Metal Plates: Challenges and Perspectives for PEM Fuel Cells and Electrolyzers

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Agenda

- *Identified challenges in PEM Fuel Cells & Electrolyzers plate materials*
  - *Performance & Durability*
  - *Cost…*
- *TreadStone's Solution…*
  - *Activities*
  - *Results*
- *Summary*

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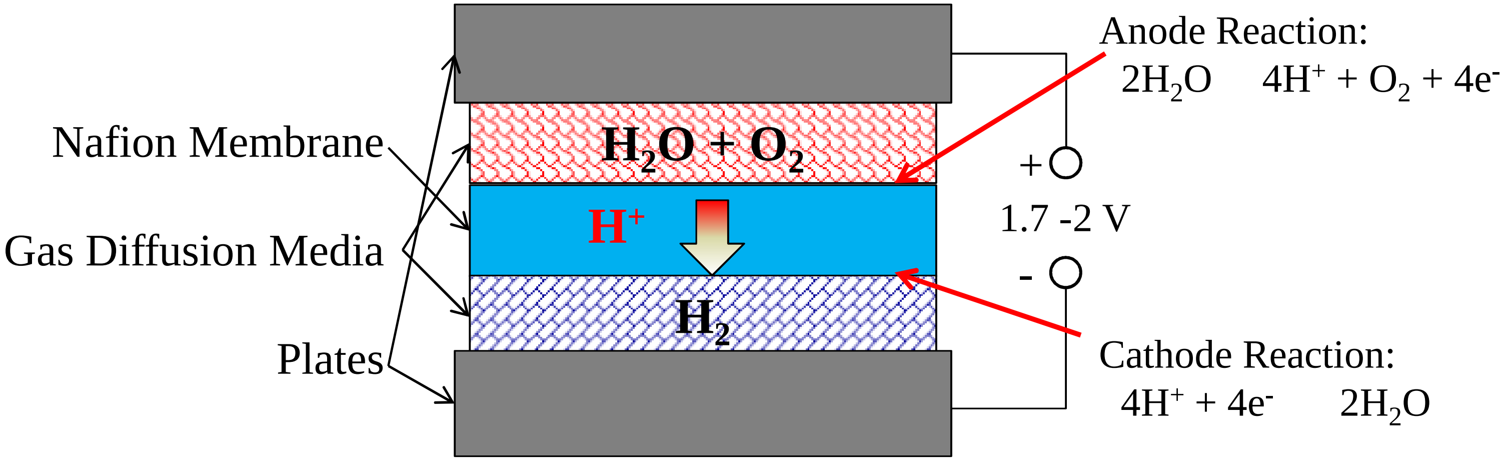
Electrolyzer: Operating Environment

Schematic diagram of typical PEM Electrolyzer Cell



Requirements for plates

1. *Low hydrogen crossover*
2. *Chemically and electrochemically stable*
3. *High mechanical strength*
4. ***Low cost***

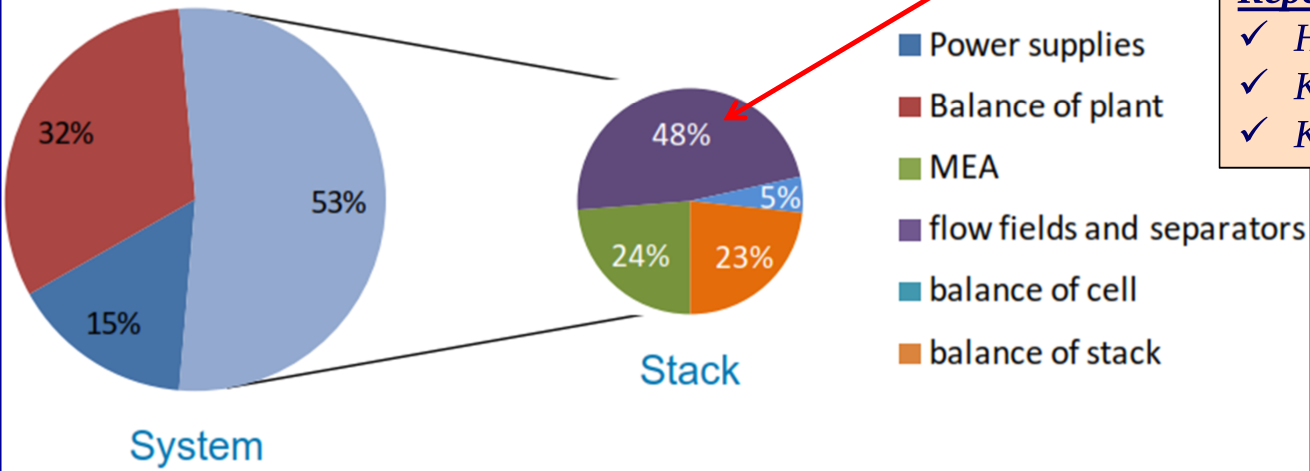
Challenges for plates

1. Corrosion on the anode side (oxygen) under high potential (~2 V_{NHE})
2. Hydrogen embrittlement on cathode side (hydrogen)
3. Cost, Cost, Cost

Electrolyzer: System Cost Break-down

Relevance
Overall Cost of Hydrogen

- Cell stack largest contributor to system cost
  - Flowfields, separators and MEAs drive stack cost



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Proton ENERGY SYSTEMS

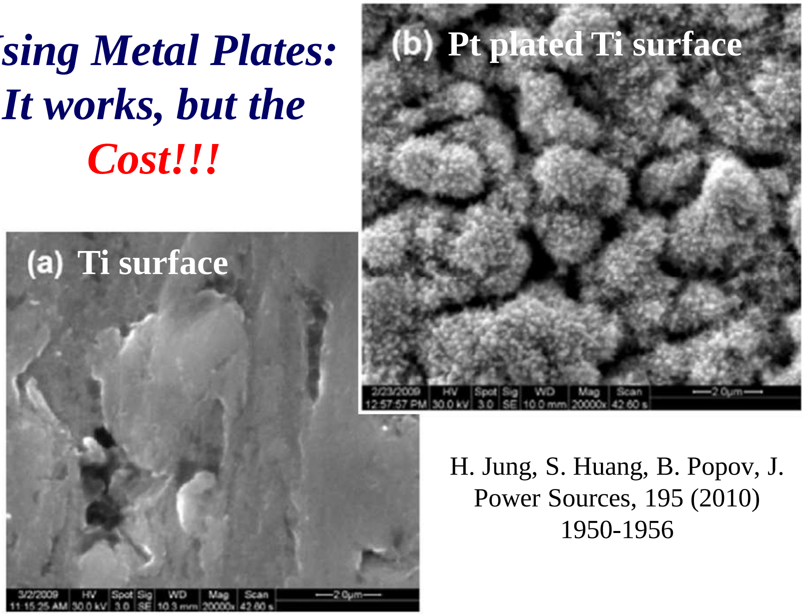
Reduce plate cost will have significant impact on the electrolyzer system cost

Repeatable Components:

- ✓ *Highest cost impact*
- ✓ *Key to performance*
- ✓ *Key to Durability*

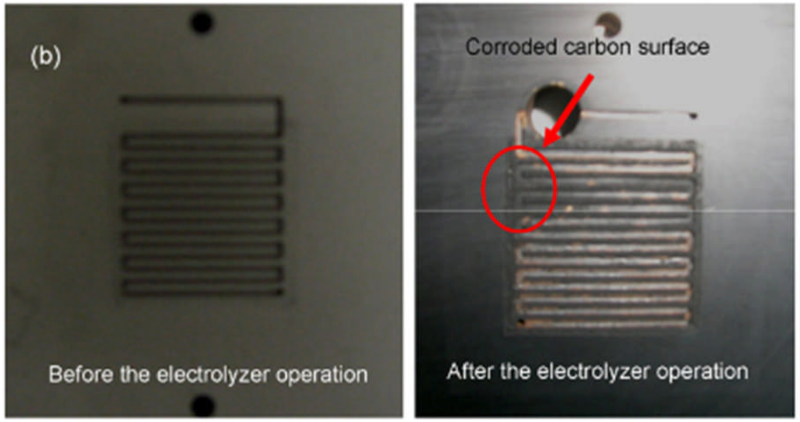
Typical Materials for PEM Electrolyzer Plates

Using Metal Plates: It works, but the Cost!!!



H. Jung, S. Huang, B. Popov, J. Power Sources, 195 (2010) 1950-1956

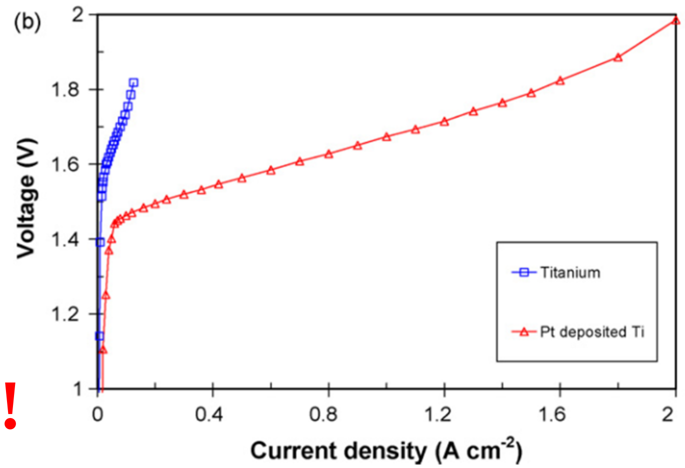
Corrosion of Graphite Plates



H. Jung, S. Huang, P. Ganesan, B. Popov, J. Power Sources, 194 (2009) 972-975

Multilayer design Ti on anode and Zr on cathode

1. *Ti layer forms a dense oxide surface scale in oxygen, which prevents further oxidization*
2. *Zr layer prevents hydrogen embrittlement of Ti*
3. *Surface electrical resistance is reduced by plating a layer of Pt on the plate surface*



Corrosion & Cost!!!

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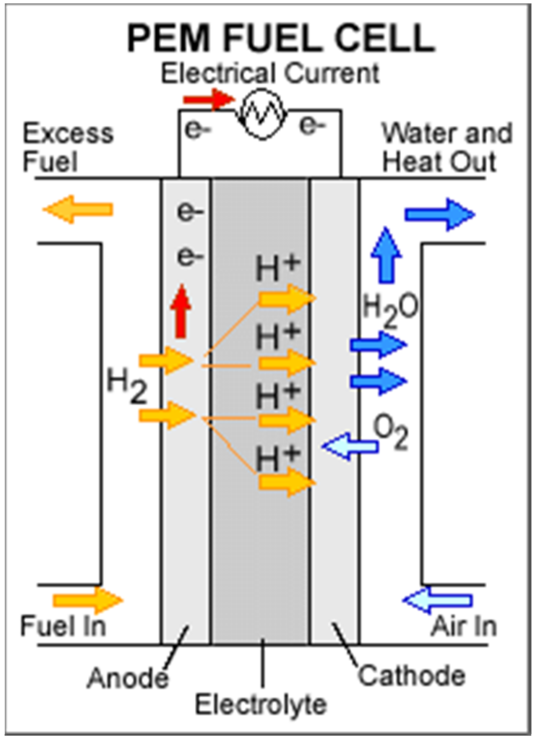
PEM Fuel Cells: Operating Environments



Schematic diagram of PEM Fuel Cell

Requirements for plates

1. *Low contact resistance*
2. *Chemically and electrochemically stable*
3. *High mechanical strength (durability)*
4. ***Low cost***

Challenges for graphite & metal plates

1. *Corrosion resistance for metal*
2. *Electrical conductivity for graphite*
3. *Brittleness & durability for graphite*
4. ***Cost, Cost, Cost***

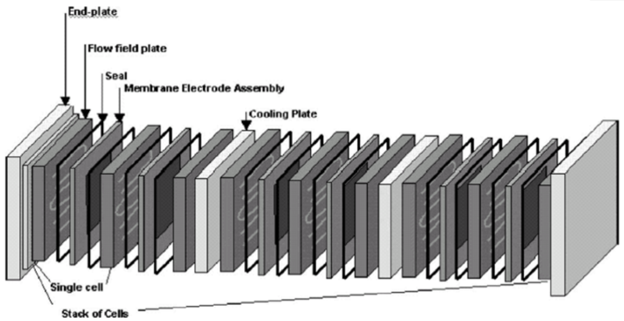
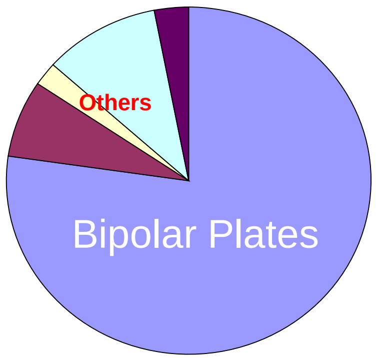


Fig. 1. PEM fuel cell stack hardware.



Typical Stack Mass Distribution Chart

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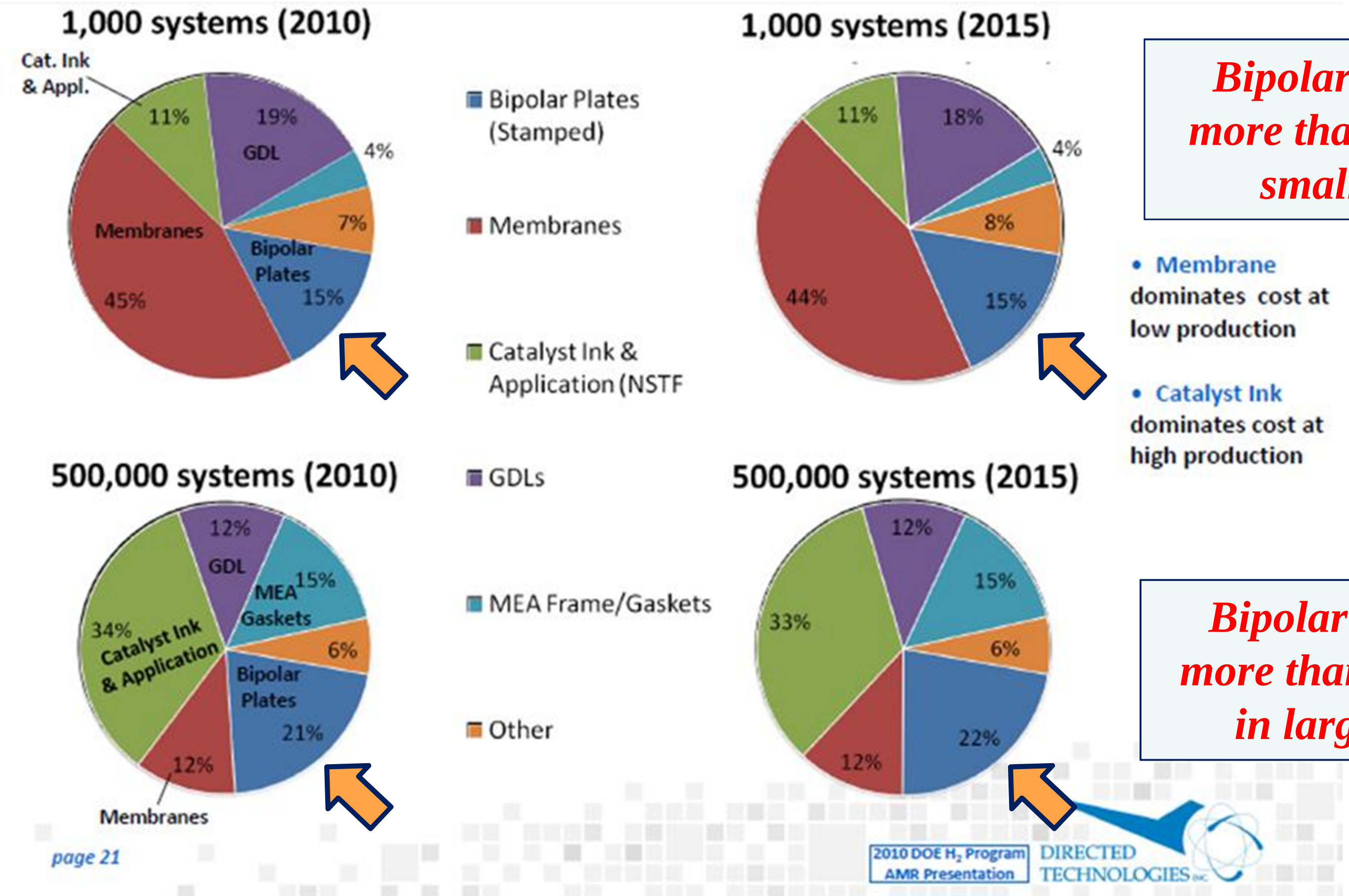
Bipolar Plates are a Major Portion of Fuel Cell Stack Costs



Bipolar plates cost more than catalyst in small volume

- **Membrane** dominates cost at low production
- **Catalyst Ink** dominates cost at high production

Bipolar plates cost more than membrane in large volume

B. James, J. Kalinoski & K. Baum, 2010 DOE H2 Program AMR Presentation

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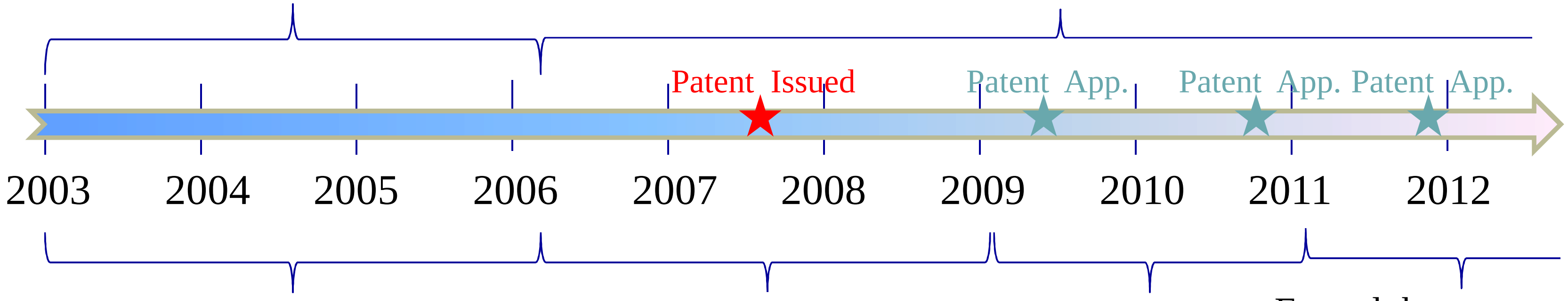
TreadStone's Metal Plate Technology Solution: History



- Plate Design Invention
- Demonstration using titanium w/gold
- Funded by:
  - Sarnoff
  - DoD Project

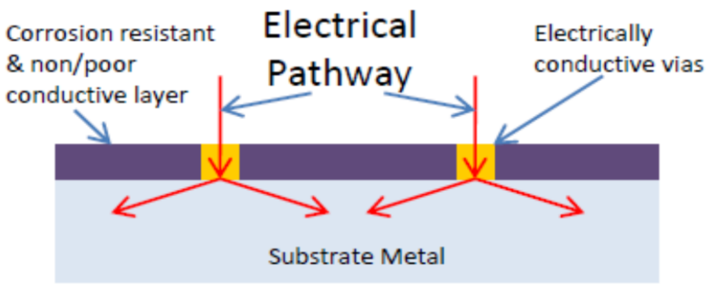
- Processing Invention
- Demonstration using SS w/gold
- Funded by:
  - Private Investors
  - NJ CST

- Demonstration in PEM fuel cells
- Commercial sales-2009
- Funded by:
  - Private Investors
  - DOE-EERE
  - DoD Project

- Extend the application into electrolyzers and flow batteries
- Used in NASA's new generation fuel cells
- Funded by:
  - Private Investors
  - DOE-EERE
  - DoD Project

TreadStone's Metal Plate Technology: Approach

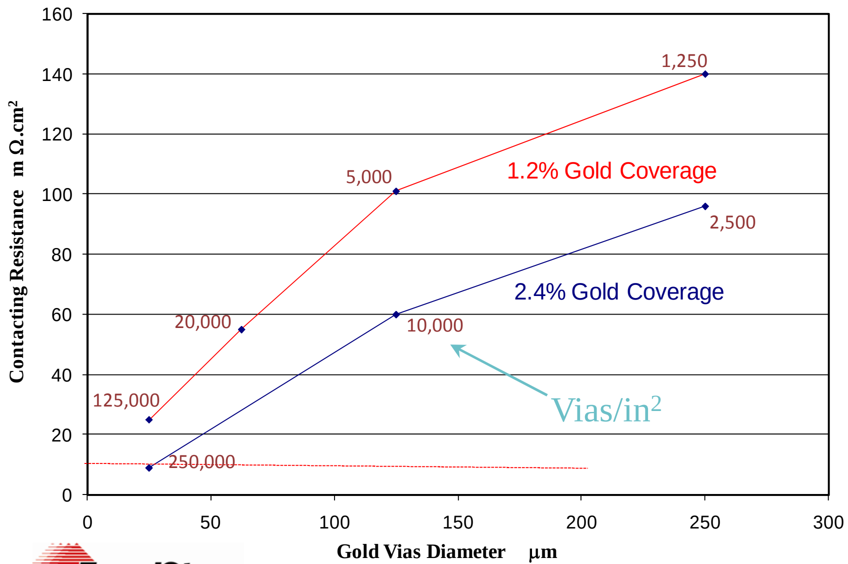
TreadStone's Plate Design



Design Feature:

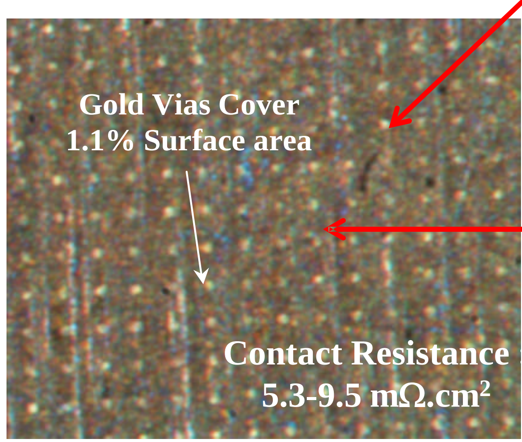
1. *Using a small amount of electrically conductive and corrosion resistant material to cover a small portion of the substrate surface in the form of isolated vias (dots)*
   - *Low cost*
2. *Using non-conductive (or poorly conductive) material to cover the rest of the substrate surface and separate conductive vias*
   - *Eliminate galvanic corrosion*
   - *Easy processing*

US 7,309,540 – Dec 18, 2007



Contact Resistance of GDL with the Cu/Plastic Film/Gold vias Plate

Electrical Resistivity	
Graphite:	*1375 µΩ.cm*
Gold:	*2.2 µΩ.cm*
Silver:	*1.6 µΩ.cm*



Highly conductive small vias can ensure the sufficient low electrical contact resistance of the metal plates for electrochemical applications

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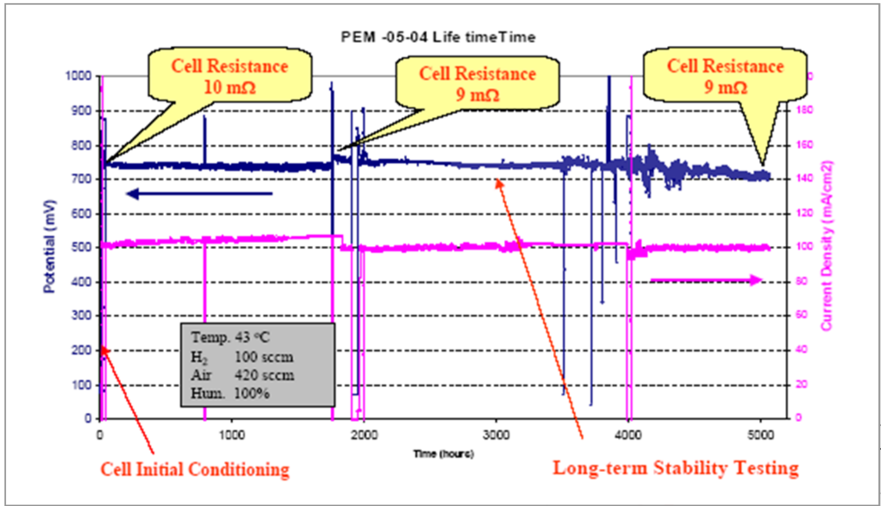
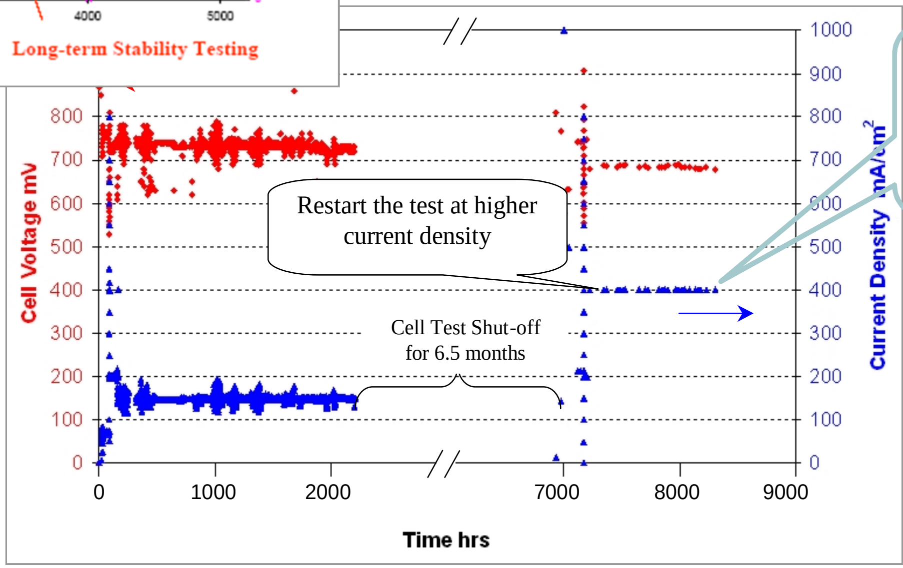
Durability Tests in Small Single Fuel Cells

TreadStone's Ti Plate Cell, H_2/air



- Lifetime performance tests were conducted under constant current condition at ambient pressure
- There was not plate performance degradation observed during the long term tests.

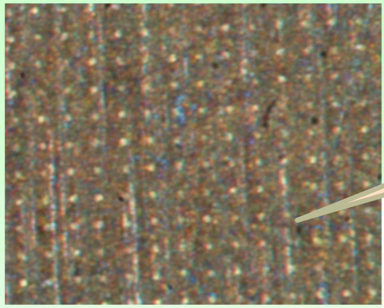
TreadStone's SS Plate Cell, H_2/air



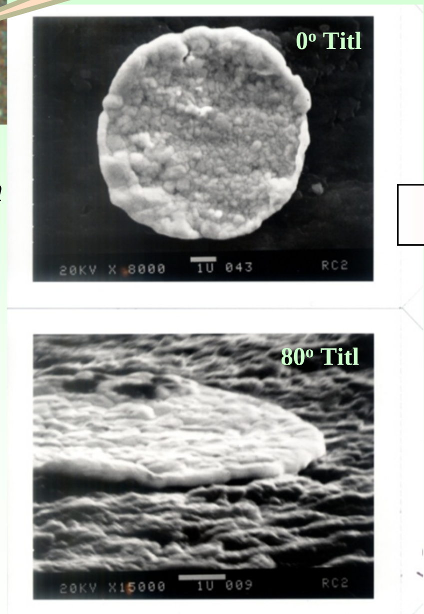
Achieved 8200 hrs (3500 hrs operation + 4700 hrs stand-by) long term stability test

Gold Deposition on Metal Surface

R&D Process: Photolithography



Precise Control
Au Particles

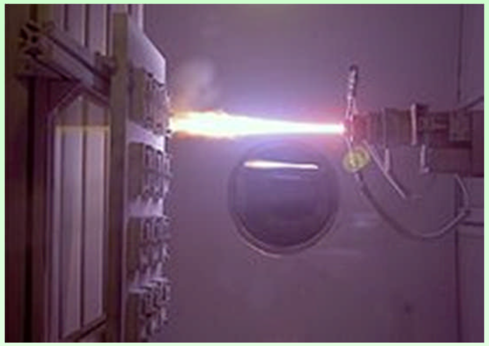


Dot Pitch: 75 x 75 μm
Diameter: ~9 μm

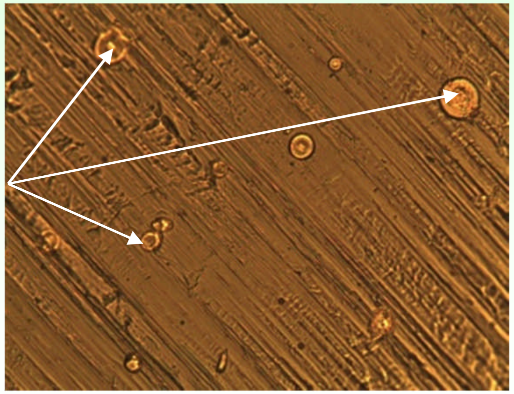
Area Coverage: 1.1%
Thickness: ~0.3 μm

Gold Loading:
~7 μg/cm²
Contact Resistant:
5.3-9.5 mΩ.cm²

Fabrication Process: Thermal Spray



Randomly Distributed Gold Splats



Gold Splats thickness: 0.2-0.4 μm

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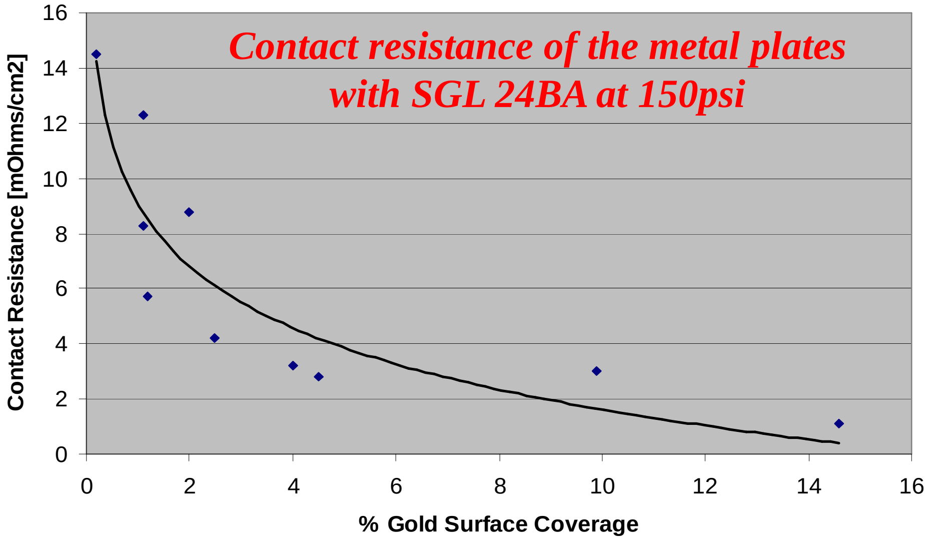
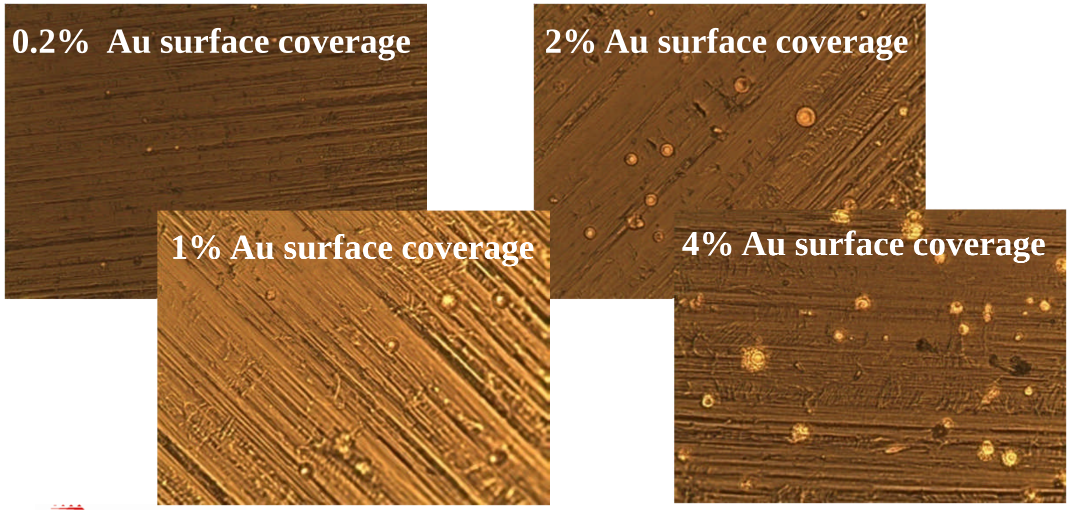
Thermal Spray Process Modification



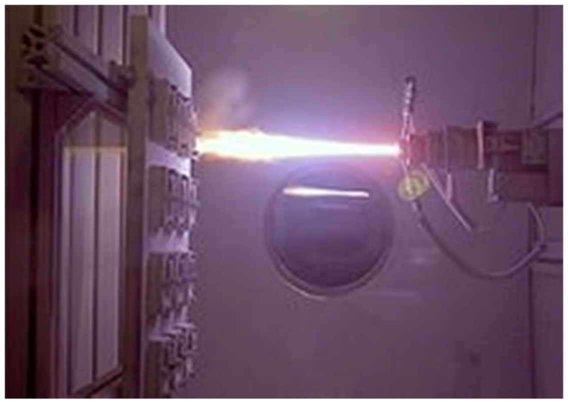


Traditional Thermal Spray:

- *Thick coating layer*
  - *High powder delivery rate*
  - *Large size powder*
  - *High power*

TreadStone's Process:

- *Small isolated splats*
  - *Slow powder deliver rate*
  - *Small powder (0.7 - 1mm)*
    - *using slurry*
  - *Low Power*
    - *avoid substrate overheat*



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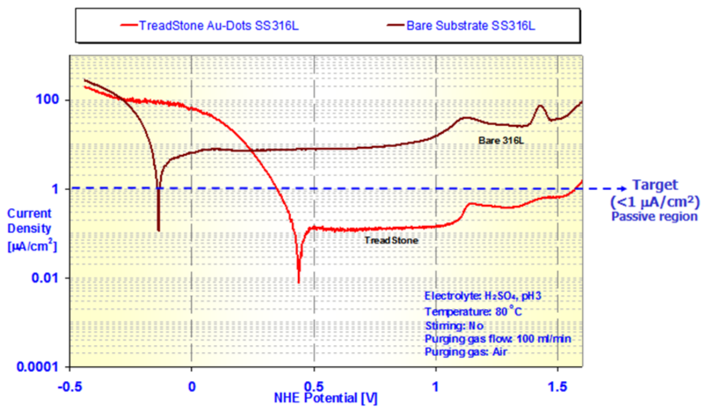
TreadStone's Au-Dots Technology Ex-situ Test

Attribute	Metric	Unit	2015 DOE Target	Ford Data on Au-Dots
Corrosion anode	**Current density at active peak in CV**	μA/cm²	<1	No active peak
Corrosion cathode	**Current density at 0.8 V_{NHE} in potentiostatic expt.**	μA/cm²	<1	~0.1
Area Specific Resistance	**ASR (measured through plane) at 6 bar contact pressure** (includes both side surface; doesn't include carbon paper contribution)	mOhm.cm²	<20	8.70 (as-recd flat samples)
Electrical Conductivity	**In-plane electrical conductivity (4-point probe)**	S/cm	>100	34 kS/cm
Formability	**% elongation** (ASTM E8M-01)	%	>40%	53(|| to RD*)/ 64 (⊥ to RD)
Weight	**Weight per unit net power** (80 kWnet system)	Kg/kW	<0.4	<0.30

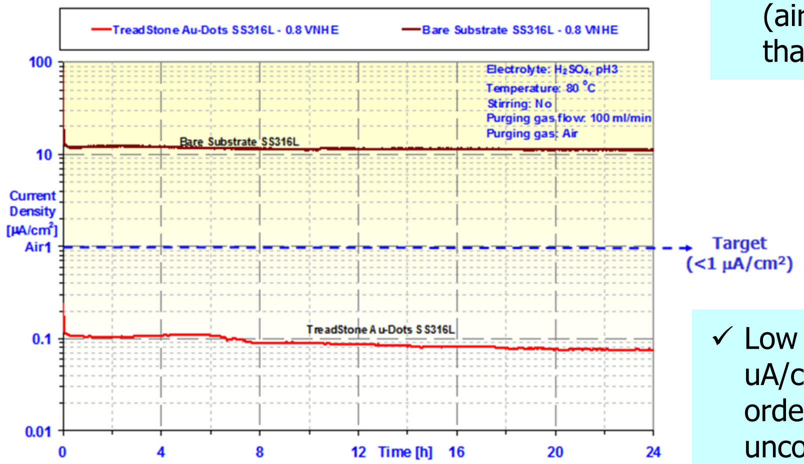
*RD: Rolling Direction

Cyclic Voltammetry Scanning



- ✓ TreadStone Au-Dots material shows passive region up to 1 V, similar to SS316L. However, Low current density (< 1 uA/cm2) at 0.8 V_{NHE} (air). Two order of magnitude lower than uncoated SS316L

Consistent Voltage at 0.8 V_{NHE}



- ✓ Low current density (< 1 uA/cm2) at 0.8 V_{NHE} (air). Two order of magnitude lower than uncoated SS316L

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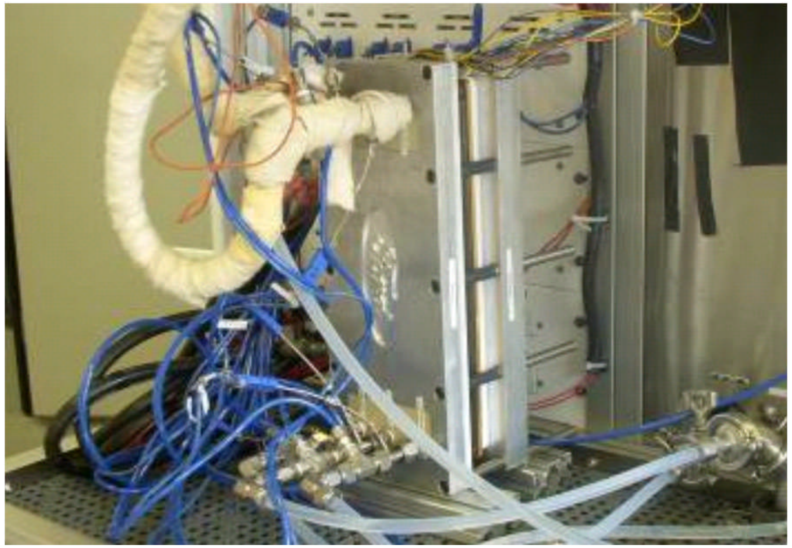
Short Stack in-situ Testing at Ford

- *TreadStone's SS plates w/ Au dots were tested in-situ for durability at Ford Motor Company.*
- *Results:*
  - *Stack performance has some degradation, mainly due to the degradation of MEAs*
  - *TPV on as-recd coated metal plates was at 15.4 mV (st dev 2 mV)*
  - *Small TPV increase (~2-3mV) is observed during first 1000 hrs. of testing*
  - *Metal cations in the stack effluent water (anode, cathode, and coolant) were below detectable limit of analyzer (~ppb)*
  - *Non visible corrosion marks of the plate after 1000 hours test*



Polarization curve at BOL and MOT (1000 hrs.)

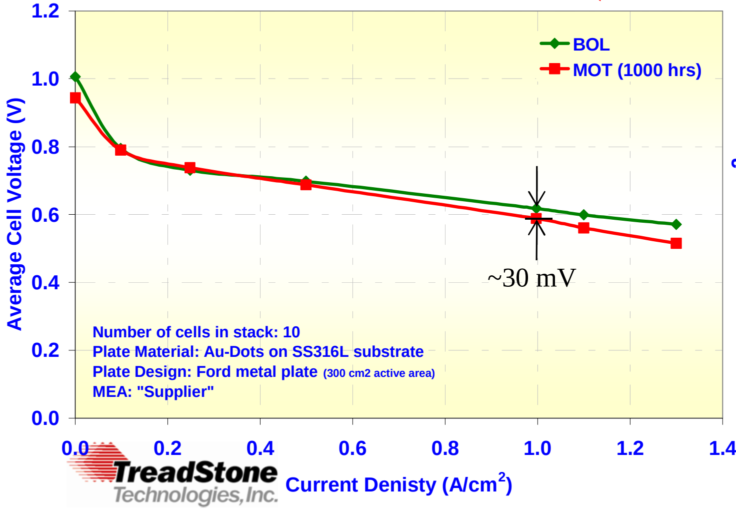
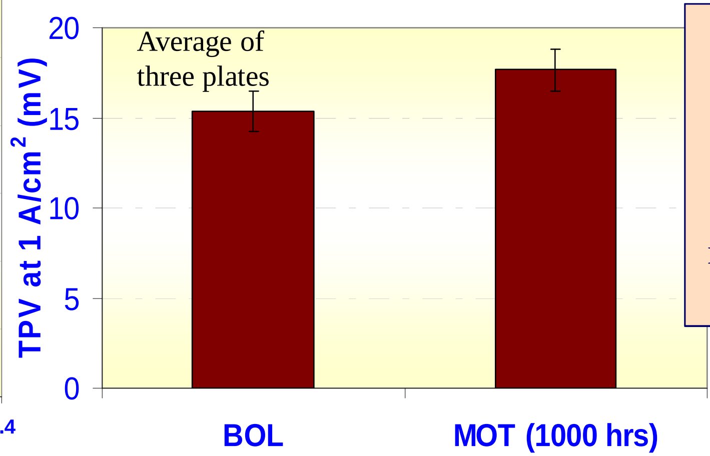


Plate TPV at BOL and MOT (1000 hrs.)



Next Step…

To build a new 20-cell stack for 2000 hours lifetime test with lower (<10 $m\Omega.cm^2$) through plate resistance

Large Scale Fabrication Cost Analysis

Plate Fabrication Process:

Stamping Cathode & Anode Plates
↓
Degrease & Cleaning
↓
Cathode & Anode Plate Welding
↓
Leak Check
↓
Plate Coating
⇩
Bipolar Plates

Material & Forming Costs 200 m/year

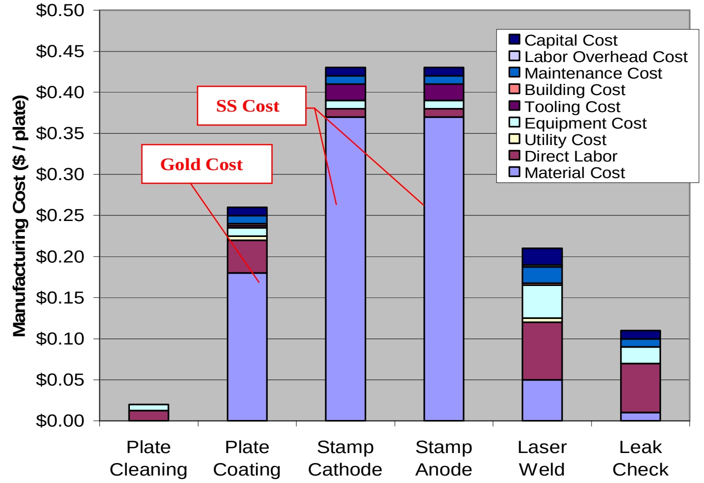
- *At $2.00/lb. (historical average)*
  - *SS material cost: $1.05/plate*
- *At $3.92/lb. (Aug. 2010)*
  - *SS material cost is $2.06/plate*

316 SS material cost accounts over 65% of the plate cost

TreadStone's Process

Baseline Au-dots: $0.33/plate
Pd dots: $0.31/plate
C-tube: $0.79/plate
Carbides : $0.30/plate

Cost Breakdown of SS Based Plates



Coating Cost: (based on $1,000/oz. Au)

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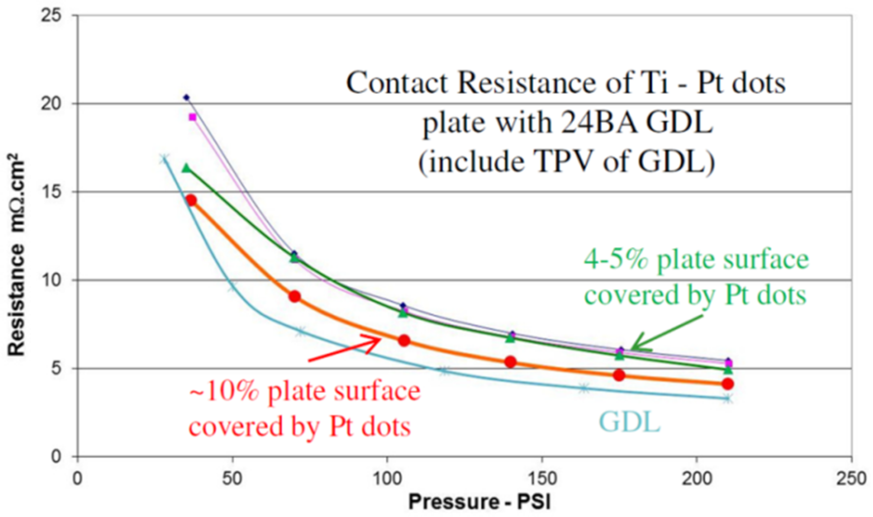
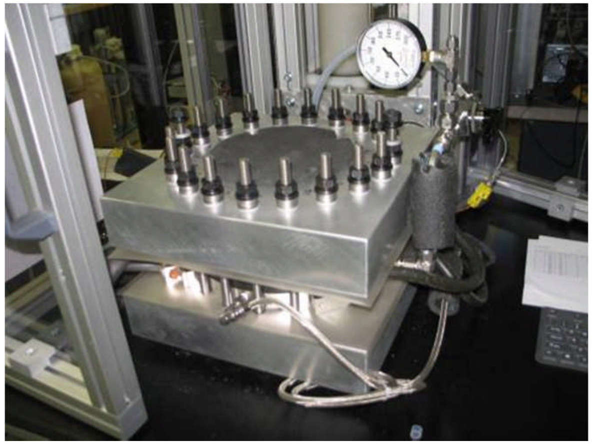
IBIS

Applications in PEM Electrolyzers

- *Current focus on the Ti separate plates*
  - *Current Standard Plate:* *Ti Substrate with 100% Pt Surface Coverage*
  - *TreadStone's approach:* *Ti Substrate with Pt-dots (cover 4-10% surface)*
    - *Lower Pt loading…lower cost, Simple fabrication process…lower cost*
  - *Long term operation stability tests show stable performance of the plates.*



Sample #	H_2 concentration in Ti strip (after 1000 hrs. in high pressure H_2)
#1	760 ppm
#2	250 ppm
#3	73 ppm



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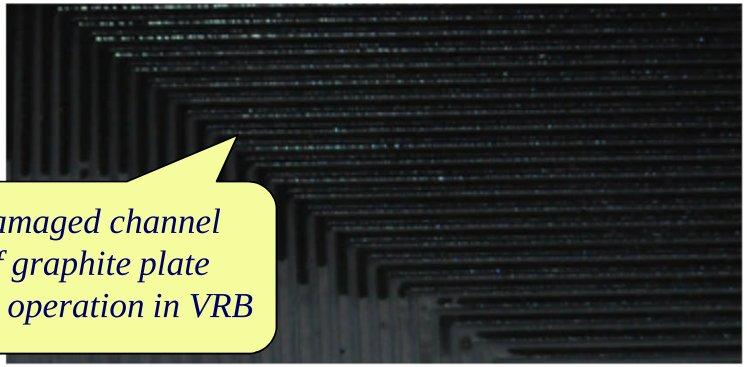
Applications in Flow Batteries

Market Needs:

- *Highly corrosive chemical environments*
  - *Requirement varies with chemical systems.*
  - *More aggressive at charge stage (high voltage).*
- *Large dimension (meters) for grid scale storage*
- *Thermal cycling stability (challenging for composite plates)*



Graphite plates after the test in VRB flow battery

Current Activity:

- *Electrochemical corrosion test of the selected materials in Br_2-HBr*
- *Conducting durability tests for soluble Pb acid flow battery*
- *Conducting corrosion test for VRB battery*

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Focused Market for Commercialization

Fuel Cell Market

----Commercial Applications ----

Automotive

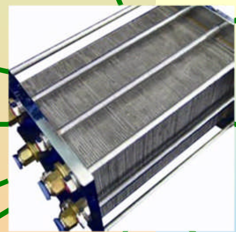
Back-up Power

Materials Handling

Combined Heat & Power

Long runtime & Short refueling time

Safe, low-emissions power



----- Military Applications -----

Shipboard Power

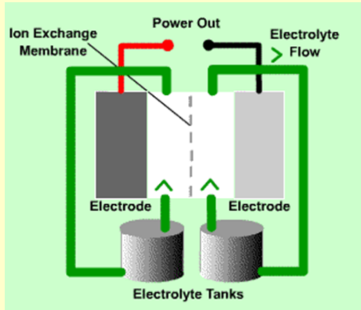
High Energy Density

UAV & UUV

Specialty Applications - NASA

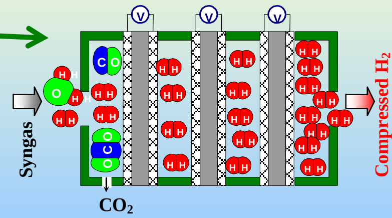
Energy Storage Applications

Flow Batteries



High energy efficiency and independence

Electrochemical Compression



Long lived – low maintenance power

Electrolyzers

Hydrogen Generation & Delivery

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Summary

- ***Metal plates are an important component for PEM electrolyzers and fuel cells for cost reduction and long term durable operation.***
- ***PEM electrolyzer developers are interested to the low cost metal plate technologies to replace expensive alternatives***
- ***TreadStone's metal plate technology has been demonstrated for low temperature PEM fuel cell applications***
  - ***8000+ hours single cell test***
  - ***1000 hours stack test under automobile dynamic operation condition***
- ***TreadStone's technology has potential to be used in PEM electrolyzers***
- ***The long term durability test is on-going with industrial partners***
- ***The investigations using TreadStone's metal plates is underway for energy storage flow batteries and electrochemical hydrogen compressors***
- ***Seeking partnerships to…***
  - ***Enhance commercialization activities***
  - ***Scale process to production quantities***