R&D for Automotive PEM Fuel Cell System - Bipolar Plates

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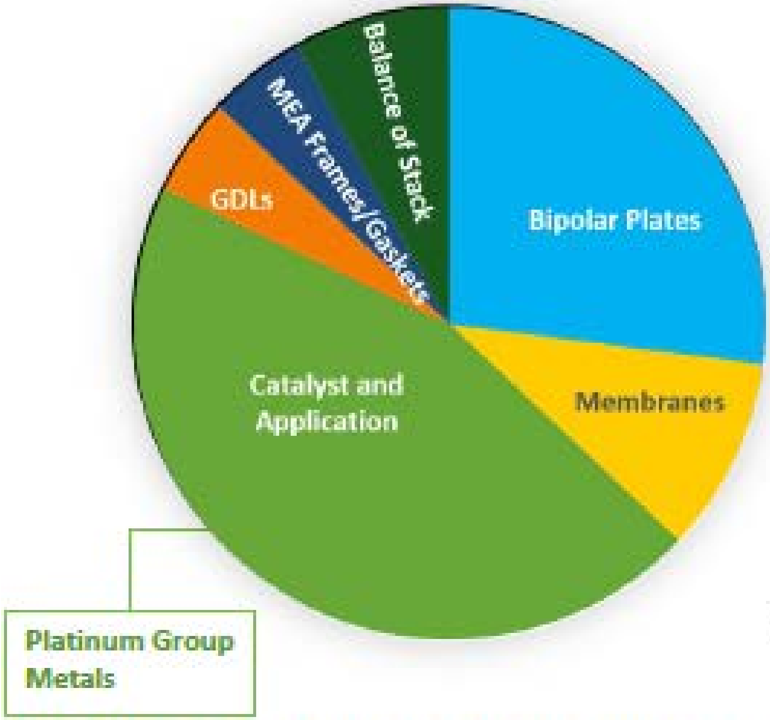
Focus Areas for Automotive Fuel Cell R&D and Priorities

USDRIVE
DRIVING RESEARCH AND INNOVATION FOR VEHICLE EFFICIENCY AND ENERGY SUSTAINABILITY

PEMFC Stack Cost Breakdown*

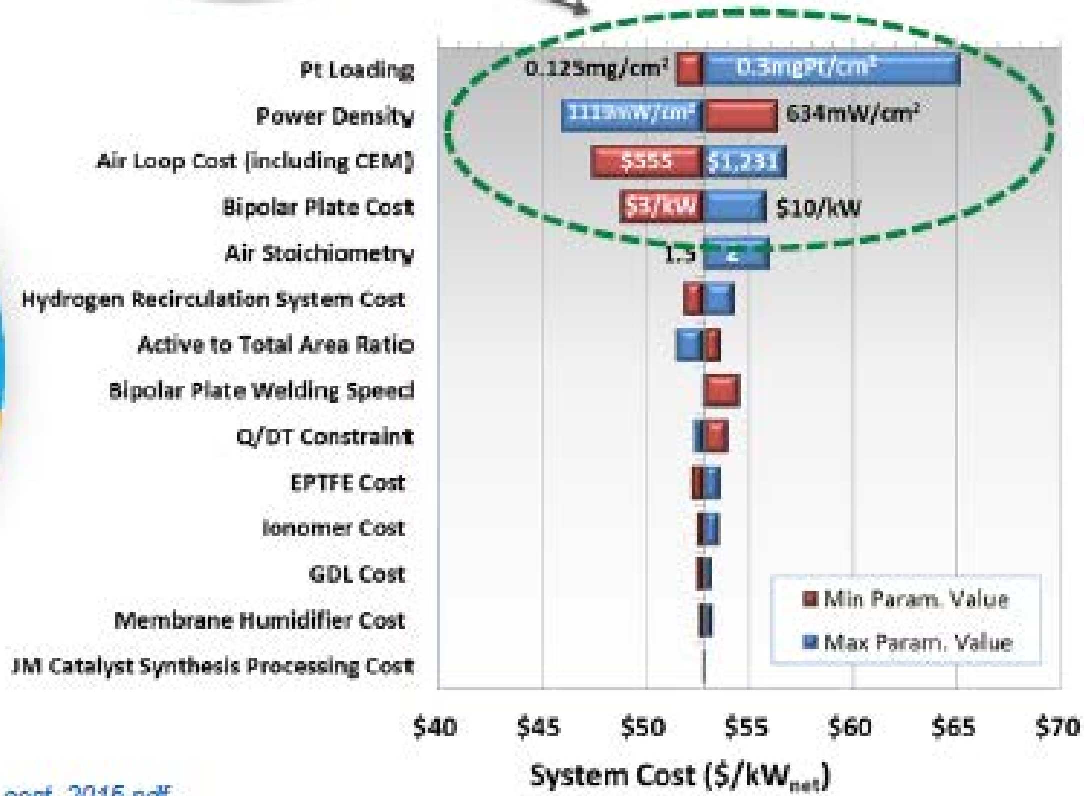
500,000 stacks/year



*https://www.hydrogen.energy.gov/pdfs/15015_fuel_cell_system_cost_2015.pdf

Key Focus Areas for R&D

Sensitivity Analysis helps guide R&D



Bipolar plate is one of the most sensitive cost factors.
Cost reduction (materials and manufacturing process) is required.

Requirements of Bipolar Plates for Automotive PEMFC

Basic Function of PEMFC Bipolar Plates

- Collect electric current
- Provide reactant gas flow field
- Mechanical Support

Basic Requirements

- Cost of both Material and Manufacturing Process
- Electrical Conductivity and its Retention under fuel cell operating conditions
- Corrosion Resistance
- Chemical Stability (mitigate effect of corrosion products)
- Gas Separation
- Manufacturability
- Thermal Conductivity

Requirements of Bipolar Plates for Automotive PEMFC

Characteristic	Units	2020 Target
Plate cost[a]	\$/kW	3
Plate weight	kg/kW	0.4
Plate H_2 permeation coefficient[e]	Std $cm^3/(sec\ cm^2\ Pa)$ @ 80°C, 3 atm 100% RH	1.3×10^{-14}
Corrosion anode[g]	$\mu A/cm^2$	1 and no active peak
Corrosion cathode[i]	$\mu A/cm^2$	1
Electrical conductivity	S/cm	100
Areal specific resistance[k]	Ohm cm^2	0.01
Flexural strength[l]	MPa	25
Forming elongation[m]	See note m	See note m

k: Measured across the bipolar plate; includes interfacial contact resistance (on as received and after potentiostatic test), measured both sides at 200 pounds per square inch (138 N/cm^2), H. Wang, M. Sweikart, and J. Turner, "Stainless steel as bipolar plate material for polymer electrolyte membrane fuel cells," Journal of Power Sources 115 (2003): 243-251.

m: 40%, per ASTM E8M-01: Standard Test Method for Tension Testing of Metallic Materials, or demonstrate ability to stamp generic channel design with width, depth, and radius.

USDRIVE Fuel Cell Technical Team Roadmap, p10 (June 2013)
http://www1.eere.energy.gov/vehiclesandfuels/pdfs/program/fctt_roadmap_june2013.pdf

Performance Metric – Electric Conductivity

Area Specific Resistance, *Ω cm²*

Mimic stacking condition
- Apply compression
- Use surrogate GDL

GDL free
- Corrected with GDL resistance

Measured across the bipolar plate; includes interfacial contact resistance (on as received and after potentiostatic test), measured both sides at 200 pounds per square inch (138 N/cm^2), H. Wang, M. Sweikart, and J. Turner, "Stainless steel as bipolar plate material for polymer electrolyte membrane fuel cells," Journal of Power Sources 115 (2003): 243-251.

USDRIVE Fuel Cell Technical Team Roadmap, p15 (June 2013)
http://www1.eere.energy.gov/vehiclesandfuels/pdfs/program/fctt_roadmap_june2013.pdf

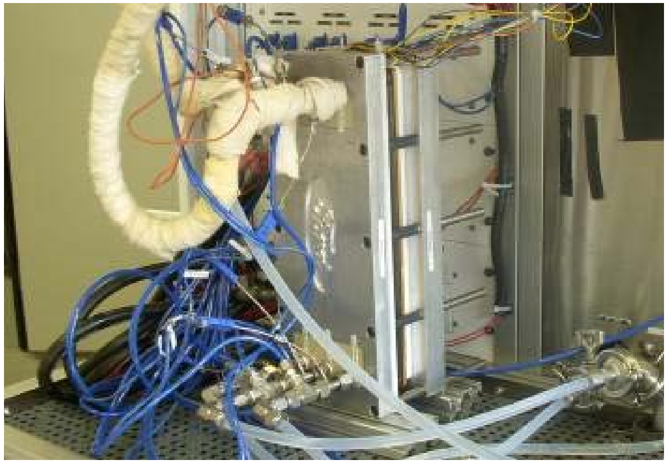
Corrosion Resistance

DOE Corrosion Test Metrics

- *Ex-situ* Corrosion Test Metrics
- Anode; potentiodyanmic 0.1mV/s, -0.4 to +0.6V (Ag/AgCl)
- Cathode; potentiostatic at 0.6V (Ag/AgCl) for >24 hours
- not to be used as a pass/fail criterion

Further Tests are recommended to evaluate corrosion resistance of bipolar plate materials

- Wider range of *ex-situ* corrosion tests (potentiodynamic, potentiostatic for both anodic and cathodic conditions) can help to understand material characteristics for real world conditions
- *In-situ* durability test is imperative to verify material's durability.
- Leached out ions



Possible Exposure of Higher Potentials

$C + 2H_2O \rightarrow CO_2 + 4H^+ + 4e^-$

$2H_2O \rightarrow O_2 + 4H^+ + 4e^-$

$Pt \rightarrow Pt^{2+} + 2e^-$

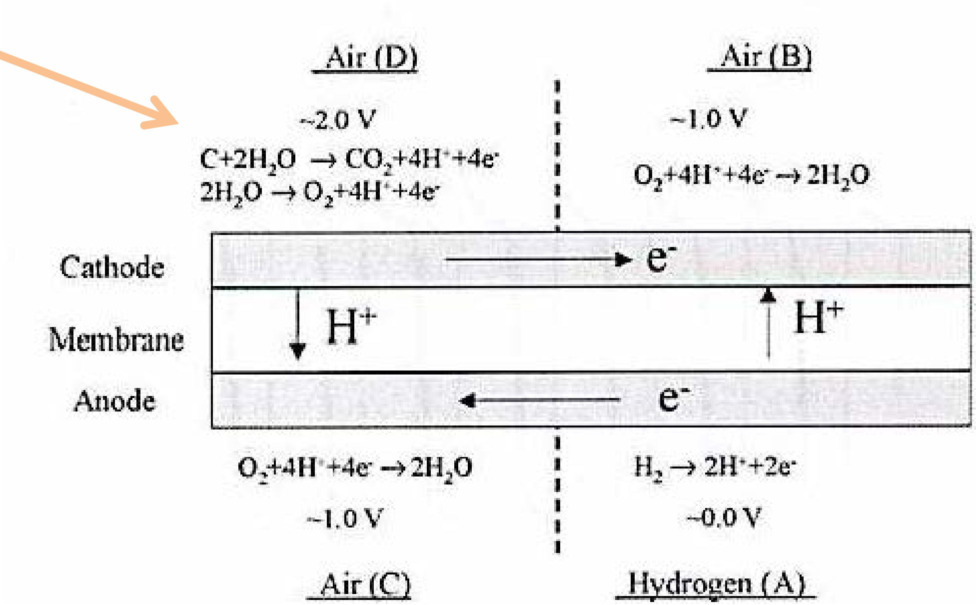
$Pt + H_2O \rightarrow PtO + 2H^+ + 2e^-$

$PtO + 2H^+ \rightarrow Pt^{2+} + H_2O$

$PtO + H_2O \rightarrow PtO_2 + 2H^+ + 2e^-$

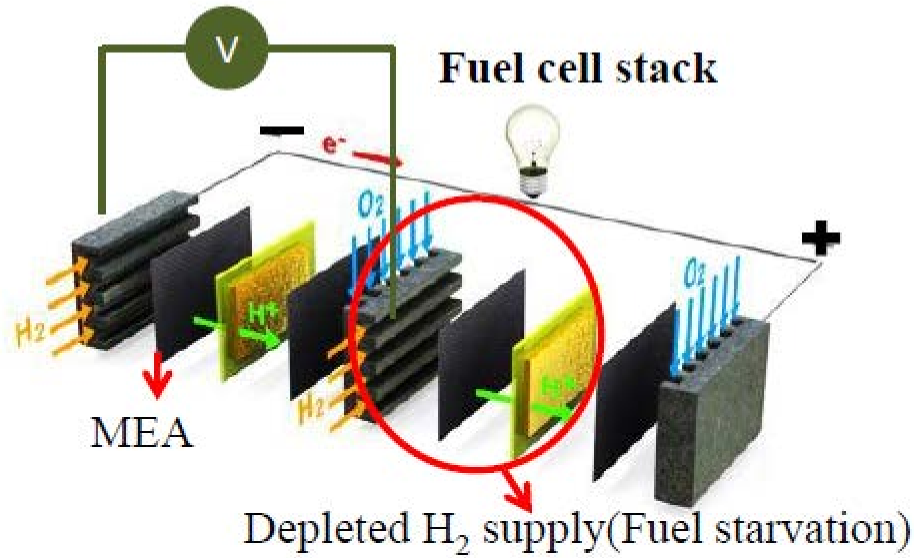
$PtO_2 + 4H^+ + 4e^- \rightarrow Pt^{2+} + 2H_2O$

PEMFC operation during hydrogen and oxygen co-exist at the anode.



H. Tang, et. al., J of Power Source 158 (2006) 1306-1312

Possible Exposure of High Potentials



Normal Anode reaction

$2H_2 \rightarrow 4H^+ + 4e^-$

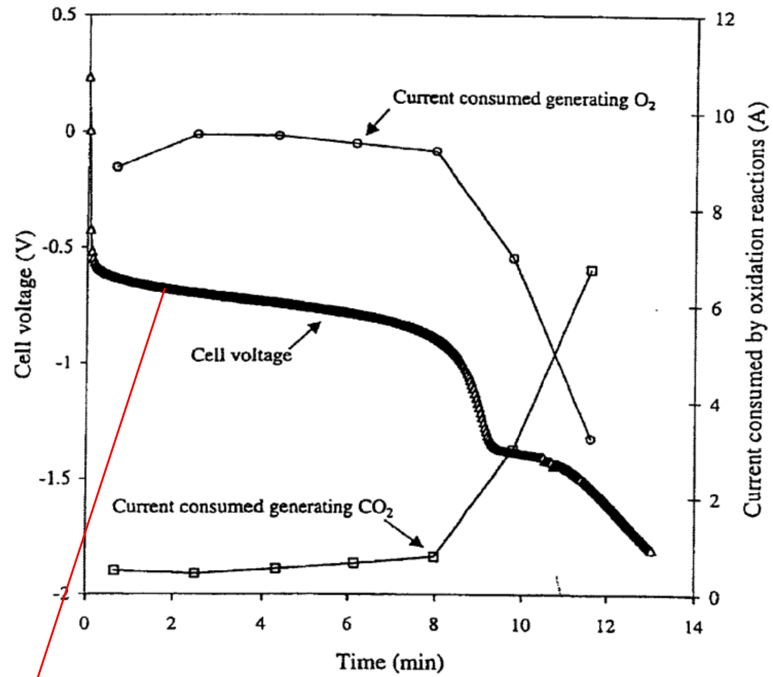
Anode under hydrogen starvation

$C + H_2O \rightarrow CO + 2H^+ + 2e^-$ $E_0 = 0.52V$

$C + 2H_2O \rightarrow CO_2 + 4H^+ + 4e^-$ $E_0 = 0.21V$

$2H_2O \rightarrow O_2 + 4H^+ + 4e^-$ $E_0 = 1.23V$

Pratiti Mandal, et. al., 3D Imaging of Fuel Cell Electrode Structure Degraded under Cell Reversal Conditions Using Nanoscale X-ray Computed Tomography, 228th ECS meeting in Phoenix, AZ



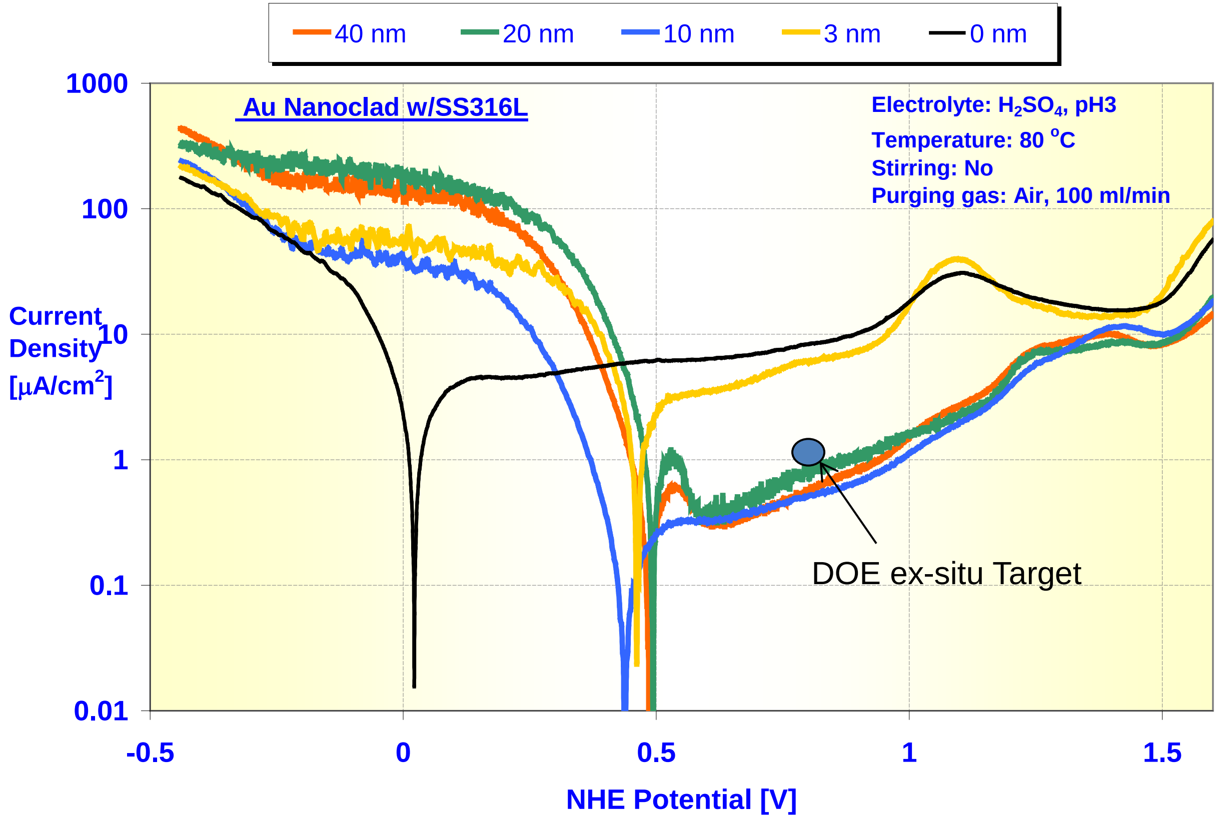
Knights *et al.*, U.S. Patent, 6,936,370 B1 (2005)

This number varies depending on mag. of H_2 starvation and current drawn, ref. to O_2 electrode

Corrosion Resistance Test - Potentiodynamic

Cathodic CV Tests

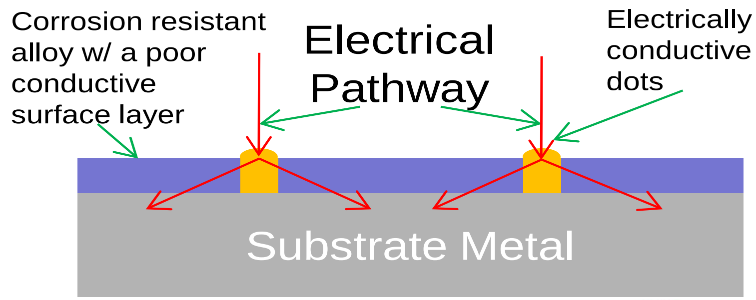
Au Nanoclad®:
Nano meter scale thickness of Au coated stainless steel foil supplied by Daido Steel.



A. Kumar, M. Ricketts, S. Hirano, "Ex-situ evaluation of nanometer range gold coating on stainless steel substrate for automotive polymer electrolyte membrane fuel cell bipolar plate," Journal of Power Sources 195 (2010): 1401–1407, September 2009.

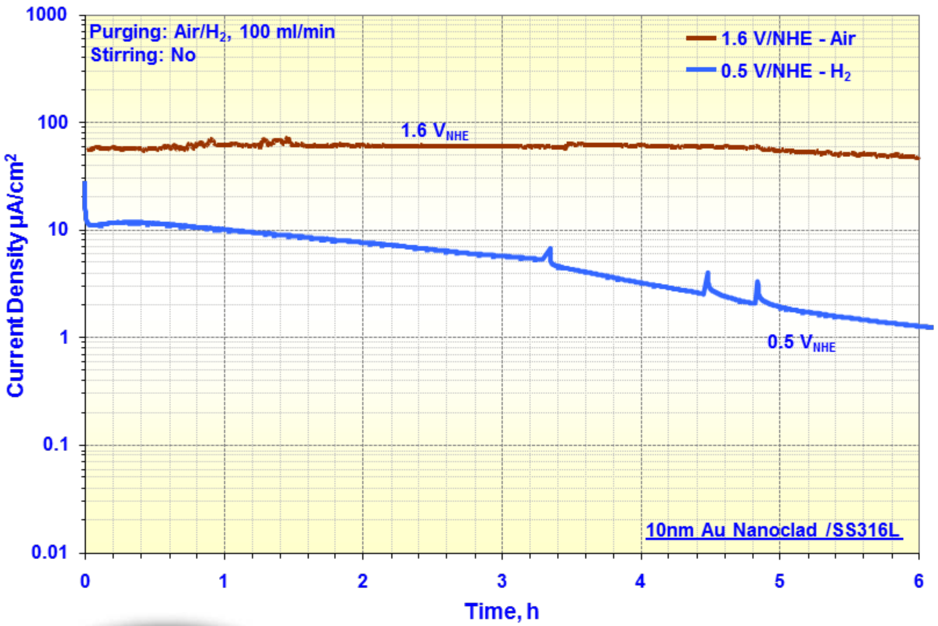
Corrosion Resistance Test - Potentiostatic

Au Dot Coating by TreadStone Technology, Inc.

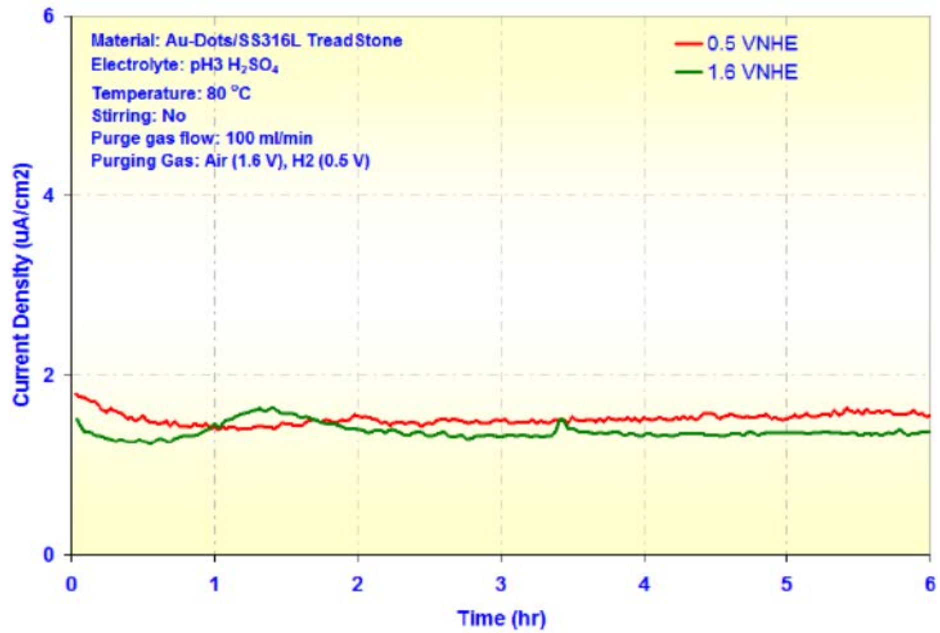


Potentiostatic Tests **1.6 V_{NHE} (Air) / 0.5 V_{NHE} (H_2)**

Au Nanoclad® coating (10 nm) on SS316L

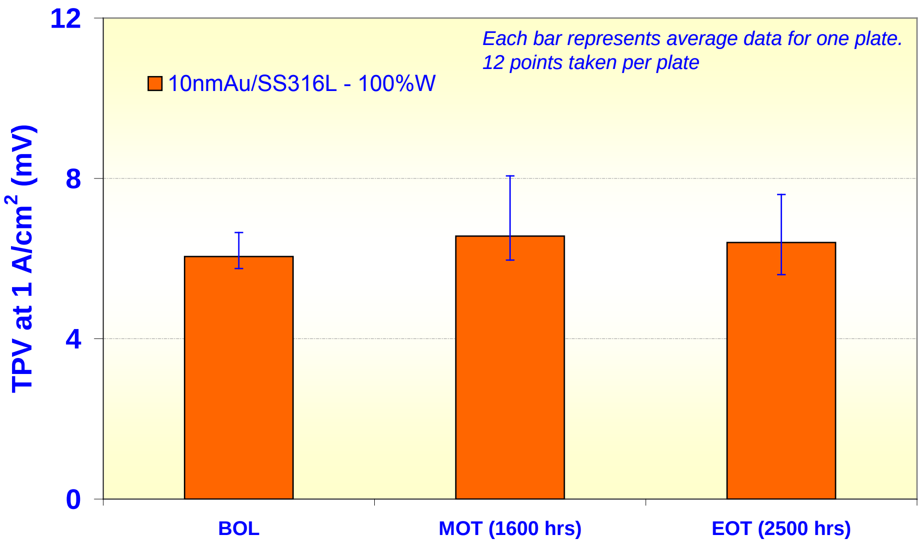


Au Dot coating (TreadStone) on SS316L

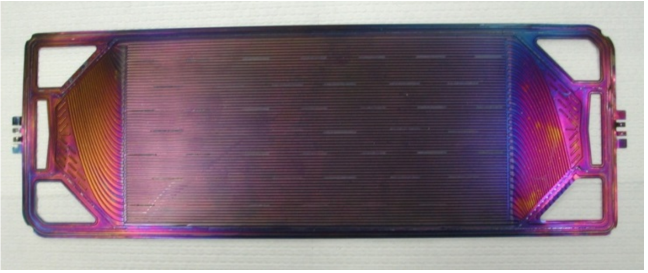


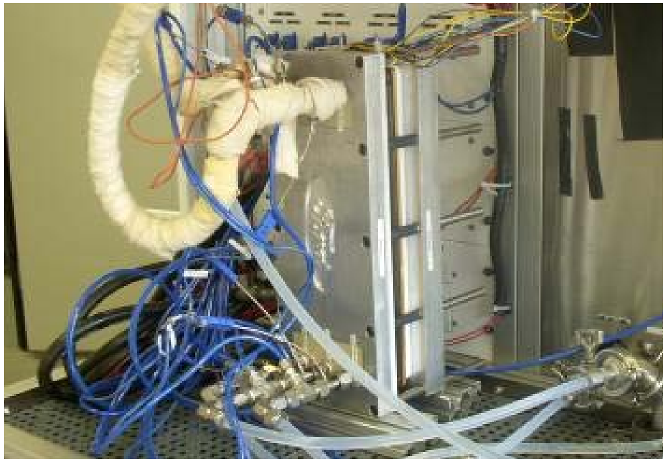
In-situ Durability Test and Post Analysis

Au-nanoclad® 20-cell Stack



BOL MOT (1600 hrs) EOT (2500 hrs)





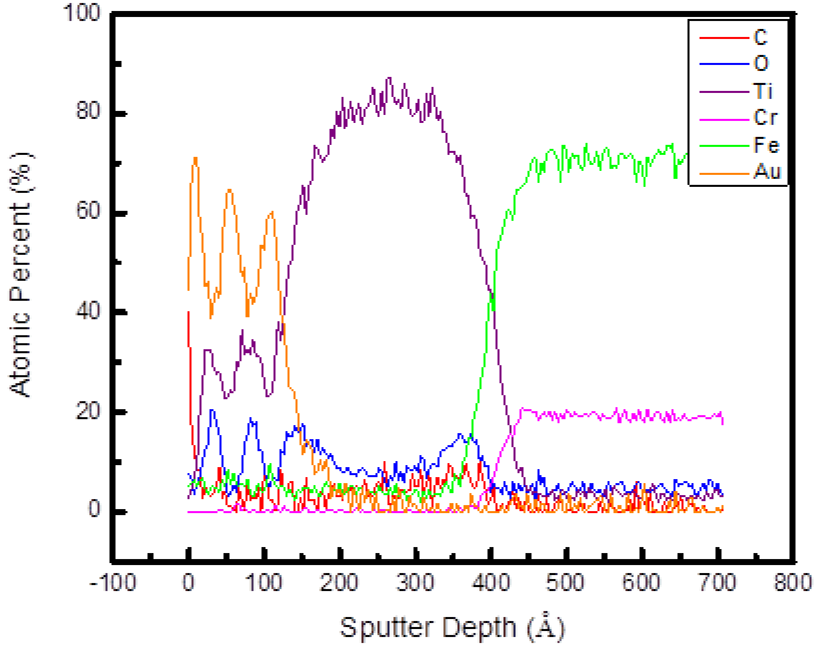
- No significant increase in area specific resistance during *in-situ* durability test.
- Metal cations in the stack effluent water (anode, cathode, and coolant) were below the detectable limit of Inductively Coupled Plasma (ICP) analyzer.

Material Analysis – AES

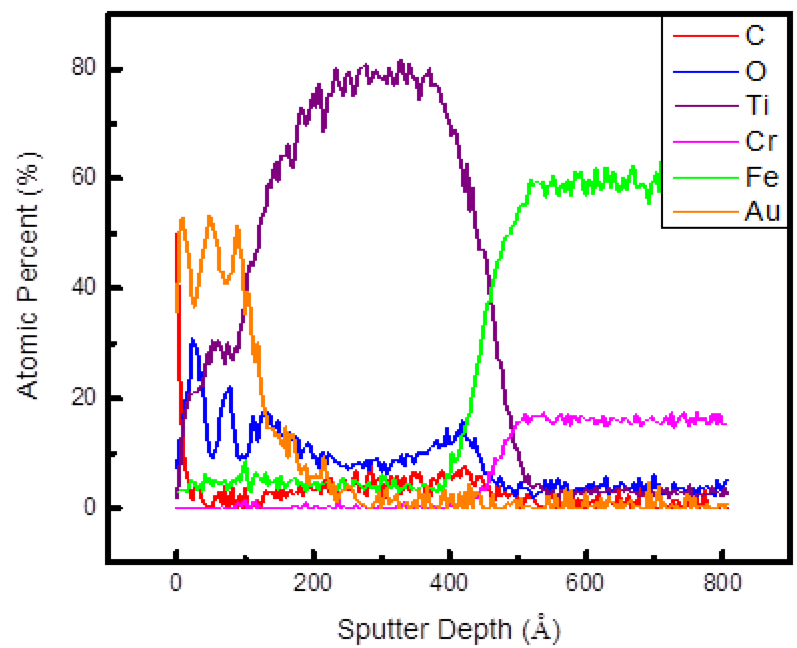
Multilayer Ti/Au Coating on Stainless Steel

S. Hirano, et al., Multi-Layer Thin Film Coating on Bipolar Plates for PEMFC, PRiME 2016 (ECS), Oct 2016

As Deposited Before Electrochemical Exposure



After Potentiostatic Tests

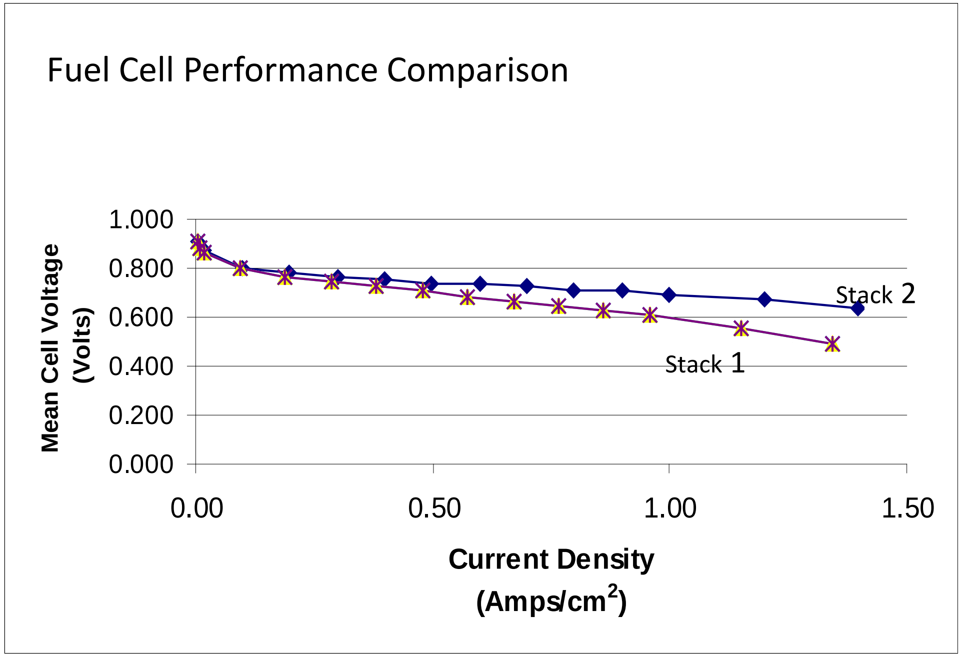


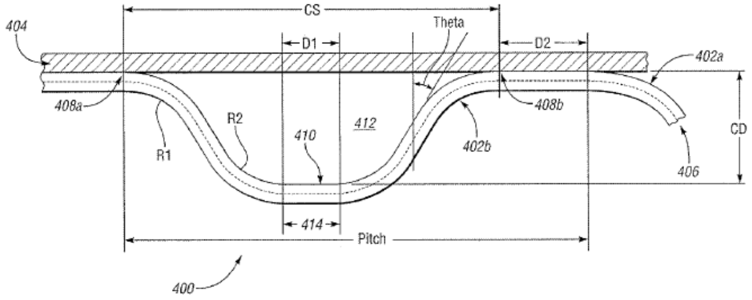
AES depth profile of multi-layer coating structure on the stainless steel substrate (316L), before and after the corrosion tests.

Manufacturing Process – Formability

PEMFC performance between two different GDL stiffness and flowfield channel width.

Hirano et al., US Patent 8,232,026B2 (2012)





Sample	Substrate	Channel Span	GDL	
			Material	Stiffness
Stack 1	SS 316 L	1.5 mm	Stiff-Type	4.09/5.59 GPa
Stack 2	SS 301	0.8 mm	Roll Good-Type	1.15/1.18 GPa

R&D Needs for Bipolar Plates (Materials)

Substrate Materials for the Metallic Bipolar Plate

Development of thin metal sheet materials that improve the forming limit.

Function without coating is an ideal, e.g. surface modification

Robust Coating Materials for the Metallic Bipolar Plate

Enable pre-coating process and mitigate coating defect (cracks and delamination) during the stamping process.

Self-protection from corrosion/degradation at coating defect area.

Chemical stability

Elimination of PGMs or precious metal from coatings.

Coatings that are amenable to high-throughput processing

Ford's response to DOE RFI (DE-FOA-0001510), June 2016

R&D Needs for Bipolar Plates (Manufacturing Process)

Numerical Forming Model for the Metallic Bipolar Plate

Development of a numerical model to simulate metallic bipolar plate forming, and to be validated with various stamping methods, substrate materials, and parameters to improve forming limit.

Model and Diagnostics of the Water Management in the Flowfield

Mechanistic understanding of multiphase fluid flow in the flowfield (bipolar plate and gas diffusion media (GDL)), including implication with the fuel cell operating conditions, flowfield configurations, surface properties and operating conditions.

Feasibility of New Joining/Sealing Techniques

High throughput welding techniques for the metallic bipolar plate.
Other adhesion techniques to improve manufacturability of bipolar plate.

R&D Needs for Bipolar Plates (New Concept)

New Concept Flowfield

Feasibility of the foam flowfield. Development of flow fields that address multiphase limitations for metal bipolar plates (e.g. plates that wick water away from the GDL/plate interface).

Study for Carbon vs. Metal

Fundamental understanding on technical limitation of various bipolar plate materials, including carbon composite and metallic plate.

Suitability for application/operating conditions for various bipolar plate materials.