Metallic Bipolar Plate Technology for Automotive Fuel Cell Stack

Shinichi Hirano

Fuel Cell Research
Electrification Research and Advanced Engineering
Ford Motor Company

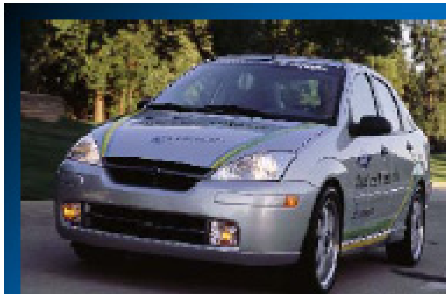
Technoport 2012 – Sharing Possibilities
April 16-18, 2012

Trondheim Norway

Ford Fuel Cell Vehicle Highlights

1999
P2000 HFC
Mk700 - CGH_2

2000
Ford Focus FC5
Mk901-Methanol



2000
Ford Focus FCV
Mk901-CGH_2

2001
Mazda Premacy
Mk901-Methanol

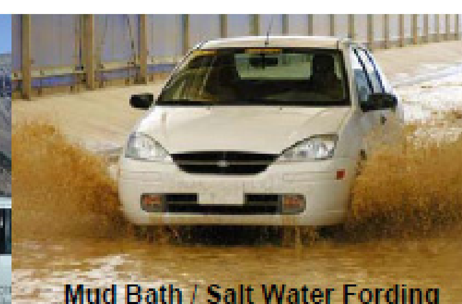
2005-2009 Focus FCEV
30 Vehicle Demonstration Program

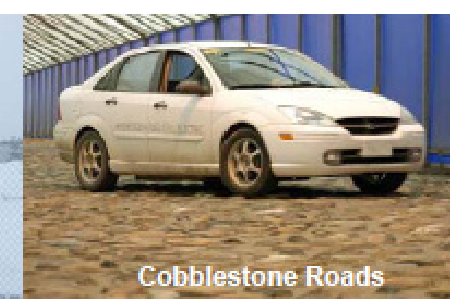
2006-2009 DOE Technology
Demonstration Vehicle (TDV) Program

Fleet Demonstration Accomplishments

- **Focus Fuel Cell Fleet Milestones**
  - ✓ Accumulated over **1,300,000 miles to date** [1]
  - ✓ Successful in-field operation past the original 36-month target with all vehicles in the field over 48 months
  - ✓ Demonstrated 50% higher fuel economy than gasoline vehicles
  - ✓ Confirmed >2000 hours fuel cell durability using on-road data
  - ✓ Validated vehicle fueling time of 5 minutes or less for a 5 kg tank
  - ✓ Fleet had a 94% up-time for user operation and availability
  - ✓ High customer satisfaction and feedback

1. Includes DOE and non-DOE Focus Fleet Vehicles



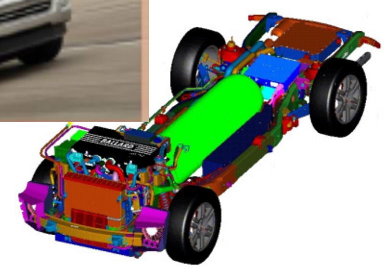


Technology Demonstration Vehicles (2006 to 09)

700 bar Demonstrator

- Demonstrated new 700 bar technology
- Achieved industry certification and field testing

Designed Around Hydrogen Demonstrator



- Demonstrated unassisted freeze start capability (-15ºC)
- Designed around hydrogen with 700 bar hydrogen fuel storage provides for a feasible range over 300 miles with a no compromise vehicle package

Plug-In Technology Demonstrator

- Modular FC APU design with less complex system
- 25 mile Li-Ion plug-in range

Remaining Challenges of Fuel Cell Vehicles

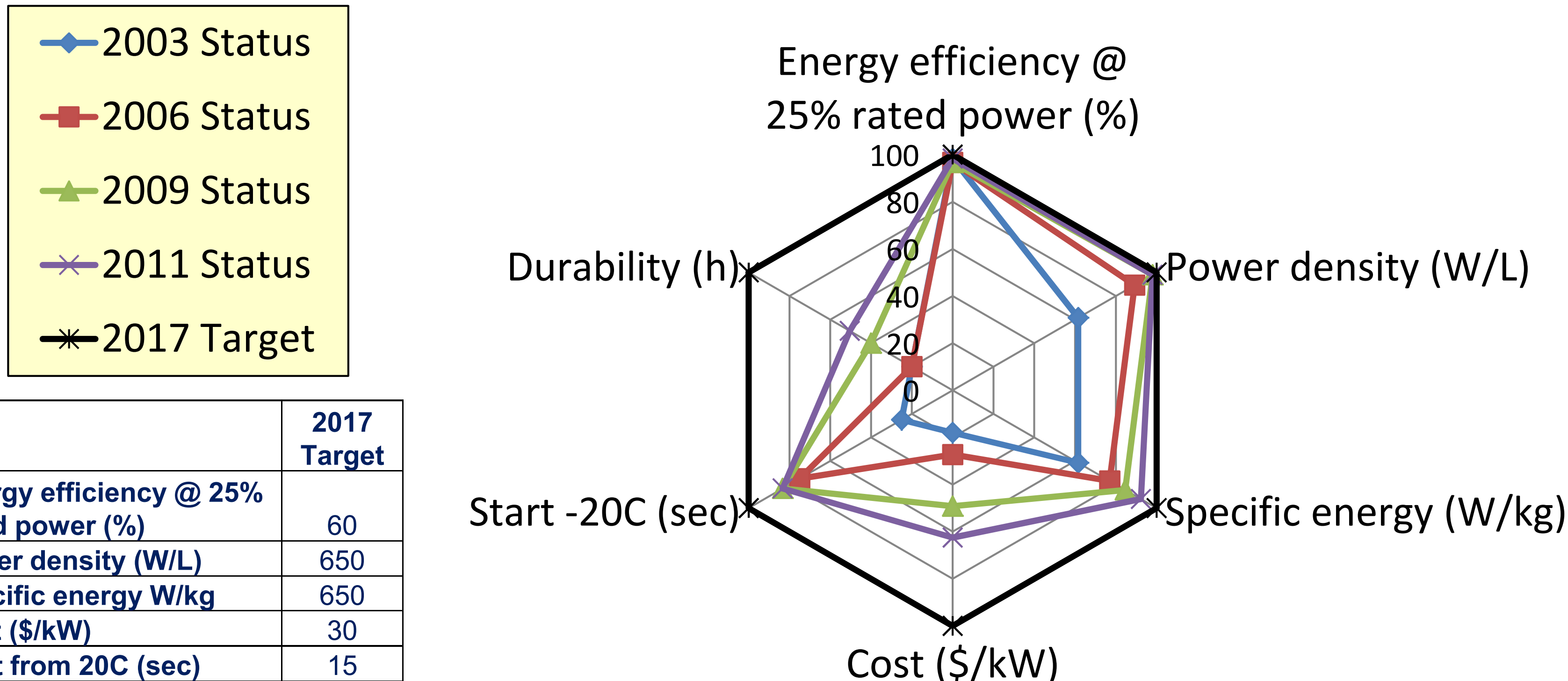
• Hydrogen fuel cell vehicles have been considered to be an important long-term solution when hydrogen fuel emerges as an energy carrier for further reduction of greenhouse gas emissions.

• Over a decade long demonstration fleet has proven that hydrogen fuel cell vehicles can meet vehicle performance expectations with state-of-the-art technologies.

• The main barriers to commercialization of fuel cell vehicles are cost and durability. Further breakthrough are required to overcome these barriers.

Remaining Challenge of Fuel Cell Vehicles

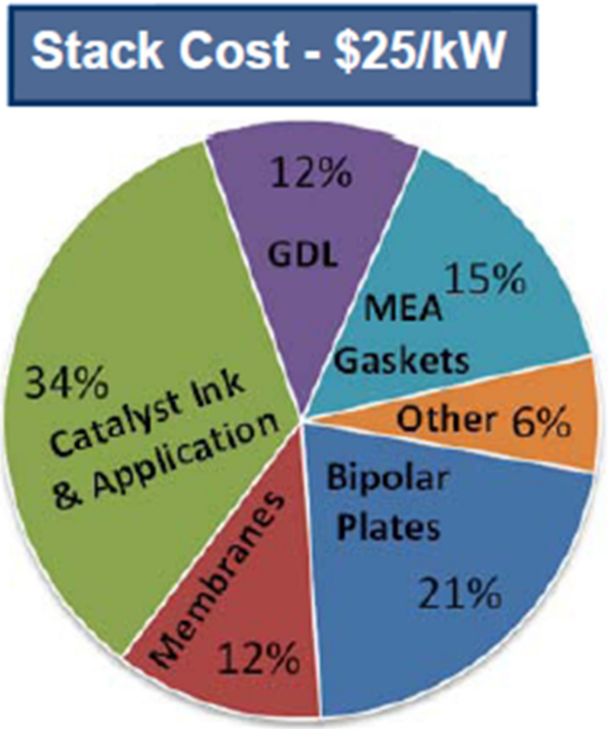
USDRIVE
DRIVING RESEARCH AND INNOVATION FOR VEHICLE EFFICIENCY AND ENERGY SUSTAINABILITY



	2017 Target
Energy efficiency @ 25% rated power (%)	60
Power density (W/L)	650
Specific energy W/kg	650
Cost ($/kW)	30
Start from 20C (sec)	15
Durability (h)	5000

Cost and Durability remain the greatest technical barriers.

Remaining Challenge of Fuel Cell Vehicles



DTI, 2010 analysis, scaled to high volume production of 500,000 units/yr

Used $1100/Troy Ounce for Pt Cost

Fuel Cell Stack is the driver for cost.

Bipolar Plate Materials

Carbon Composite (Molding)

Pros

- Excellent corrosion resistance
- Design flexibility

Cons

- High material cost (synthesized graphite)
- Long resin cure time
- Lower electrical conductivity
- Lower stack volumetric power density (due to thick plates)

Metal Sheet (Stamping)

Pros

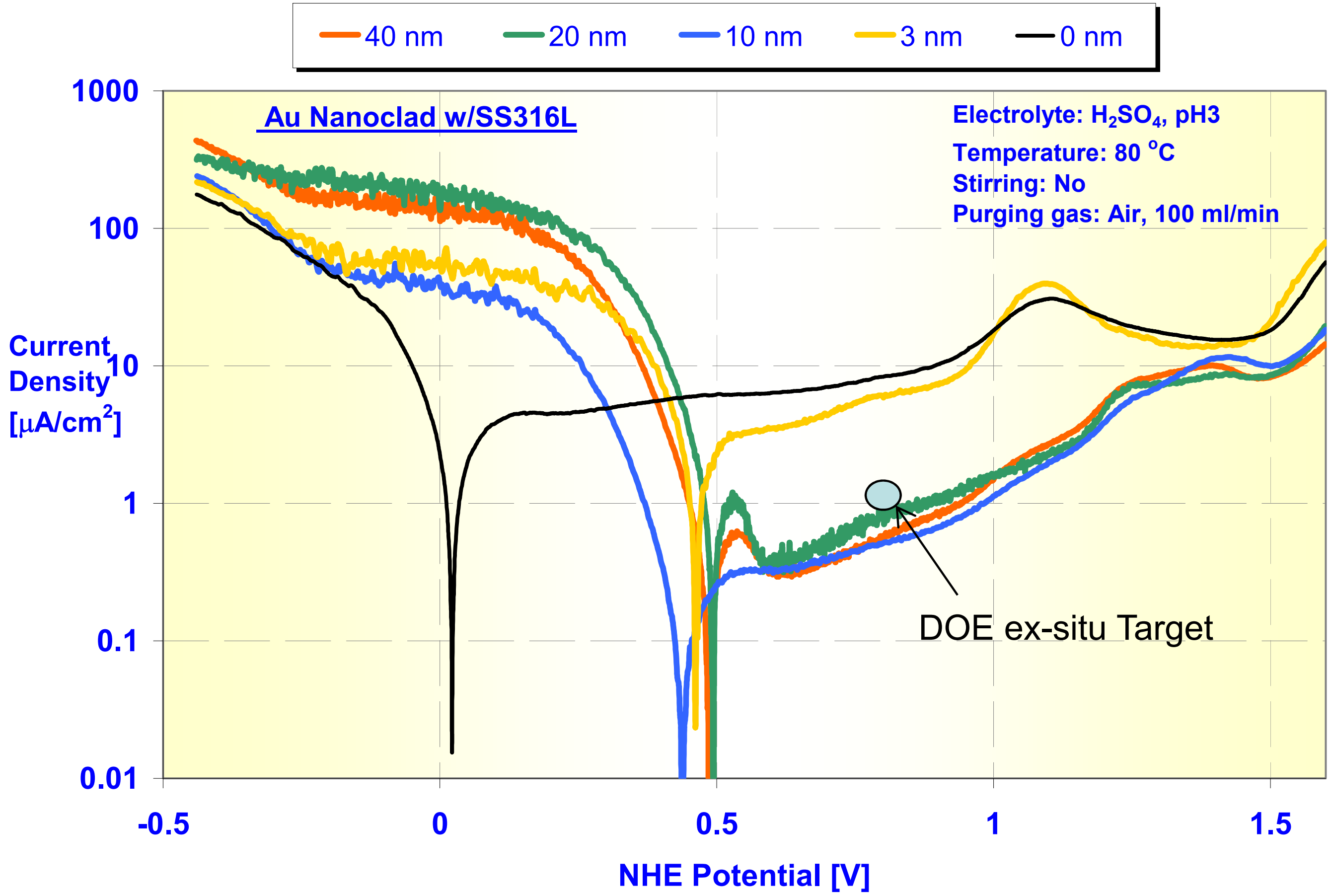
- High volume manufacturing capability (stamping)
- Use of conventionally available stainless steel foil
- Higher stack volumetric power density (due to thin plates)
- Higher electrical conductivity

Cons

- Low corrosion resistance to retain electrical conductivity (need of corrosion resistant coating or treatment – increase the cost)
- Stamp forming limitations

Metallic Bipolar Plate Materials – Au Nanoclad ®

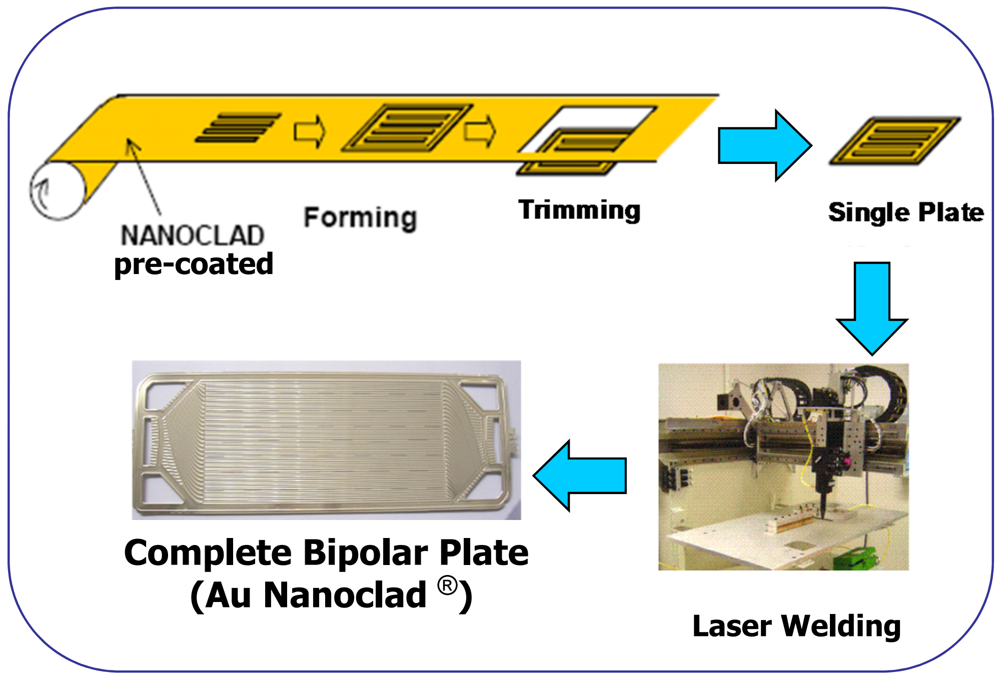
Nanometer scale thickness of Au coated stainless steel foil supplied by Daido Steel.



10 nm thickness is sufficient to retain the noble property of Au which provides corrosion resistivity.

Metallic Bipolar Plate Materials – Au Nanoclad ®

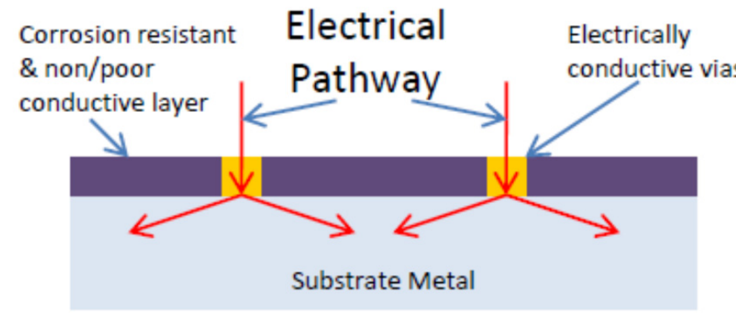
Anodic passivation characteristic of Au Nanoclad® allows it to be applied prior to fabricating (stamping) metallic bipolar plates (pre-coat process).

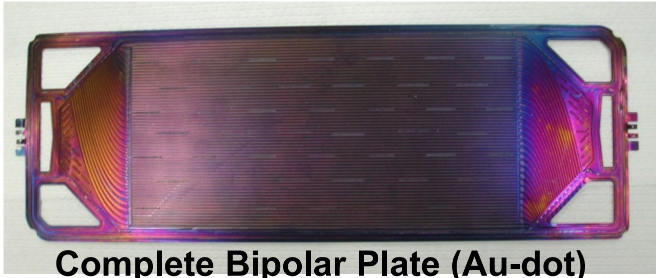


Metallic Bipolar Plate Materials – Au Dot

TreadStone Au-dot coating

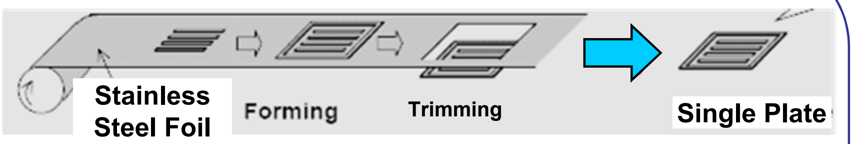
- TreadStone (Princeton, NJ) developed Au-dot coating metallic bipolar plate materials (USP7309540).
- Stainless steel substrate is covered by corrosion resistance coating (e.g. TiO_2) and Au-dots sprayed on the surface and penetrated through corrosion resistance layer to provide electrical conductivity.
- Post-coating process).

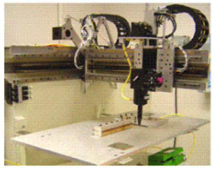




Complete Bipolar Plate (Au-dot)

Stainless Steel Foil

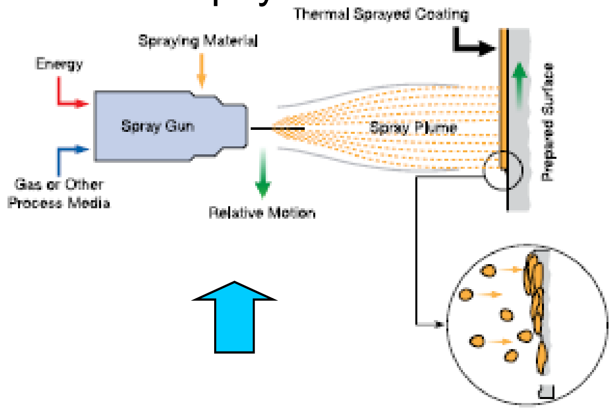




Laser Welding

Non-coated Bipolar Plate

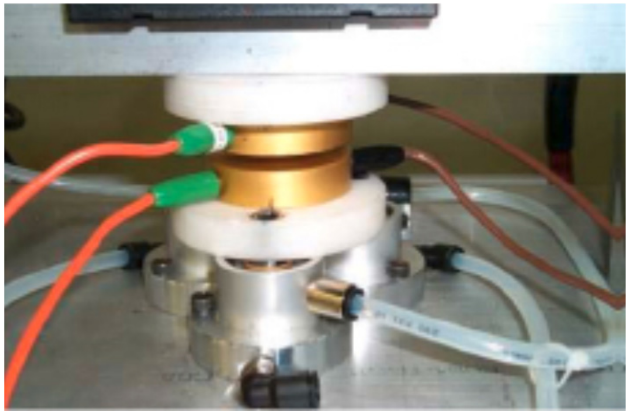
Au-dot spay/Heat treatment



Corrosion resistance layer coating (PVD)

Ex-situ Electrical Conductivity

Material (flat sample)	**Area Specific Resistance**
Au-dot 'baseline material', coated on SS316L (0.1 mm thickness)	8.7 mΩcm^2
Au Nanoclad® 10 nm Au coating on SS316L (0.1 mm thickness)	0.9 mΩcm^2
Graphite Composite (0.28 mm thickness)	7.2 mΩcm^2
US DOE Target	20 mΩcm^2



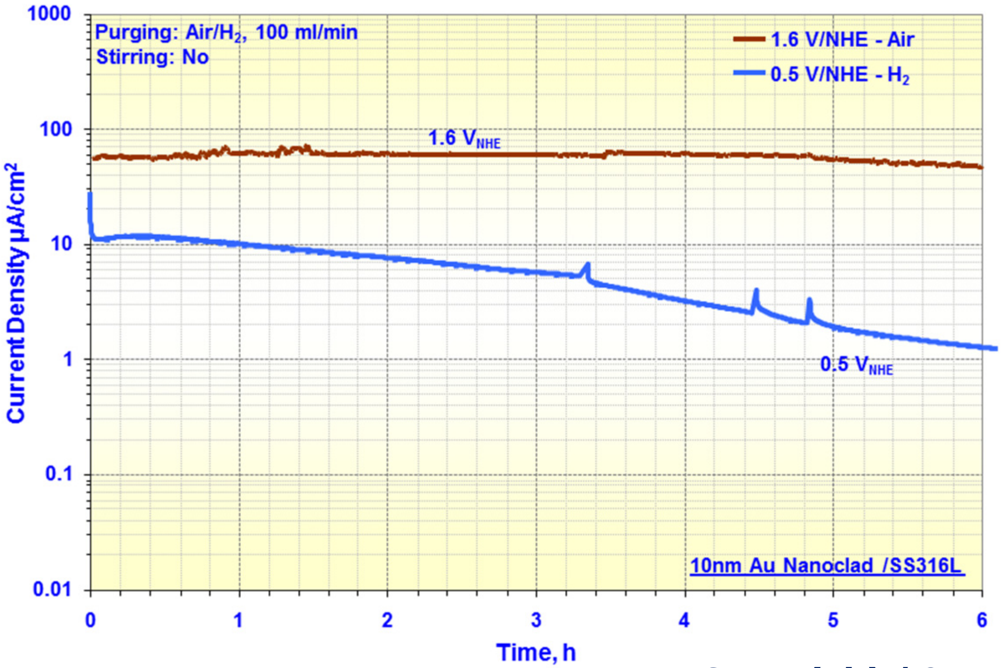
Area Specific Resistance Measurement

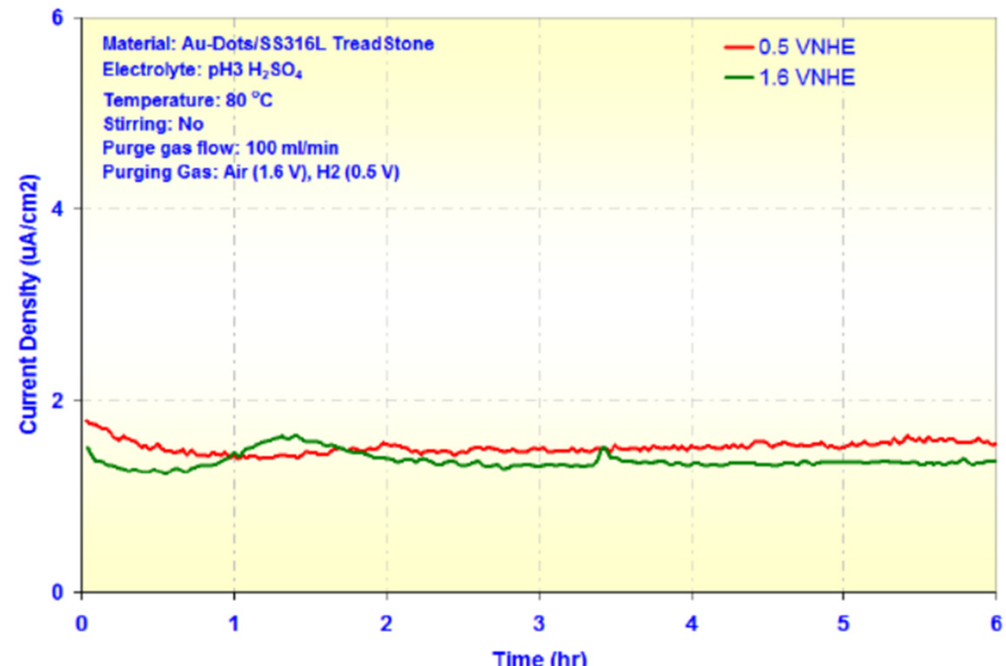
Area specific resistance of Au-nanoclad® and Au dot material is meeting USDOE target.

Ex-situ Corrosion Resistance

Attribute	Metric	Unit	2015 DOE Target	Ford Data on Au-Nanoclad®	Ford Data on Au-Dots
Corrosion anode	**Current density at active peak in CV**	μA/cm²	<1	No active peak	No active peak
Corrosion cathode	**Current density at 0.8 V_{NHE} in potentiostatic expt.**	μA/cm²	<1	~1.0	~0.1

Robustness; Potentiostatic - High Potential Anodic and Cathodic

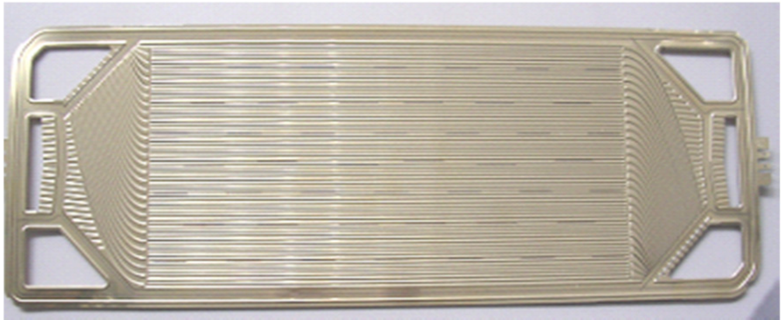




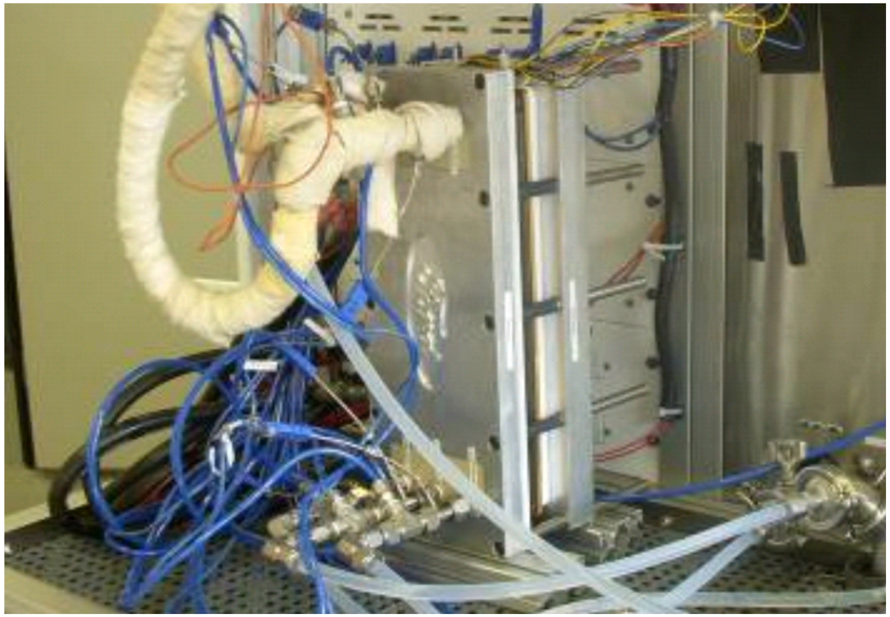
1.6 V_{NHE} (Air) / 0.5 V_{NHE} (H_2) Potentiostatic

Short Stack Development

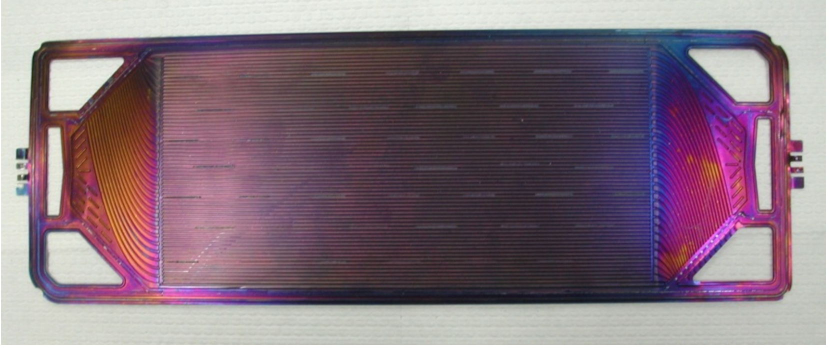
- Two short stacks were assembled with Au-nanoclad and Au-Dots *baseline* materials.
- Ford designed metallic bipolar plate with 300 cm^2 active area
- Durability Cycle:
  - The stack is being tested for durability utilizing durability cycle (which includes FTP cycle along with others) mimicking real world operating conditions.



Metal bipolar plate with Daido Au-nanoclad®



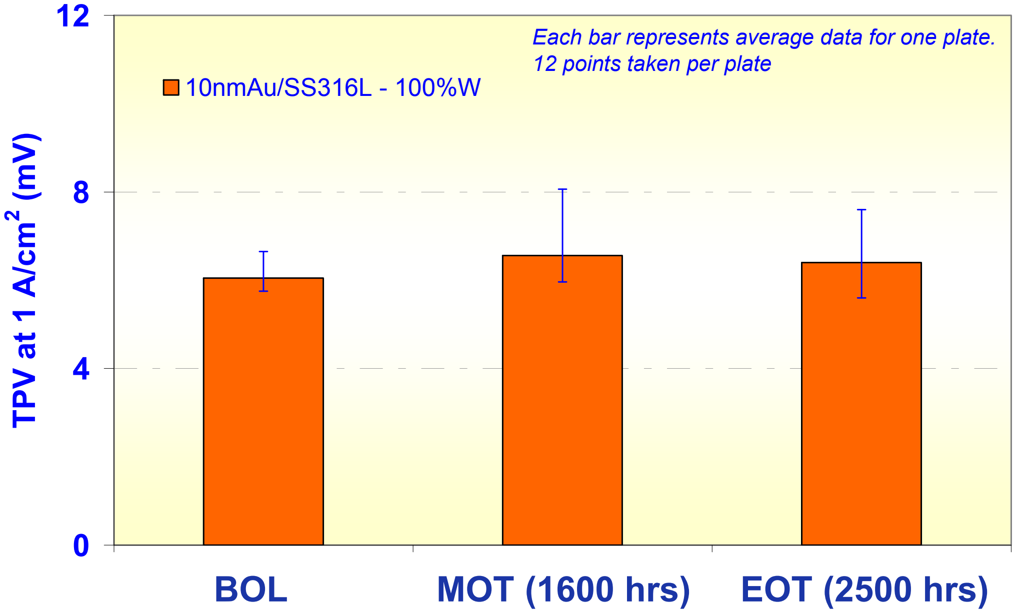
Short stack on the test stand at Ford



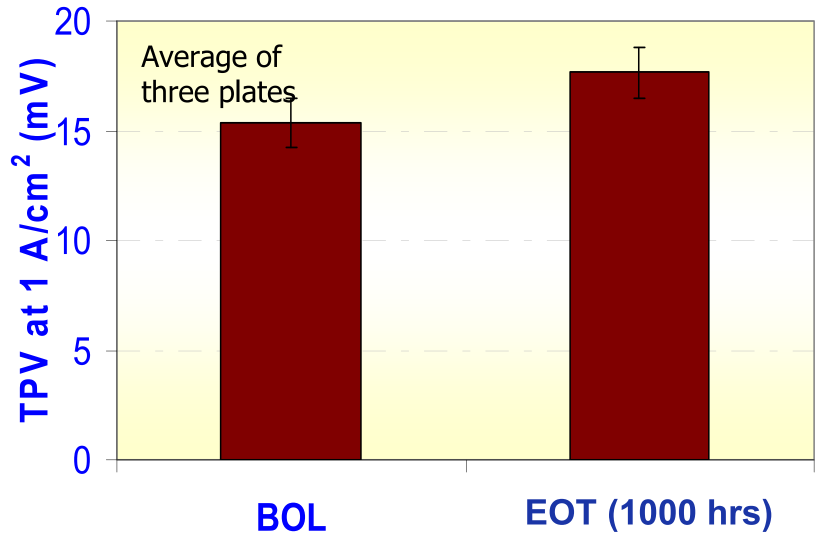
Metal bipolar plate with TreadStone Au-Dot *Baseline* Material

In-situ Durability Test

Au-nanoclad® 20-cell Stack



Au Dot 10-cell Stack



- No significant increase in plate area specific resistance was observed during in-situ durability test.
- Post analysis revealed no significant corrosion issues. Metal cations in the stack effluent water (anode, cathode, and coolant) were below the detectable limit of Inductively Coupled Plasma (ICP) analyzer (~ppm).

Summary

• *Ex-situ* and *in-situ* test results show that Au-nanoclad® and Au-dot materials have a significant potential to be used in automotive fuel cell stacks.

• Au-dot baseline material has a room to improve area specific resistance (electrical conductivity) which can improve fuel cell performance.

• While Au is an expensive commodity, however the amounts of Au for both materials are very small and should not pose a large cost penalty.

• A Ford 20-cell stack development with improved Au-dot technology materials is undergoing for further durability cycle testings with TreadStone Technologies, Inc. (US Department of Energy Agreement # 09EE0000463, PI CH Wang, TreadStone).

Shinichi Hirano
shirano7@ford.com