FC144

Highly-Accessible Catalysts for Durable High-Power Performance

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General Motors, Fuel Cell Business

May 1, 2019

Overview

Timeline

- Project start date: 1 Apr 2016
- Project end date: 30 Jun 2019
- Percent complete: 75%

Budget

- Total Funding Spent as of 12/31/18: $2.4M
- Total DOE Project Value: $4.0M
  (additional direct funding to NREL $0.6M)
- Cost Share: 21.7%

Barriers

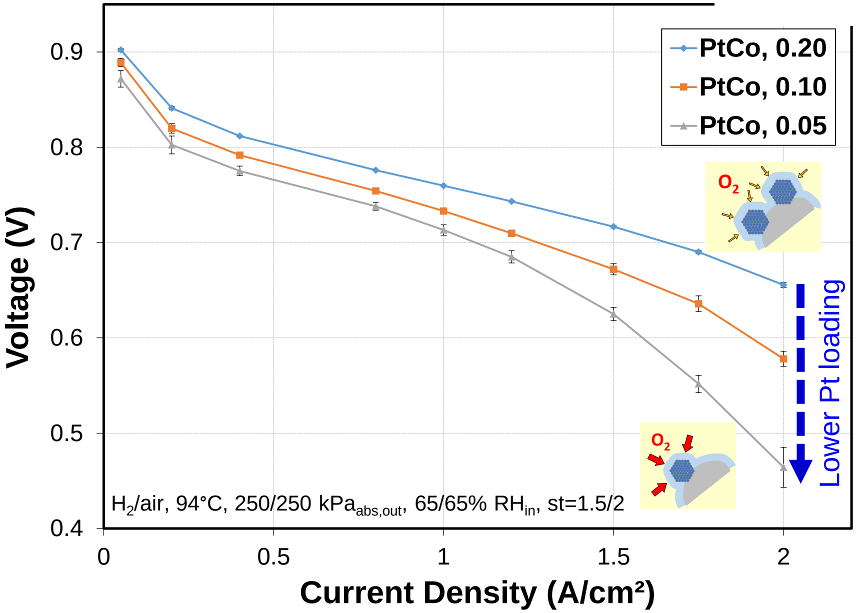
- B. Cost
  - Decrease amount of precious metals.
- A. Durability
  - Improve kinetic activity and high current density performance
- C. Performance
  - Achieve and maintain high current densities at acceptably-high voltages

Partners

- Subcontractors:
  - 3M Company
  - Carnegie Mellon University
  - Cornell University
  - Drexel University
  - NREL
- Project lead: GM

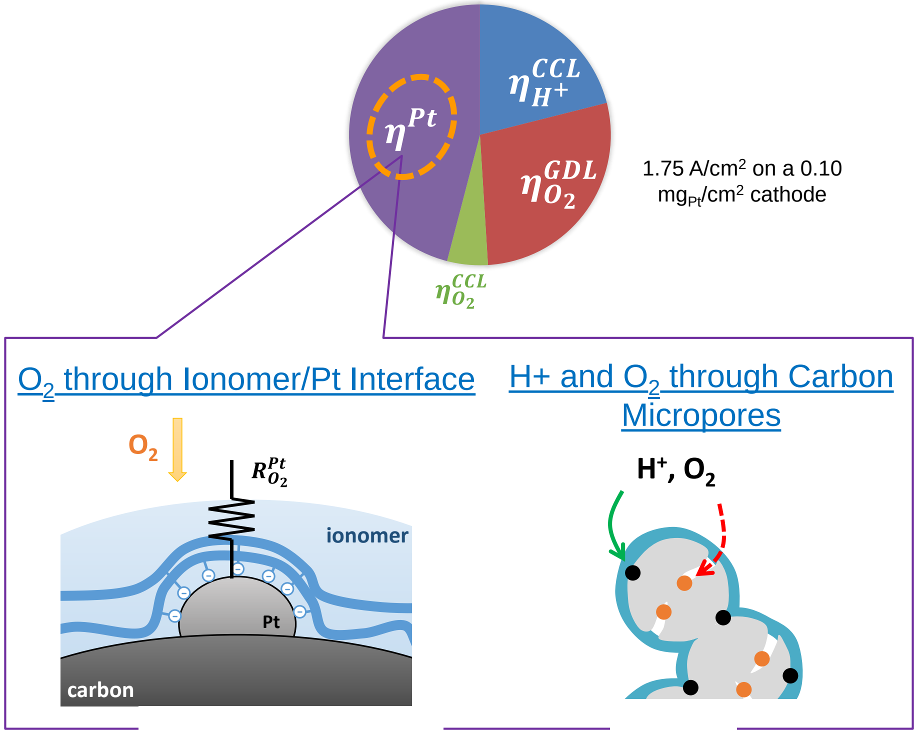
Relevance:

Challenge: Local Transport Losses



H_2/air, 94°C, 250/250 $kPa_{abs,out}$, 65/65% RH_{in}, st=1.5/2

Mass-transport Voltage Losses



1.75 A/cm^2 on a 0.10 mg_{Pt}/cm^2 cathode

O_2 through Ionomer/Pt Interface

H+ and O_2 through Carbon Micropores

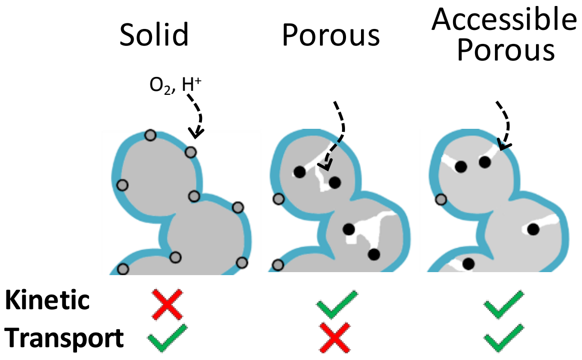
- ❑ FC087 Dealloyed PtCo and PtNi *met Catalyst Targets* (activity and durability) ***but not MEA Targets*** (high current density, HCD).
- ❑ At HCD, high flux of O_2 and proton per a given Pt area causes large voltage loss on low-Pt cathode.
- ❑ The ‘local transport resistance’ dominates the mass transport related loss (purple).
- ❑ Likely a sum of H^+ and O_2 resistance at ionomer/Pt interface and in carbon micropores.
- ❑ Want to reduce *apparent* R^{Pt} from ~25 s/cm to <10 s/cm, or double the Pt ECSA.

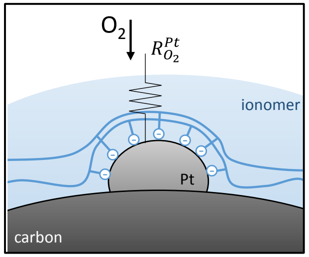
J. Phys. Chem. Lett. (2016) 1127.

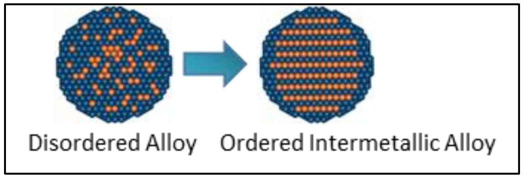
Approach:

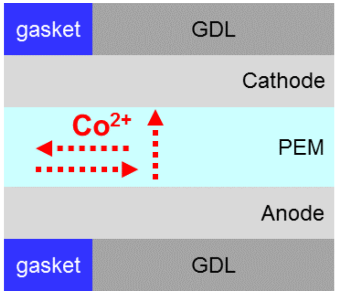
Work Focuses in the Past Year

- ❑ New Carbon Supports
  - ➢ Study local transport using MEA electrochemical diagnostics, microscopy, and simulation.
  - ➢ Understand support effects on durability.
  - ➢ Optimize PtCo on accessible carbon with emphasis on stability
- ❑ Electrolyte-Pt Interfaces: Ionomer and Ionic Liquid
  - ➢ Develop process to add ionic liquid in MEA and study its effect.
  - ➢ Identify new electrolyte-Pt interface affects fuel cell performance.
- ❑ Ordered Intermetallic Alloys
  - ➢ Use advanced in-situ techniques to optimize activity/stability vs Pt-particle-size growth
- ❑ Effects of Co^{2+} and Ce^{3+}
  - ➢ Validate cation performance model with in-situ visualization.









Relevance:

Targets and Status

Metric	Units	PtCo/KB 2016	PtCo/HSC-f	Ordered-PtCo/HSC-f	Ordered-PtCo/KB	PtCo/HSC-f	DOE 2020 Target	Project Target
PGM total loading (both electrodes)	mg/cm^2	0.125 (0.025+0.10)	←	←	←	0.075 (0.015+0.06)	<0.125	←
Mass activity @ 900 mV$_{iR\text{-free}}$	A/mg$_{PGM}$	0.62†	0.7†	0.7†	0.53†	0.7†	>0.44	←
Loss in catalytic (mass) activity	% loss	30%	59%*	45%*	16%	tbd	<40%	←
Performance at 0.8V (150kPa, 80°C)	A/cm^2	0.304	tbd	tbd	0.301	tbd	>0.3	←
Power at rated power (150kPa, 94°C)	W/cm^2	0.8	0.95	0.94	tbd	0.91	>1.0	-
Power at rated power (250kPa, 94°C)	W/cm^2	1.01	**1.31**	1.29	1.15	1.23	-	>1.1
PGM utilization (150kPa, 94°C)	kW/g$_{PGM}$	6.4	7.6	7.5	tbd	**12.1**	>8	←
PGM utilization (250kPa, 94°C)	kW/g$_{PGM}$	8.1	10.5	10.3	9.2	**16.4**	-	>9.1
Catalyst cycling (0.6-0.95V, 30k cycles)	mV loss at $0.8A/cm^2$	24	39*	25	8	tbd	<30	←
Support cycling (1.0-1.5V, 5k cycles)	mV loss at $1.5A/cm^2$	>500	>500	tbd	tbd	tbd	<30	-

Green: meet target
Red: not yet meet target
Black: NA

Must meet Q/ΔT <1.45 or >0.67 V at 94°C

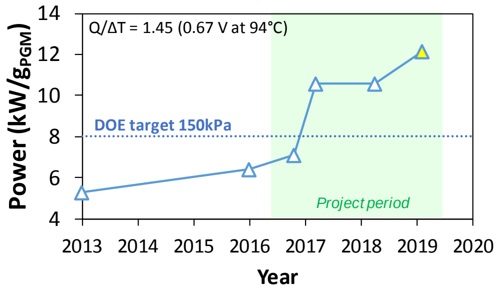
* *Meet target in absolute term (e.g. >0.26 A/mg$_{PGM}$)*
† *MA at 0.9V$_{RHE}$ in cathodic direction*

Objectives

- ❑ Reduce overall stack cost by improving high-current-density (HCD) performance adequate to meet DOE heat rejection and Pt-loading targets.
- ❑ Maintain high kinetic mass activities.
- ❑ Minimize catalyst HCD degradation.

This Year Target Highlights

- ❑ Improved durability of accessible-PtCo with minimal performance penalty using intermetallic ordering.
- ❑ Narrowed gap to 1 W/cm^2 (150kPa) target (now 0.95 W/cm^2).
- ❑ Boosted PGM Utilization (to 12.1 vs target of 8 kW/g$_{PGM}$ at 150kPa) by reducing Pt in both anode and cathode.



Approach:

Milestones and Go/No Go

TASK 1 - Development of Highly-Accessible Pt Catalysts

Go/No-go criteria: >1.0 W/cm^2, >8 kW_{rated}/g_{Pt}, and $Q/\Delta T$ <1.7 with Pt/C ✓

	2018 AMR	2019 AMR
☐ Downselect carbon support, ionomer, ionic liquid	100%	100%
☐ Measure the effect of leached Co^{2+} and Pt surface area	100%	100%
☐ Develop dealloyed catalyst from ordered intermetallic alloy	100%	100%
☐ Visualize carbon structure and Pt location on selected catalysts	100%	100%
☐ Model baseline material	100%	100%

TASK 2 - Development of Dealloyed Catalyst with Preferred Catalyst Design

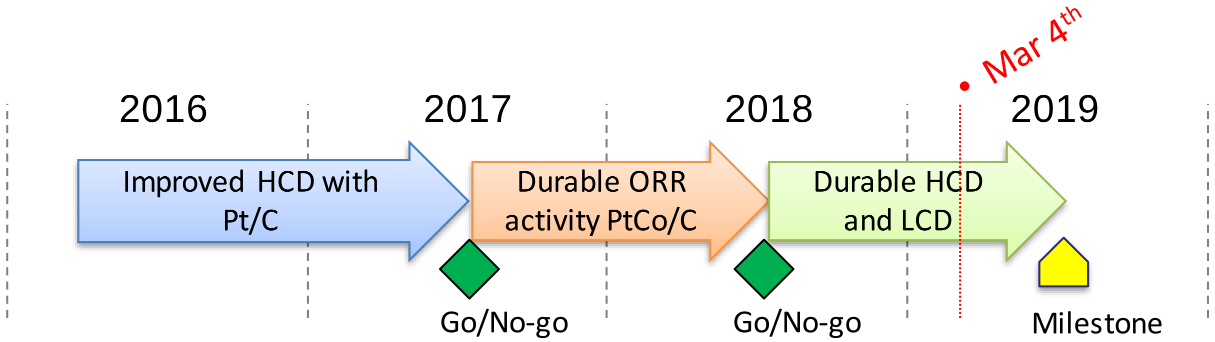
Go/No-go criteria : >0.44 A/mg_{PGM}, <40% mass activity loss with preferred design ✓

	2018 AMR	2019 AMR
☐ Develop dealloyed catalyst on preferred support	80%	100%
☐ Implement selected ionomer and ionic liquid with selected catalysts	60%	100%
☐ Visualize fresh PtCo/C and post-AST Pt/C	90%	100%
☐ Model PtCo/C before and after AST	70%	100%

TASK 3 - Optimization for Durable HCD and LCD Performance

Milestone: >1.1 W/cm^2, >9.1 kW_{rated}/g_{Pt}, and $Q/\Delta T$ <1.45 ✓ ***Jun 2019***

	2018 AMR	2019 AMR
☐ Identify root cause and improve durability and performance of PtCo/C	20%	70%
☐ Evaluate effect of selected ionomer/IL on HCD and durability of improved PtCo catalyst	10%	80%
☐ Integrate new catalyst design with other state-of-the-art FC components	20%	80%
☐ Make available to DOE the improved catalyst in 50 cm^2 MEAs	10%	10%
☐ Visualize and model improved catalyst	10%	50%



Mar 4th

2016

2017

2018

2019

Improved HCD with Pt/C

Durable ORR activity PtCo/C

Durable HCD and LCD

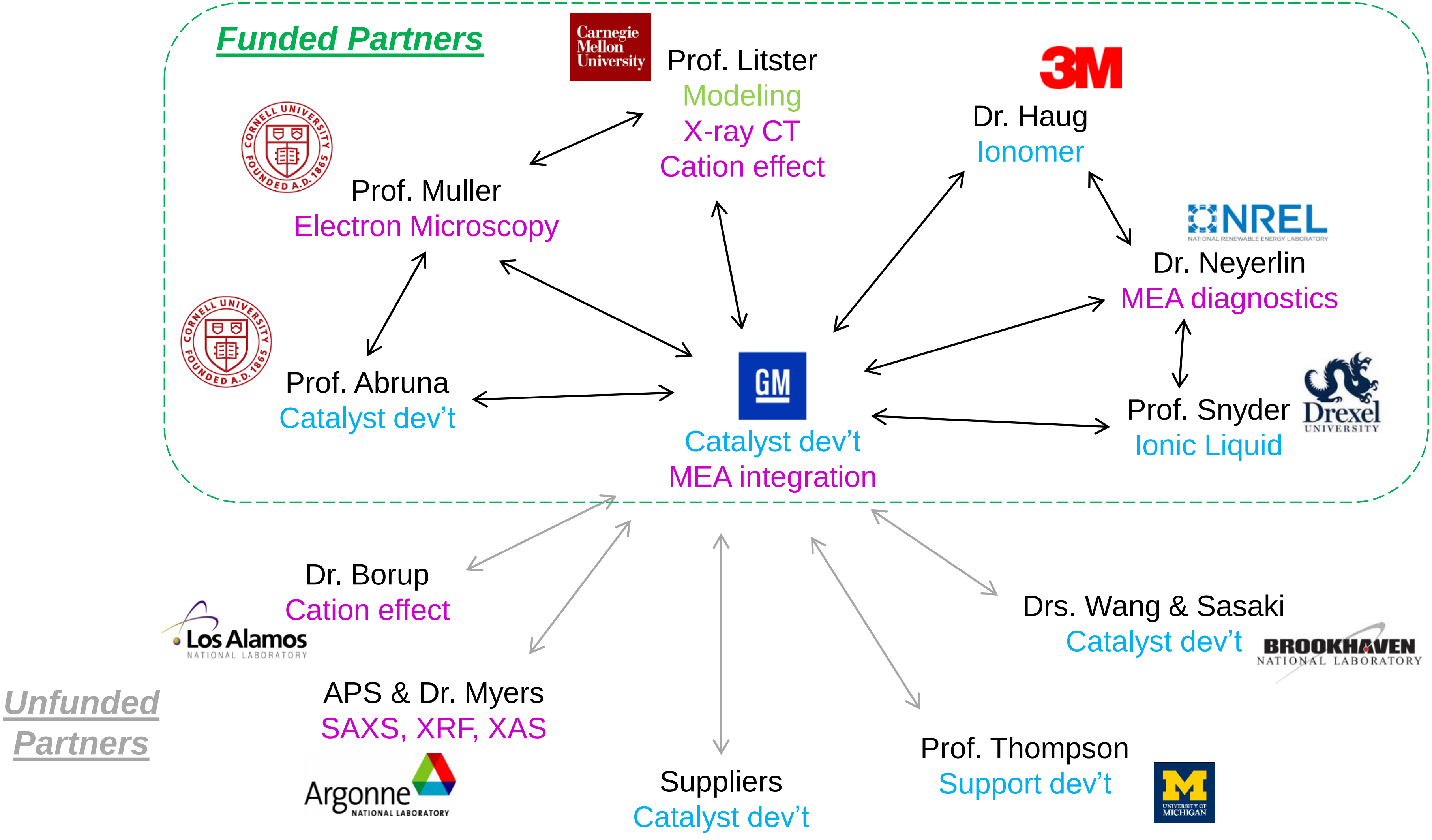
Go/No-go

Go/No-go

Milestone

Collaborations

Materials dev't
Characterization
Modeling



Funded Partners

Carnegie Mellon University
Prof. Litster
Modeling
X-ray CT
Cation effect

3M
Dr. Haug
Ionomer

Prof. Muller
Electron Microscopy

NREL NATIONAL RENEWABLE ENERGY LABORATORY
Dr. Neyerlin
MEA diagnostics

Prof. Abruna
Catalyst dev't

GM
Catalyst dev't
MEA integration

Prof. Snyder
Ionic Liquid
Drexel UNIVERSITY

Unfunded Partners

Dr. Borup
Cation effect
Los Alamos NATIONAL LABORATORY

APS & Dr. Myers
SAXS, XRF, XAS
Argonne NATIONAL LABORATORY

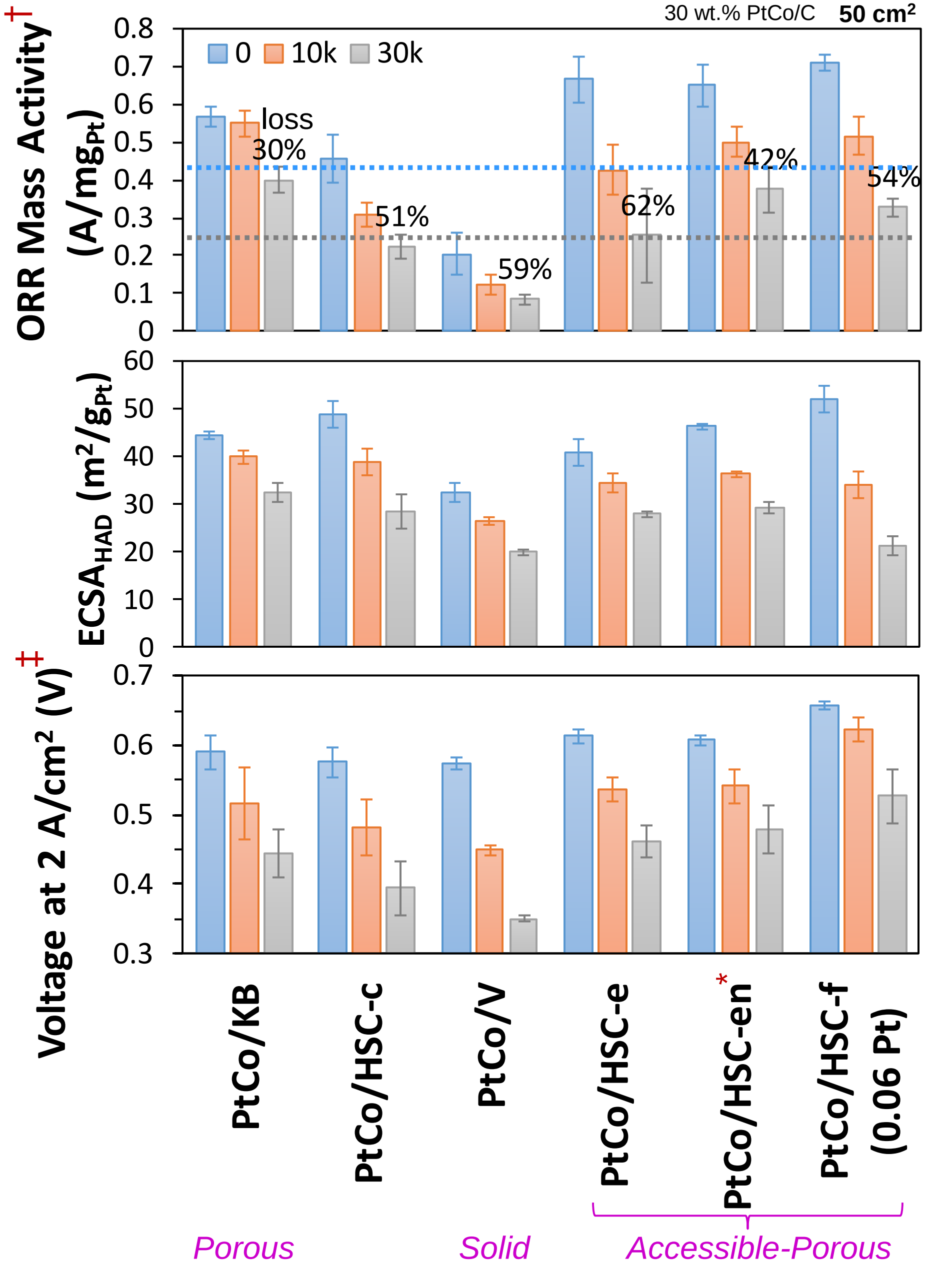
Suppliers
Catalyst dev't

Drs. Wang & Sasaki
Catalyst dev't
BROOKHAVEN NATIONAL LABORATORY

Prof. Thompson
Support dev't
UNIVERSITY OF MICHIGAN

From 2018 AMR

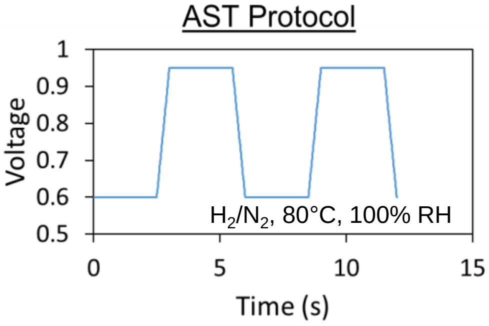
Accessible-PtCo Stability



ORR Targets

.44 A/mg_{Pt} BOL

.26 A/mg_{Pt} EOT



- Although catalysts with Accessible-porous carbons outperform other catalysts at HCD (2 A/cm²) throughout the test, they show larger % losses of ORR MA and ECSA compared to KB.

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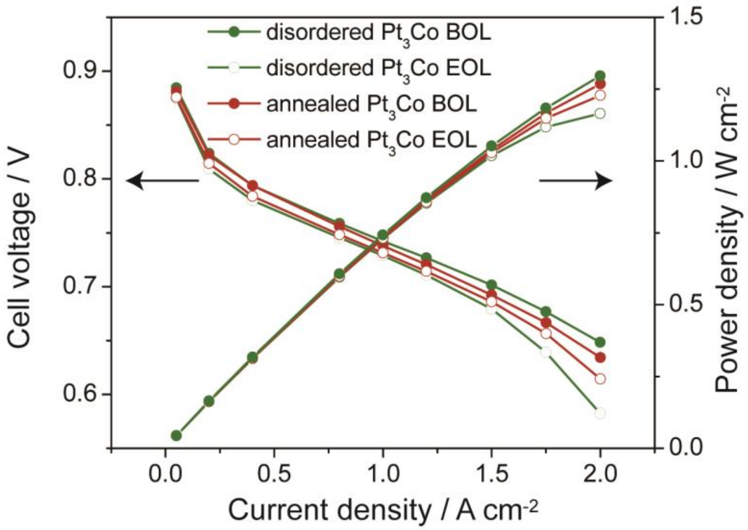
* HSC-en is an optimized and up-scale (20 g) of HSC-e

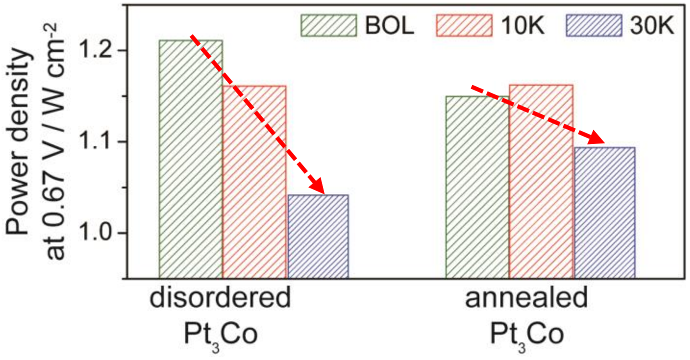
† MA at 0.9 V_{RHE} measured in cathodic direction

‡ H_2/air, 94°C, 250 kPa_{abs}, 65% RH, stoich 1.5/2

Technical Accomplishment:

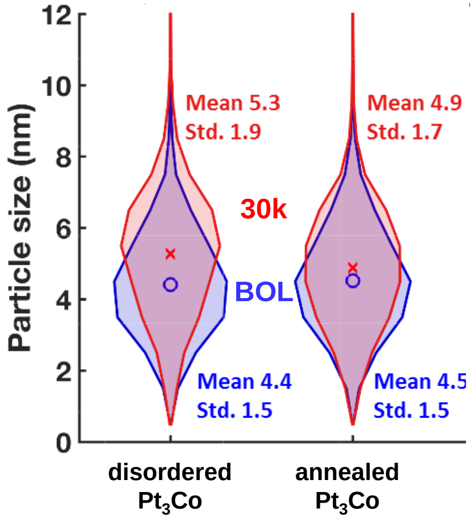
Improving Stability with Intermetallic Pt_3Co

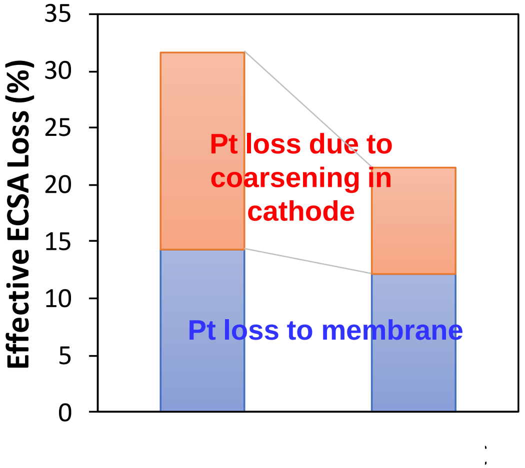




PNAS (2019) 116, 1974

Pt Loss Determined by TEM



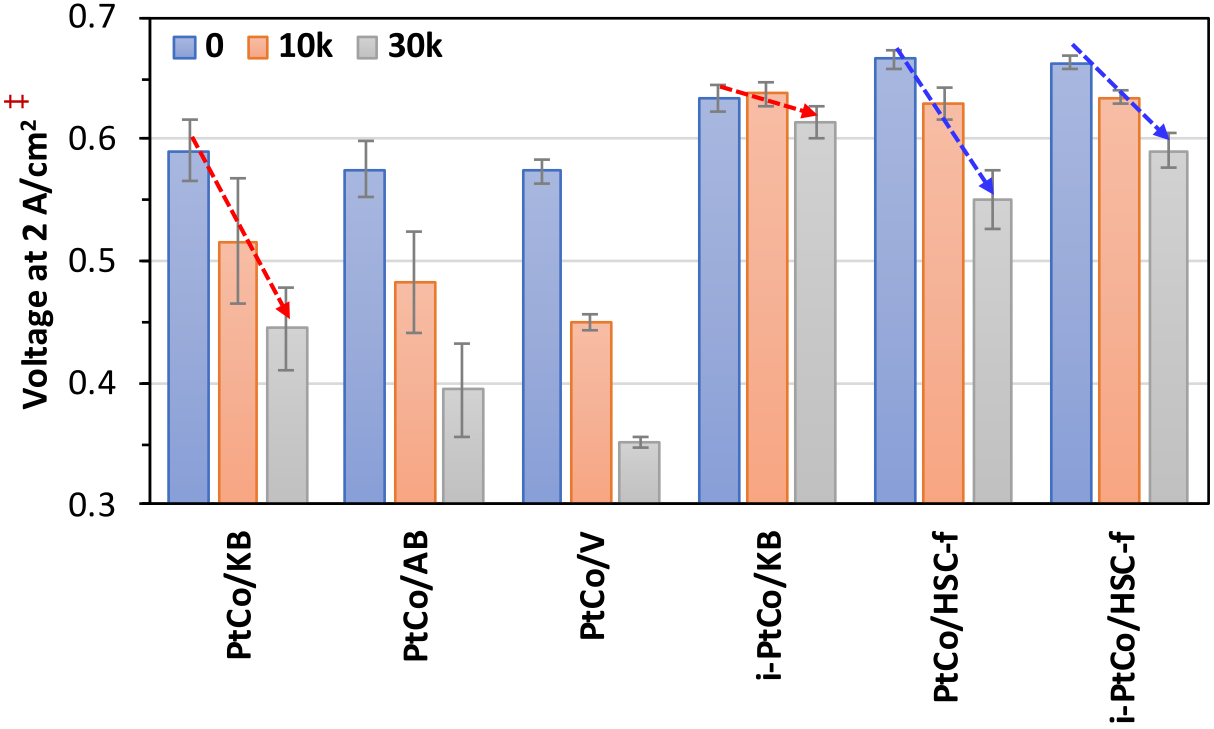


- Thermal annealing to encourage intermetallic ordering decreases ORR activity, ECSA, and HCD losses by about one half.
- TEM confirms MEA results: less particle growth, less Pt loss to membrane.
- Changes in Co/Pt ratio in cathode catalyst were comparable (~45%).

Technical Accomplishment:

Also Effective on Accessible-PtCo

Carbon Supports and Annealing Effects on HCD Stability



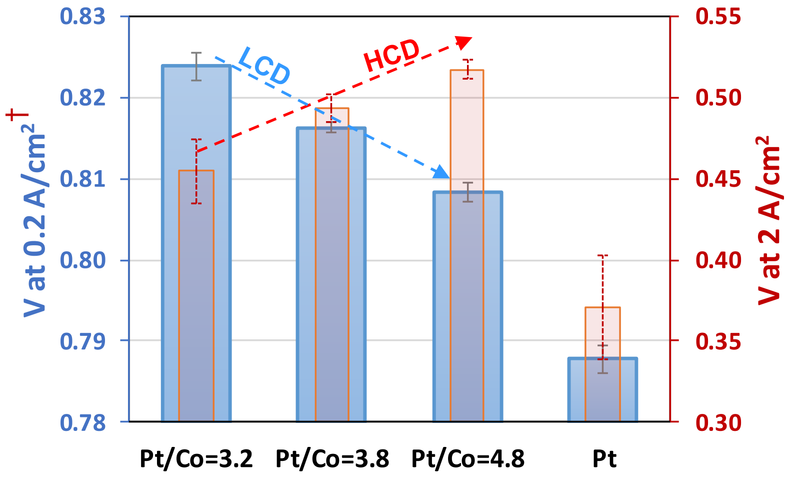
- ☐ Thermal annealing optimization study (time & temperature) was done on PtCo/KB and PtCo/HSC-f.
- ☐ Results from the best treatment condition are shown, although it was found that similar results were achievable among a wide range of condition, reflecting its robustness.
- ☐ Appears to be effective on accessible-porous carbon as well.

‡ H_2/air, 94°C, 250 kPa_{abs}, 65% RH, stoich 1.5/2
Error bars: two σ

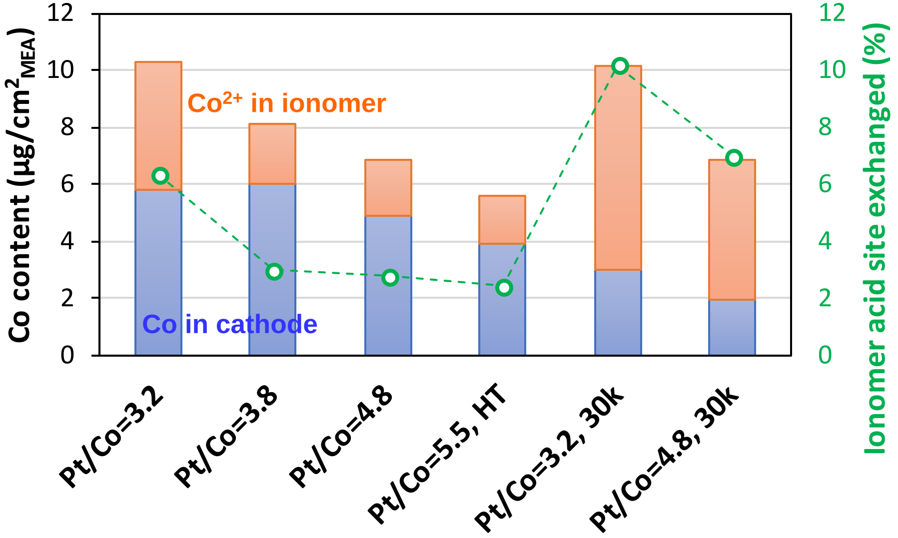
Technical Accomplishment:

Pt/Co Composition Trade-off

Voltages at LCD and HCD vs Pt/Co ratio



Co loss to ionomer phase‡



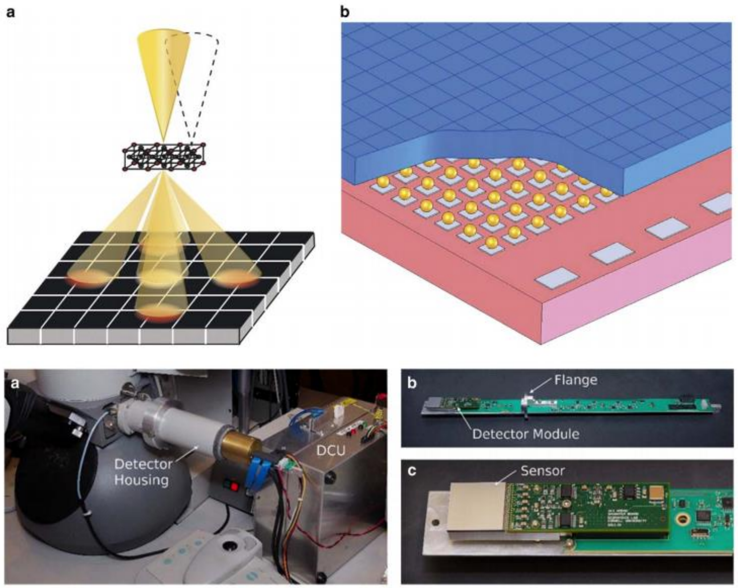
- ☐ Catalysts with higher Co content give higher LCD but lower HCD.
- ☐ Noticeable amount of Co is lost from the catalyst even at beginning-of-life, further loss after AST.
- ☐ Trade-off is not simple, depending on users' operating condition, drive cycle, and MEA design.
- ☐ Need to better quantify/monitor Co amount during life, and ultimately, make the catalyst less prone to Co dissolution.

† H_2/air, 80°C, 150 kPa_{abs}, 40% RH_{in}, stoich 1.5/1.8
Error bars: two σ
‡ Co content measured by EPMA and ICP

Technical Accomplishment:

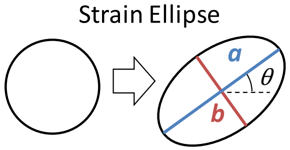
Sub-nm Resolution Lattice Strain Mapping

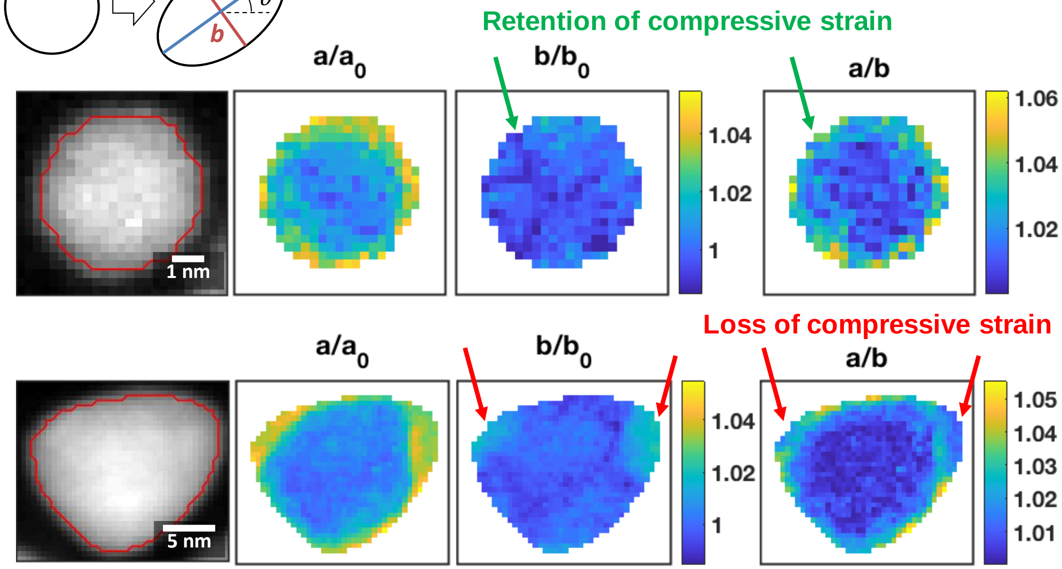
Cornell’s Electron Microscope Pixel Array Detector

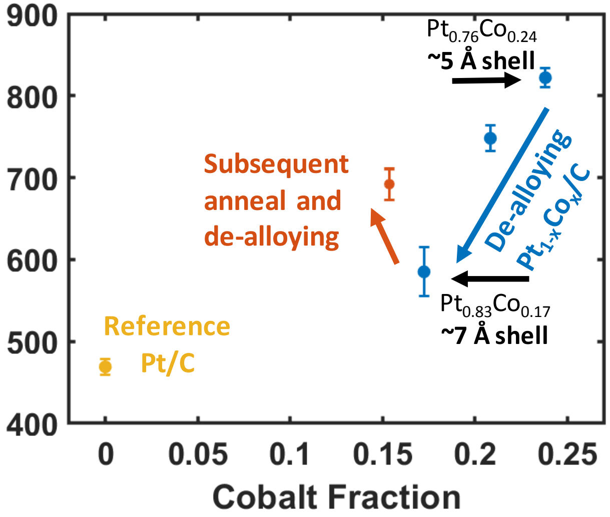


Microscopy and Microanalysis, *22*(1), 237–249, 2016.

Imaging Coherent and Relaxed Strain in EOL PtCo



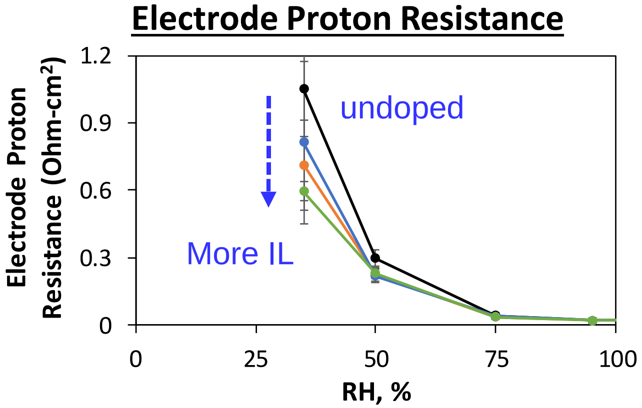




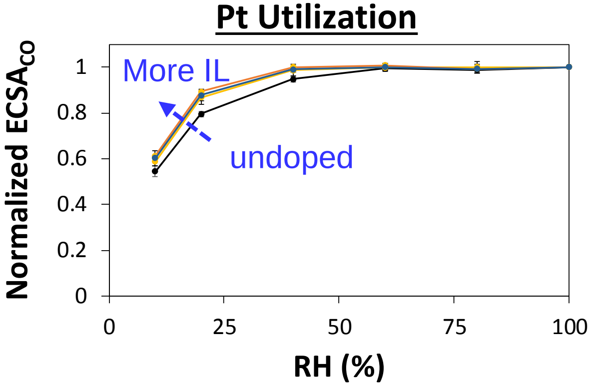
- Fast *direct* characterization of lattice strain with <1nm resolution
- When acid leached PtCo, activity loss is more than expected from geometric strain relaxation alone.
- Subsequent annealing can recover activity, possibly by removing lattice dislocations
- Observed some dislocations (defects) in cycled and aggressively leached particles.

Technical Accomplishment:

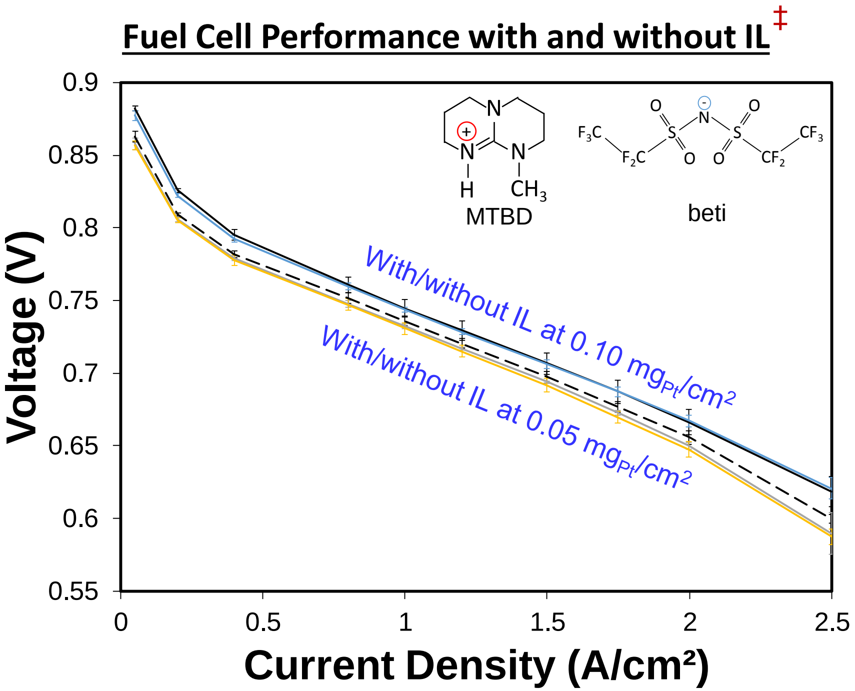
Ionic Liquid with Accessible-PtCo



Electrode Proton Resistance



Pt Utilization



Fuel Cell Performance with and without IL‡

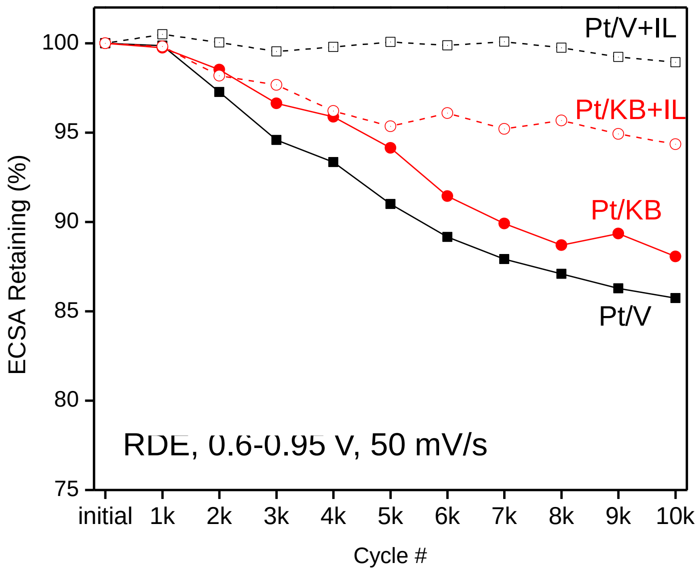
‡ H_2/air, 94°C, 250 kPa_{abs}, 65% RH, stoich 1.5/2
Error bars: two σ

- ☐ Improved electrode proton conduction and Pt utilization under dry conditions were confirmed.
- ☐ Unfortunately, IL benefits on fuel cell HCD performance hasn't been observed on PtCo/HSC-f.
  - ➢ Because of the fact that we had observed several times its benefit on PtCo/KB, makes us believe that the benefit is muted on PtCo/HSC-f due to its already-high Pt utilization at a relatively wet condition under normal operation.
- ☐ Ongoing effort to optimize IL application, and to evaluate IL potential durability benefit (next slide).

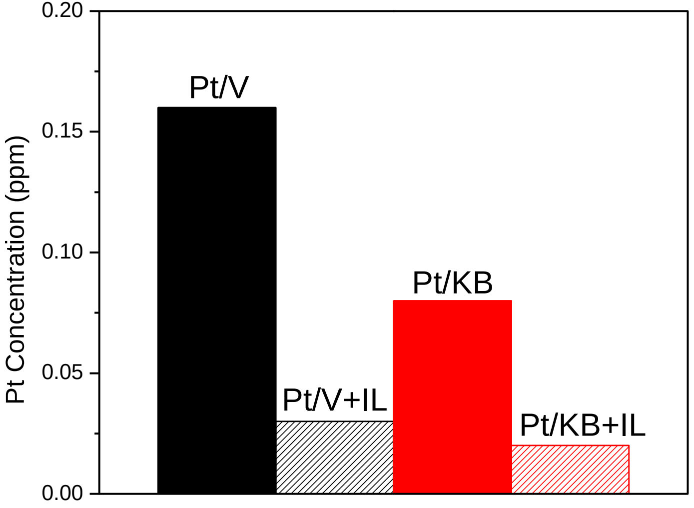
Technical Accomplishment:

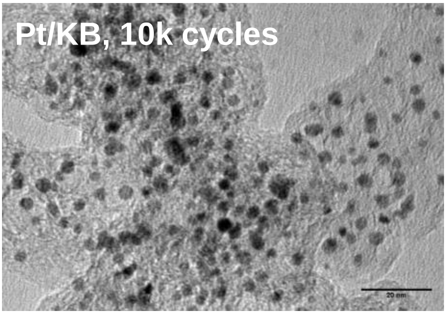
Ionic Liquid Reduces Pt Dissolution

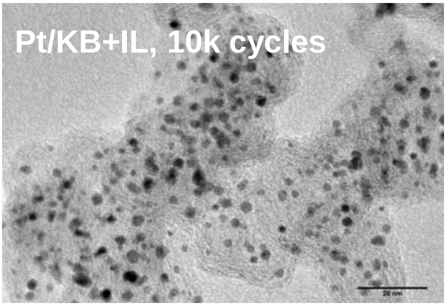
ECSA Retained during RDE-AST



Pt Dissolution by ICP-OES





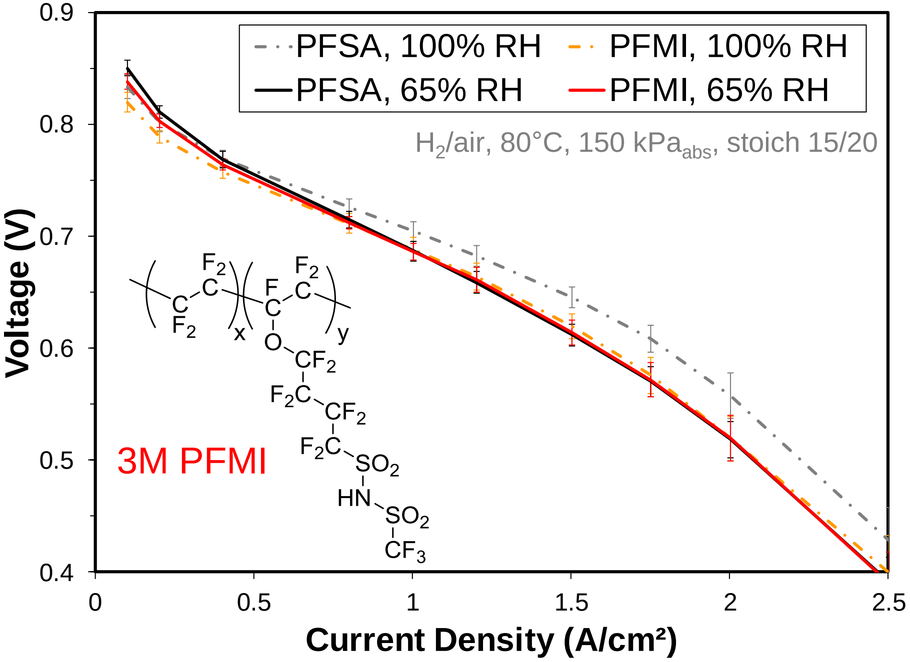


- ❑ Presence of IL thin film on Pt/V and Pt/HSC leads to significant improvements in ECSA and ORR activity retention during RDE AST test (0.6-0.95 and 0.6-1.1 V). Lower Pt dissolution was confirmed by ICP.
- ❑ Ex-situ XPS and UPS analysis of IL thin film on Pt electrodes pre- and post-AST (0.6 – 1.2 V vs. RHE, 10,000 cycles) indicates little changes in IL chemistry.
- ❑ CO displacement charge at 0.4 V is lower in the presence of IL, indicating decreased anionic species. Intermediary IL thin film both limits ionic species specific adsorption, screening of SO^{3-} groups, and lower site blocking from hydrophobic domains of PFSA polymer.

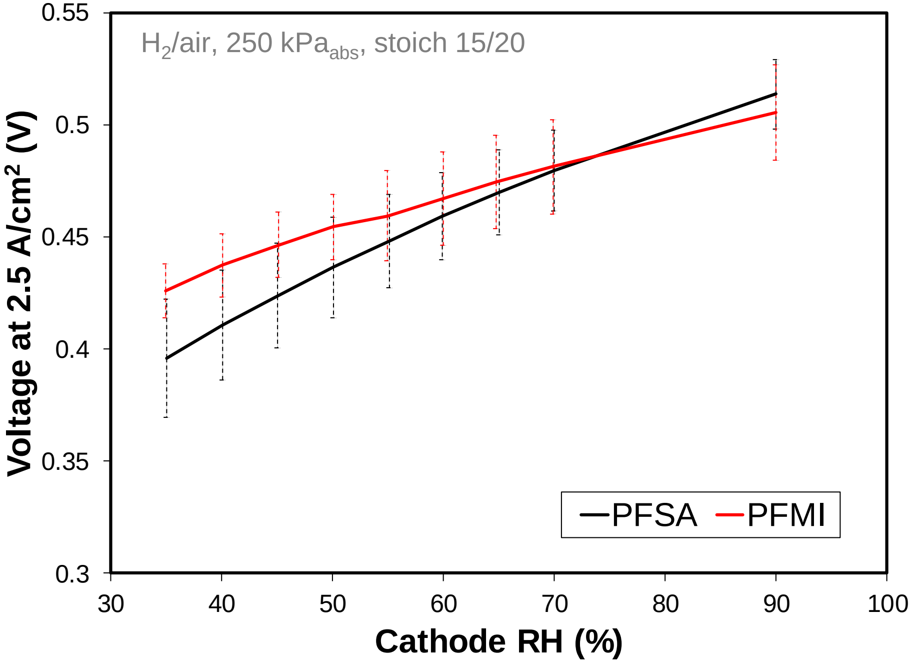
Technical Accomplishment:

PFMI Ionomer

Fuel Cell Performance under Wet and Dry



RH Sensitivity. V at 2.5 A/cm²



- ❑ While 3M observed improved performance when PFMI [Perfluoromethyl bis(sulfonyl)imide] ionomer was used with Pt/C, first test at GM with PtCo/KB gave lower mass activity compared to PFSA ionomer.
- ❑ PFMI appeared to have less performance sensitivity to humidity.
- ❑ Were not yet able to confirm whether PFMI ionomer can improve HCD through less adsorbing acid group.

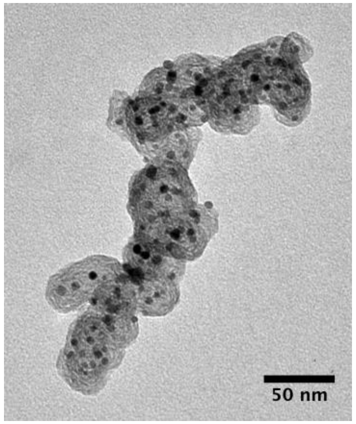
PtCo/KB, 0.1 mg_{Pt}/cm^2
Error bars: two σ

Technical Accomplishment:

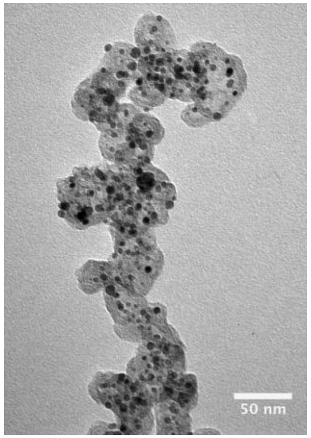
Accessible Carbons Appears More Open

STEM Tomography

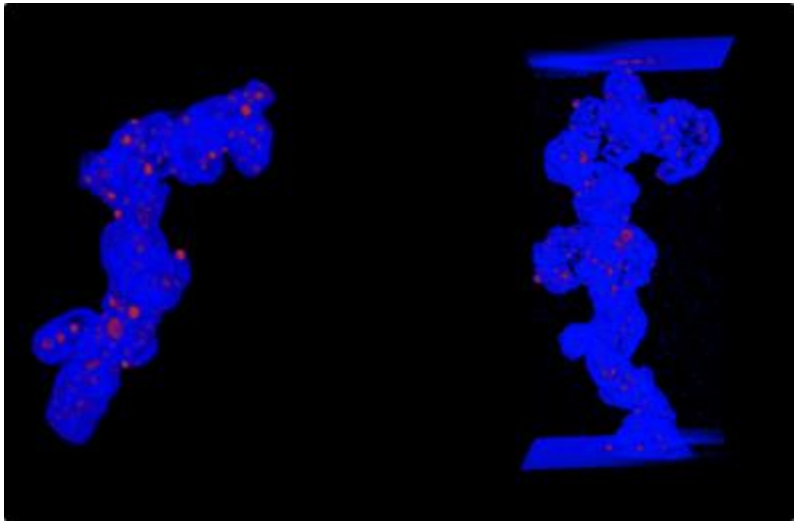
PtCo/KB



Accessible-PtCo/HSC

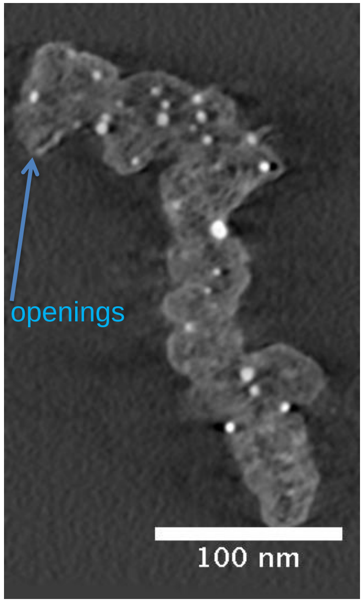


Reconstructing Carbon, Pore, and Pt

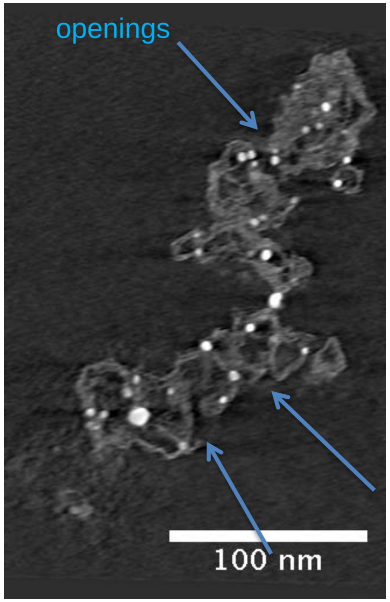


Sliced Images showing Pore Openings

PtCo/KB



Accessible-PtCo/HSC



- Comparatively, KB has smaller pore size (2-5 vs 5-10 nm) and smaller pore opening (1-2 vs 3-7 nm), and likely a more tortuous path.

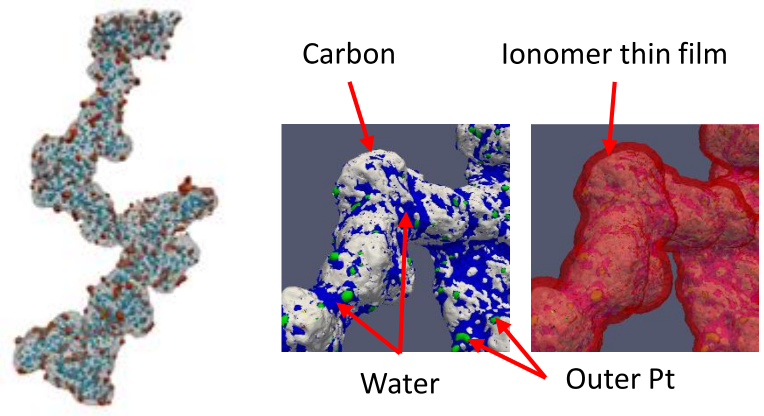
- Neither looks optimized

Technical Accomplishment:

STEM-CT based Catalyst Aggregate Model

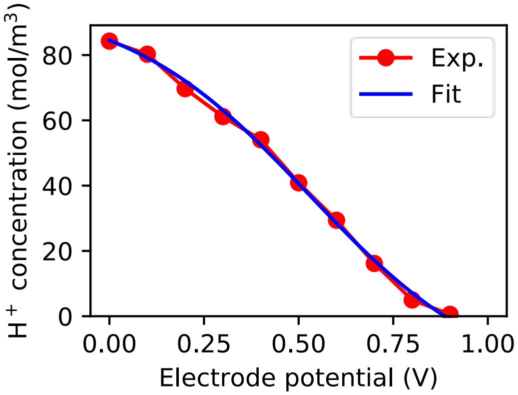
Microscopy data input

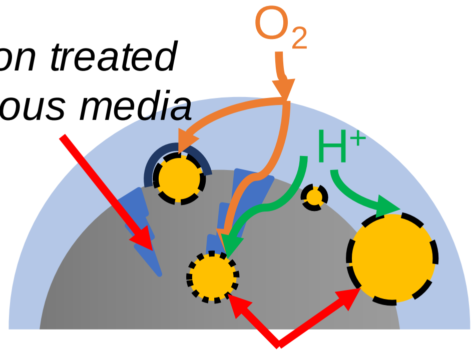
50 wt. % Pt/HSC STEM CT images



Synthetic addition of ionomer and water volumes to STEM images

Potential dependent H^+ conc. from EIS conductivity measurements on ionomer-free carbon black





Carbon treated as porous media

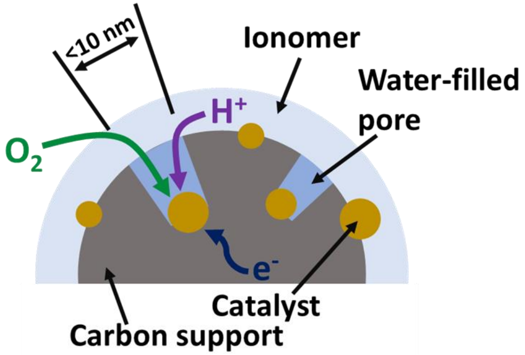
Partially oxidized Pt with negative surface charge

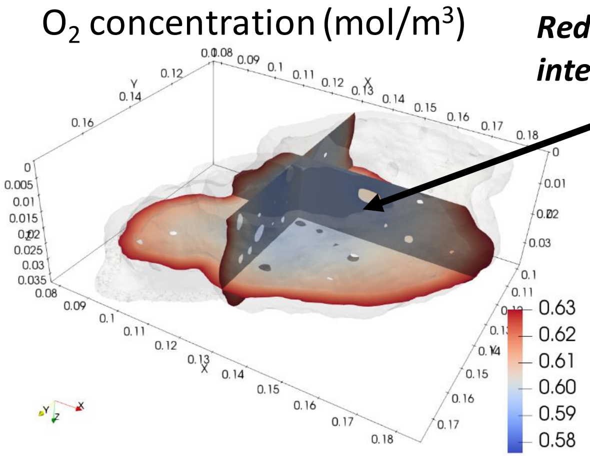
Transport and reaction models

- Poisson-Nernst-Planck equation to resolve various charge effects for H^+ concentration and electric potential in the electrolytes
- Fixed space charges in ionomer and porous carbon
- Constant negative surface charge on Pt surfaces
- Diffusion equation for O_2 concentration
- Pt/ionomer interface O_2 transport limited Butler-Volmer type reaction model with Pt oxide coverage model

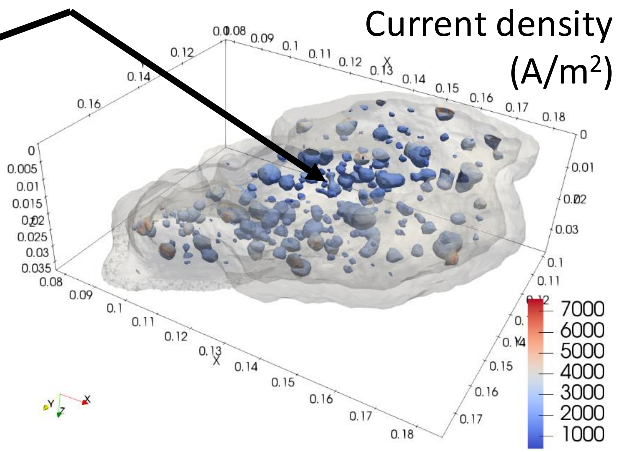
Technical Accomplishment:

O_2 Diffusivity Through Water-Filled Pores

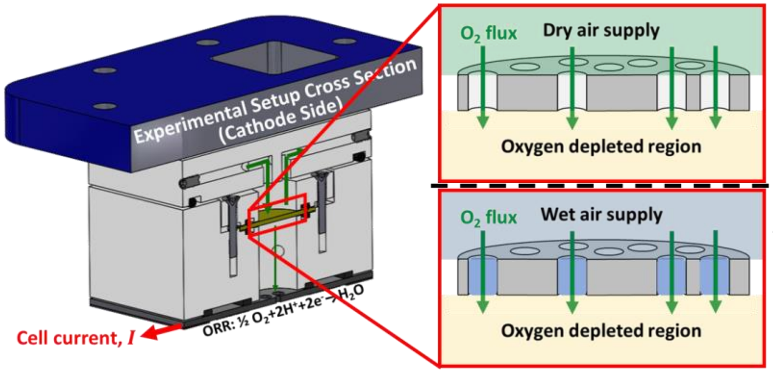



O_2 concentration (mol/m³)

Reduced O_2 concentration & internal Pt current density


Current density (A/m²)

Measurement of O_2 diffusivity in 10 nm water-filled micropores



Knudsen diffusivity recovered for unfilled pore case

Pores filled using capillary condensation at high RH

Measurements for filled pore case are ongoing

- Cannot explain performance difference between PtCo/KB and Accessible-porous catalysts, with their relatively small difference in pore sizes, using known values for O_2 transport.
- Literature has indicated quickly reduced gas diffusivity in <10 nm liquid-filled micropores (*J. Phys. Chem. C*, 2017, 26539 & *J. Phys. Chem. C*, 2017, 15675)
- Ex-situ O_2 diffusivity measurement in water-filled <10 nm pore is underway.

Technical Accomplishment:

SOA Integration & DOE Validation

SOA Components

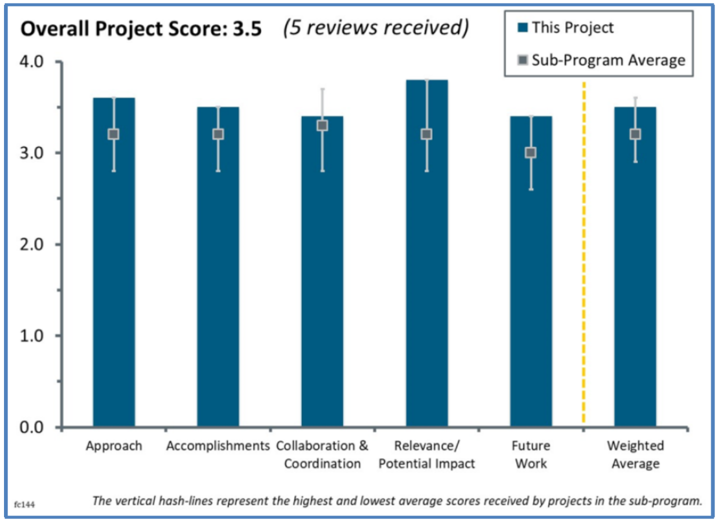
Cathode:	30 wt.% Intermetallic ordered Pt_3Co/HSC-f at 0.06 and 0.10 mg_{Pt}/cm^2, PFSA ionomer, 900 EW, I/C ratio of 0.8,
Anode:	Pt/HSC, 0.015 mg_{Pt}/cm^2
PEM:	PFSA with reinforcement layer, ~10 µm thick
GDL:	~100 µm thick carbon fiber layer with 30 µm MPL. Water proof.

Metric	Units	PtCo/KB 2016	PtCo/HSC-f	Ordered-PtCo/HSC-f	Ordered-PtCo/KB	PtCo/HSC-f	DOE 2020 Target	Project Target
PGM total loading (both electrodes)	mg/cm^2	0.125 (0.025+0.10)	←	←	←	0.075 (0.015+0.06)	<0.125	←
Mass activity @ 900 $mV_{\text{iR-free}}$	A/mg_{PGM}	0.62†	0.7†	0.7†	0.53†	0.7†	>0.44	←
Loss in catalytic (mass) activity	% loss	30%	59%*	45%*	16%	tbd	<40%	←
Performance at 0.8V (150kPa, 80°C)	A/cm^2	0.304	tbd	tbd	0.301	tbd	>0.3	←
Power at rated power (150kPa, 94°C)	W/cm^2	0.8	0.95	0.94	tbd	0.91	>1.0	-
Power at rated power (250kPa, 94°C)	W/cm^2	1.01	**1.31**	1.29	1.15	1.23	-	>1.1
PGM utilization (150kPa, 94°C)	kW/g_{PGM}	6.4	7.6	7.5	tbd	**12.1**	>8	←
PGM utilization (250kPa, 94°C)	kW/g_{PGM}	8.1	10.5	10.3	9.2	**16.4**	-	>9.1
Catalyst cycling (0.6-0.95V, 30k cycles)	mV loss at 0.8A/cm^2	24	39*	25	8	tbd	<30	←
Support cycling (1.0-1.5V, 5k cycles)	mV loss at 1.5A/cm^2	>500	>500	tbd	tbd	tbd	<30	-

- Reduce anode Pt loading by shifting to high ECSA Pt/HSC catalyst.
- Will prepare MEAs (38cm^2) for DOE validation at NREL.

Responses to Last Year AMR Reviewers’ Comments

- “should benchmark against new commercial catalysts, which are showing very high mass activity in MEAs”
  - We routinely benchmark against suppliers’ catalysts. Our PtCo/KB and PtCo/V baseline catalysts reported here are competitive. Note that some high mass activity reported by some groups are due to difference in measurement protocols.
- “Investigate whether increased ORR activities after more conditioning has any effect on HCDs”
  - It does. We’re aware of it and ensure that it does not affect our conclusion.



The vertical hash-lines represent the highest and lowest average scores received by projects in the sub-program.

- Modeling “serves only as a confirmation of what is already understood”, “not apparent that it is critical to the project”, “benefit for the greater community are difficult to derive”
  - Fuel cell is a complicated device and until we apply numbers with reasonable assumption to try to explain the phenomenon, it is impossible to prove the hypothesis. The model allows us to do so.
  - Notable findings from modeling: (a) how internal vs external Pt dissolve/redeposit, (b) importance of high negative Pt surface charge in carbon pores on kinetic and proton transport, (c) existence of high O_2 diffusion resistance in carbon pores. These will be published in detail.
- “should increase the understanding of ionic liquid stability”
  - Although we agree that durability testing should be done, we do not have resource to do so. Another issue is that we do not have a method to characterize the IL once it is made into an MEA, other than watching the voltage which is an indirect measurement. This complicates the effort.
  - That being said, we value IL as a tool to understand the Pt-ionomer interface. It’s also shown that IL could mitigate Pt dissolution.

Future Work

Validation

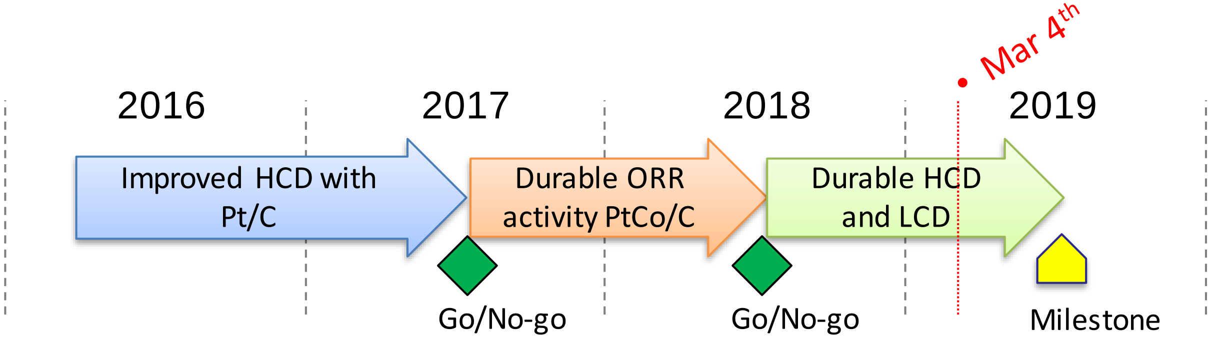
- Evaluate durability of low-loaded (0.075 mg_{Pt}/cm^2, cathode+anode) MEA. Employ MEA diagnostics and modeling to understand performance loss.
- Prepare MEAs for DOE validation at NREL.

Materials Development

- Implement new ionomer on accessible-porous carbons.
- Optimize IL application and evaluate potential durability benefit of IL.
- Catalyst synthesis path for intermetallic ordered PtCo with well controlled size.

Fundamentals

- Finalize catalyst particle-pore performance model and cation fundamental performance model.
- Study effects of local lattice strain on ORR activity using STEM with pixel array detector.
- Ex-situ measurement of O_2 diffusivity in water-filled nanopores



Mar 4th

2016 2017 2018 2019

Improved HCD with Pt/C

Durable ORR activity PtCo/C

Durable HCD and LCD

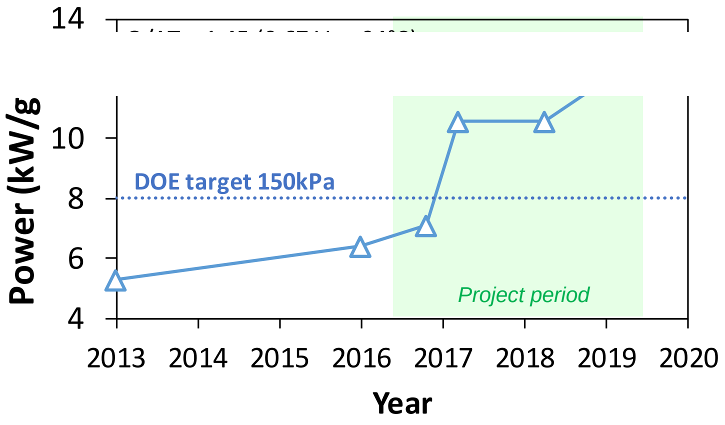
Go/No-go

Go/No-go

Milestone

Any proposed future work is subject to change based on funding levels.

Summary



- ☐ Progress to DOE target status
  - ➢ Advanced PGM Utilization status by 15% by reducing Pt in both anode and cathode.
  - ➢ Narrowed gap to 1 W/cm^2 (150kPa) target (now 0.95 W/cm^2).
- ☐ Promising materials
  - ➢ Intermetallic ordering was effective for improving durability of accessible-PtCo with minimal performance penalty.
  - ➢ While ionic liquid were beneficial for some PtCo/HSC, benefits on our best accessible-catalyst was not yet realized. Potential merit on stability awaits confirmation in MEA.
- ☐ Improved understanding of low-PGM electrode
  - ➢ 3D-TEM and modeling confirmed that internal pore size (opening) is the key factor for good ORR activity and transport properties in porous carbon catalysts.
  - ➢ Ex-situ tests and modeling highlighted (a) importance of high negative Pt surface charge in carbon pores on kinetic and proton transport and (b) unusually strong dependent of O_2 diffusivity on carbon pore size.
  - ➢ STEM Nanobeam Diffraction allows study of how lattice strain and defect in Pt shell affect ORR activity in MEAs.

This Year: 3 Articles, 12 Talks (3 invited)

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- Leiming Hu
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- Elliot Padgett
- Matthew Ko
- Barnaby Levin
- Yin Xiong
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- Dr. Ross N. Andrews
- Dr. Jan Ilavsky

LANL

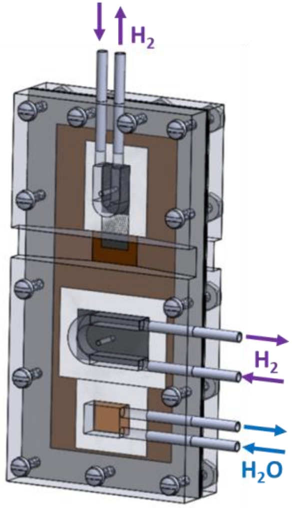
- Dr. Andrew M. Baker
- Dr. Rangachary Mukundan
- Dr. Rod L. Borup

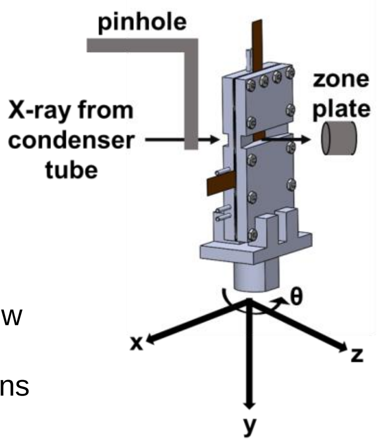
Technical Back-Up Slides

Technical Accomplishment:

In-Operando Co^{2+} Migration with Nano-CT

Migration Cell
(Hydrogen pump config.)

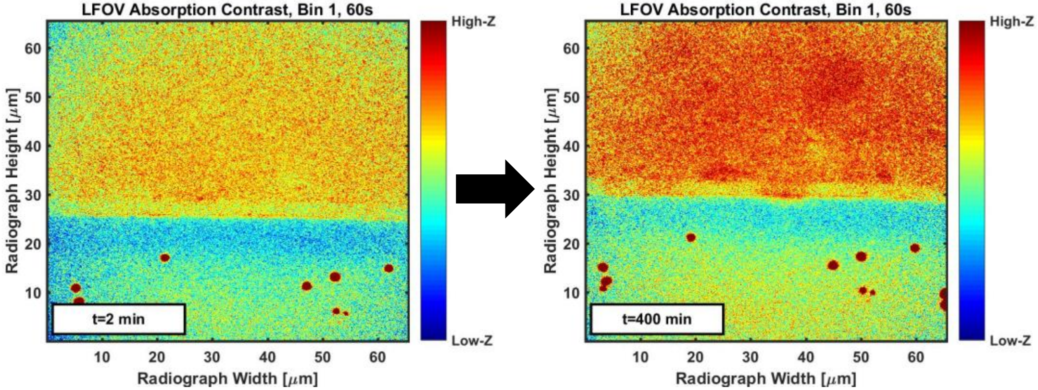




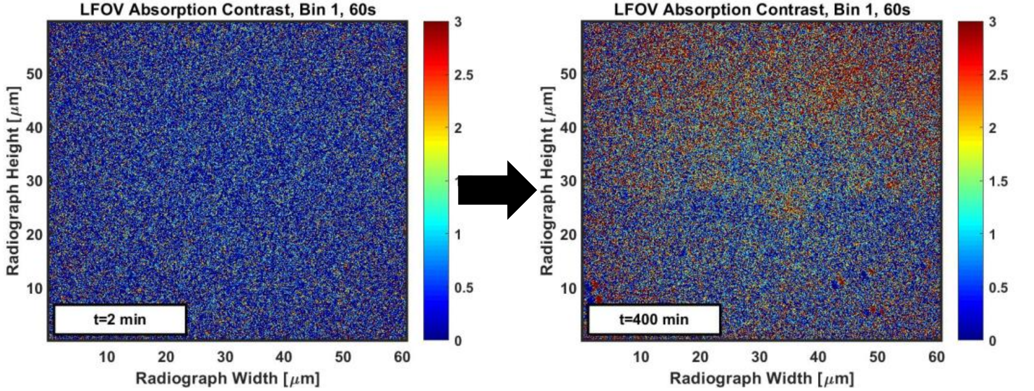
Experimental details:

- ☐ 20 wt% Pt/V CL in X-ray view
- ☐ Nafion 211 membrane
- ☐ Migration under 1V conditions
- ☐ Nano-CT imaging
  - ☐ LFOV (65x65 µm)
  - ☐ Absorption contrast mode
  - ☐ 60s per image, bin1 (64 nm pixel)
- ☐ >10 hour duration, data shown at 2 & 400 min

Raw high-Z color mapping
(histogram adjusted)



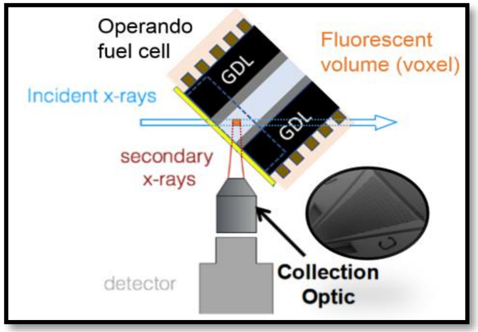
Co^{2+} attenuation mapping



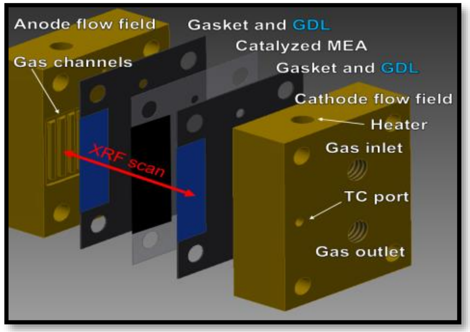
Technical Accomplishment:

In-Operando Cation Transport with Confocal µ-XRF

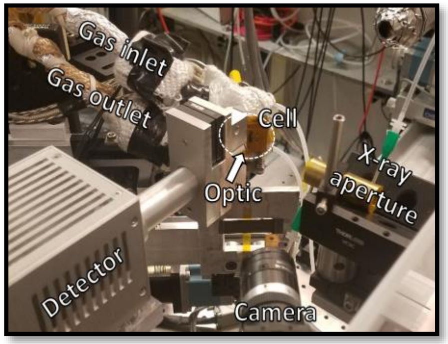
☐ ***Experimental Setup***



Confocal micro-XRF



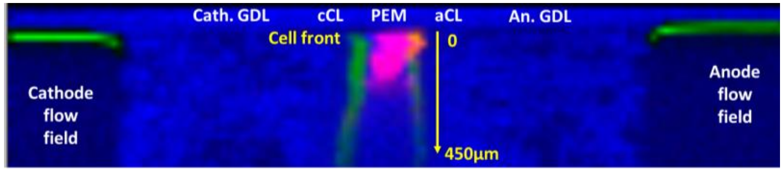
Operando Cell



Setup at CHESS beamline G3

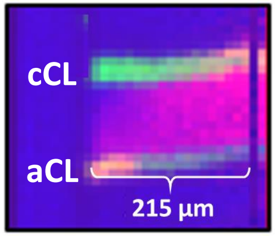
☐ ***3D-Cation Transport:*** Ce profile in a MEA (13% Ce-NR212) under a load of 50mA/cm^2

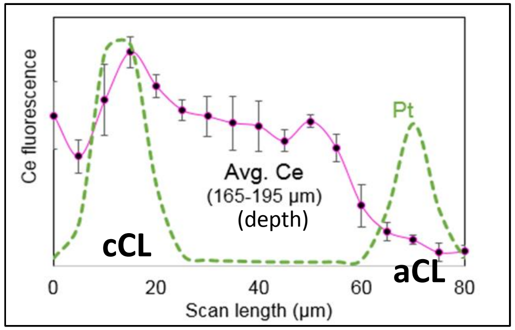
80°C, 50% RH, H_2/air at 100/200 sccm



● **Ce L** ● **Pt (Au) L3**

* :at depth > 200um, Ce signal is greatly attenuated by the PFSA/water matrix.



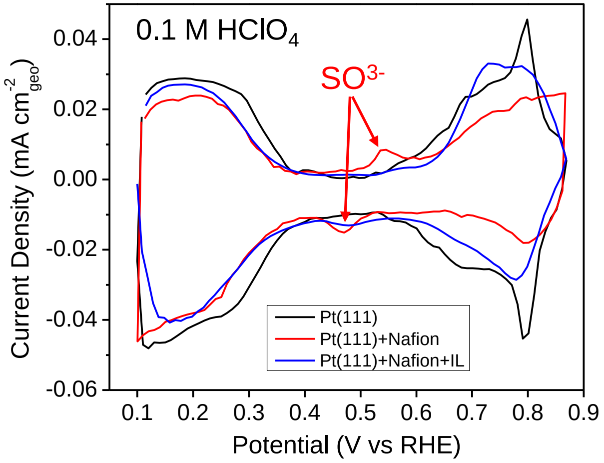


- At cell front (~30µm of depth) , Ce cations at cCL move toward the inner cell due to the in-plane potential gradient in addition to the through-plane potential from the load.
- At >150µm of depth, Ce cations accumulate toward cCL side driven by through-plane potential only.

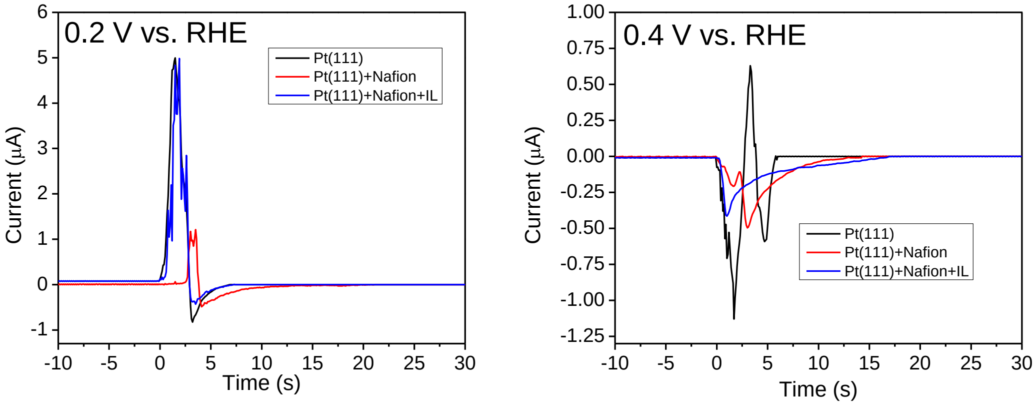
Technical Accomplishment:

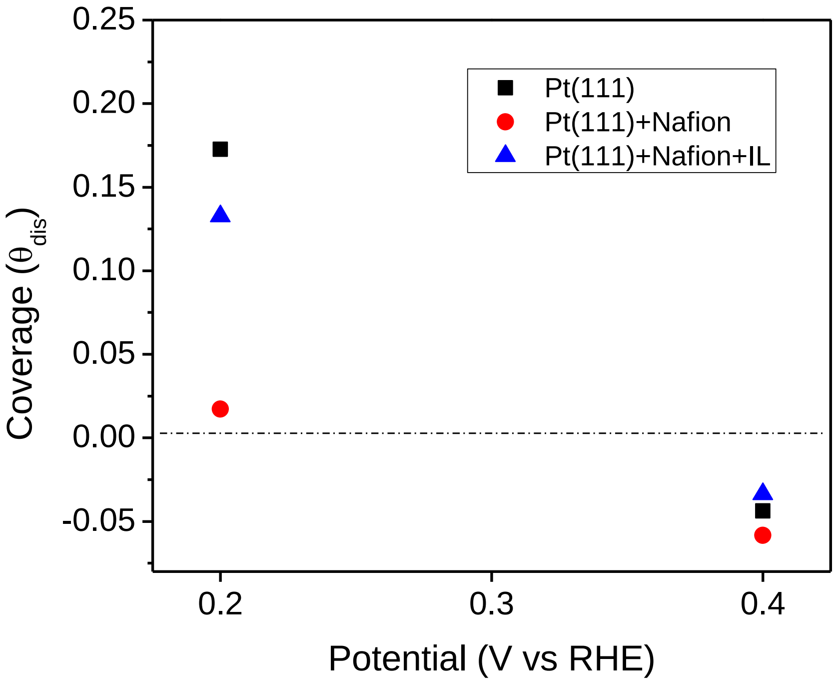
IL Mediation of Nafion Specific Adsorption

Nafion/IL Thin Films on Pt(111)



CO displacement





- CO displacement charge at 0.4 V vs. RHE is lower in the presence of IL, indicating decreased anionic species
- CO displacement below the Pt PZC, < 0.3 V vs. RHE at pH 1, indicates increased H adsorption, approaching that of bare Pt(111), in the presence of IL
- Intermediary IL thin film both limits ionic species specific adsorption, screening of SO^{3-} groups, and lower site blocking from hydrophobic domains of Nafion polymer