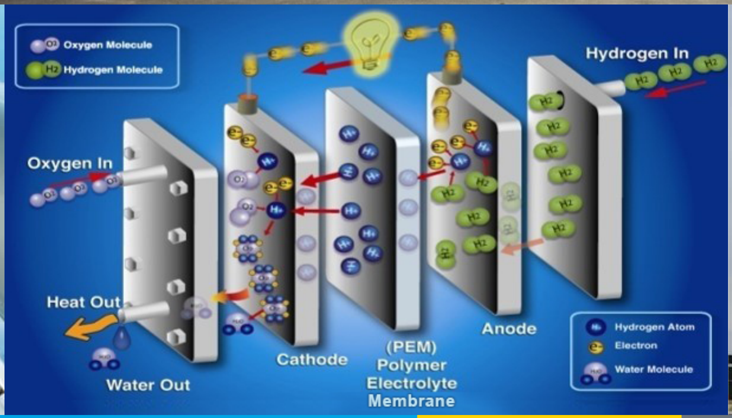
U.S. Department of Energy Fuel Cell Technologies Office

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



Opening Remarks and Workshop Overview

Southfield, MI

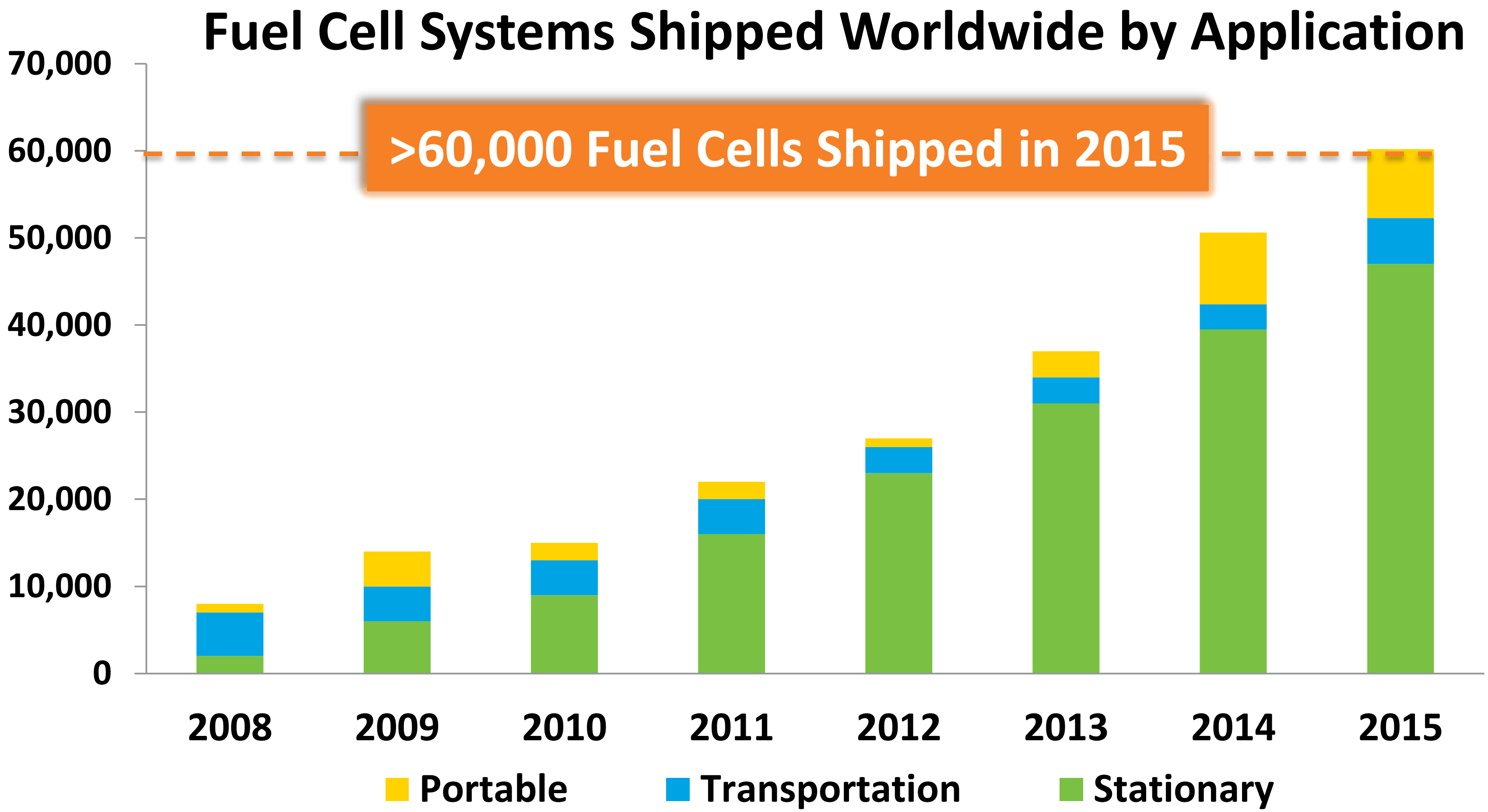
Feb. 14, 2017

Dr. Dimitrios Papageorgopoulos

Dr. Bahman Habibzadeh

Fuel Cell Technologies Office
U.S. Department of Energy

Market Growth in Fuel Cell Sales



Capacity shipped **in 2015** → Approximately **300 MW** & **~2X** → the capacity **in 2014**

Source: Navigant Research (2008-2013) & E4tech (2014-2015)

Consistent ~30% annual growth since 2010

For the first time in history: Commercial FCEVs


Hyundai Tucson Fuel Cell SUV


Toyota Mirai


Honda FCV

Commercial FCEVs are here **today!**

Can reduce total GHG emissions 50-90% vs. today's gasoline vehicles

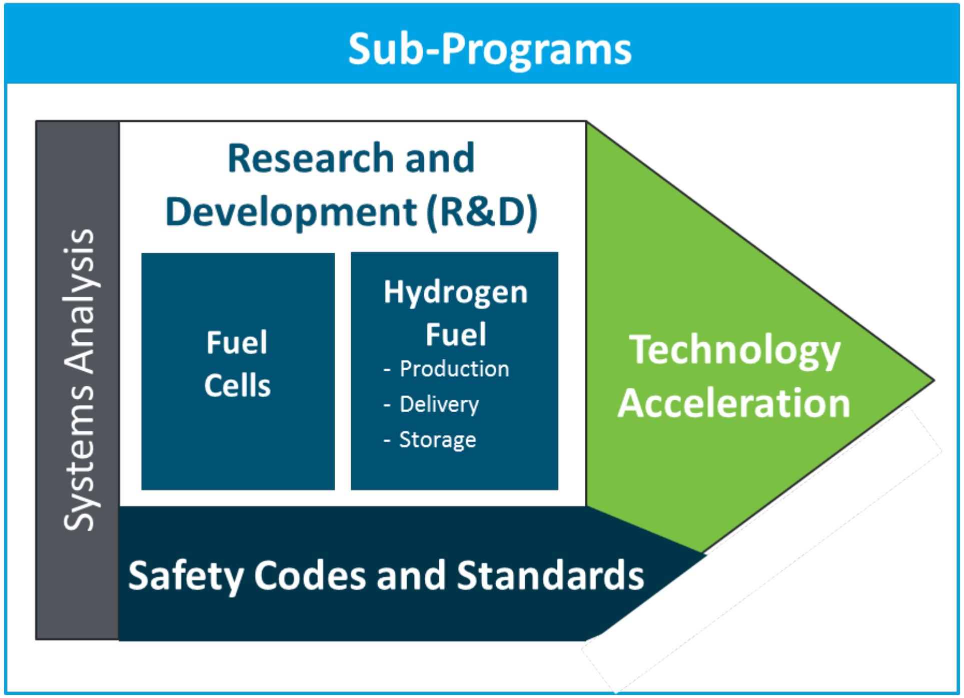
More than 1,100 FCEVs sold or leased in the U.S.

FCEV: Fuel Cell Electric Vehicle
GHG: Greenhouse Gases

DOE Hydrogen and Fuel Cells Program

Mission

To enable the ***widespread commercialization of hydrogen and fuel cell technologies***, which will reduce petroleum use, greenhouse gas (GHG) emissions, and criteria air pollutants, and will contribute to a more diverse energy supply and more efficient use of energy.



2020 Targets by Application

	Vehicles	Stationary
Fuel Cell Cost	\$40/kW	\$1,000/kW* \$1,500/kW**
Durability	5,000 hrs	80,000 hrs
H_2 Storage Cost (On-Board)	\$10/kWh 1.8 kWh/L, 1.3 kWh/kg	
H_2 Cost at Pump	<\$4/gge <\$7/gge (early market)	

*For Natural Gas
**For Biogas

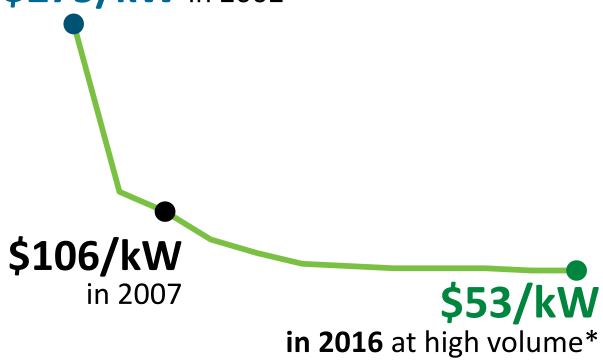
Integrated approach to widespread commercialization of H_2 and fuel cells

DOE Activities Span from R&D to Deployment

1. Research & Development

Fuel Cells

- **80% lower cost** since 2002
- **5X less platinum** since 2005
- **4X increase in durability** since 2006



*$230/kW low volume, $59/KW at 100K units

2. Demonstration

Forklifts, back-up power, airport cargo trucks, parcel delivery vans, marine APUs, buses, mobile lighting, refuse trucks

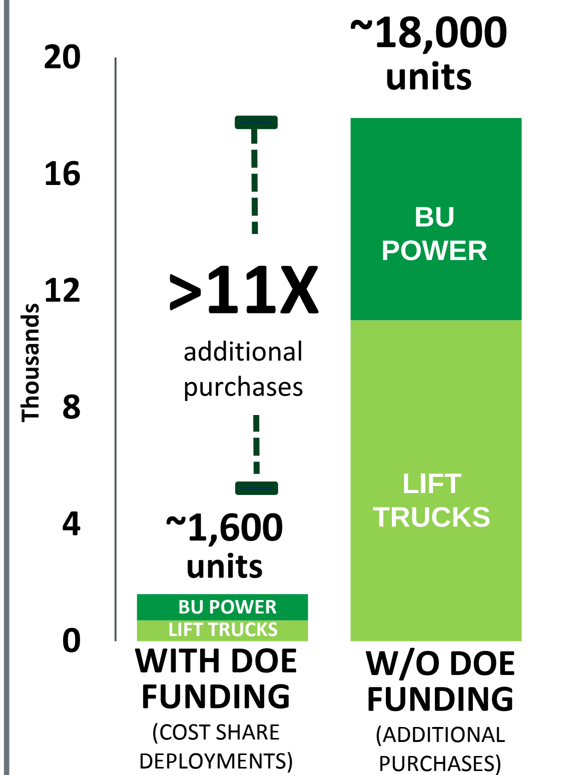
>220 FCEVs, >30 stations, >6M miles traveled

World's first tri-gen station

H_2 technology station in Washington D.C.

FCEV: Fuel Cell Electric Vehicle

3. Deployment



BU: Back Up Power

Examples of consortia supporting R&D

- FCPAD (Fuel Cell Performance and Durability) — Fuel Cell Performance & Durability
- HyMARC — Advanced H_2 Storage Materials
- ElectroCat (Electrocatalysis Consortium) — PGM-Free Catalysts for Fuel Cells
- HydroGEN (Advanced Water Splitting Materials) — Renewable H_2 Production

Supporting Deployment

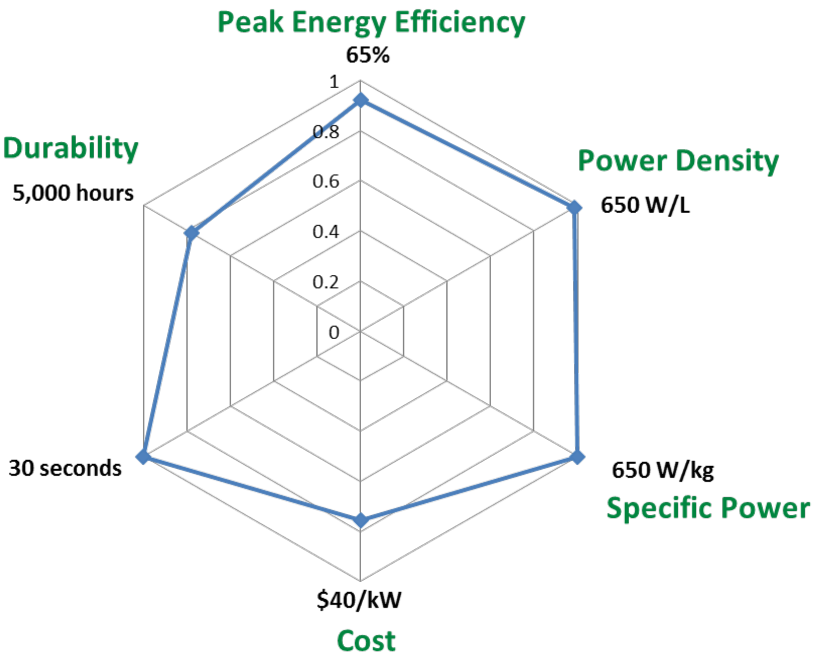
H_2USA

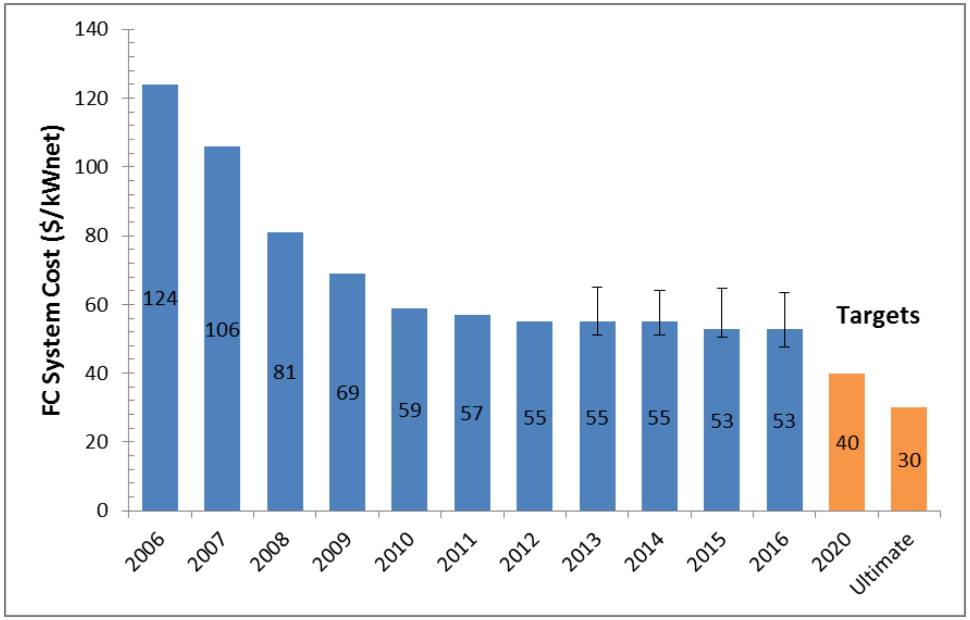
Collaboration to address H_2 Infrastructure Barriers

Fuel Cell System Status and Targets

2020 Goals: 65% peak efficiency, $40/kW, 5000 hour durability

2016 Status: 60% peak efficiency, $53/kW*, >4100 hour durability**





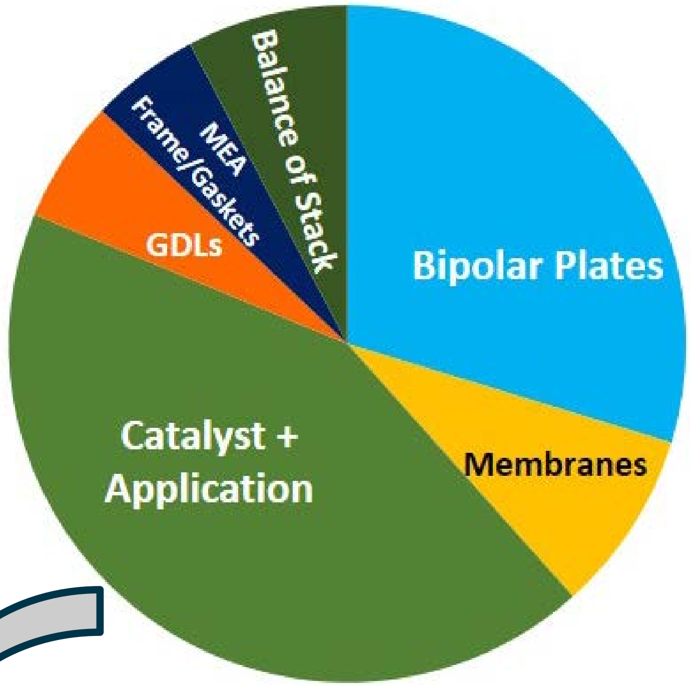
*For 500,000 units/year. https://www.hydrogen.energy.gov/pdfs/16020_fuel_cell_system_cost_2016.pdf

**On road fuel cell stack durability. https://www.hydrogen.energy.gov/pdfs/16019_fuel_cell_stack_durability_2016.pdf

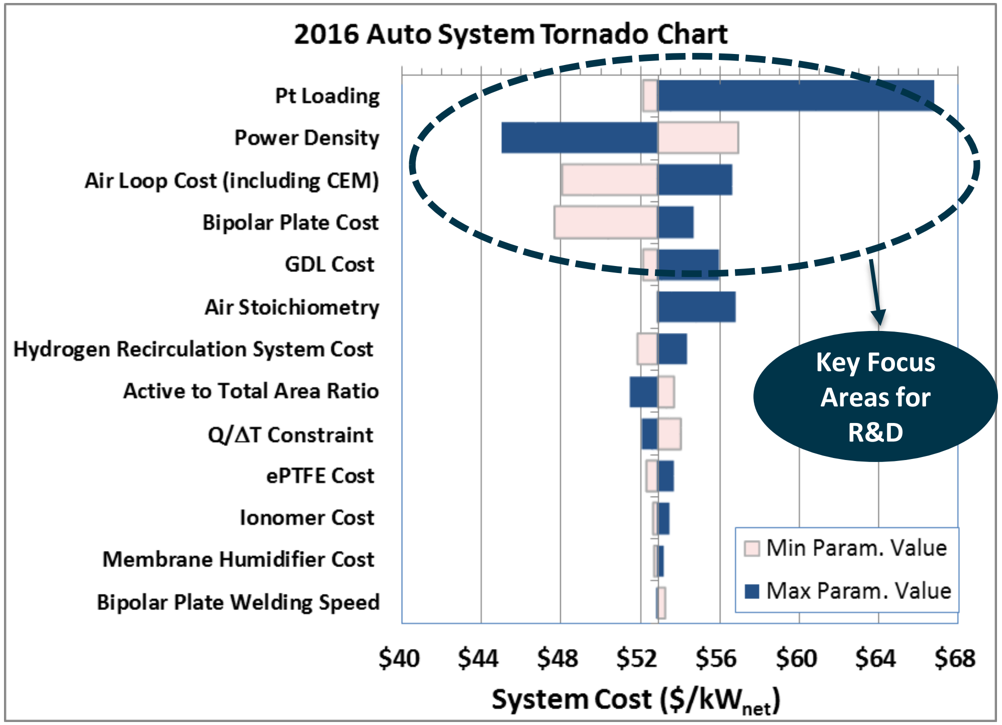
Significant progress has been achieved. However, further R&D is needed to overcome challenges - durability and cost.

Fuel Cell R&D Focus Areas and Priorities

PEMFC Stack Cost Breakdown*



Sensitivity Analysis

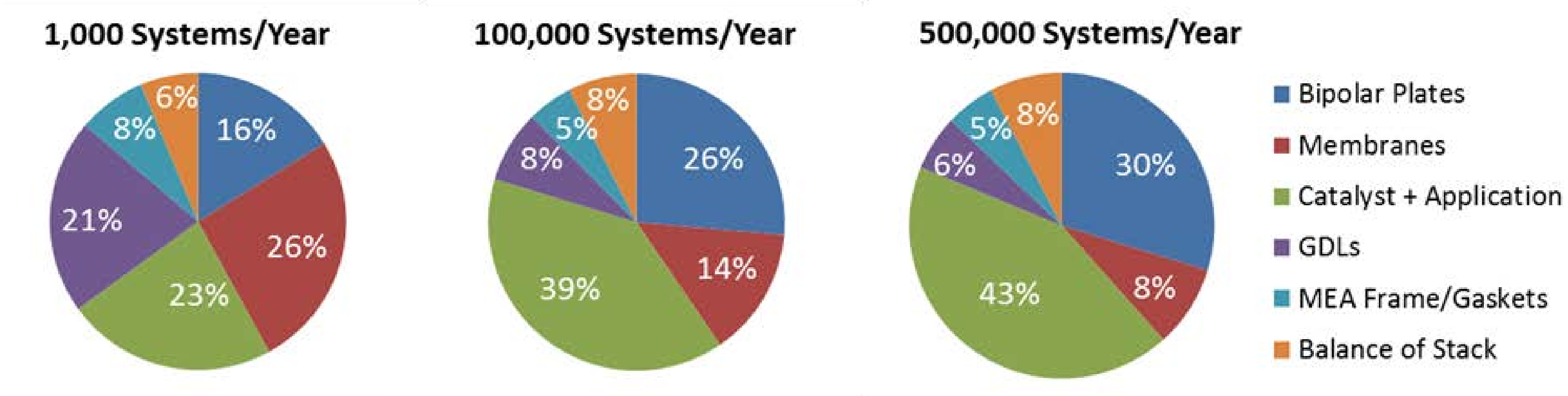


***Catalyst cost** is projected to be the largest single component of the cost of a PEMFC manufactured at high volume. **Bipolar plate cost** is also projected to be significant (30%).*

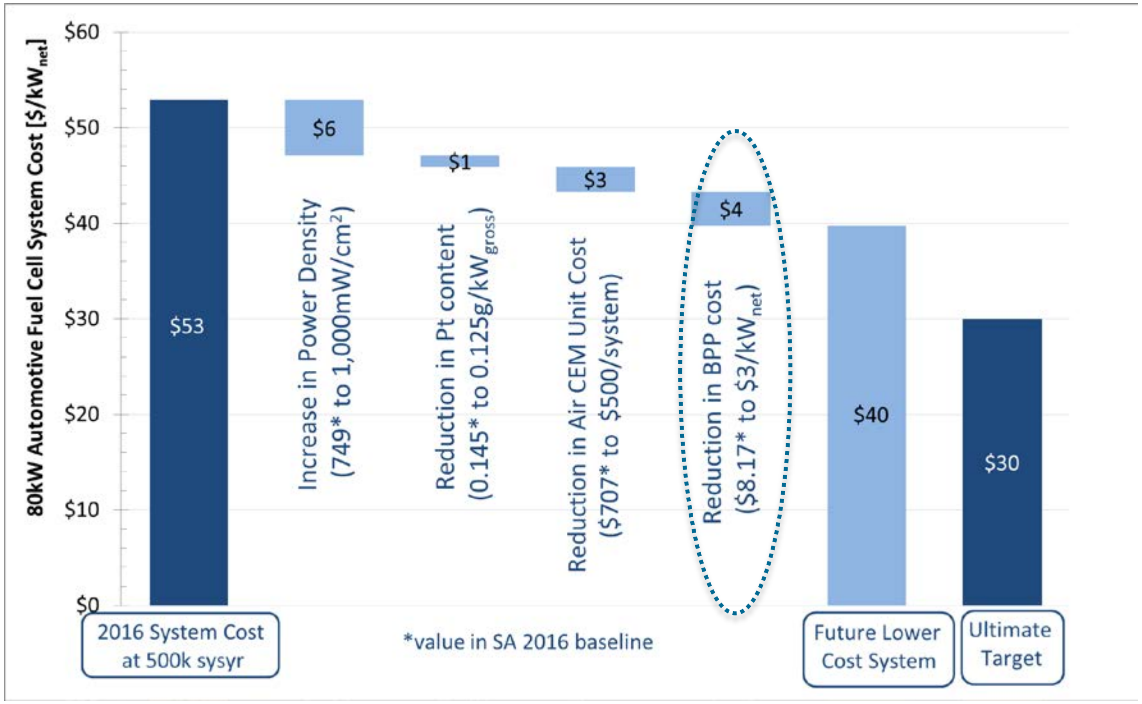
*@ 500,000 systems/year

R&D Need: Low Cost Bipolar Plates

Bipolar plate cost dominated by commodity material costs, relatively insensitive to manufacturing volume



Meeting bipolar plate cost guideline target significantly contributes toward meeting 2020 40 $/kW target



DOE's MYPP Targets for Bipolar Plates

Table 3.4.8 Technical Targets: Bipolar Plates for Transportation Applications			
Characteristic	Units	2015 Status	2020 Targets
Cost[a]	$ / kW_{net}	7[b]	3
Plate weight	kg / kW_{net}	<0.4[c]	0.4
Plate H_2 permeation coefficient[d]	Std $cm^3/(sec\ cm^2 Pa)$ @ 80°C, 3 atm 100% RH	0[e]	$<1.3 \times 10^{-14}$[f]
Corrosion, anode[g]	$\mu A / cm^2$	No active peak[h]	<1 and no active peak
Corrosion, cathode[i]	$\mu A / cm^2$	<0.1[c]	<1
Electrical conductivity	S / cm	>100[j]	>100
Areal specific resistance[k]	ohm cm^2	0.006[h]	<0.01
Flexural strength[l]	MPa	>34 (carbon plate)[m]	>25
Forming elongation[n]	%	20–40[o]	40

https://energy.gov/sites/prod/files/2016/10/f33/fcto_myrdd_fuel_cells.pdf

Some of Completed Projects Funded by DOE

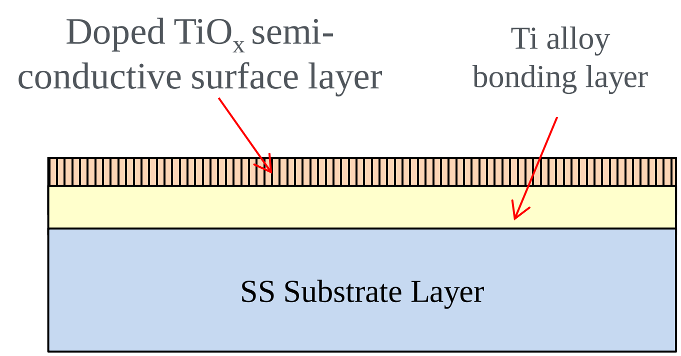
- Development of Corrosion-Resistant Coatings for Fuel Cell Bipolar Plates, Physical Sciences Inc. (1999)
- Economical High Performance Thermoplastic Composite Bipolar Plates, NanoSonic Inc., (2006)
- Next Generation Bipolar Plates for Automotive PEM Fuel Cells, GrafTech Int. Ltd. (2009)
- Nitrided Metallic Bipolar Plates, ORNL (2010)
- Metallic Bipolar Plates with Composite Coatings, ANL (2011)
- Low-Cost PEM Fuel Cell Metal Bipolar Plates, TreadStone Technologies Inc. (2011)

Active Project Funded by DOE

Novel Structured Metal Bipolar Plates for Low Cost Manufacturing - TreadStone

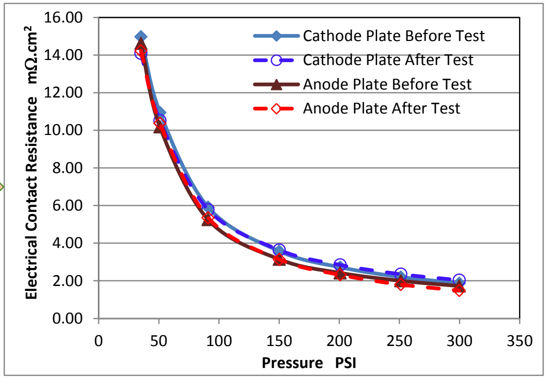
- Developed the coating process to obtain the coating with designed composition and phase structure
- Identified the chemical composition and microstructure of doped titanium oxide and showed this coating as the most promising coating material.
- Demonstrated the stable long term operation of the doped titanium oxide coating with *in-situ* performance test using single cell and stack.

TreadStone's TiOx Coating Structure



TreadStone has demonstrated low electrical resistance, low corrosion current, and durable performance

Contact Resistance of Ti_2Nb coated SS plates before and after 1,100 hrs. single cell test



TreadStone Technologies, Inc.

FCTO's Request for Information (RFI) on Bipolar Plate

- Material

1. What **material** has the potential to meet Cost, Durability and Performance targets?
2. State-of-the-art **coating**? Improve adhesion minimize interfacial contact resistance
3. Improvement **beyond 2020** targets

- Process

1. **Improvement** to current manufacturing methods
2. **Advanced manufacturing** processes
3. Solutions for **low-cost manufacturing**
4. Advances in process **quality control** to lower manufacturing costs

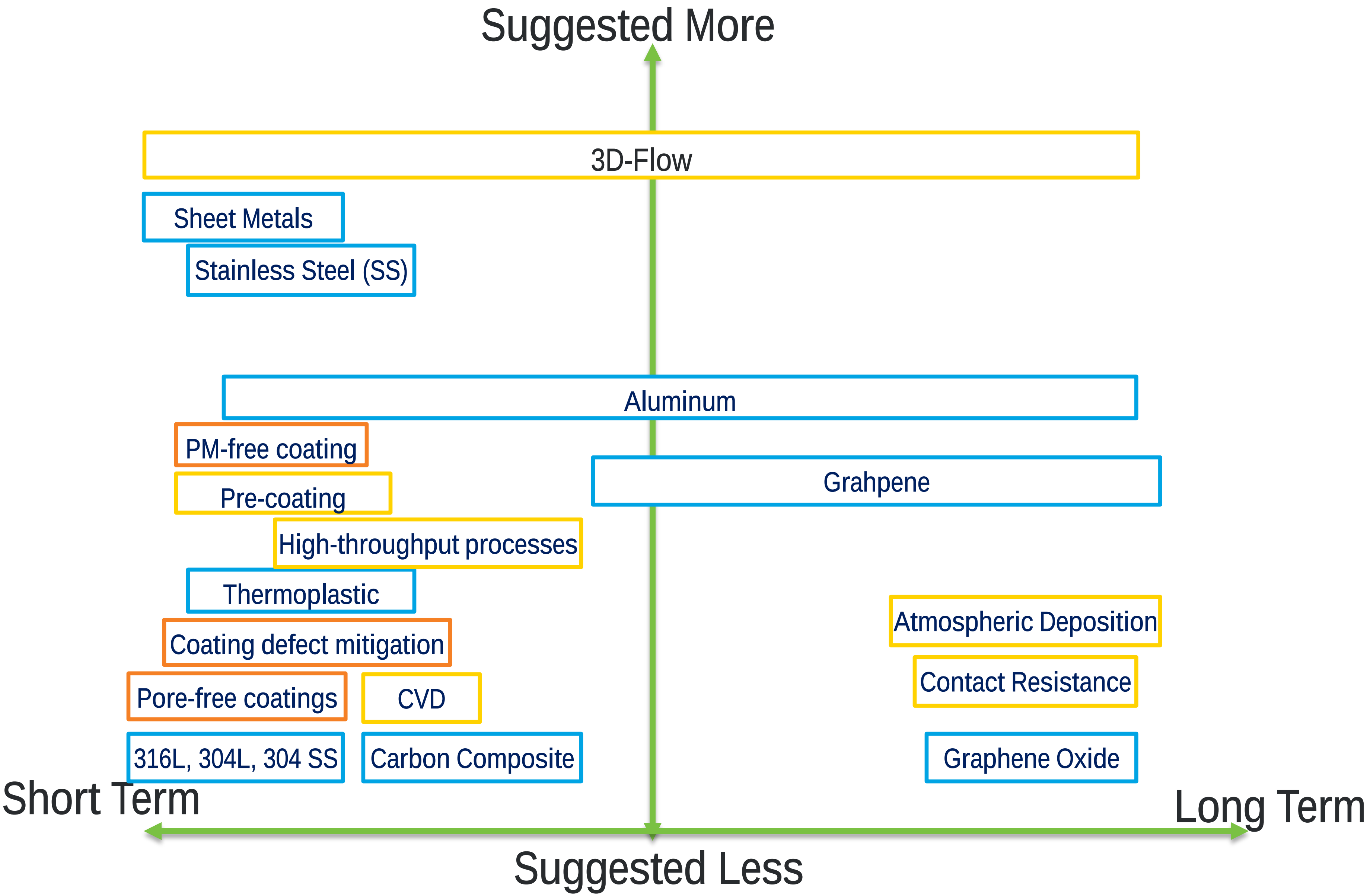
- Technology barriers

1. Novel **Corrosion protection**
2. Optimized **fluid and thermal flow**
3. Is (further) **modeling** required?

- Testing/Durability/Targets

1. **Durability and accelerated stress test** protocol need
2. Foundational studies on **degradation and mitigation approaches**
3. Suggestions on DOE's **technical targets** for bipolar plates

RFI Result on Short- and Long-term R&D Needs



Goal of the Workshop

- How to achieve technical and economical targets?
  These include:
  - Technical
    - High electric conductivity
    - Low gas permeability
    - High thermal conductivity
    - High chemical stability
    - High corrosion resistance
    - Low resistance and accessible gas flow channels
    - Matching thermal expansion
    - Acceptable hydrophobicity
  - Economical
    - Low cost
    - Light weight
    - Low volume
    - Ease of manufacturing
- What should be the focus of research and development activities?
  - Long-term vs. short-term
  - Importance of the topic area
- What is the role of stakeholders in achieving the targets?
  - To what extend DOE's support is required?
  - What is industry and research community's role in achieving the targets?

Questions to be Discussed (Materials and Coatings)

Materials and Coatings

- Current cost estimates show that bipolar plate materials and coating technology exceeds cost targets. How can materials and coating costs be reduced and performance/durability be improved?
- What base materials provide the most potential to meet bipolar plate cost, durability and performance targets for automotive applications?

Metallic Base

- What are the issues limiting use of metals in bipolar plates?
- Are there grade or compositional requirements/limitations (e.g. limitations on Fe or Ni content)
- What are the main issues limiting current coating technologies for bipolar plates?
- What R&D is needed to address these issues? What are the priorities?

Non-Metallic Base

- What are the issues limiting use of non-metallic (carbon, carbon composite) based bipolar plates?
- What R&D is needed to address these issues? What are the priorities?
- Are there improvements in other cell/stack components that could alleviate plate requirements?

Questions to be Discussed (Manufacturing)

- Are current forming, methods adequate (quality, cycle time, cost)?
- Are current joining/sealing methods adequate (quality, cycle time, cost)?
- Are current coating methods adequate (quality, cycle time, cost)?
- Can multiple steps be combined into a single step (e.g., stamping and joining; stamping and coating during forming).
- How can manufacturing costs be reduced?

Questions to be Discussed (Modeling/Testing)

Modeling:

- Can a fundamental understanding of technical limitations of various bipolar plate materials, including carbon composite and metallic plates be gained by modeling?
- Are models for fluid flow and water transport adequate?
- Where else can modeling address bipolar plate needs?

Testing:

- Are existing test protocols sufficient and appropriate for all plate types, or will new tests be needed for new materials/coatings?
- Are technical targets and parameters comprehensive? What needs to be added, changed, improved or deleted?
- Are ex-situ tests instructive?
- Do we have appropriate accelerated tests for bipolar plate ageing ex-situ? In-situ?

Upcoming Events

DOE Annual Merit Review

- The U.S. Department of Energy's (DOE's) 2017 Annual Merit Review and Peer Evaluation Meeting (AMR) for the Hydrogen and Fuel Cells Program and the Vehicle Technologies Office will be held on June 5–9, 2017, in Washington, D.C

- The 2018 AMR, held in late spring, will be a combination of our traditional peer review and an interagency and industry showcase event.

BOP and Supply Chain for fuel cells

Thank You

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Fuel Cell Technologies Office (on detail from Building Technologies Office**)**

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hydrogenandfuelcells.energy.gov

Back up

References for MYPP Targets for Bipolar Plates

[a] Costs projected to high volume production (500,000 80 kW systems per year), assuming MEA meets performance target of 1,000 mW/cm^2.

[b] Cost when producing sufficient plates for 500,000 systems per year. DOE Hydrogen and Fuel Cells Program Record 15015, "Fuel Cell System Cost—2015." http://www.hydrogen.energy.gov/program_records.html.

[c] C.H. Wang (Treadstone), "Low-cost PEM Fuel Cell Metal Bipolar Plates," 2012 Annual Progress Report, http://www.hydrogen.energy.gov/pdfs/progress12/v_h_1_wang_2012.pdf.

[d] Per the standard gas transport test (ASTM D1434).

[e] C.H. Wang (Treadstone), private communication, October 2014.

[f] Blunk, *et al*, J. Power Sources 159 (2006) 533–542.

[g] pH 3 0.1ppm HF, 80°C, peak active current $<1\times10^{-6}$ A/cm^2 (potentiodynamic test at 0.1 mV/s, -0.4V to +0.6V (Ag/AgCl)), de-aerated with Ar purge.

[h] Kumar, M. Ricketts, and 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.

[i] pH 3 0.1ppm HF, 80°C, passive current $<5\times10^{-8}$ A/cm^2 (potentiostatic test at +0.6V (Ag/AgCl) for >24h, aerated solution.

[j] O. Adrianowycz (GrafTech), "Next Generation Bipolar Plates for Automotive PEM Fuel Cells," 2009 Annual Progress Report, http://www.hydrogen.energy.gov/pdfs/progress09/v_g_2_adrianowycz.pdf.

[k] Includes interfacial contact resistance (on as received and after potentiostatic test) measured both sides per Wang, *et al*. J. Power Sources 115 (2003) 243–251 at 200 psi (138 N/cm^2).

[l] ASTM-D 790-10 Standard Test Method for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials.

[m] D. Haack et al. (Porvair), "Carbon-Carbon Bipolar Plates," 2007 Annual Progress Report, http://www.hydrogen.energy.gov/pdfs/progress07/v_b_3_haack.pdf.

[n] Per ASTM E8M-01 Standard Test Methods for Tension Testing of Metallic Materials, or demonstrate ability to stamp generic channel design with width, depth, and radius.

[o] M. Brady et al. (Oak Ridge National Laboratory), "Nitrided Metallic Bipolar Plates," 2010 Annual Progress Report, http://www.hydrogen.energy.gov/pdfs/progress10/v_1_1_brady.pdf.

Bipolar Plate RFI Responses Statistics