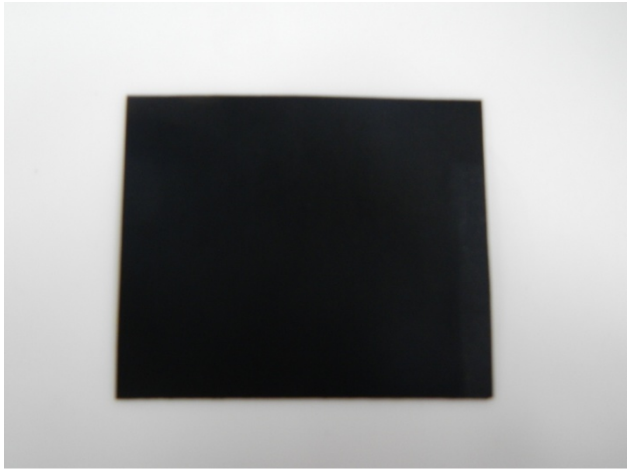
- Optimize composition and microstructure of cathode catalysts on carbon-based substrates
- Demonstrate equivalent cathode performance to baseline with ultra-low catalyst loading
- Screen promising candidates for core-shell anode catalysts and non-carbon catalyst supports
- Demonstrate feasibility of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

Approach
Task Breakdown

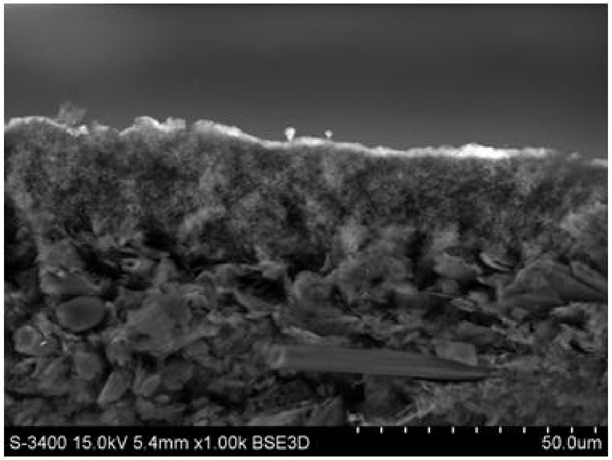
- Task 1.0 Cathode
  - Subtask 1.1 Catalyst synthesis and characterization
  - Subtask 1.2 Optimization of GDE fabrication
  - Subtask 1.3 500 hours durability test
- Task 2.0 Anode
  - Subtask 2.1 Catalyst screening and synthesis
  - Subtask 2.2 Studying support and GDL materials
  - Subtask 2.3 Initial 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_2

Approach: Low Catalyst Loading Concept

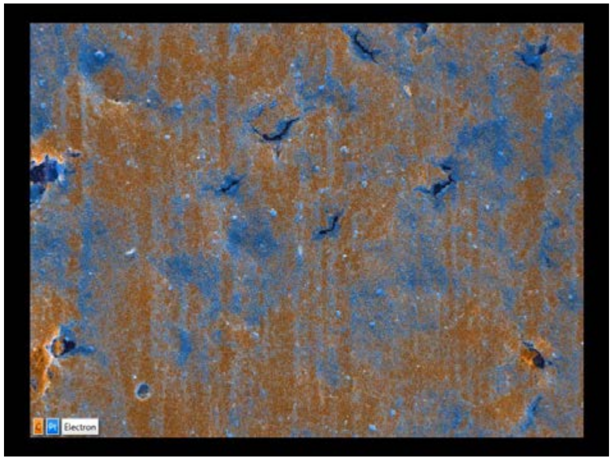
- Increase the Pt specific surface area by synthesizing sized-controlled, core-shell nanocatalysts
- Better utilization achieved with a more effective GDE structure
- Translates into a 98% reduction of Pt.



GDE



Microporous layer minimizes surface roughness. Catalyst layer is 1-3 um thick.



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

Technical Accomplishments

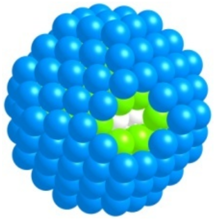
Task	Task description and significant achivements	Completion
1.1	Ru_1Pt_1 core-shell nanoparticles were synthesized via green chemistry and their uniform 2-monolayer-thick Pt shells were characterized using STEM and XRD.	100%
1.2	Cathode GDE samples with different GDLs, carbon supports, and ionomer contents 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 TiO2 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	H2A Analysis	100%
	Final Reporting and Phase 2 proposal	3/27/2013

Technical Accomplishments

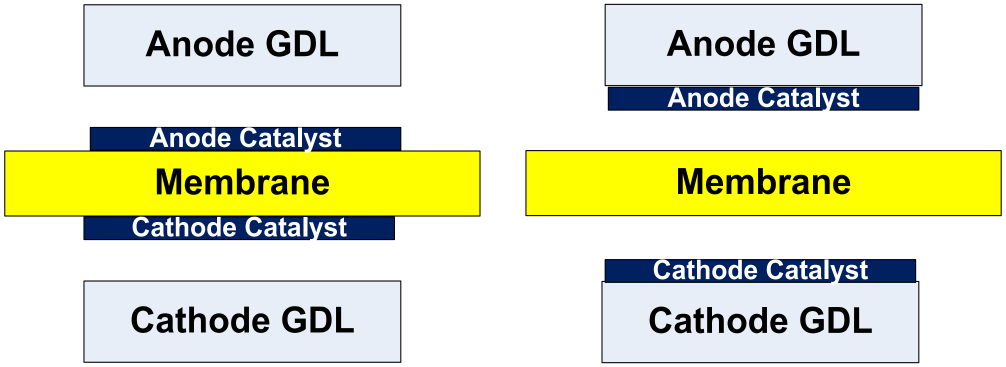
- Task 1: Cathode
  - Successfully synthesized and characterized catalysts for use on the cathode coated GDEs
  - Successfully fabricated catalyst coated GDEs for operational testing
  - Durability target of 500 hours met and continues to operate
- Task 2: Anode
  - Successfully synthesized and screened 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)



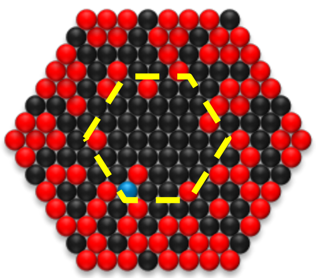
Catalyst coated membrane (CCM)

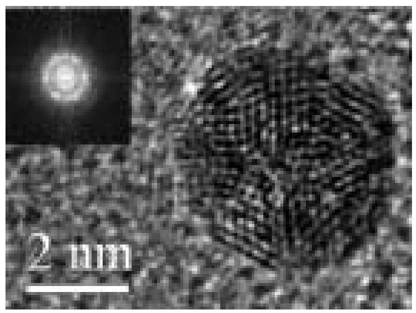
Gas diffusion electrodes (GDE)

Technical Accomplishments

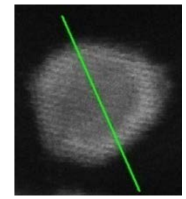
- Task 1.1 Cathode catalyst, Ru@Pt-bilayer core-shell nanoparticles

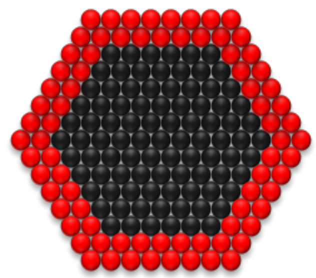
Previous methods produced Ru-rich core and Pt-rich shell

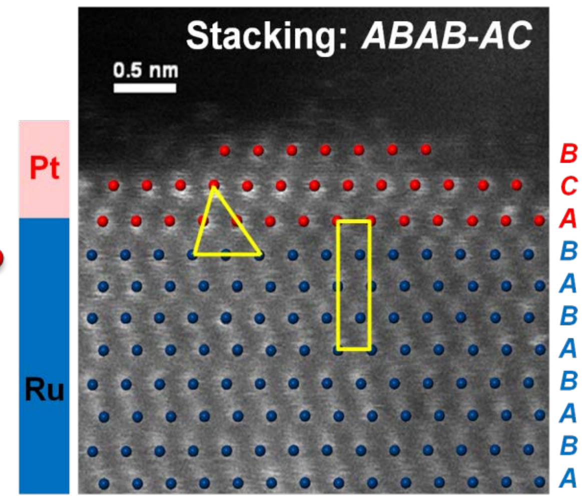




Defect-induced partial alloying eliminated.

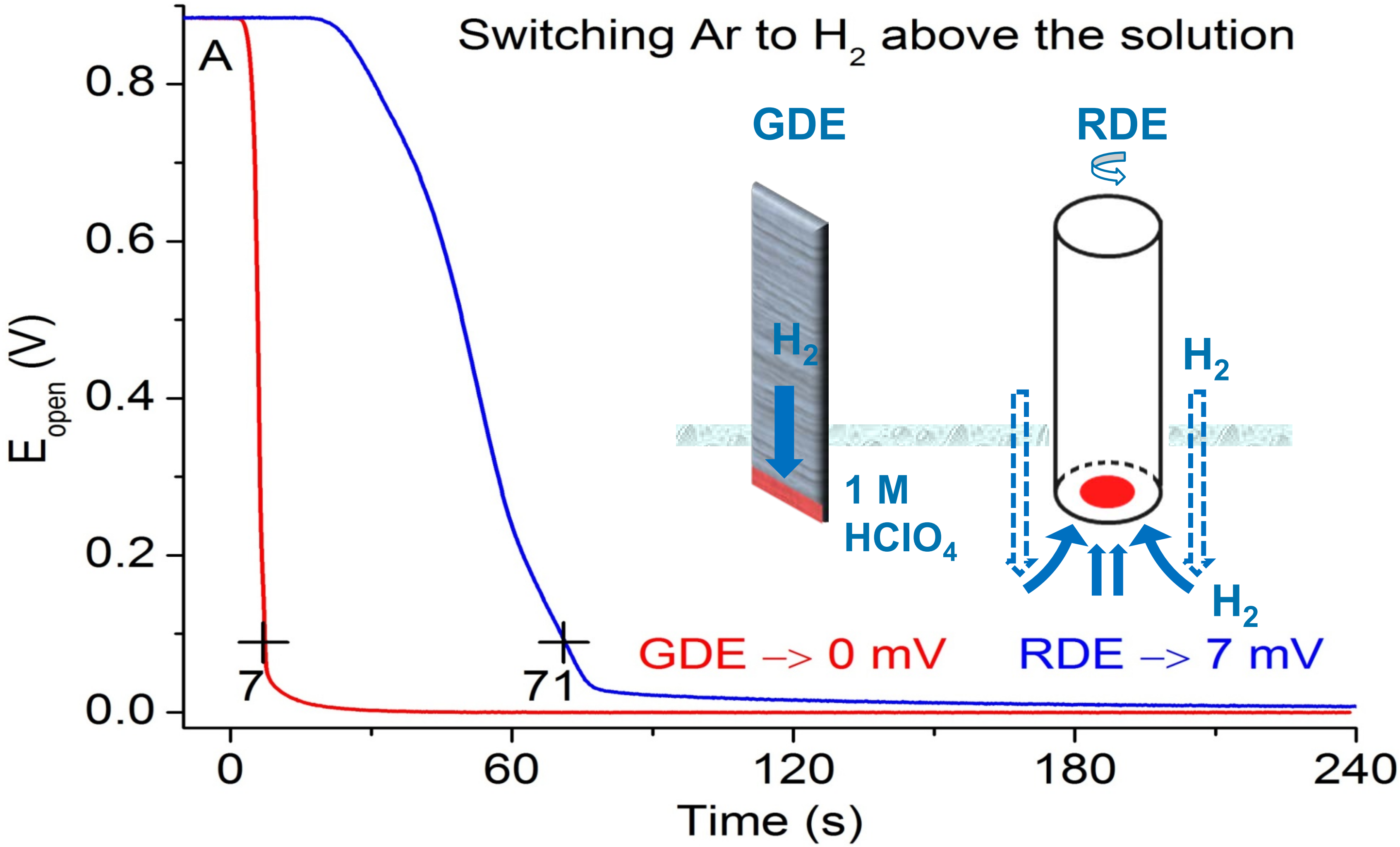






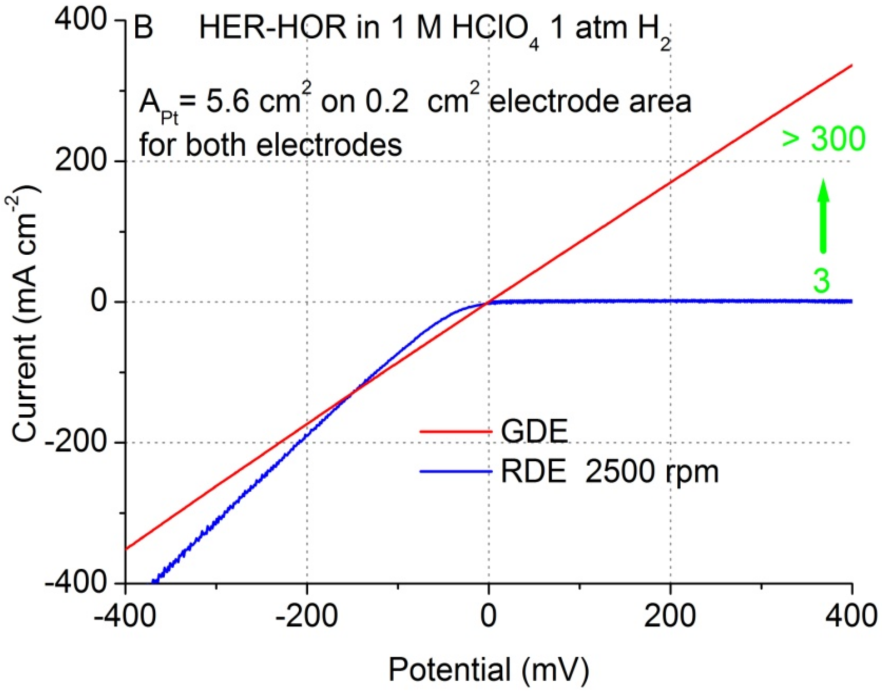
Atomic-level perfection was achieved in synthesizing core-shell electrocatalysts via green chemistry – ethanol as the solvent and reductant without capping agents and templates.

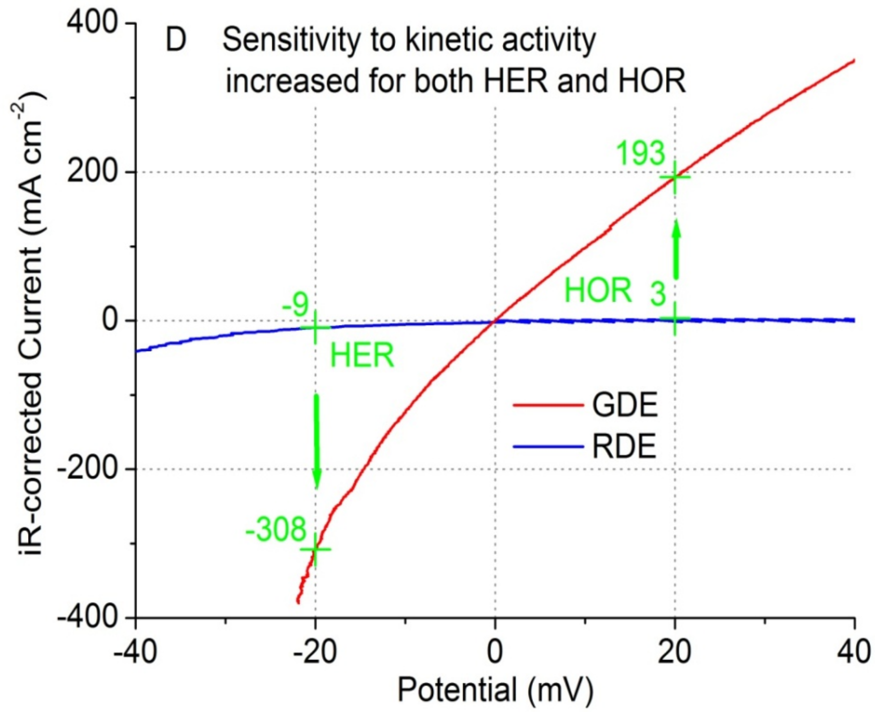
Technical Accomplishments:
GDE hanging-strip measurement



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

Technical Accomplishments
Current Voltage Analysis

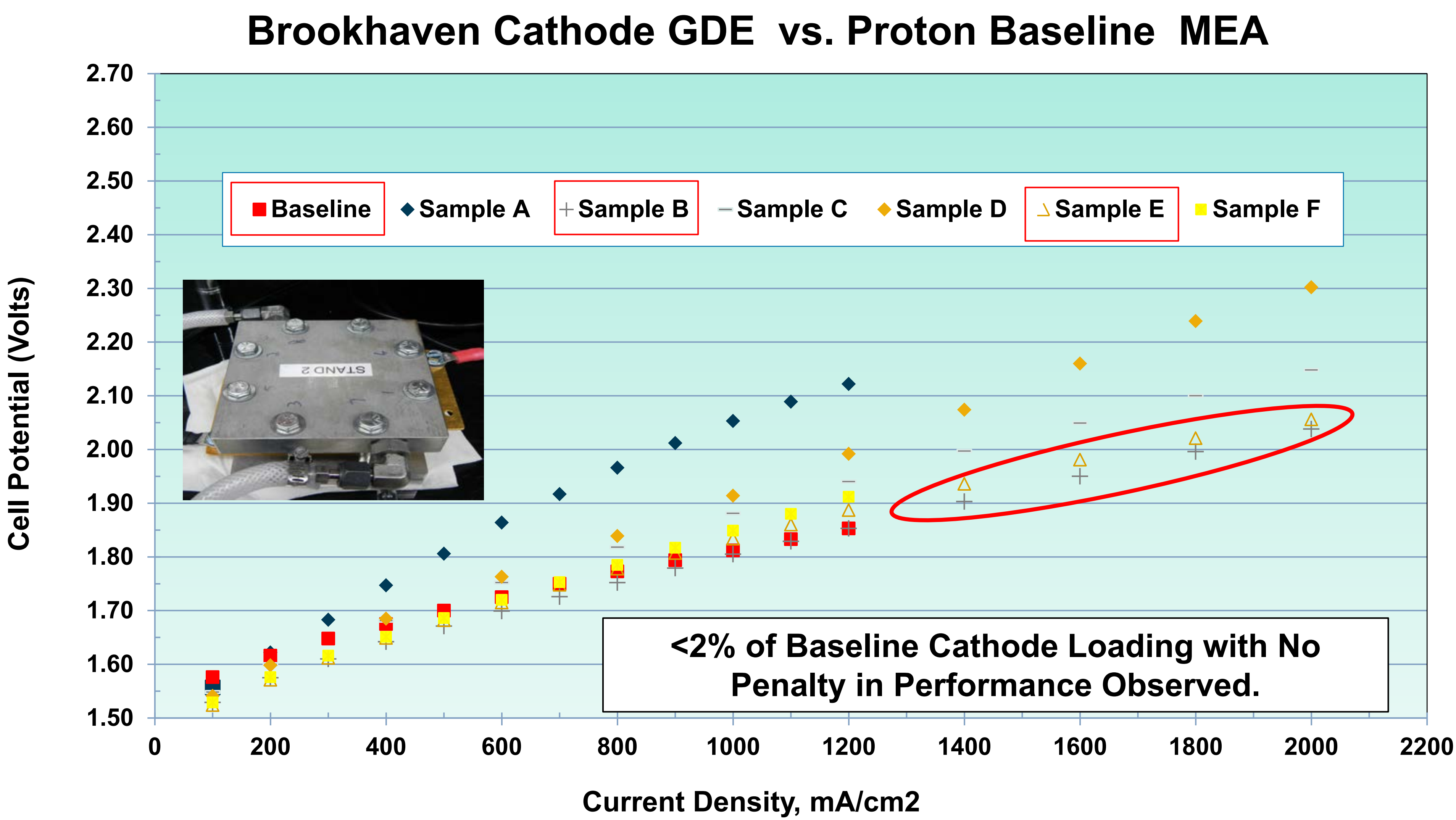




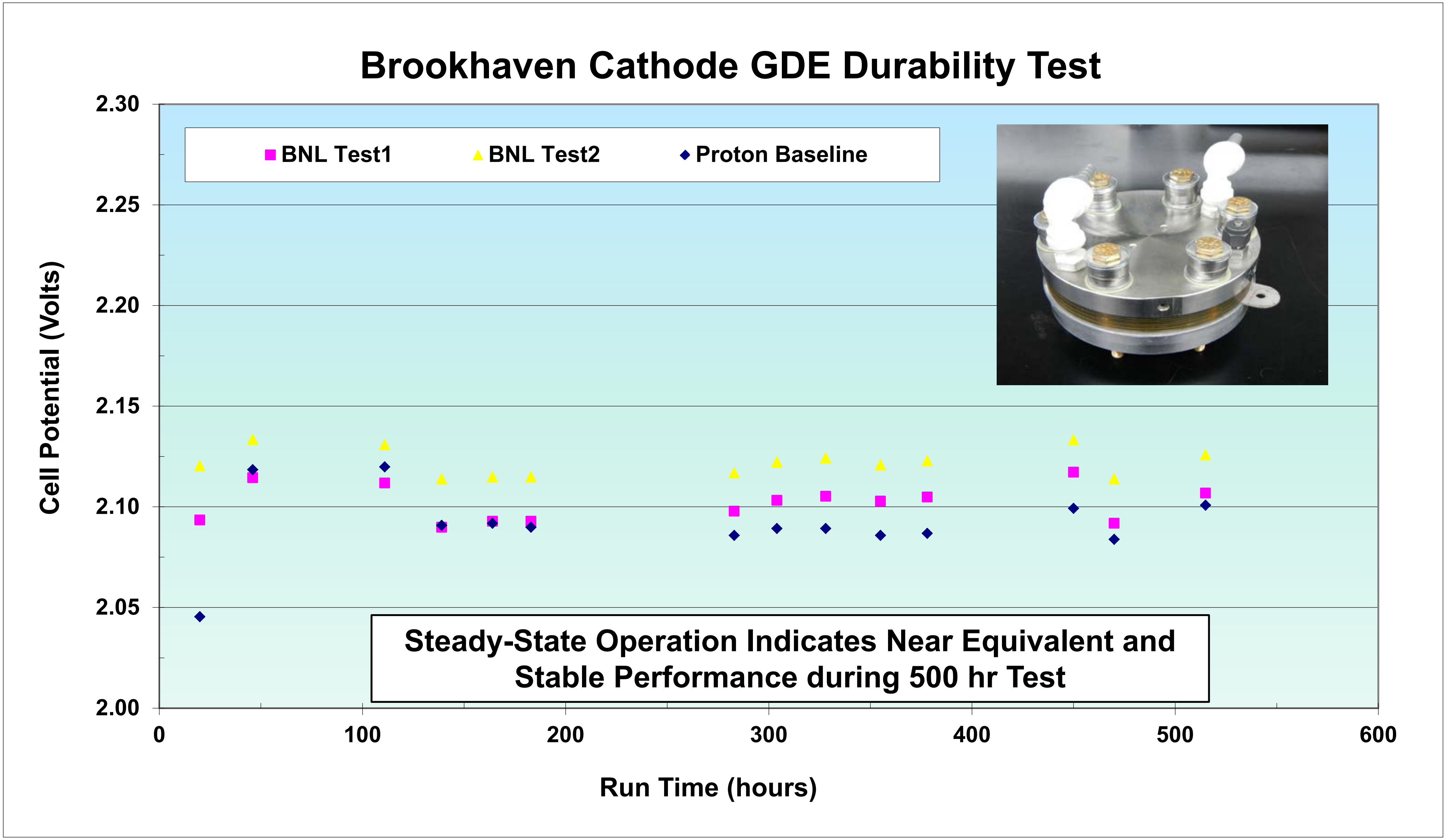
The mass transport current for HOR is increased more than 100 times.

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

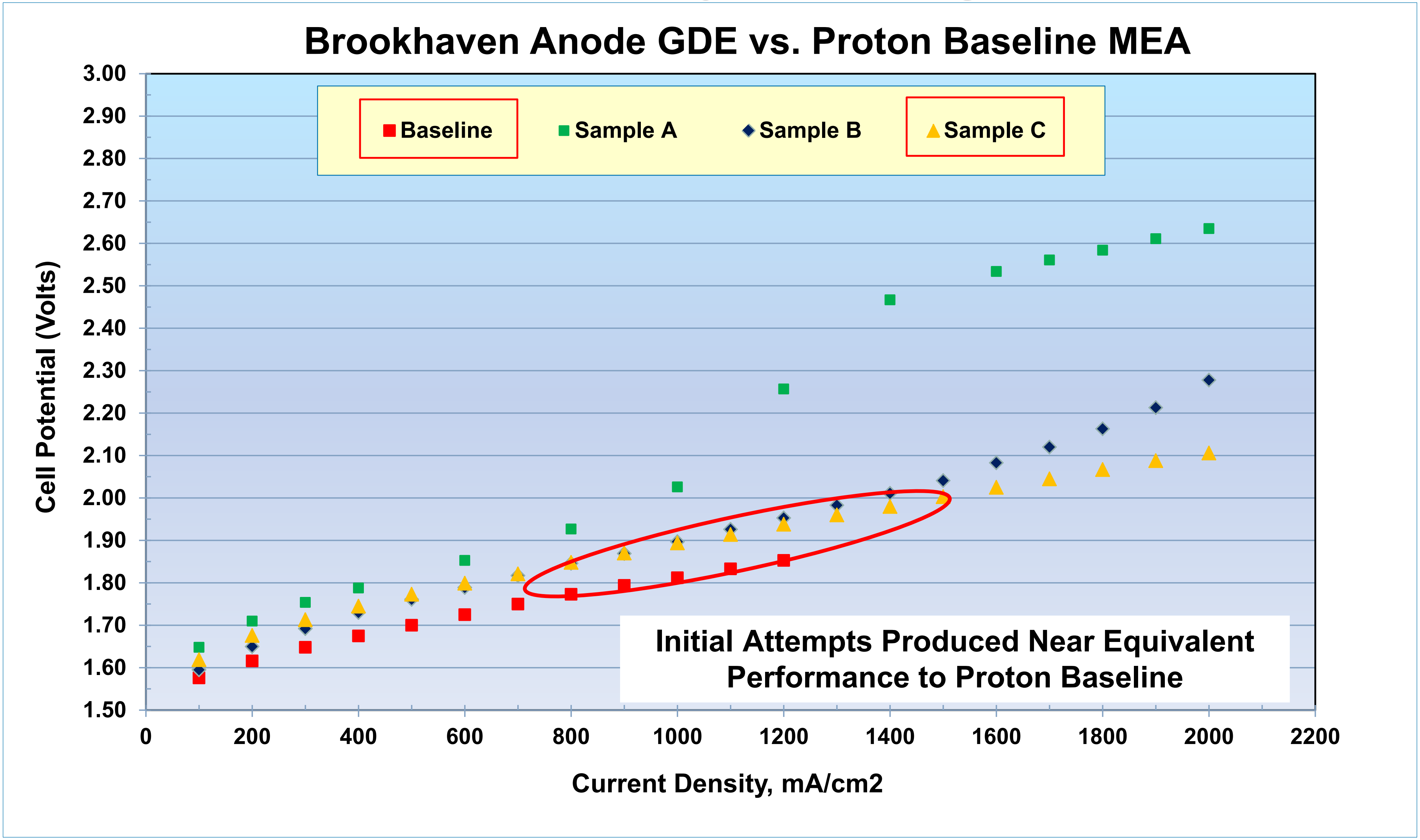
Technical Accomplishments
Cathode GDE Performance Screening



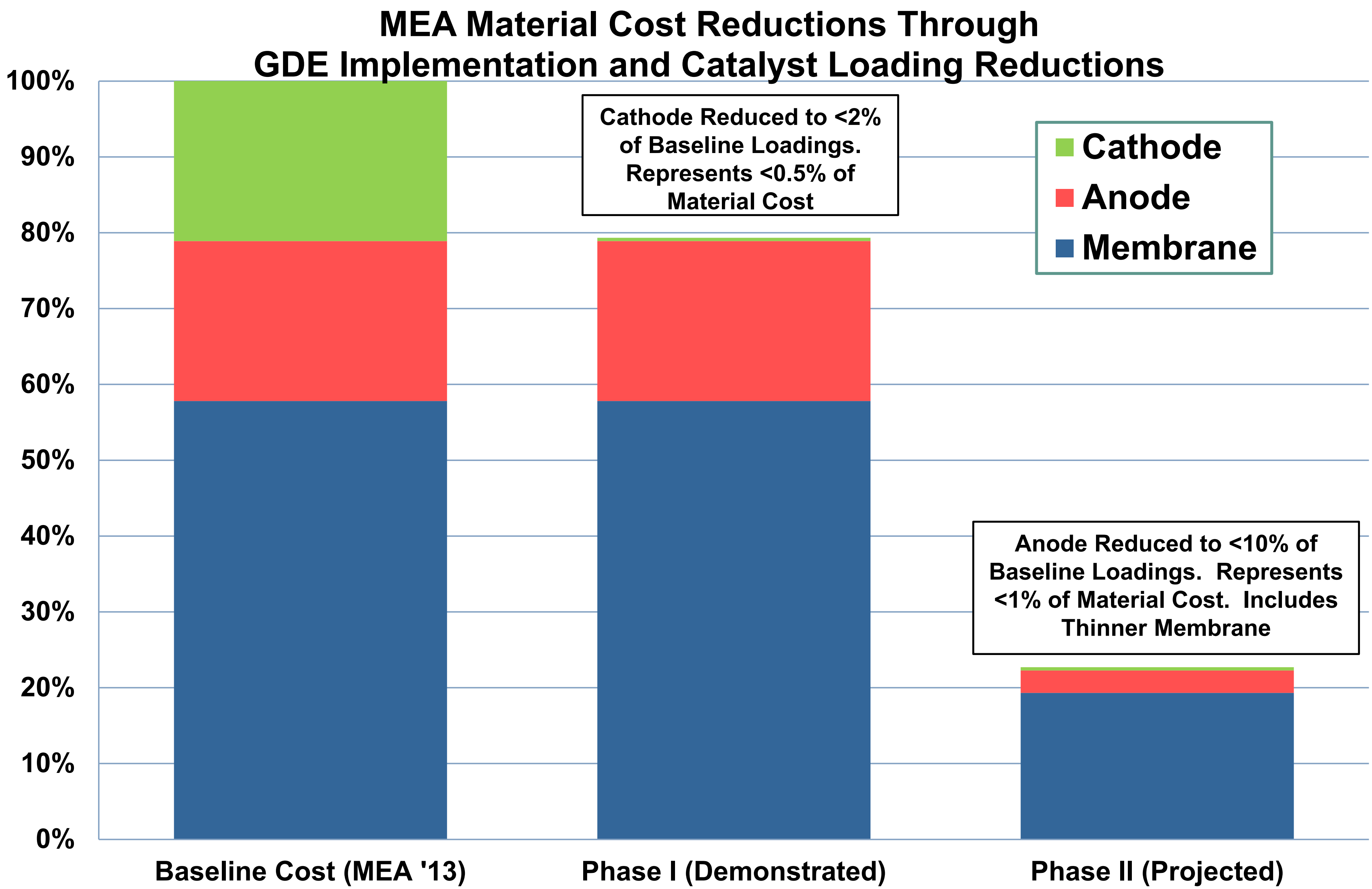
Technical Accomplishments
Cathode GDE Durability Testing



Technical Accomplishments
Anode GDE Feasibility Testing

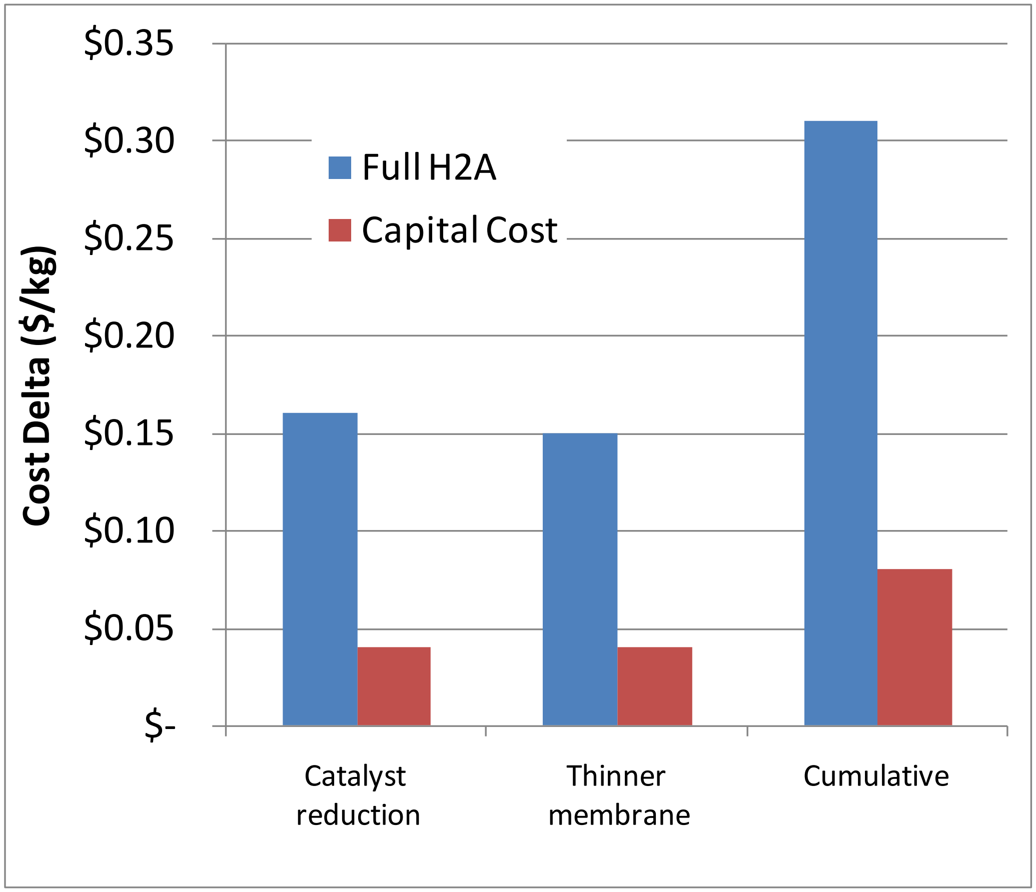


Technical Accomplishments



Technical Accomplishments
Cost Analysis

- Phase 1 Approach:
  - H2A Analysis shows \$.30/kg reduction in overall H_2 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^2 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^2 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 H2A model $/kg cost analysis