Fuel Cell Technologies Update

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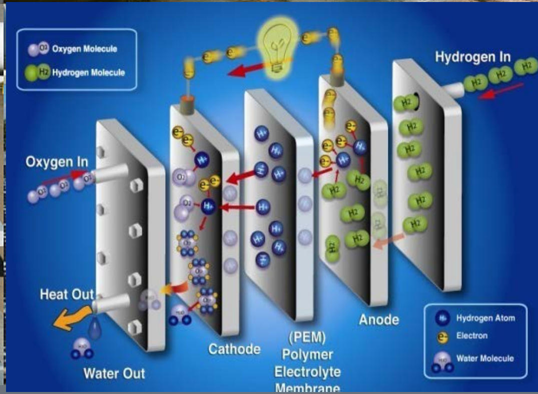

HTAC Meeting

Washington, DC

4/23/2013

Dr. Sunita Satyapal

Director, Fuel Cell Technologies Office
Energy Efficiency and Renewable Energy
U.S. Department of Energy

Agenda

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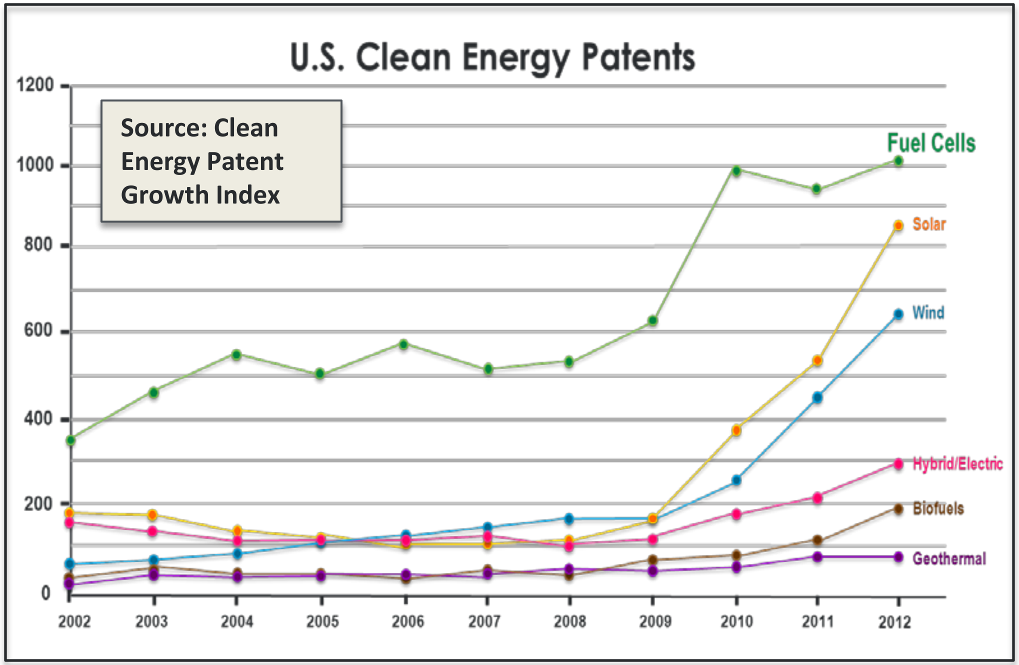
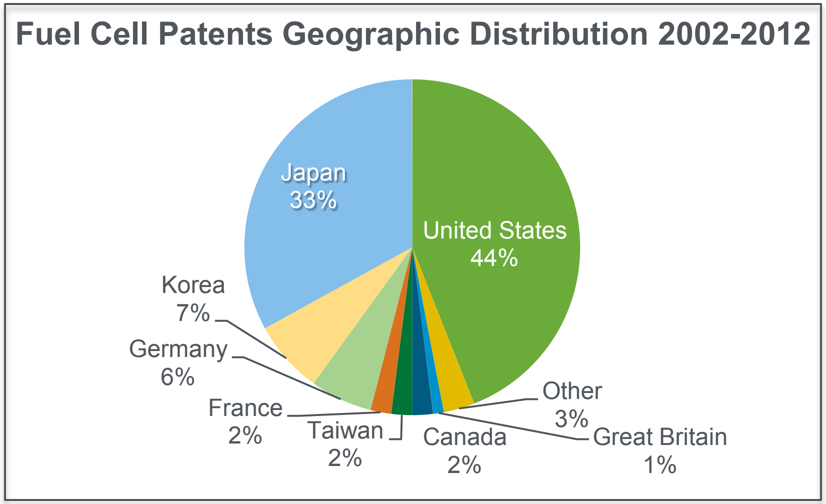
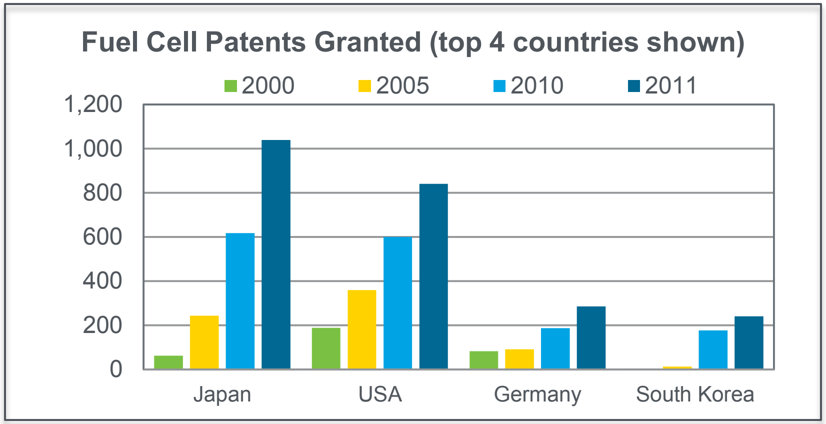
Summary of Program Activities and Highlights since previous HTAC update (November, 2012)

- Program Update
  - Clean Energy Patents
  - Recent Accomplishments
  - Budget Update (FY14 Request)
- Additional Information
  - Workshop examples
  - Budget details
  - SBIR Update
  - Funding Opportunity Announcements

Fuel Cells – An Emerging Global Industry







Source: Fuel Cell Today

Top 10 companies: GM, Honda, Toyota, Samsung, UTC Power, Nissan, Ballard, Panasonic, Plug Power, Delphi Technologies

Clean Energy Patent Growth Index shows growth in fuel cell patents along with other clean energy technologies.

(http://cepgi.typepad.com/files/cepgi-4th-quarter-2012.pdf)

DOE Hydrogen & Fuel Cells Program

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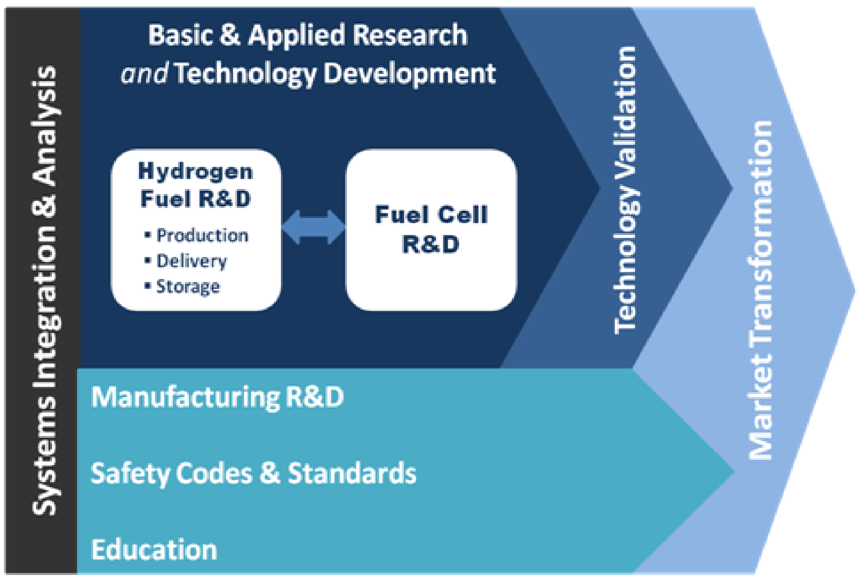
Mission: Enable widespread commercialization of a portfolio of hydrogen and fuel cell technologies through applied research, technology development and demonstration, and diverse efforts to overcome institutional and market challenges.

Key Goals: Develop hydrogen and fuel cell technologies for early markets (stationary power, lift trucks, portable power), mid-term markets (CHP, APUs, fleets and buses), and long-term markets (light duty vehicles).

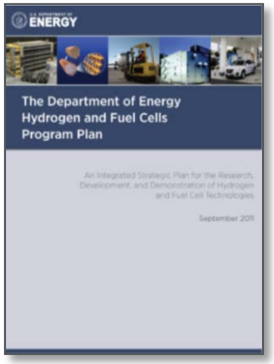


WIDESPREAD COMMERCIALIZATION ACROSS ALL SECTORS

- Transportation
- Stationary Power
- Auxiliary Power
- Backup Power
- Portable Power

Key Targets for FCEVs

- **$30/kW**
- **5000-hr durability *(150,000 miles)***
- **60% efficiency**
- **> 300-mile driving range**



Hydrogen & Fuel Cells Program Plan Update to the *Hydrogen Posture Plan* (2006). Includes Four DOE Offices: EERE, FE, NE, and Science.

DOE has a long-standing and substantial commitment to hydrogen and fuel cells:

- **Nearly 300 projects currently funded by DOE at companies, national labs, and universities/institutes**
- **More than $1.3 billion invested from FY 2007 to FY 2012 across four DOE offices**

Impact of DOE Funding for Hydrogen and Fuel Cells

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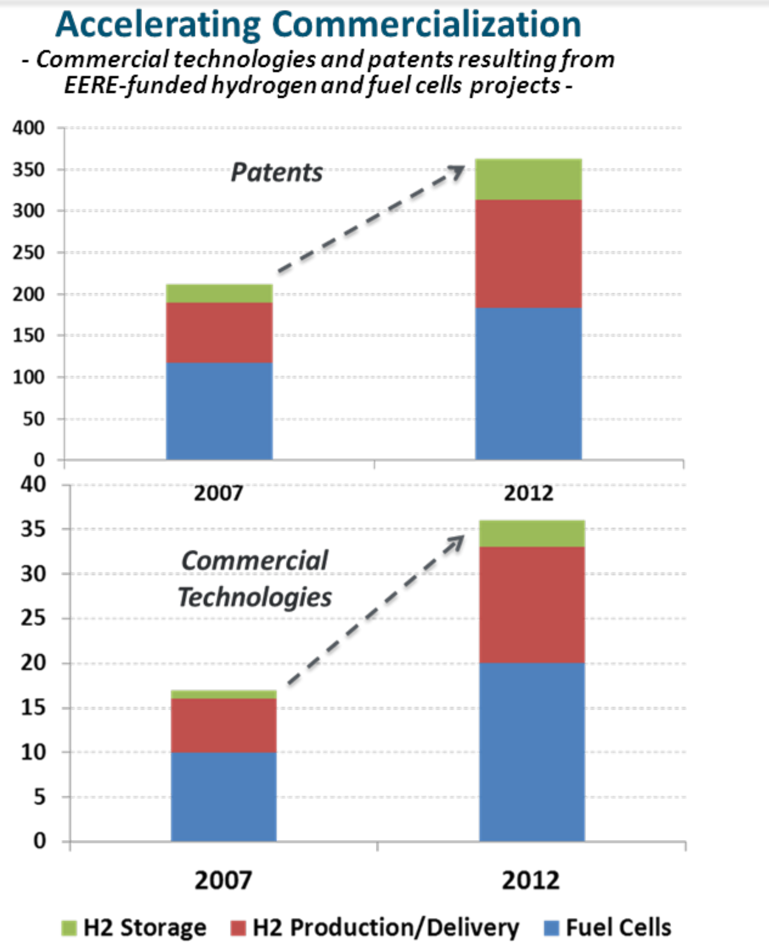
Spurring Innovation & Accelerating Commercialization:

>360 patents, >35 commercial technologies and **65 emerging technologies**

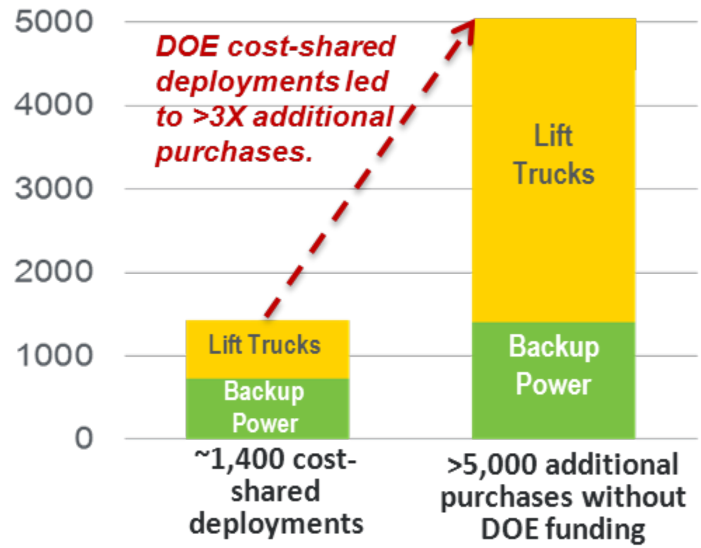


Source: PNNL, www1.eere.energy.gov/hydrogenandfuelcells/pdfs/pathways_success_hfcit.pdf

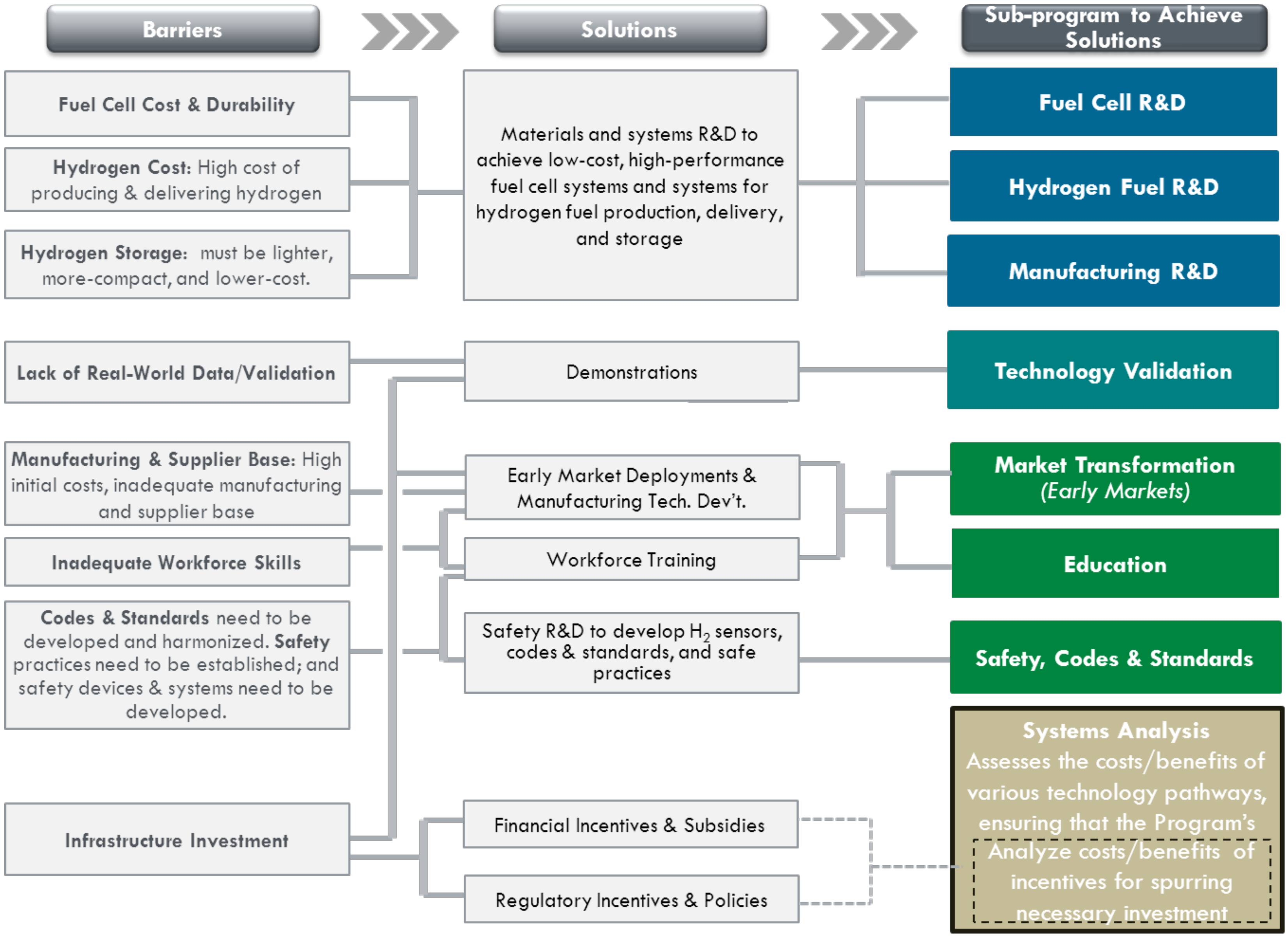
DOE FCT funding has enabled:

- > 80% cost reduction in PEM fuel cells since 2002, > 35% since 2008
- Reduction in Pt by a factor of 5 since 2005
- > Double the durability since 2006
- > 80% cost reduction in electrolyzer stacks in the last decade

Leveraging DOE Funds: Government as "catalyst" for market success of emerging technologies



DOE Program Strategy



Budget: H_2 and Fuel Cells Program

	Funding *($ in thousands)*						
	FY 2008 Approp.	**FY 2009** Approp.	**FY 2010** Approp.	**FY 2011** Allocation	**FY 2012** Approp.	**FY 2013** Continuing Resolution	**FY 2014** Request
EERE Hydrogen & Fuel Cells	206,241	195,865	170,297	95,847	101,326	95,845	100,000
Fossil Energy (FE)	14,891	20,151	13,970	11,394	0	0	0
Nuclear Energy (NE)	9,668	7,340	5,000	2,800	0	0	0
Science (SC)	36,483	38,284	38,053	34,611	27,466	27,466	TBD
DOE TOTAL	**267,283**	**261,640**	**227,320**	**144,652**	**128,792**	**123,311**	**TBD**

Notes

Nuclear Energy: In 2010 and 2011, development of HTSE at the Idaho National Laboratory (INL) continued with funding from the NGNP project. Several industry partners now have stack technologies for high temperature steam electrolysis in development. After demonstration of pressurized HTSE stack operation in FY 2012 by INL, the technology readiness is expected to be sufficiently advanced (TRL5) to allow for further development by industry.

EERE: FY 2013 and FY 2014 Requests includes SBIR/STTR. In, all prior years, SBIR/STTR has been subtracted from the appropriation.

SECA: Funding in FY 2013 is projected to be about $25 million, similar to FY 2012, less sequestration. No funding was requested for FY 2014.

Budget Request: EERE Key Activities

Funding *($ in thousands)*			
Key Activity	**FY 2013 Request**	**2013 Continuing Resolution**	**FY 2014 Request**
Fuel Cell R&D	36,899	41,266	37,500
Hydrogen Fuel R&D	26,177	31,682	38,500
Manufacturing R&D	1,939	1,899	4,000
Technology Validation	4,992	8,514	6,000
Safety, Codes and Standards	4,921	6,808	7,000
Market Transformation	0	2,838	3,000
Education	0	0	0
Systems Analysis	2,922	2,838	3,000
SBIR/STTR	2,150	2,139	- *
NREL Site-Wide Facilities Support	0	0	1,000
Total	$80,000	$97,984	100,000

*Funds for the SBIR/STTR programs for FY 2014 will be subtracted at later date.

Note: The FY 2012 and FY 2013 numbers shown on page 384 of the White House's FY 2014 Budget Request (www.whitehouse.gov/sites/default/files/omb/budget/fy2014/assets/doe.pdf) reflect $9.7 million that was carried over from FY 2012 to FY 2013 for obligation in FY 2013.

In FY 2014, the Program will continue to coordinate with other EERE Programs (e.g., Advanced Manufacturing and Vehicle Technologies) in key areas.

FY 2014 Budget Background

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- **The FY 2014 Budget Request is 25% higher than the FY 2013 request.** The FY 2014 request provides stable funding to enable continued progress in developing hydrogen and fuel cell technologies for stationary, portable, and transportation applications.
- **Hydrogen and fuel cells are an integral part of the Administration's "all-of-the above" energy strategy**—and the Department is committed to sustaining technical progress to support fuel cell electric vehicle (FCEV) commercialization in the 2015 timeframe and beyond—as announced by several major automakers.
- **Increased funding for Hydrogen Fuel R&D** to focus on improving renewable hydrogen production technologies (e.g., improving electrolyzer stack efficiency and lowering the cost of longer-term technologies using solar resources, including wide bandgap semiconductors) and lowering the carbon fiber composite cost for hydrogen storage vessels
- **Increased funding for Manufacturing R&D** to improve domestic capabilities in hydrogen and fuel cell manufacturing
- **Increased funding for Market Transformation** to spur the growth of key early markets, support the development of a domestic industry, and provide feedback to testing programs, manufacturers, and potential end users
- **FY 2014 activities will focus on technology advancements in key areas**—including ongoing reductions in the cost and improvement in the durability of fuel cells, reductions in the cost of renewably produced hydrogen, and improvements in systems for storing hydrogen.

DOE has made substantial progress in fuel cell technologies

✓ *reduced cost by > 80% since 2002 and > 30% since 2008 (projected to high volume)*

✓ *doubled fuel cell durability since 2006*

✓ *reduced platinum content 5-fold since 2005*

Government vs. Private Sector Roles

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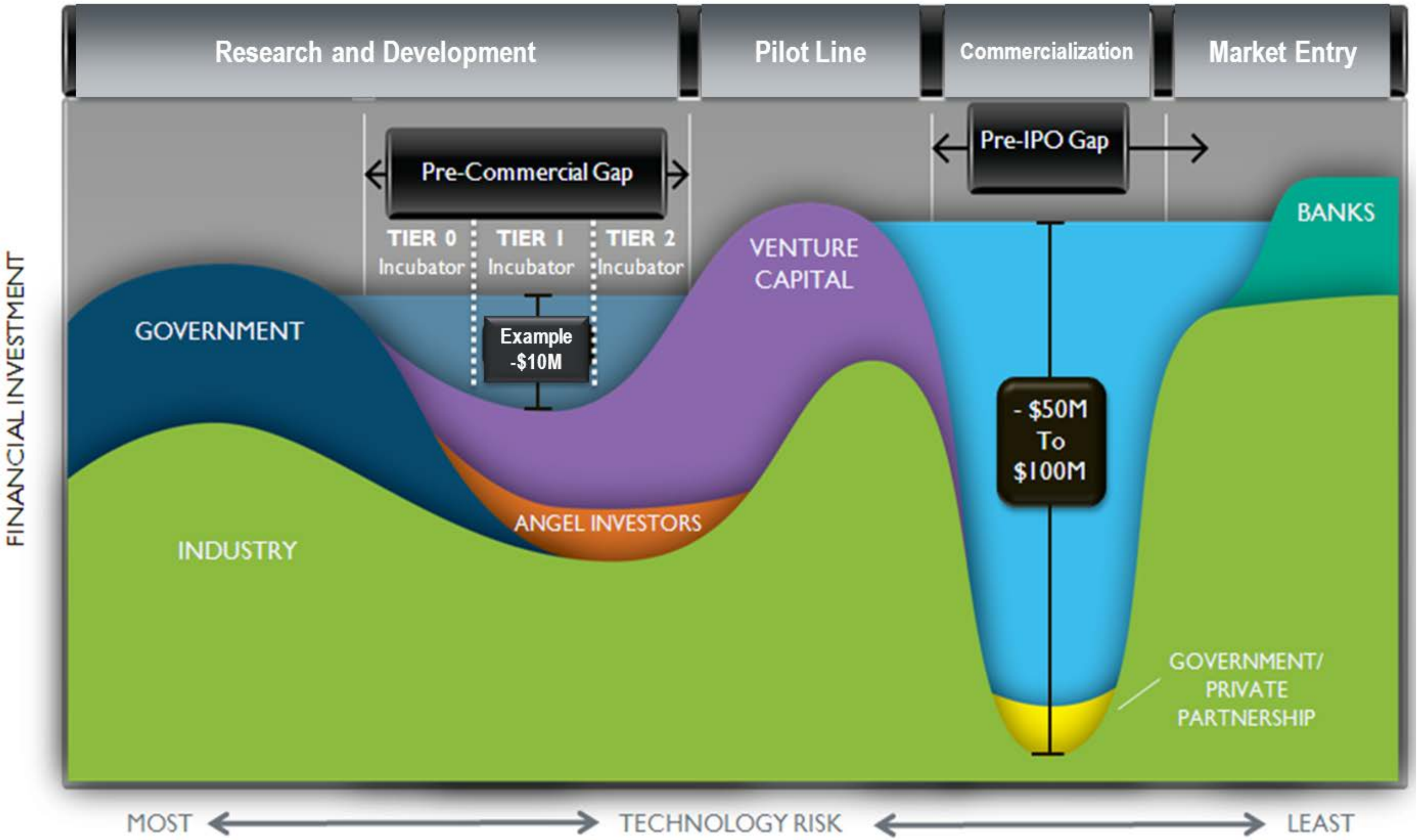
FY 2014 Budget Request will include "Incubator" activities:

Pilot expansion of "Sunshot Incubator Program" in Solar Energy Technology Office to other EERE Technology Offices
Enables ongoing on-ramp for "off-road-map" emerging technology approaches
Small fraction of annual R&D budget

Example—a potential timeline for innovation & commercialization



Adapted from SunShot Incubator briefing. Pictorial example, not representative of all industry start ups

Program R&D – Federal Role

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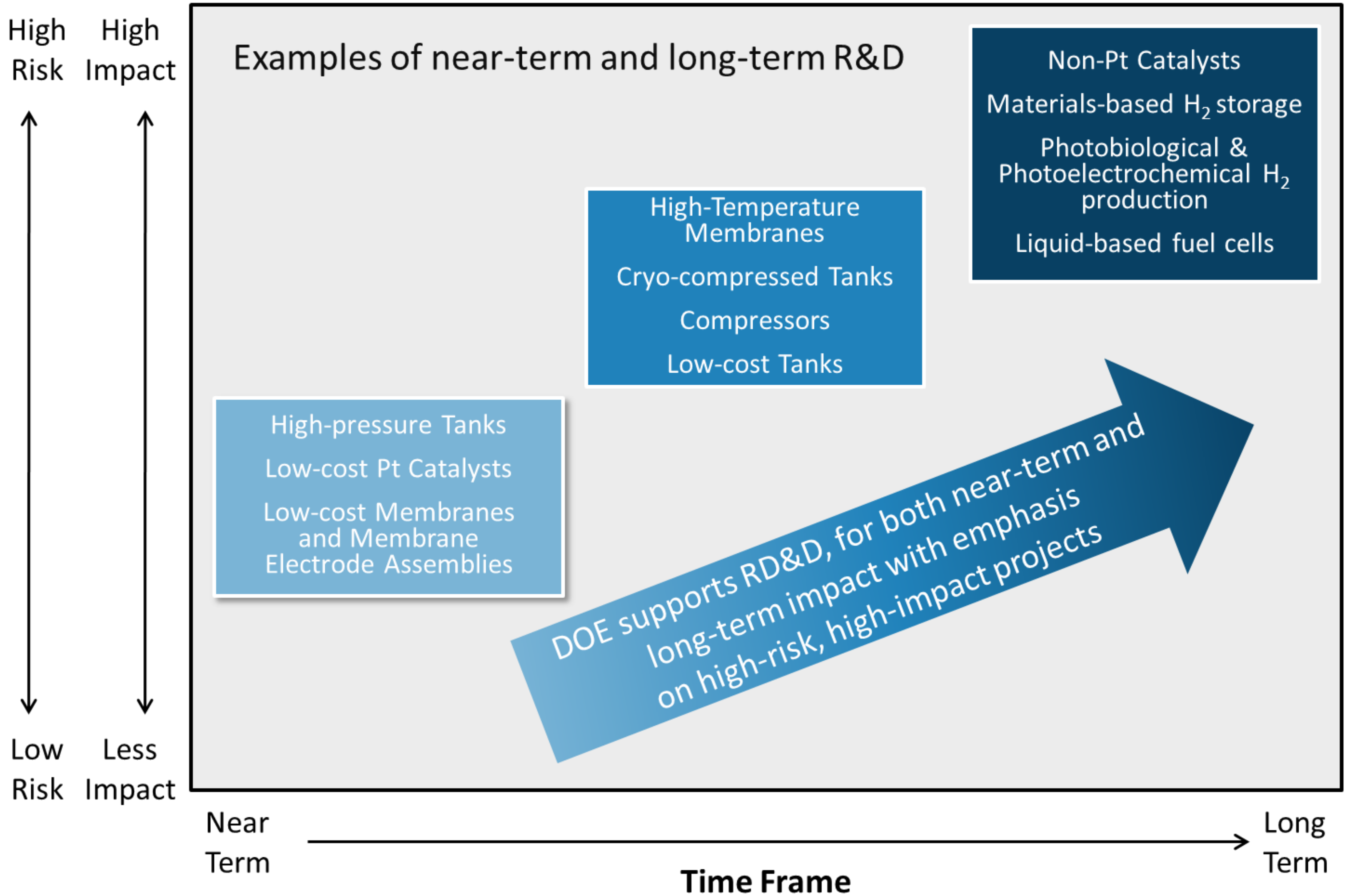
R&D efforts are focused on pre-competitive, high-risk technologies



Progress – Fuel Cells (status & targets)

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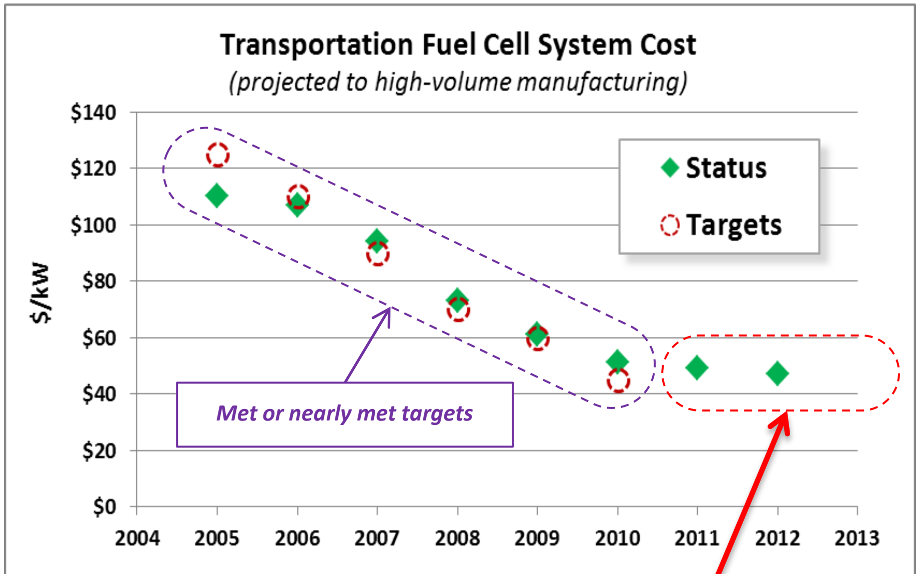
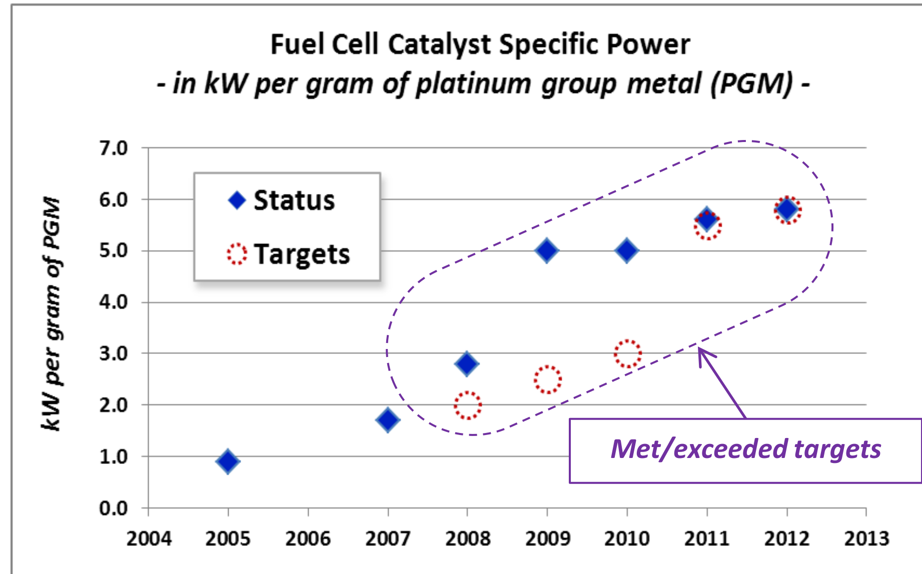
Fuel Cell R&D has consistently reduced fuel cell system cost and fuel cell platinum group metal catalyst content *(increasing the power per gram of platinum-group-metal [PGM] catalyst).*





No annual targets for ***fuel cell system cost*** after 2010—next target is $30/kW in 2017 (*cost status varies with platinum price volatility*).

In 2011, ***increasing catalyst specific power*** (reducing platinum-group-metal content) replaced *fuel cell system cost* as the primary fuel cell R&D performance metric.

Challenges & Strategy

The Fuel Cells subprogram supports research and development of fuel cell and fuel cell systems with a primary focus on reducing cost and improving durability. Efforts are balanced to achieve a comprehensive approach to fuel cells for near-, mid-, and longer-term applications.

Fuel Cell MYRD&D recently updated.
http://www1.eere.energy.gov/hydrogenandfuelcells/mypp/index.html

Barriers

Cost
Durability
Performance

Strategy

Materials, components, and systems R&D to achieve low-cost, high-performance fuel cell systems

Fuel Cell R&D

Testing and Cost/Technical Assessments

R&D portfolio is technology neutral and includes different types of fuel cells

FOCUS AREAS

Stack Components
Catalysts
Electrolytes
MEAs, Gas diffusion media, and Cells
Seals, Bipolar plates, and Interconnects

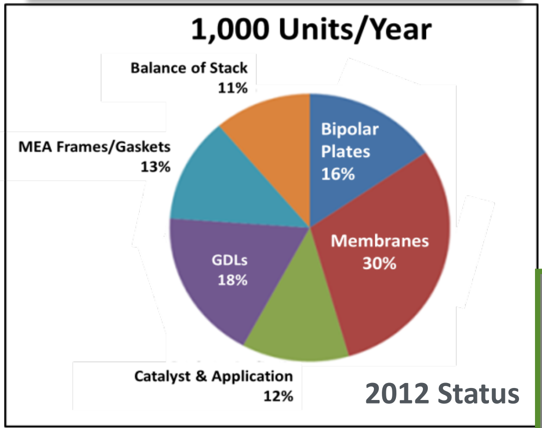
Operation and Performance
Mass transport
Durability
Impurities

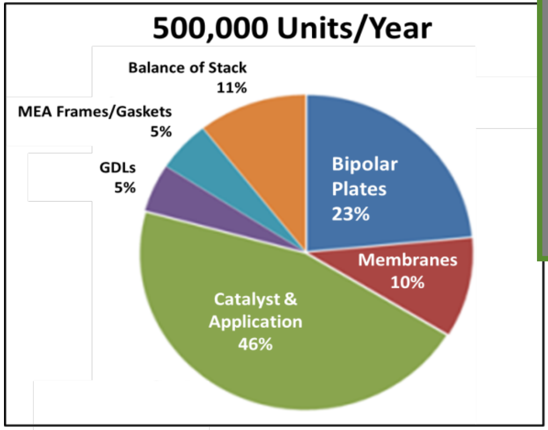
Systems and Balance of Plant (BOP)
BOP components
Stationary power
Fuel processor subsystems
Portable power
APUs and emerging markets

Strategy to Address High-Impact Areas – PEM Example

- Strategic technical analysis guides focus areas for R&D and priorities for budget
- Need to reduce cost, but also increase durability
- Advances in PEMFC materials and components could benefit a range of applications

PEMFC Stack Cost Breakdown

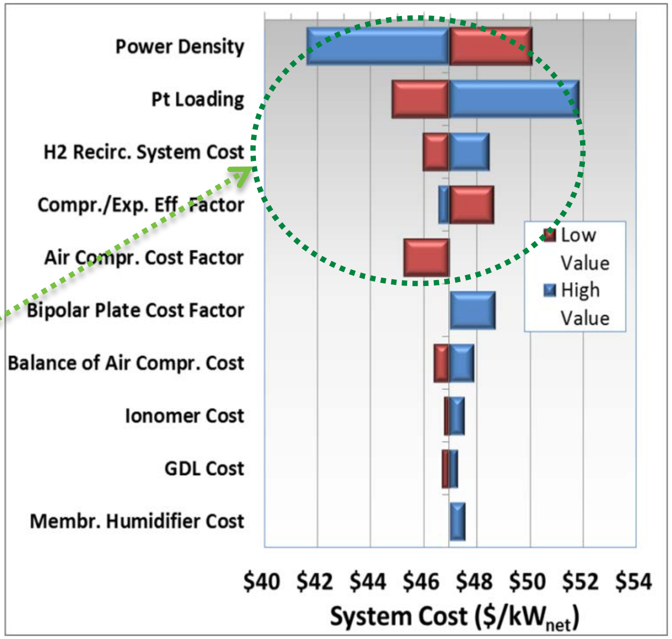




Key Focus Areas for R&D

- Membrane cost is projected to be the largest single component of a PEMFC stack cost, manufactured at low volume.
- Catalyst cost is the largest component at high volume.

Automotive Fuel Cell System



Sensitivity Analysis helps guide R&D

Strategies to Address Challenges – Catalyst Examples

- Lower PGM Content
- Pt Alloys
- Novel Support Structures
- Non-PGM catalysts

Fuel Cell R&D - Plans

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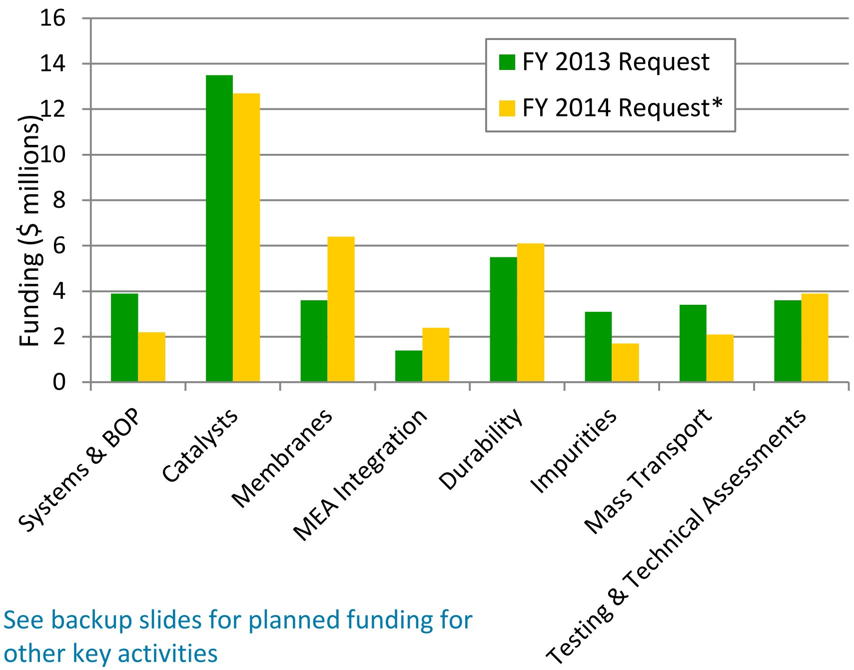
Maintains critical fuel cell R&D to improve the durability, reduce cost, and improve the performance of fuel cell systems for stationary, transportation, and portable power. Key goals: Increase PEM fuel cell power output per gram of PGM catalyst from 2.8 kW/g (in 2008) to 6.0 kW/g in 2014 and 8.0 kW/g by 2017.

FY 2014 Request = $37.5M

FY 2013 Request= $38.0M



See backup slides for planned funding for other key activities

*Subject to appropriations, project go/no go decisions and competitive selections. Exact amounts will be determined based on R&D progress in each area and the relative merit and applicability of projects competitively selected through planned funding opportunity announcements (FOAs).

EMPHASIS

- Focus on approaches that will increase activity and utilization of current PGM and PGM-alloy catalysts, as well as non-PGM catalyst approaches for long-term applications.
- Improve PEM-MEAs through integration of state-of-the-art MEA components.
- Develop transport models and in-situ and ex-situ experiments to provide data for model validation.
- Identify degradation mechanisms and develop approaches to mitigate their effects.
- Maintain core activities on components, sub-systems and systems specifically tailored for stationary and portable power applications (e.g. SOFC)

H_2 Production and Delivery Challenges & Strategy

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The Hydrogen Production and Delivery subprogram supports research and development of technologies for low-cost, carbon-free hydrogen production from diverse renewable pathways, and low-cost, delivery of hydrogen to achieve a produced, delivered and dispensed (untaxed) cost of $2-$4/kg of hydrogen by 2020.

Barriers

Production and delivery cost of renewable & low-carbon hydrogen

- Feedstock costs
- Capital costs
- O&M costs

Strategy

Near-term

Minimize cost of 700 bar hydrogen at refueling stations

Long-term

Improve performance and durability of materials and systems for production from renewable sources.

R&D Focus

- Reliability and cost of compression, storage and dispensing
- Renewable integration
- Balance of plant improvements
- Technoeconomic analysis

R&D Focus

- Innovations in materials, devices and reactors for renewable H_2 production
- Advanced materials and systems for H_2 delivery
- Technoeconomic analysis

Key Areas

Production

- Electrolysis
- Bio-Derived Liquids
- Hybrid fossil/renewable approaches
- Solar Water Splitting: PEC, STCH, Biological
- Fermentation

Delivery

- Polymers & composites for delivery technologies
- Liquefaction technologies
- Compressor reliability
- Low cost onsite storage

***H_2 Production and Delivery MYRD&D chapters available at:** http://www1.eere.energy.gov/hydrogenandfuelcells/mypp/index.html*

Hydrogen Production — Status & Pathways

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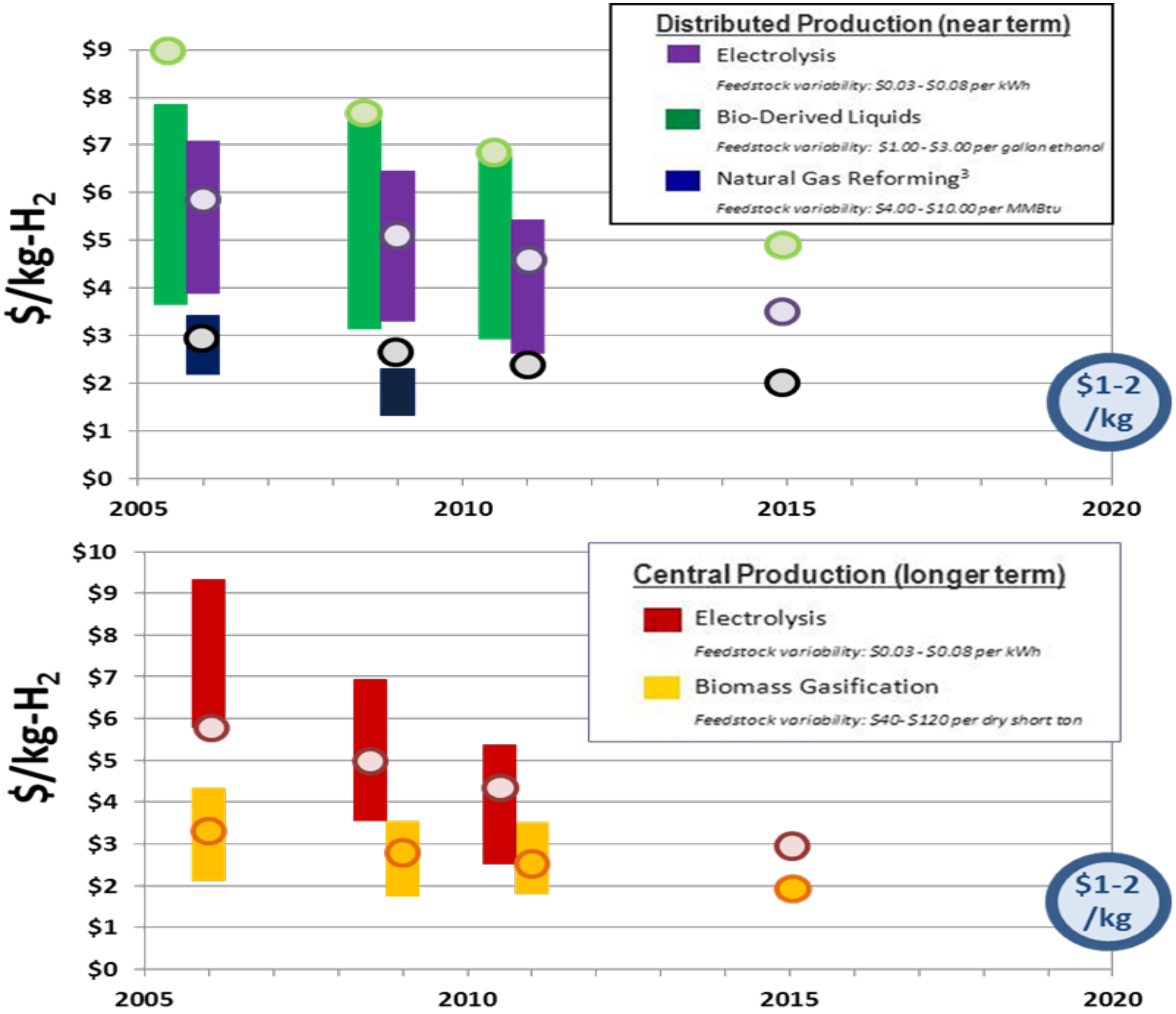
Projected High-Volume Cost of Hydrogen Production for Different Pathways



- ***Status of hydrogen cost is shown in vertical bars, reflecting values based on a range of assumptions (feedstock/capital costs).***
- ***Targets for hydrogen cost are shown in circles.***
- ***Targets shown are normalized for consistency in feedstock assumptions and year-cost basis (2007 dollars)***
- ***Targets prior to 2015 extrapolated based on 2015 and 2020 targets in the FCT Office's Multi-year RD&D Plan.***
- **Cost ranges are shown in 2007 dollars, based on projections from H2A analyses, and reflect variability in major feedstock pricing and a bounded range for capital cost estimates.**
- **Projections of costs assume Nth-plant construction, distributed station capacities of 1,500 kg/day, and centralized station capacities of ≥50,000 kg/day.**

Primary Hydrogen Delivery Pathways

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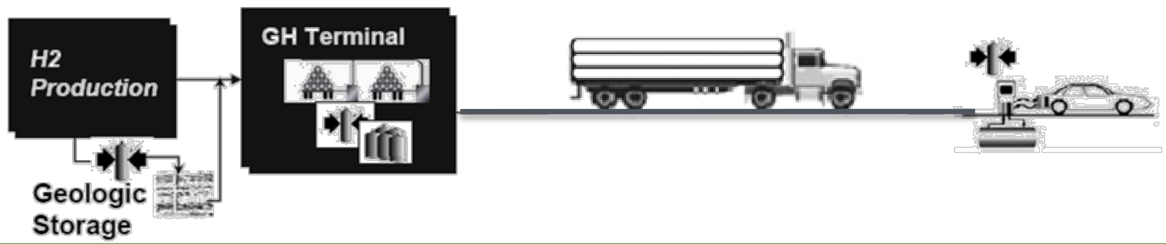
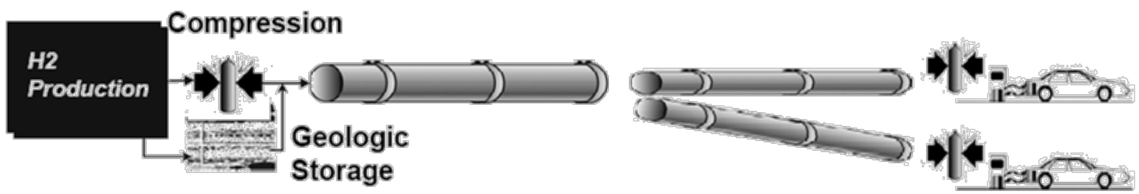
Key challenge: reduce the cost of hydrogen delivery to enable overall cost that is competitive with other energy carriers and fuels

Gaseous H_2 – via tube trailer



Refueling

Gaseous H_2 –via pipeline

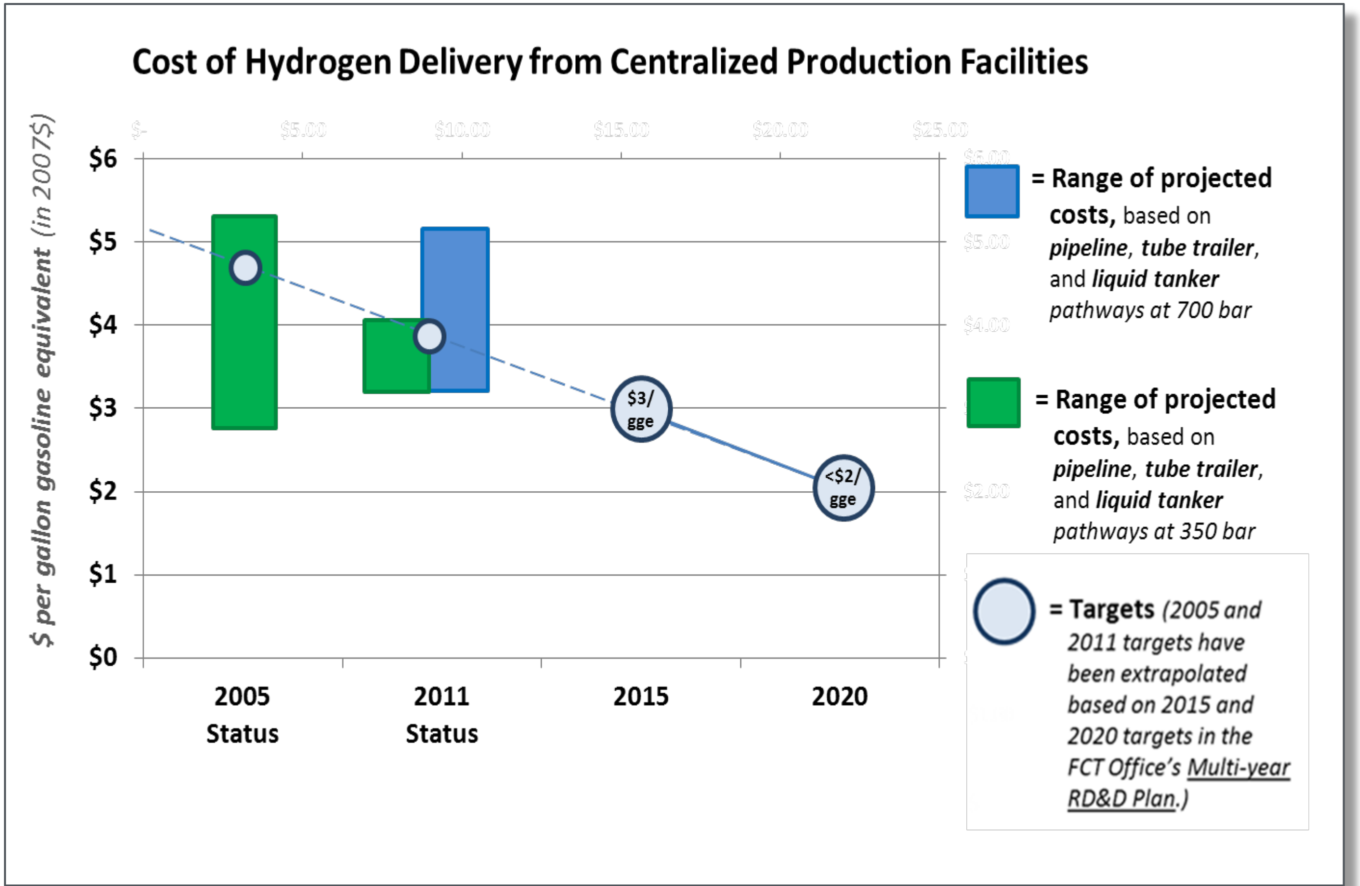


Refueling

Liquid H_2 –via tanker truck

Refueling

Hydrogen Delivery Status & Targets



Hydrogen Delivery R&D Focus

- ✓ Identify cost drivers for H_2 delivery in early market applications
- ✓ Evaluate options to improve station compressor reliability
- ✓ Investigate the role of high-pressure tube trailers in reducing station costs

Reducing Station Costs – Pathways

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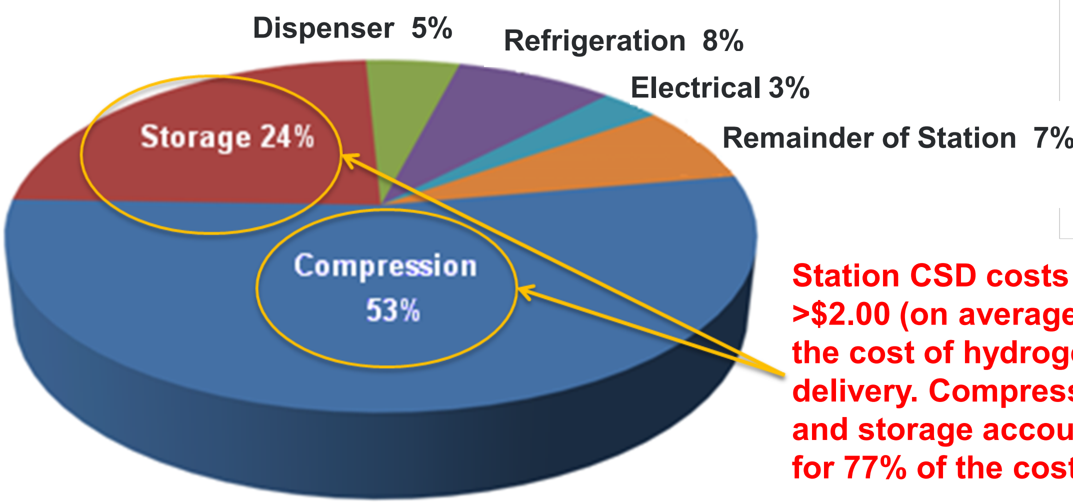
Station costs dominate delivery costs—key focus area.



Station CSD costs add >$2.00 (on average) to the cost of hydrogen delivery. Compression and storage account for 77% of the cost.[1]

Fueling Station (CSD) Costs		
	2011 Projected Cost*	2020 Projected Cost*
Centralized Production	$1.70-$2.20/kg	<$0.70/kg
Distributed Production	$2.50/kg	<$1.70/kg

Workshop March 20–21, 2013 to identify key RD&D areas for CSD → **RFI to collect public feedback on workshop report** → **FOA on RD&D topics to address cost reduction at the forecourt.**

[1] **Hydrogen & Fuel Cells Program Record 12021,** Cost Projections for Delivery Operations at a Distributed H_2 Production/Refueling Site, may 2012, **http://www.hydrogen.energy.gov/program_records.html**

H_2 Storage Challenges & Strategy

- **H_2 Storage supports R&D of advanced hydrogen storage technologies, with a primary focus on reducing system cost, weight, and volume.**
- **Near-term focus** = lowering costs; **long-term focus** = achieving all performance targets
- **R&D portfolio is technology neutral** and includes a broad spectrum of storage technologies.
- DOE has **validated a vehicle capable of up to 430-mile driving range**, but cost is a key challenge.

Barriers
Cost
Volume
Weight
Refill time
Cycle-life

Strategy

Near-term
High-pressure Compressed H_2 Systems

Long-term
Cold/Cryo-compressed H_2
Materials-based H_2 storage

R&D Focus
Cost reduction
Advanced designs
Improved manufacturing

R&D Focus
Advanced designs
Novel materials discovery
Performance Analysis

KEY AREAS

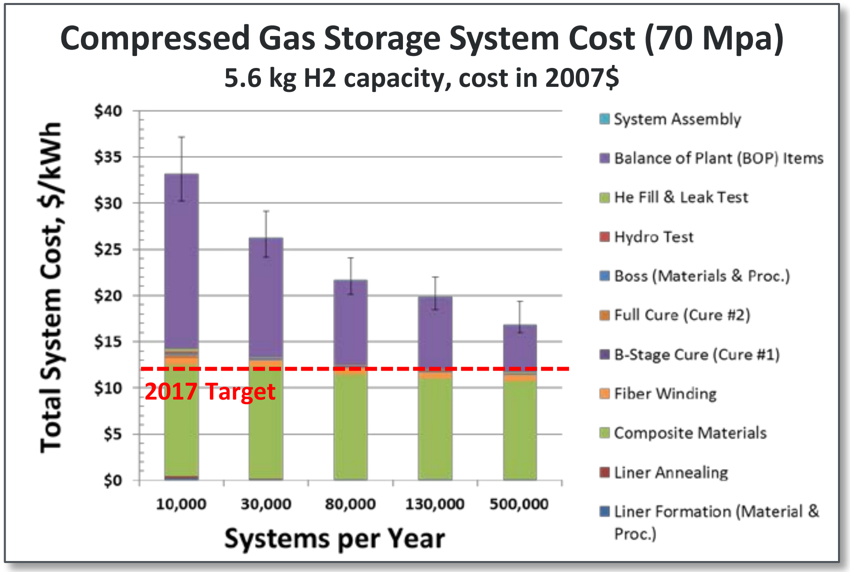
Pressure Vessels
Lower cost carbon fiber
Improved composite
Conformable designs
Lower cost BOP

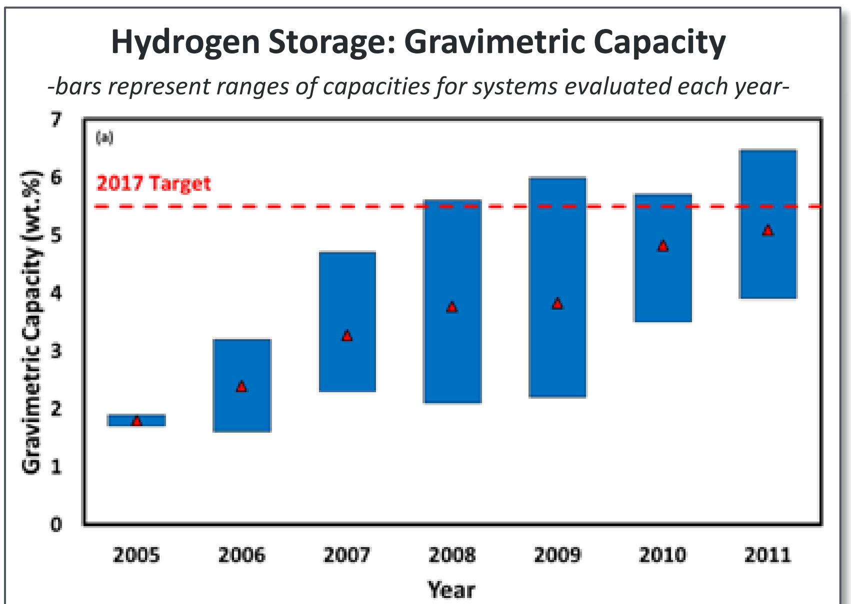
Cold/Cryo-compressed
System engineering
Advanced insulation
Improved dormancy
Composite development

Materials-based H_2 Storage
Materials development
Materials characterization
System engineering
Materials/system manufacture

H_2 Storage MYRD&D available at:
http://www1.eere.energy.gov/hydrogenandfuelcells/mypp/index.html

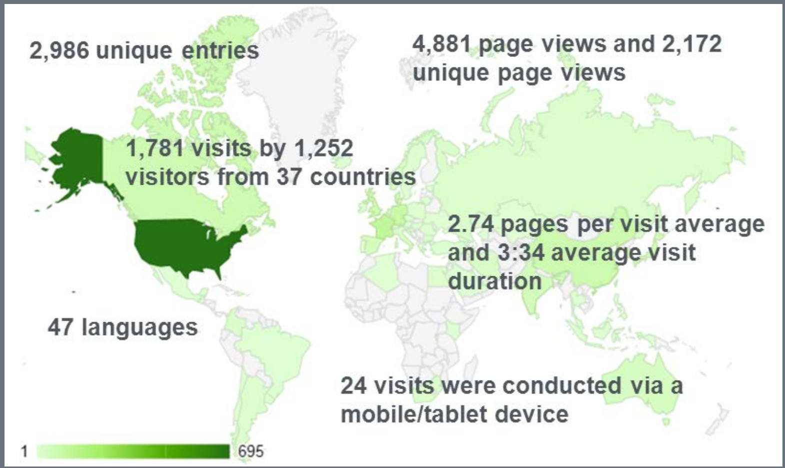
Hydrogen Storage

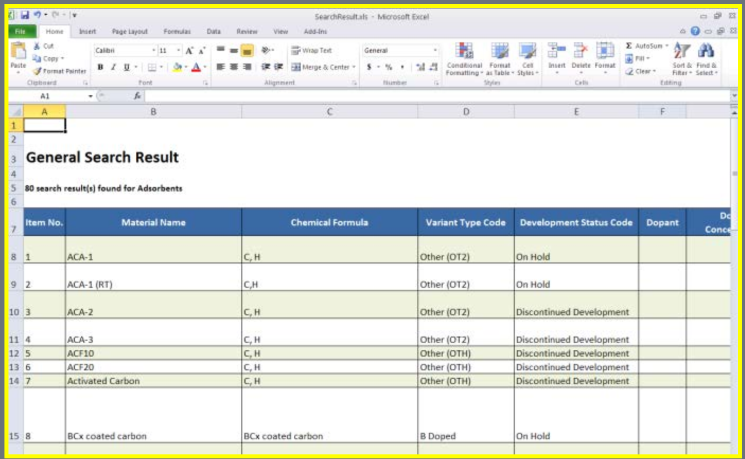




Launched open source database* on Hydrogen Storage Materials Properties

(http://hydrogenmaterialssearch.govtools.us/)



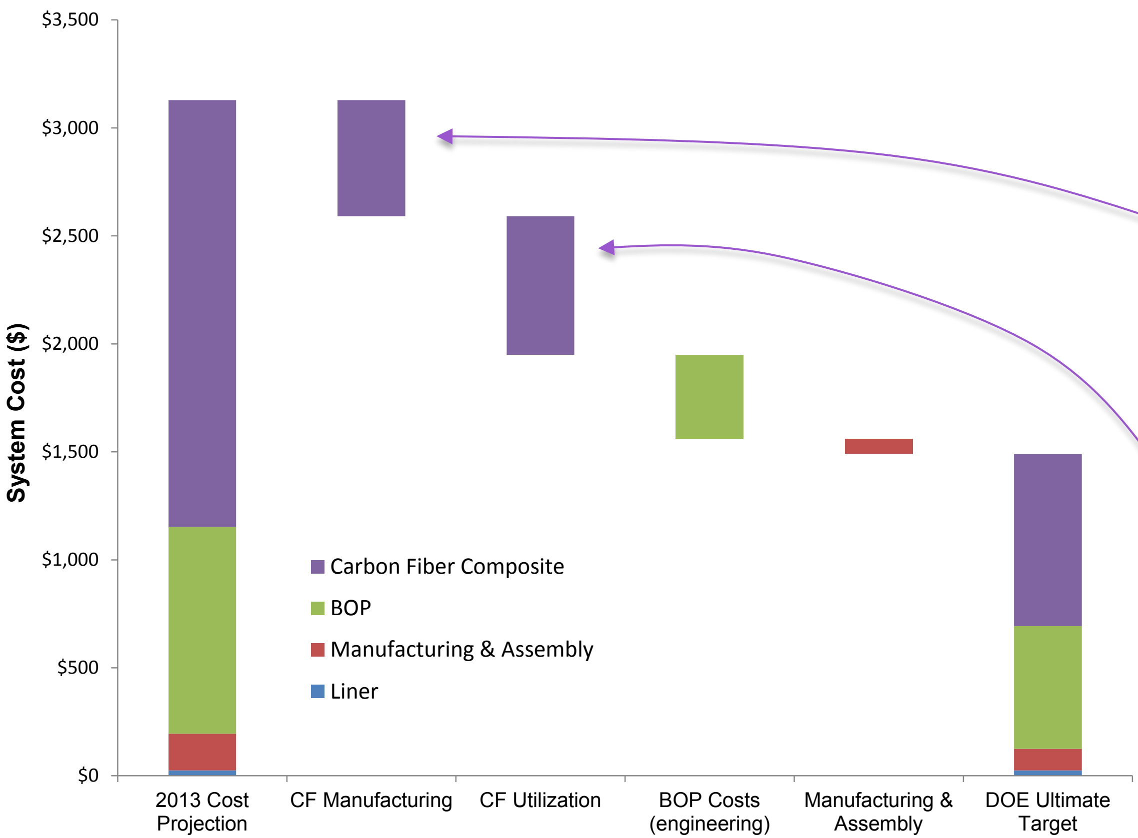


* Included in President's Materials Genome Initiative (MGI), http://www.whitehouse.gov/mgi

Lowering the Cost of Compressed Gas Vessels is Key to Adoption

Strategy is to reduce cost through strategic investments and leveraging Vehicle Technologies & Advanced Manufacturing Offices

- Preliminary Analysis -



Research to Address R&D Gaps:

Analyses to identify cost reduction potentials

- Performance analyses to identify R&D needs
- Cost analyses to identify savings potential and trade-offs

Lowering cost of carbon fiber

- Lower cost precursors – 25% reduction in carbon fiber cost (17% vessel cost savings)
- Advanced precursor processing – 30% reduction in carbon fiber cost (20% vessel cost savings)
- Leverage investments by VTO & AMO

Lowering cost of composite systems

- Advanced resins to increase composite strength (20% vessel cost savings)
- Graded fiber approach to increase fiber usage efficiency (20% vessel cost savings)
- Leverage investments by VTO & AMO

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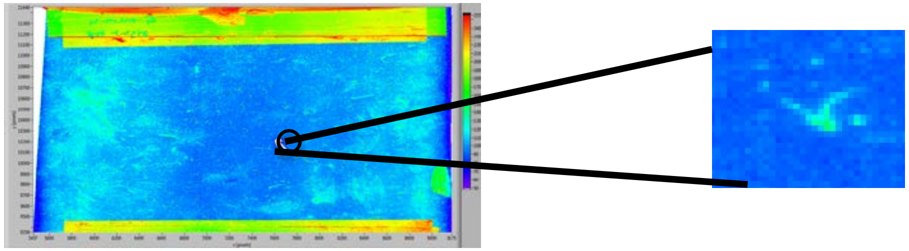
Developing and demonstrating technologies and processes to reduce cost of fuel cell components and systems and grow domestic supplier base

Manufacturing R&D Subprogram Key Accomplishments

- Reduced manufacturing labor cost of gas diffusion electrodes (GDEs) by 75% through development of a higher throughput coating process
- Demonstrated off-line and in-line diagnostics for measurement of variability and defects in fuel cell membranes, GDLs, electrodes, and full MEAs
- Moving from batch coating and hand-drying cathode electrodes to pilot scale roll-to-roll cathode coating

Development Platform for Diagnostics: Industrial webline



Membrane sample spliced into carrier web, moving at 30 ft/min

Manufacturing Workshop Results

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Workshop Held to Inform Potential Focus Areas for Future FOAs/Activities

- **Gathered input on barriers to reducing cost of manufacturing hydrogen and fuel cell systems and components**
- **Identified high-priority needs and R&D activities that government can support to overcome those barriers**

Issue	Votes
PEM Fuel Cells/Electrolyzers BOP: Facilitate a manufacturing group for DOE to expand supply chain.	21
Electrodes: How to apply ink directly to membrane; dual direct coating of CCM; *membrane dimensional change with deposition of current inks (overlaps with purview of Fuel Cell R&D subprogram)*	20
PEM Fuel Cells/Electrolyzers BOP: *Develop low cost manufacturing of natural gas reformers (overlaps with purview of Fuel Cell R&D subprogram*	18
Stack Assembly: High volume stack assembly processes: reduced labor, improved automation	15
Quality/Inspection/Process Control: Develop methods of identifying coating defects on a moving web, then rejecting single pieces downstream; defect detection after MEA assembly when defect may no longer be visible; ability to separate materials with defects from rolled goods with minimum production of scrap	15
SOFC: Multi-layer/component sintering	14

Identified high-priority topics for Manufacturing R&D

Workshop organized by the National Renewable Energy Laboratory for the U.S. Department of Energy
Minutes posted at: http://www1.eere.energy.gov/hydrogenandfuelcells/wkshp_h2_fc_manufacturing.html

PEMFC and SOFC Manufacturing Status vs. Needs

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

PEM Fuel Cells

Current MEA

- Large batch mixing
- Roll-to-roll processes for membrane, electrode, and GDL fabrication
- Decal transfer of electrode to membrane
- Manual assembly of MEA with seals
- Hot pressing

Advancements

- Continuous mixing
- Robotic or roll-to-roll assembly of MEAs with seals
- Direct coating of electrode on membrane
- Hot-roll lamination or improved pressing

Current Stack

- Manual assembly
- Manual leak/performance test

Advancements

- Automated assembly
- Automatic leak/performance test

Current BOP

- Lean manufacturing cells and flow
- Unique components

Advancements

- Standardized designs
- Robotic BOP/system assembly line

Solid Oxide Fuel Cells

Current Cell

- Large batch mixing of powders and slurries
- Single layer tape casting with lamination of layers (planar)
- Batch pressing or extrusion of tubes (tubular)
- Semi-automated coating of electrolyte and cathode (tubular)
- Batch heat treatment and sintering
- Manual assembly of cells with seals
- Manual winding of interconnect wire (tubular)

Advancements

- Continuous mixing
- Multi-layer tape casting (planar)
- Continuous pressing or extrusion of tubes (tubular)
- Continuous firing and sintering
- Robotic assembly of cells with seals
- Automated winding of interconnect wire (tubular)

Current Stack

- Manual assembly
- Manual shaping of insulation
- Manual leak/performance test

Advancements

- Automated assembly
- Net-shape or other methods for insulation
- Automatic leak/performance test

Current BOP

- Manual assembly
- Unique components

- Lean manufacturing cells and flow

Advancements

- Standardized designs
- Robotic BOP/system assembly line

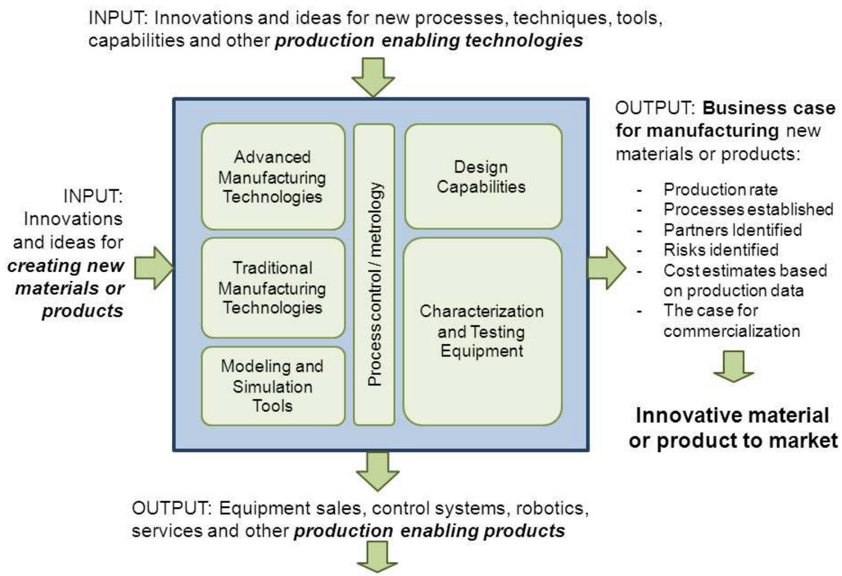
Opportunities for Collaboration with AMO: Manufacturing Demonstration Facilities (MDFs)

Barriers addressed:

- Access to expensive technologies and capabilities
  Sharing overhead costs -more efficient use of capital
- Increases visibility of unknown process options
- Accelerates partnership development and supplier relationships

Effect on U.S. competitiveness:

- Increased pool of domestic competitors, especially SMEs
- Increased rate of new product development
- Positive feedback between production and research/design accelerates both

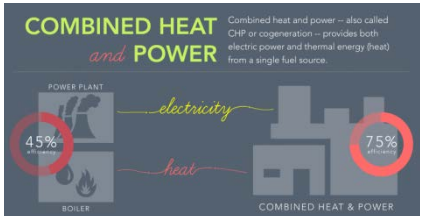


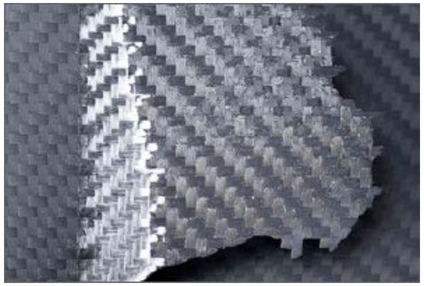
MDFs funded by AMO

http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/webinarslides_fct-amo_mfg_112012.pdf

Clean Energy Manufacturing Initiative

1. **Increase U.S. competeveness in the production of clean energy products**
   – *Invest in competitive advantages, overcome competitive disadvantages*
2. **Increase U.S. manufacturing competitiveness across the board by increasing energy productivity**
   – *Enhancing competitiveness of US companies*





Completed World's Largest FCEV & Hydrogen Demonstration to Date

- with 50-50 DOE-Industry cost share –

- **>180 fuel cell vehicles** and **25 hydrogen stations**
- **3.6 million miles** traveled; 500,000 trips
- **~152,000 kg of hydrogen** produced or dispensed *(some of this hydrogen used by vehicles not in the learning demonstration)*
- **>33,000 refuelings**

	Status	Project Target
Durability	~2,500	2,000
Range	196 – 254*	250*
Efficiency	53 – 59%	60%
Refueling Rate	0.77 kg/min	1 kg/min

*Independently validated a vehicle that can achieve a 430 mile range.

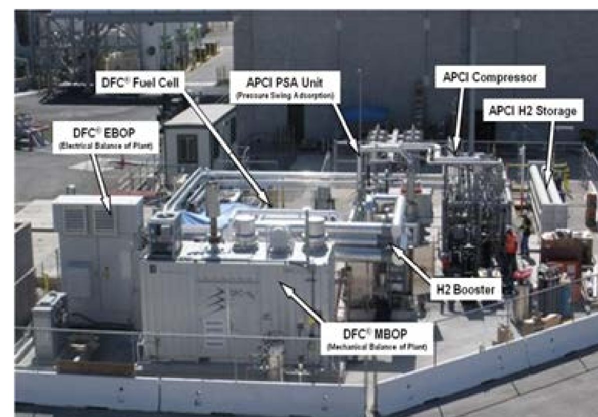
	Status *(NG Reforming)*	Status *(Electroylsis)*	Ultimate Target
H_2 Cost at Station	$7.70–$10.30/kg	$10.00–12.90/kg	$2.00–4.00/kg

Partners: Air Products, BP, Chevron, Daimler, Ford, GM, Hyundai, Kia, UTC Power

Demonstrated World's First "Tri-generation" Station

- Capable of co-producing electricity, hydrogen, and heat -

- Utilizes anaerobic digestion of municipal wastewater (from the Orange County Sanitation District)
- Produces 100 kg/day H_2; generates ~ 250 kW; 54% efficiency co-producing H_2 and electricity
- Nearly 1 million kWh of operation
- >4,000 kg H_2 produced



Partners: Air Products, California Air Resources Board, FuelCell Energy, South Coast Air Quality Management District, UC Irvine

Funding Opportunity Announcement

RFI Issued: ***"Fuel cell technology validation, commercial acceleration and potential deployment strategies in early market applications"***

http://www1.eere.energy.gov/hydrogenandfuelcells/news_detail.html?news_id=19089.

Closed April 10, 2013.

Potential Technology Validation FOA Topics

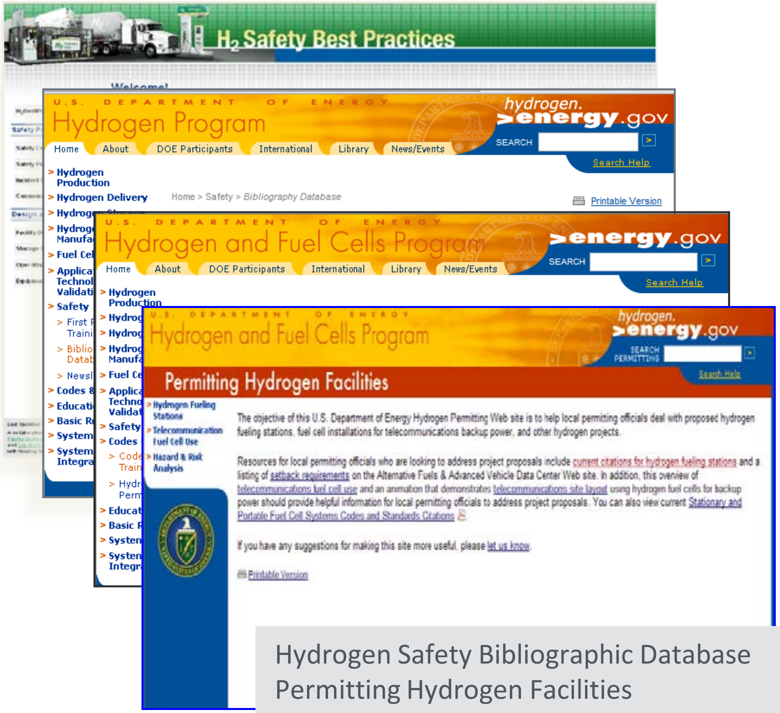
- Advanced Refueling Components (H_2 Meters, Dispensers, Compressors, Hydrogen Tank-Trailers).
- Highly-efficient Combined Hydrogen, Electricity and Heat Generation (trigeneration) at fueling stations.
- Building-Integrated Fuel Cell Combined Heat and Power Systems.
- Innovative On-board hydrogen storage systems for FCEVS

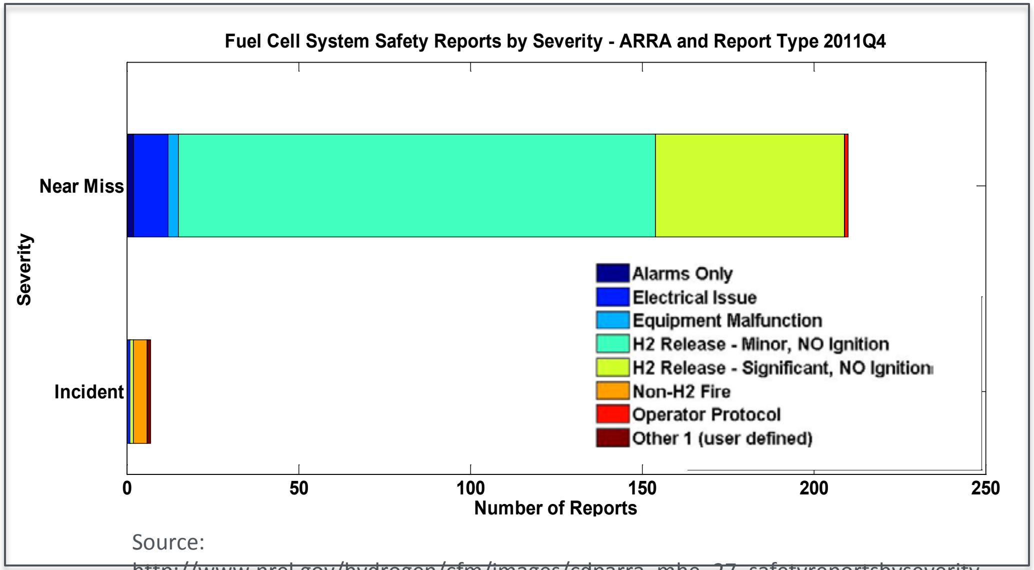
Planned for FY 2014

Potential opportunities for leveraging state activities (e.g. CA state funding for fueling stations)

FCT will not be funding infrastructure but can fund technology innovation that could be applicable to/enable infrastructure (e.g. innovative refueling/compression technologies)

Safety, Codes and Standards





Source: http://www.nrel.gov/hydrogen/cfm/images/cdparra_mhe_27_safetyreportsbyseverity.jpg

Hydrogen Safety Bibliographic Database
Permitting Hydrogen Facilities
Introduction to Hydrogen for Code Officials
Hydrogen Safety Best Practices Manual

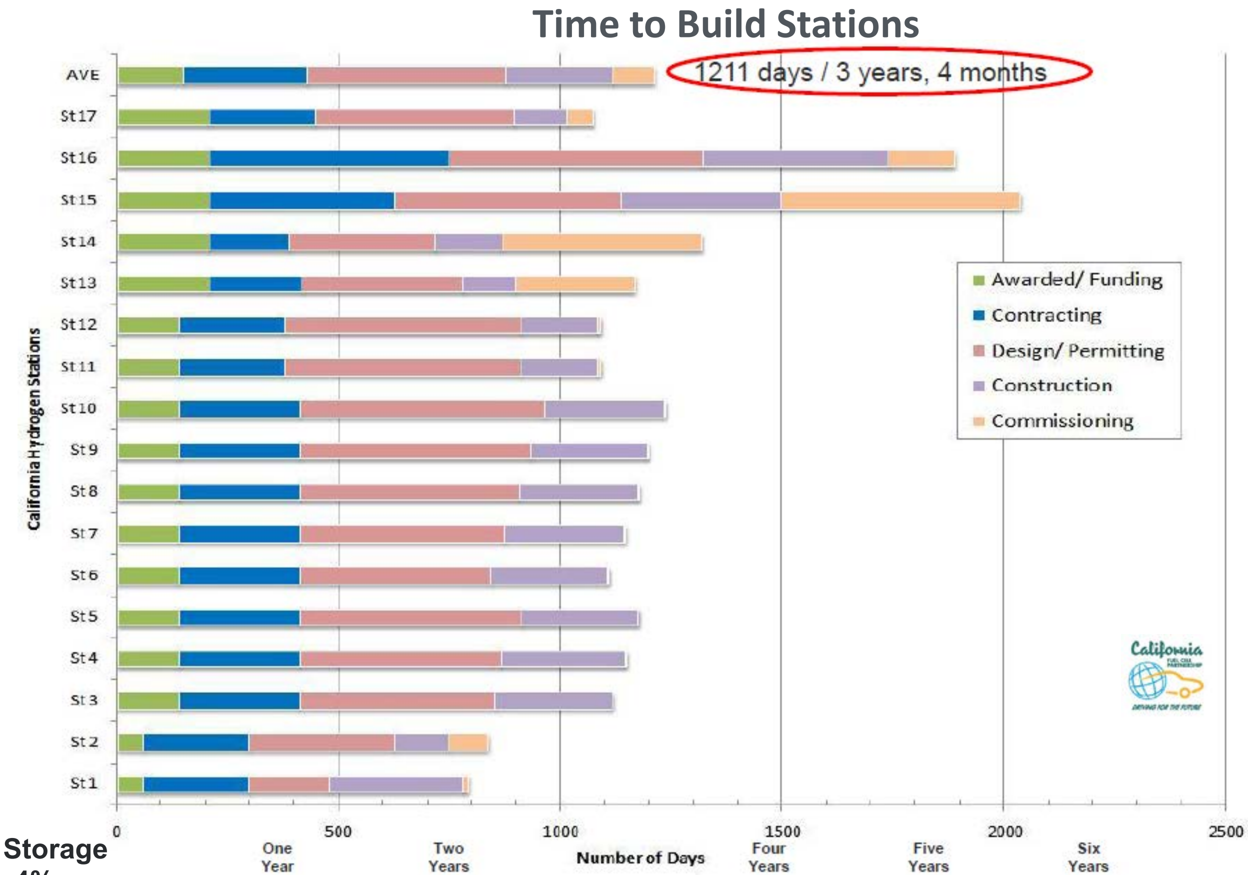
Other Supporting Websites
H_2 Safety Snapshot bulletin
Introduction to Hydrogen Safety for First Responders
Hydrogen Incident Reporting Database

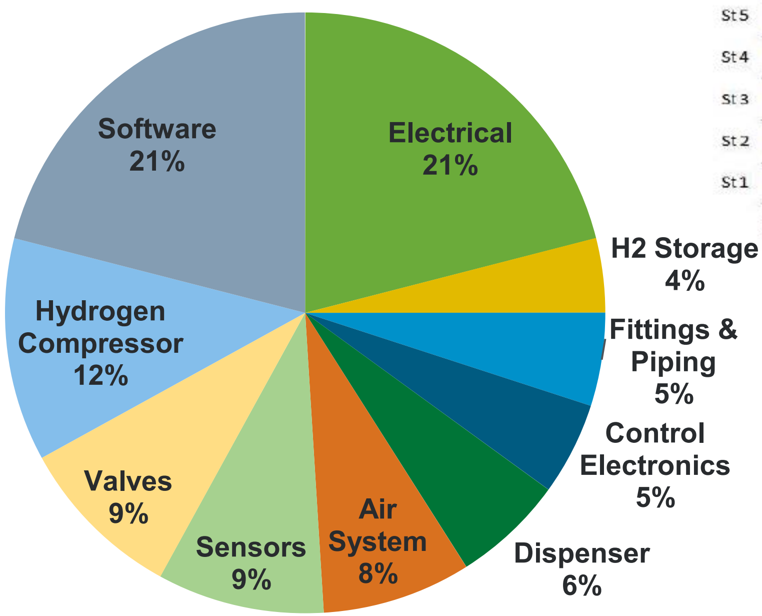
- Trained > 23,000 first-responders and code officials on hydrogen safety and permitting through on-line and in-classroom courses
- 206 Lessons Learned Events in "H2Incidents.org"
- Approximately 750 entries in the Hydrogen Safety Bibliographic Database

www.eere.energy.gov/hydrogenandfuelcells/codes/

Infrastructure: Current Barriers

Despite progress in infrastructure development, more work is needed to address permitting times, contract issues, and equipment reliability.





Infrastructure Maintenance by Equipment Type

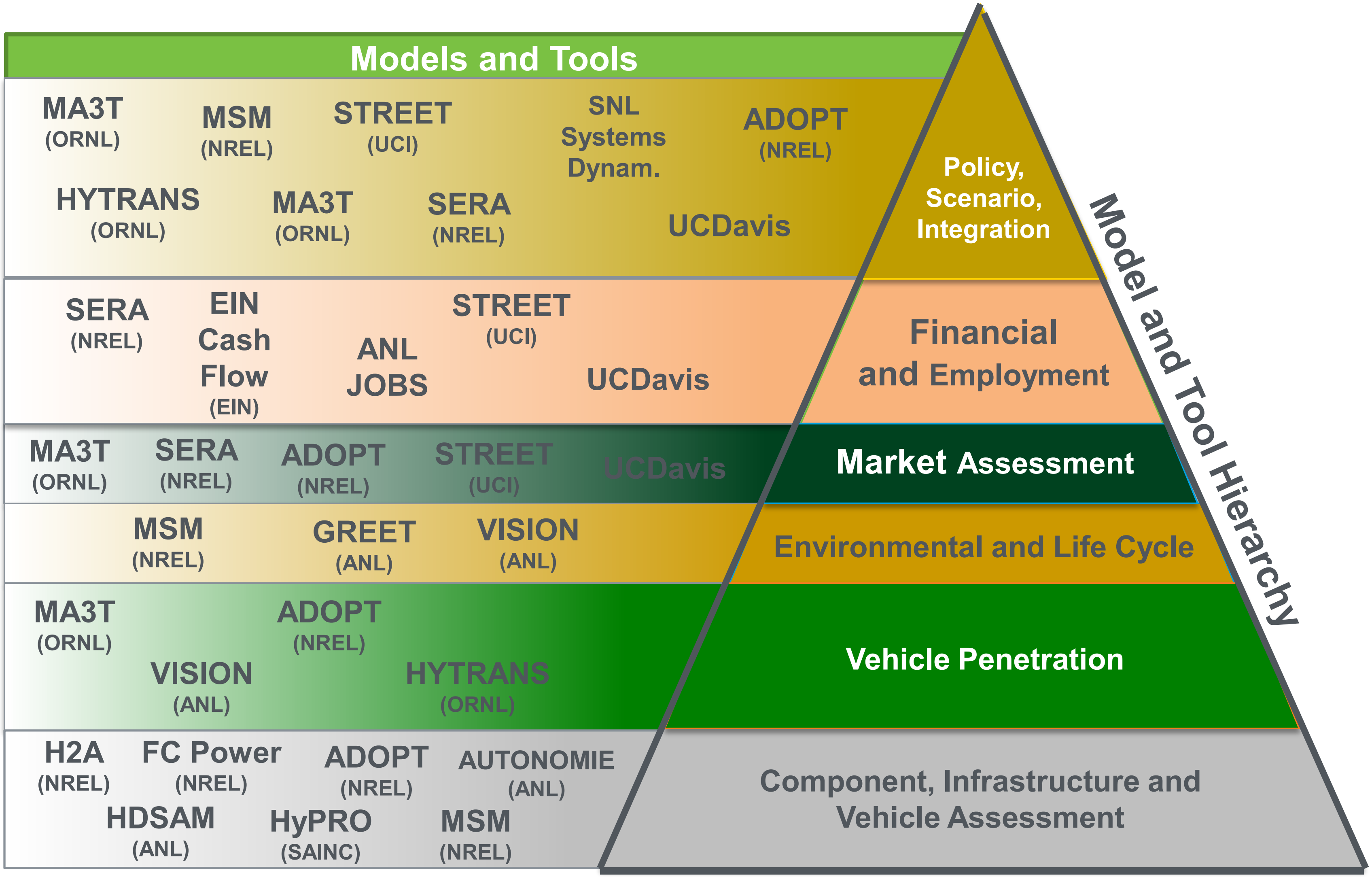
Over 50% of maintenance is associated with the compressor, electrical, and software systems.

Source: NREL http://www.nrel.gov/hydrogen/docs/cdp/cdp_94.jpg

Systems Analysis- Model development, use and validation

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

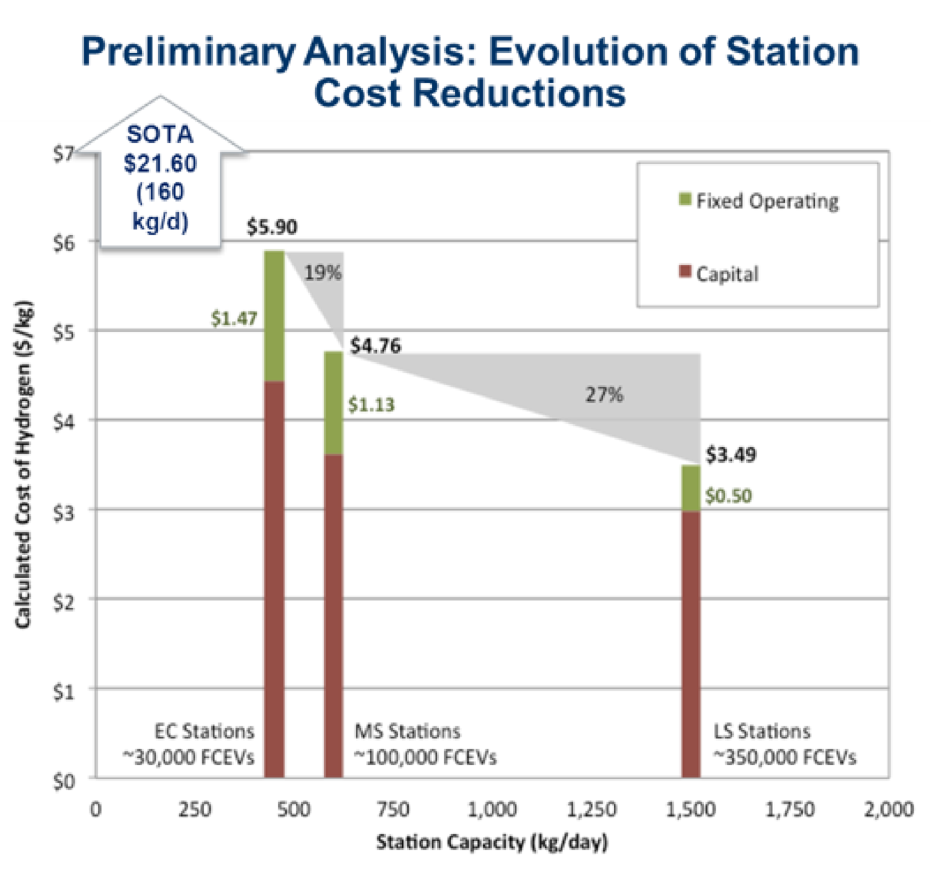
DOE's Fuel Cell Technologies Office model and tool portfolio is comprehensive and multi-functional



Systems Analysis – Analysis Examples

Hydrogen Station Cost Tool—Infrastructure analysis on station cost reduction

Stakeholders' input identified >80% reduction in hydrogen fueling station cost



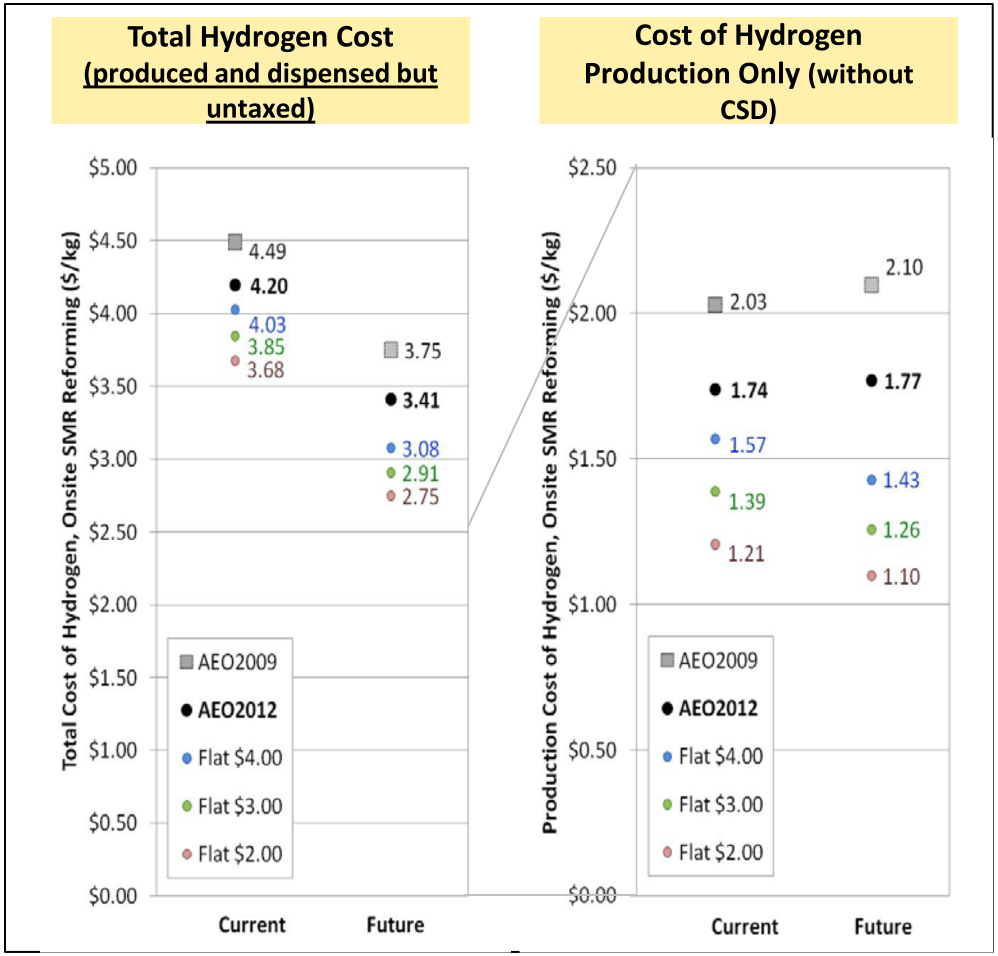
Peer-reviewed employment model for job creation potential for states and regions released for public use

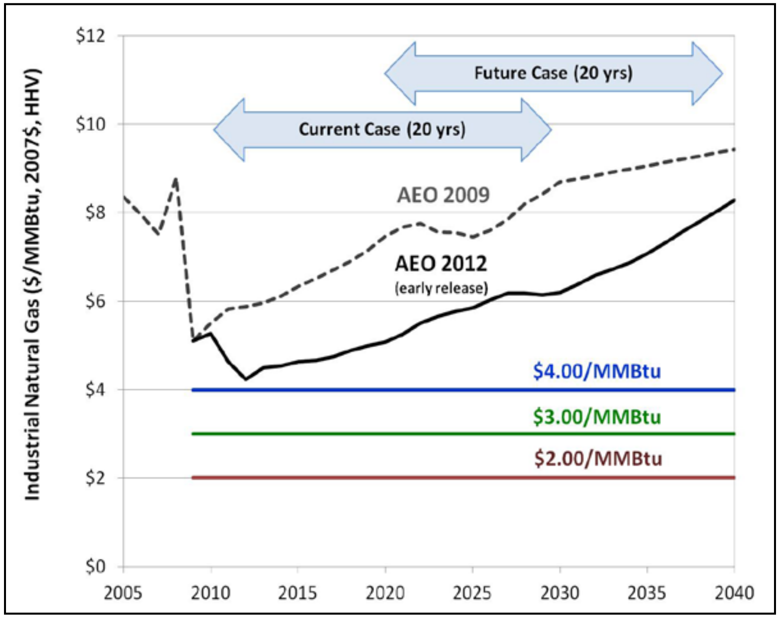
- ANL-RCF developed an employment and economic impact tool to estimate stationary FC industry impacts:
  - Production (PEMFC, PAFC and MCFC) in target applications
  - Installation of FCs and required infrastructure
  - O&M including fuel
  - Construction/expansion of manufacturing capacity
- State, regional and national level analyses including supply chain impacts
- Applications included forklifts, back-up power, specialty vehicles, etc.
- Jobs model will enable analysis of gross and net jobs, and revenues generated from fuel cell installation and investment.

Next application of model will be to assess employment impact of H_2 infrastructure build-out.

Model available from ANL website: JOBSFC.es.anl.gov

Cost of Hydrogen Produced from Distributed Natural Gas Reforming





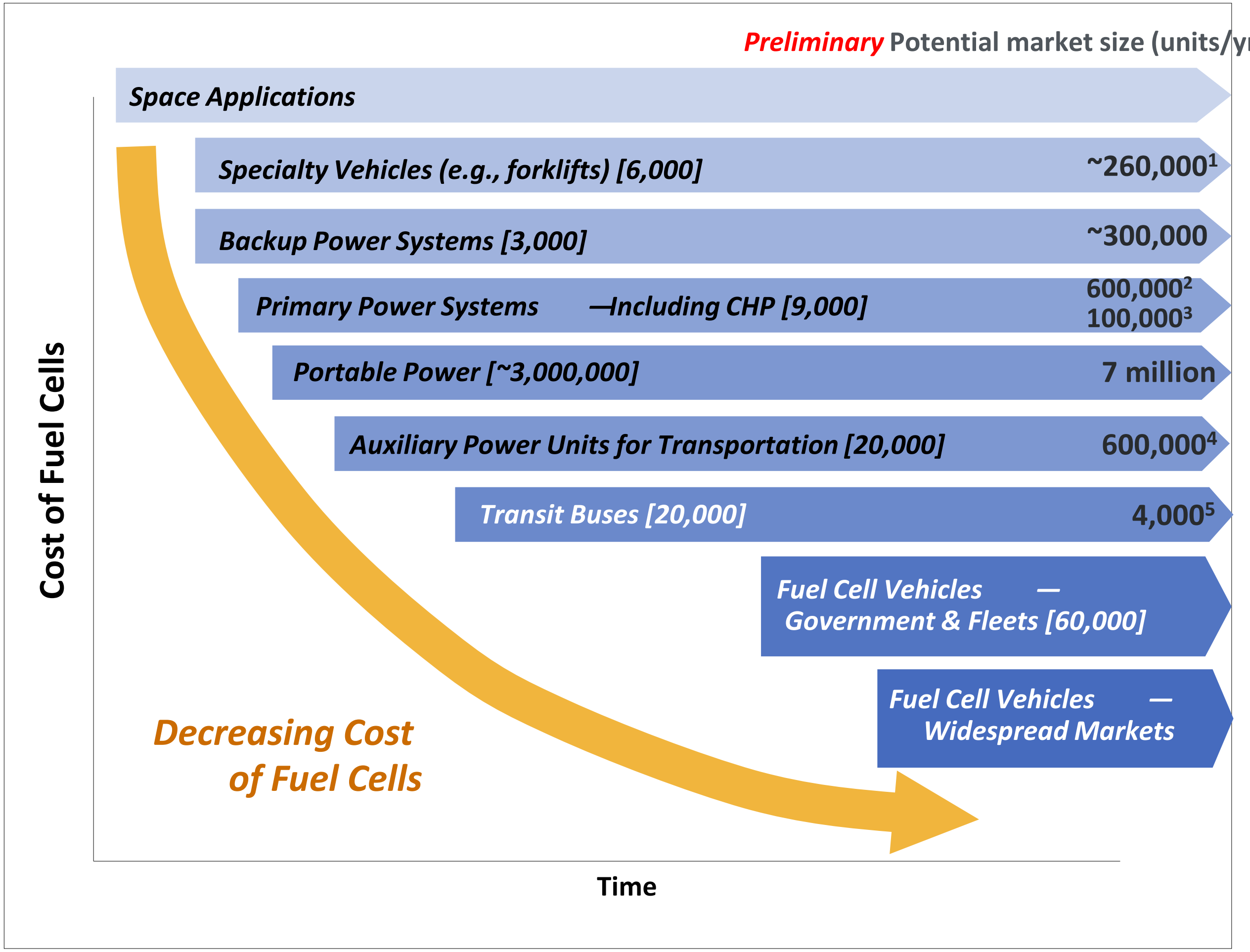
Notes: The values shown reflect the AEO 2009 and AEO 2012 (early release) prices for industrial natural gas. The flat prices of $4.00, $3.00 and $2.00 per MMBtu were used to conduct sensitivity analyses and are not associated with AEO data. Prices beyond AEO projections are extrapolated using AEO data and the results of the Pacific Northwest National Laboratory's MiniCAM model for 2035 and 2050.

Source: DOE Hydrogen and Fuel Cells Program Record #12024, http://hydrogen.energy.gov/pdfs/12024_h2_production_cost_natural_gas.pdf

Potential Early Markets to Reduce Cost

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

As the cost of fuel cells comes down (through technological improvements and economies of scale), they will become competitive in a growing number of markets.



Critical Role of Early Markets

DOE aims to achieve advances for a wide variety of fuel cell applications, with varying time frames for commercial success.

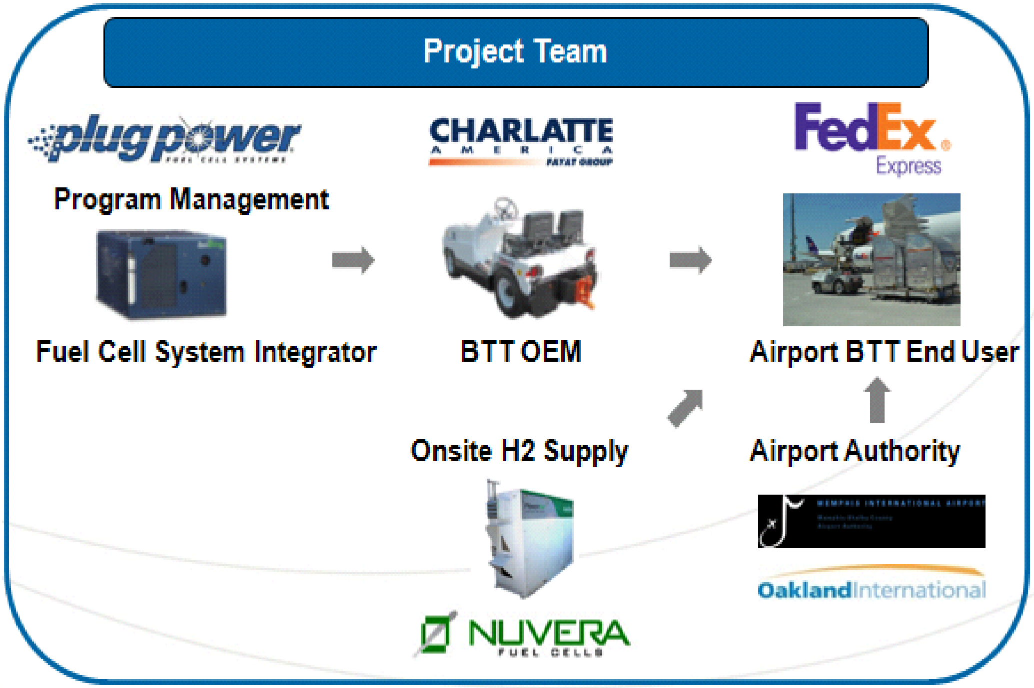
Growth of early markets can help to:

- Reduce costs industry-wide
- Strengthen consumer acceptance
- Grow the domestic supplier base
- Expand infrastructure
- Overcome a variety of logistical challenges

References: [1]ITA 2010 Outlook, [2]MicroCHP, [3]Large scale CHP, [4]Industry estimate based on refrigerated truck and trailer APUs (total number), [5]http://hydrogen.energy.gov/pdfs/12012_fuel_cell_bus_targets.pdf

Background/Status:

- Awarded January 31, 2013
- Fuel Cell Powered Airport Ground Support Equipment (GSE) Deployment
- 3 years, $2.5M DOE share, 50% cost share, two phases:
- Product development and testing
- Demonstrations under "real world" operating environments
- 15 Baggage Tow Tractors with ~20kW fuel cell systems
- 10 units at FedEx in Memphis, TN
- 5 units at FedEx in Oakland, CA



Preliminary Estimate

	Near Term	50 % Total Market
US Market Potentials	1,400	31,000
Diesel reduction (gal/yr)	8,000,000	~ 177,000,000
NOx, PM, HC,CO reduction (MTs/yr)	2,875	~ 63,250
CO_2 reduction (MTs/yr)	80,000	~ 1,760,000

RFI for Early Market Opportunities and Short Haul fleet Demos

RFI: Opened March 11, 2012 – Closes April 10, 2013

Requesting Stakeholder feedback on the commercial readiness and novel finance methods for hydrogen and fuel cell technologies, including:

- **Fuel Cells for Seaport Operations**
  - **E.g., deployment projects for cargo port medium duty delivery electric truck using fuel cell recharging systems.**
- **Low-Interest Loan Pilot Program**
- **Innovative Hydrogen and Fuel Cell Technologies (e.g. Incubator)**
  - Applications successful in research and proof-of-concept work that need funding to accelerate the transition of pre-commercial prototypes.

And VTP Funded projects in FY 2012 (Vehicle Technologies Program)

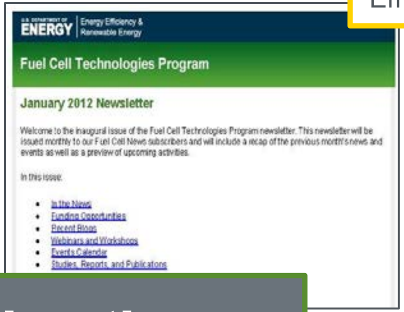
- 2 Demo-Deploy projects awarded for on board fuel cell rechargers
  - SCAQMD project in Port of LA for 3 eHDV with rechargers
  - HARC project in Port of Houston for 20 eHDV with rechargers.

Communication & Outreach

Published more than 70 news articles in FY 2012 (including blogs, progress alerts, DOE news alerts)

- ***Monthly Webinar Series***
  - Hydrogen Refueling Protocols
  - Advanced Electrocatalysts for PEM Fuel Cells
  - Wind-to-Hydrogen Cost Modeling and Project Findings
  - Mobile lighting
  - Register at - http://www1.eere.energy.gov/hydrogenandfuelcells/webinars.html
- ***News Items***
- New Report Analyzes Options for Blending Hydrogen into Natural Gas Pipelines (March 14, 2013)
- Automotive Fuel Cell Cost and Durability Target Request For Information Issued (Feb 4, 2013)
- ***Monthly Newsletter***
- Visit the web site to register or to see archives (http://www1.eere.energy.gov/hydrogenandfuelcells/newsletter.html)

"Fuel cells are an important part of our energy portfolio…deployments in early markets are helping to drive innovations in fuel cell technologies across multiple applications."
- Dr. David Danielson
Assistant Secretary for Energy Efficiency and Renewable Energy


ENERGY | Energy Efficiency & Renewable Energy

Fuel Cell Technologies Program

January 2012 Newsletter

In this issue:

- In the News
- Funding Opportunities
- Recent Blogs
- Webinars and Workshops
- Events Calendar
- Studies, Reports, and Publications

Hydrogen fuel cell powers lights at entertainment industry events.

Developed education materials and educated more than 9,600 teachers on H_2 and fuel cells to date.

Hydrogen fuel cell powered light tower at Space Shuttle launch

Competitive review processes, peer reviews, active project management & go/no-go decisions

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

Topic Selection

- Stakeholders
  - e.g.: RFIs, industry, HTAC, etc.
- U.S. DRIVE
- Peer Reviews
  - NAS
  - GAO
  - Others

→

- Targets
- "Critical Path" needs
- Technology Gaps

→

- Risk Analysis
- Technology Reviews

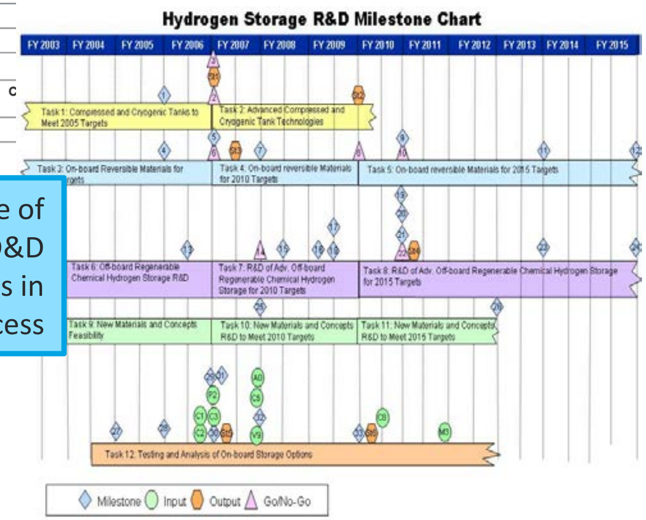
↓

RD&D Plan and Solicitation Topics

Example Fuel Cell Membrane Targets

Characteristic	Units	2011 status	2017 target	Nafion® NRE211
Maximum oxygen crossover	mA/cm²	<1	2	2.7
Maximum hydrogen crossover	mA/cm²	<1.8	2	2.2
Area specific resistance at:				
Max operating temp and 40 – 80 kPa water partial pressure	ohm cm²	0.023 (40 kPa) 0.012 (80 kPa)	0.02	0.186
80°C and water partial pressures from 25 - 45 kPa	ohm cm²	0.017 (25 kPa) 0.006 (44 kPa)	0.02	0.03-0.12
30°C and water partial pressures up to 4 kPa	ohm cm²	0.02 (3.8 kPa)	0.03	0.049
-20°C	ohm cm²	0.1	0.2	0.179
Operating temperature				
Minimum electrical resistance				
Cost				
Durability				
Mechanical	C			
Chemical				

Technical targets help guide go/no-go decisions.



Update of Multiyear RD&D Plan and Targets in process

Project & Program Review Processes

- **Annual Merit Review & Peer Evaluation meetings**
- **Tech Team reviews (monthly)**
- **Other peer reviews- National Academies, GAO, etc.**
- **DOE quarterly reviews and progress reports**

Project Number	Project Title *PI Name & Organization*	Final Score	Continue	Discontinue	Other	Summary Comment
123	New Polymer/ Inorganic Proton Conductive Composite Membranes for PEMFC	2.1		X		The project was unable to meet conductivity targets or significantly improve upon Nafion®, and the membranes developed have poor chemical stability. The project will not be continued.

Reviewer comments for projects posted online annually. Projects discontinued/ work scope altered based on performance & likelihood of meeting goals.

Over $25M saved in the last 4 years through active project management.

Project scope redirected or terminated to increase impact

Key Reports

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

Pathways to Commercial Success: Technologies and Products Supported by the Fuel Cell Technologies Program

By PNNL, http://www.pnl.gov/

See report: http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/pathways_2011.pdf

The Business Case for Fuel Cells 2011: Energizing America's Top Companies

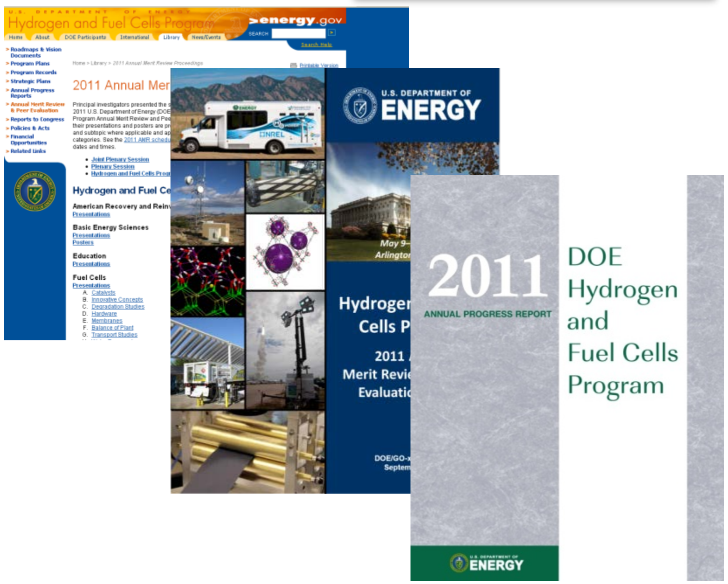
By FuelCells2000, http://www.fuelcells.org

See report: http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/business_case_fuel_cells_2011.pdf

State of the States 2011: Fuel Cells in America

By FuelCells2000, http://www.fuelcells.org

See report: http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/stateofthestates2011.pdf



Annual Merit Review & Peer Evaluation Proceedings

Includes downloadable versions of all presentations at the Annual Merit Review

http://www.hydrogen.energy.gov/annual_review11_proceedings.html

Annual Merit Review & Peer Evaluation Report

Summarizes the comments of the Peer Review Panel at the Annual Merit Review and Peer Evaluation Meeting

http://hydrogen.energy.gov/annual_review11_report.html

Annual Progress Report

Summarizes activities and accomplishments within the Program over the preceding year, with reports on individual projects

www.hydrogen.energy.gov/annual_progress.html

Next Annual Review: May 13– 17, 2013 Arlington, VA

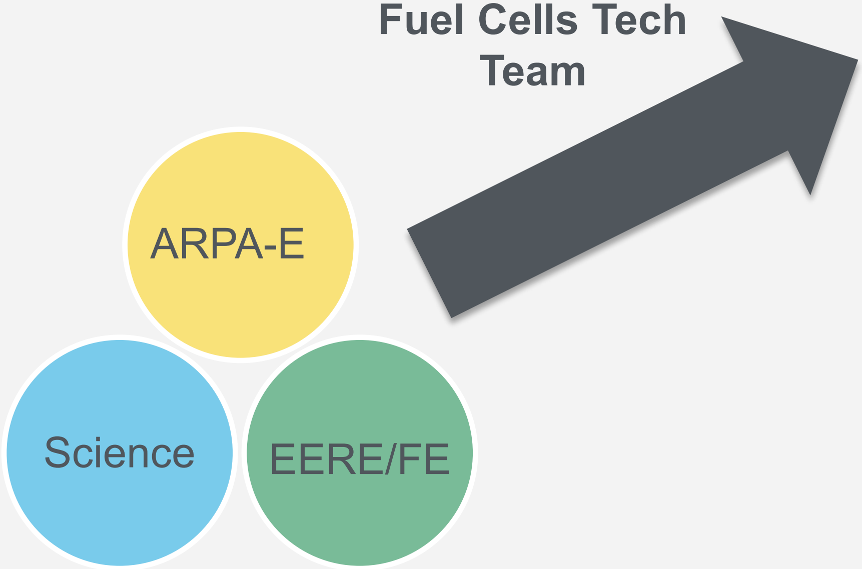
http://annualmeritreview.energy.gov/

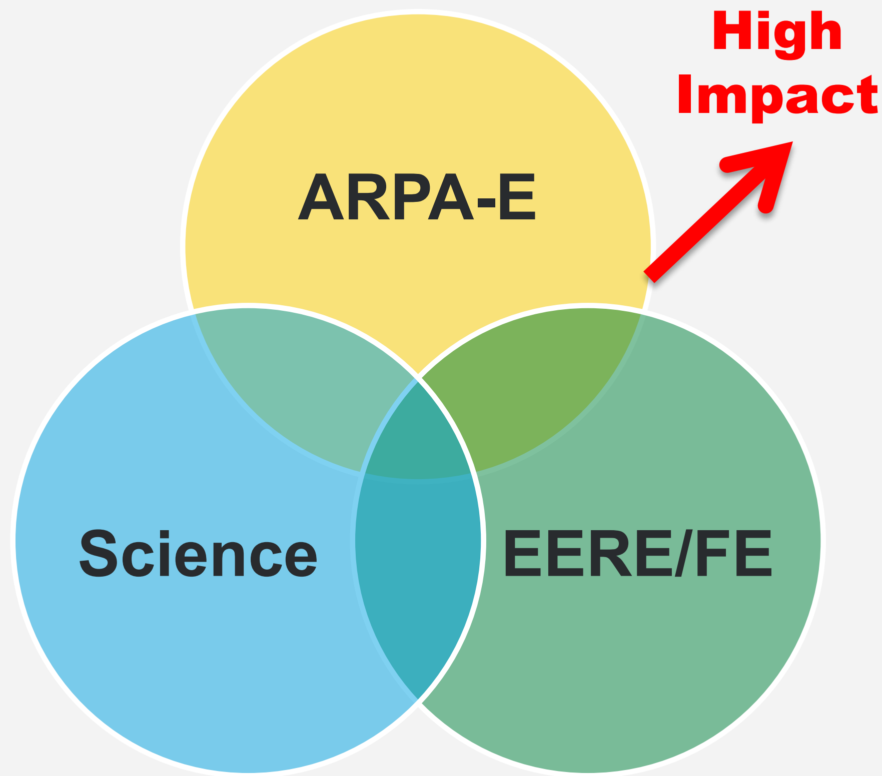
DOE Tech Team enables greater impact and helps break down stove pipes

Examples of Information Sharing

- Best practices/protocols on diagnostics
- Biweekly meetings/telecons
- Identification of synergies, leveraging activities (catalysts, membranes, mechanistic understanding, etc.)

High-impact Interactions - DOE Fuel Cells Tech Team





Examples of Tech Team Outputs

Annual Merit Review coordination
Interoffice project list
Portfolio optimization
Specific example to impact scientific R&D community planned: Develop best practices in diagnostics, protocol development, round robin testing- disseminate to basic science and applied R&D community

Home Hydrogen Refueler H-Prize RFI

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

- Update from previous HTAC telecon: DOE is considering Home Hydrogen Refueling as a possible H-Prize topic for a $1 million prize
- An RFI will gather information on:
  - Current and near-term status of home hydrogen refueling systems
  - Key barriers to wide-spread acceptance
  - Applicable criteria for a competition
- All interested parties are encouraged to respond to all or part of the RFI
- The RFI can be found through the News section of the FCTO website at https://eere-exchange.energy.gov/default.aspx#FoaId2e67f6df-fd51-4da2-953c-ab515231abb0

Future Plans - Summary

Continue to promote and strengthen R&D activities

- Hydrogen, fuel cells, safety, manufacturing, etc.
- Cost, performance, durability need to be addressed

Conduct strategic, selective demonstrations of innovative technologies

- Industry cost share and potential to accelerate market transformation
- New awards for advanced technology & data collection at stations

Continue to conduct key analyses to guide RD&D and path forward

- Life cycle cost; economic & environmental analyses, etc.

Leverage activities to maximize impact

- U.S. and global partnerships
- H2USA: Public-Private partnership to enable widespread commercialization of hydrogen vehicles in the United States

Job Posting for Safety, Codes & Standards – Closes May 3rd, 2013
https://www.usajobs.gov/GetJob/ViewDetails/341695700

Examples of Key Activities: HTAC and Program Impact

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

- Annual Report
- Input on Program Requests
  - H_2 threshold cost revision
  - H_2 Enabling Renewables Working Group (subcommittee)
  - H_2 Production Expert Panel
    - **Goals:**
      - Evaluate current status of hydrogen production technologies
      - Identify remaining challenges
      - Prioritize R&D needs
      - Strategize how to best leverage R&D among DOE Offices and with other agencies

Request:

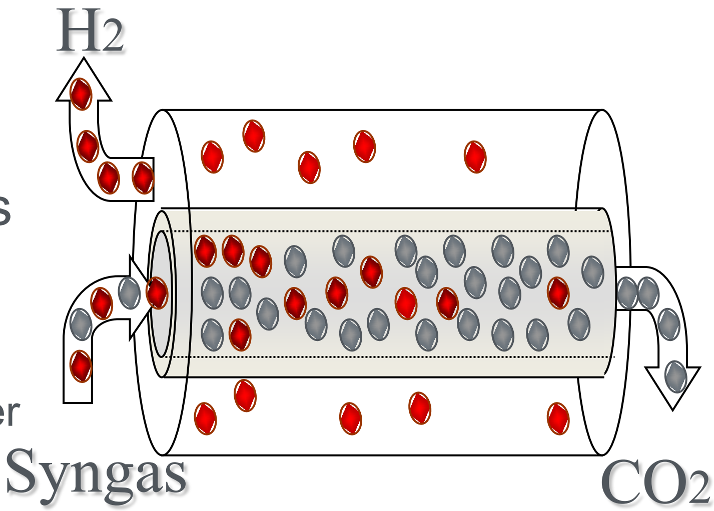
HTAC Fuel Cell Manufacturing Subcommittee:

- Provide feedback to DOE on manufacturing R&D gaps and opportunities for government to accelerate progress and widespread commercialization of fuel cell technologies

Additional Information

Downselect of 4 base program funded projects to 2 projects for scale-up

- 4 hydrogen membrane separation projects operated at 2 lb/day
- Results from the projects led to selection of 2 projects for scale-up to up to 50 lb/day units
  - Worcester Polytechnic Institute
    - Worcester, Mass
  - Praxair
    - Tonawanda, NY
- Slip stream from existing operating gasifiers
  - WPI at National Carbon Capture Center in Wilsonville, AL
  - Praxair at Environmental Energy Research Center in Grand Forks, ND



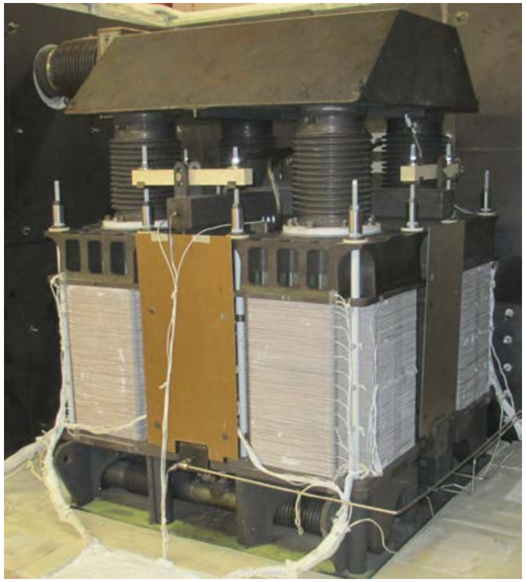
- Hydrogen from coal funding in FY 2014 is to be determined

Funding for Praxair and WPI was ~$2.9M and $3.3M respectively since 2008

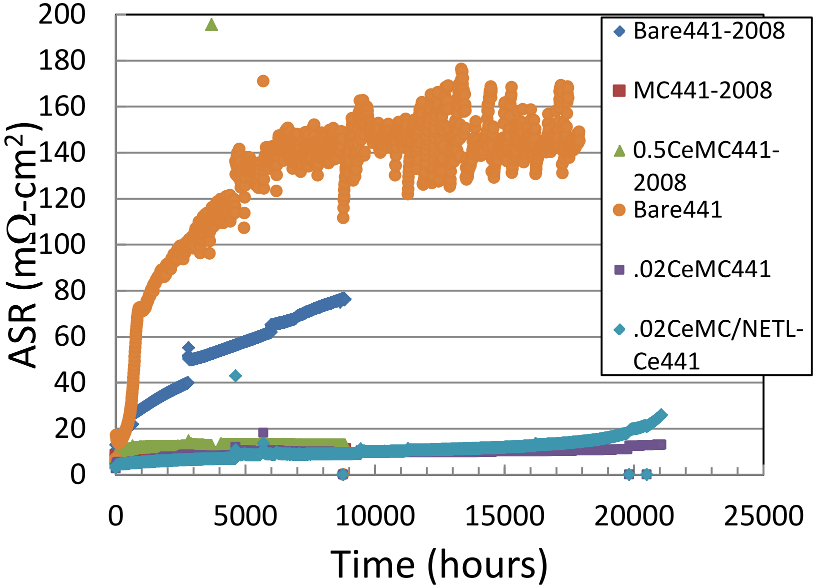
Fuel Cells Program - SECA

Accomplishments

- 30 kWe stack test exceeded 1500 hours target test duration – FCE
- Scaled-up cell active area by 4x (Gen 4 vs Gen 3) - >400cm^2 - Delphi
- Pressurized (6.4 bara) subscale tests exceeded 16,000 hrs, degradation rate <1%/1,000 hrs – LG
- Achieved low and stable Area-Specific Resistance (ASR) for >2 years at 800 ° C with coated low-cost 441 stainless steel for interconnects – PNNL
- FY 13 budget ~24 M. No funding requested in FY 14



FCE 30 kW Stack Tower (192 cells)

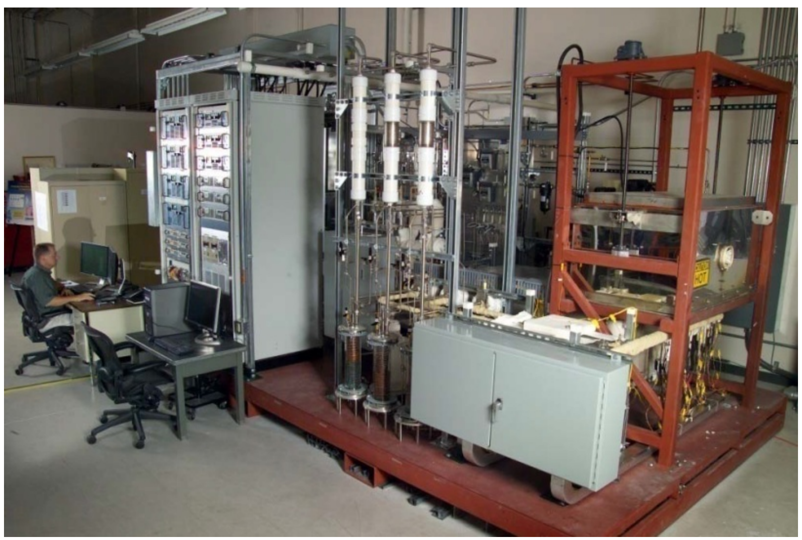


ASR with Coated 441 Stainless Steel

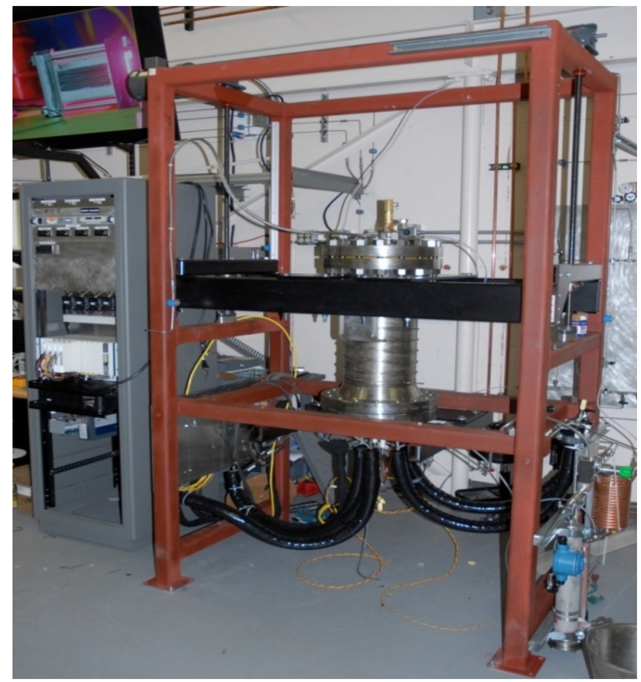
High Temperature Steam Electrolysis

Accomplishments

- R&D on cell & stack manufacturing for HTSE.
- 1080-hour 15 kW integrated laboratory scale operation at INL.
- Completed pressurized testing of HTSE in September 2012 (1.5 Mpa,4kW, 1000 hours)
- No funding requested in FY 13 and FY 14



Integrated Laboratory-Scale Experiment (>5,000NL/h, 15kW) at INL



Pressurized Test Stand 1.5 Mpa (217.5 psi) at INL

~$5.1M in funding for high temperature electrolysis since 2008

June 2012

Systems Analysis - Plans

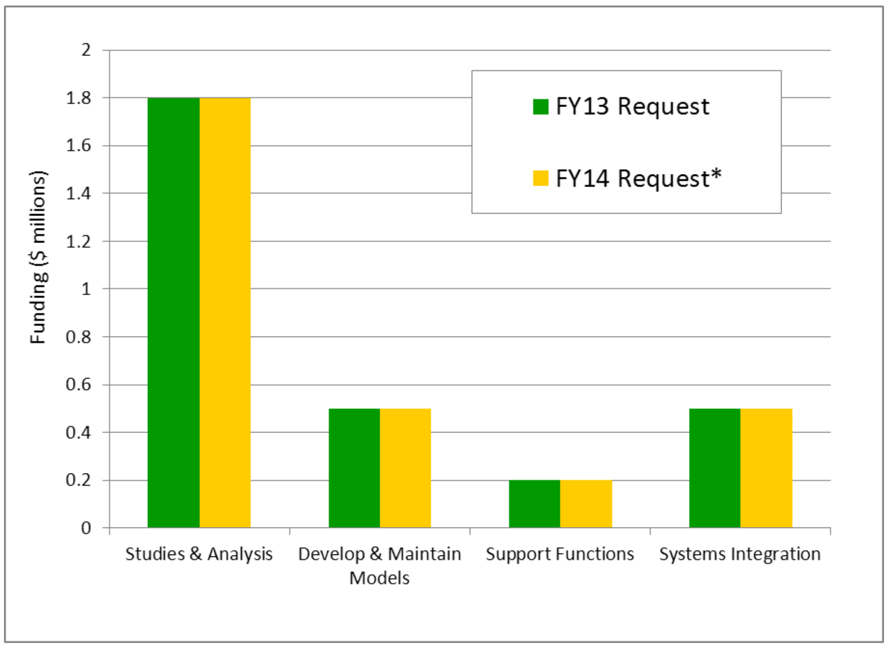
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Focus: Determine technology gaps, economic/jobs potential, and benefits of key technology advances; and quantify 2013 technology advancement.

FY 2014 Request = $3.0 M

FY 2013 Request = $3.0 M

Systems Analysis Funding



* Subject to appropriations, project go/no go decisions and competitive selections. Exact amounts will be determined based on R&D progress in each area and the relative merit and applicability of projects competitively selected through planned funding opportunity announcements (FOAs).

EMPHASIS

- Update and refine models for program analysis using cost, performance and environmental (emissions, etc.) information.
- Continue life-cycle analyses of cost, greenhouse gas emissions, petroleum use and criteria emissions, and impacts on water use.
- Assess gaps and drivers for early market infrastructure cost for transportation and power generation applications
- Assess programmatic impacts on market penetration, job creation, return on investment, and opportunities for fuel cell applications in the near term.

Hydrogen Production & Delivery - Plans

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

Key goals include: Achieve a 10% reduction in the delivered, untaxed hydrogen cost from the baseline of \$8/gge. Construct and test a hydrogen storage vessel that reduces refueling station vessel costs by 25%. Demonstrate 750 hour operational lifetime in a high efficiency (≥10%) photoelectrochemical device.

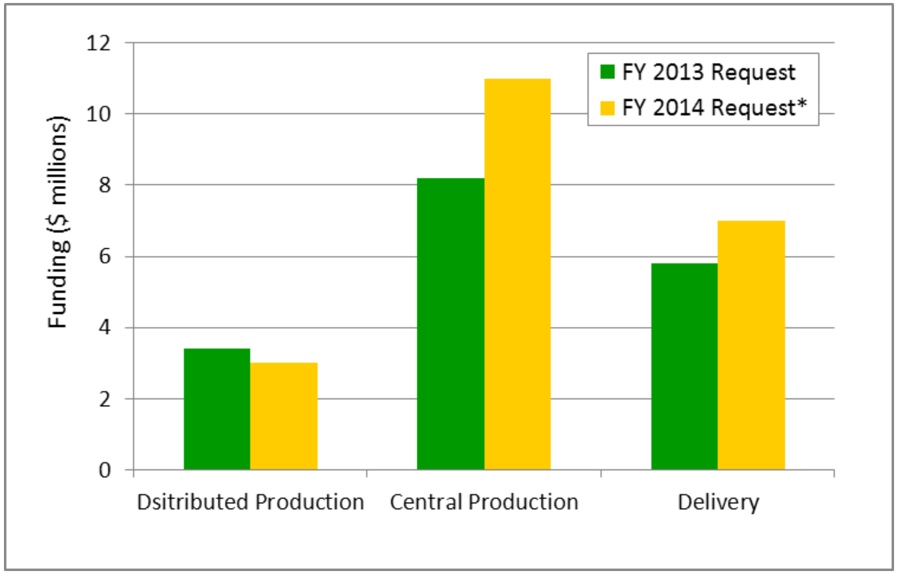
Hydrogen Fuel R&D

(for Production, Delivery & Storage)

FY 2014 Request = \$38.5M

FY 2013 Request= \$27.0 M

Production & Delivery Portion of Hydrogen Fuel R&D



* Subject to appropriations, project go/no go decisions and competitive selections. Exact amounts will be determined based on R&D progress in each area and the relative merit and applicability of projects competitively selected through planned funding opportunity announcements (FOAs).

EMPHASIS

- Maintain core efforts in key pathways
- Improve performance and durability of materials and systems for production from renewable sources: photoelectrochemical, biological, and solar thermochemical.
- Implement optimized delivery technologies and strategies to minimize cost of 700 bar hydrogen at refueling stations.

Production & Delivery FOAs in FY 2013 for FY 2014 funds

Notices of Intent will be posted soon

Hydrogen Storage R&D – Plans

Focused on advanced tanks for near-term hydrogen storage and materials R&D for long-term hydrogen storage.

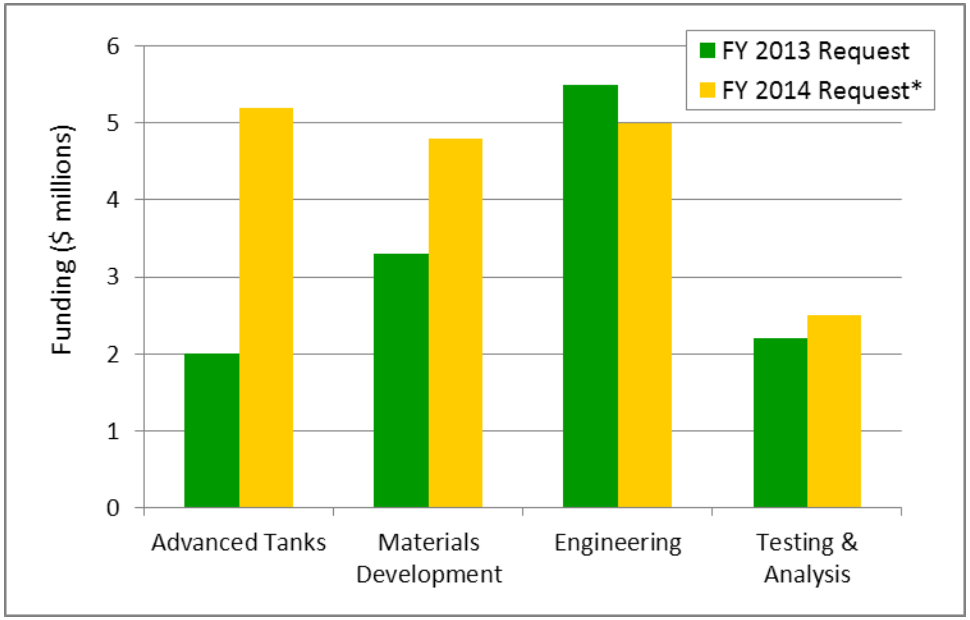
Hydrogen Fuel R&D

(for Production, Delivery & Storage)

FY 2014 Request = $38.5M

FY 2013 Request = $27.0 M

Storage Portion of Hydrogen Fuel R&D



* Subject to appropriations, project go/no go decisions and competitive selections. Exact amounts will be determined based on R&D progress in each area and the relative merit and applicability of projects competitively selected through planned funding opportunity announcements (FOAs).

EMPHASIS

- Reduce projected costs of high pressure composite vessels for hydrogen storage by at least 10% from the 2011 projected costs of $17/kWh through reduced cost carbon fiber materials, improved composite materials and improved vessel design (leverage manufacturing sub-program)
- Continue Engineering Center of Excellence including system engineering design of materials-based technologies to meet key 2017 storage system targets.
- Maintain core efforts on new materials development to increase the capacity and temperature of operation of adsorbent materials from cryogenic conditions (e.g. liquid nitrogen) to near room temperature by increasing the surface area and tailoring heats of adsorption.

Manufacturing R&D - Plans

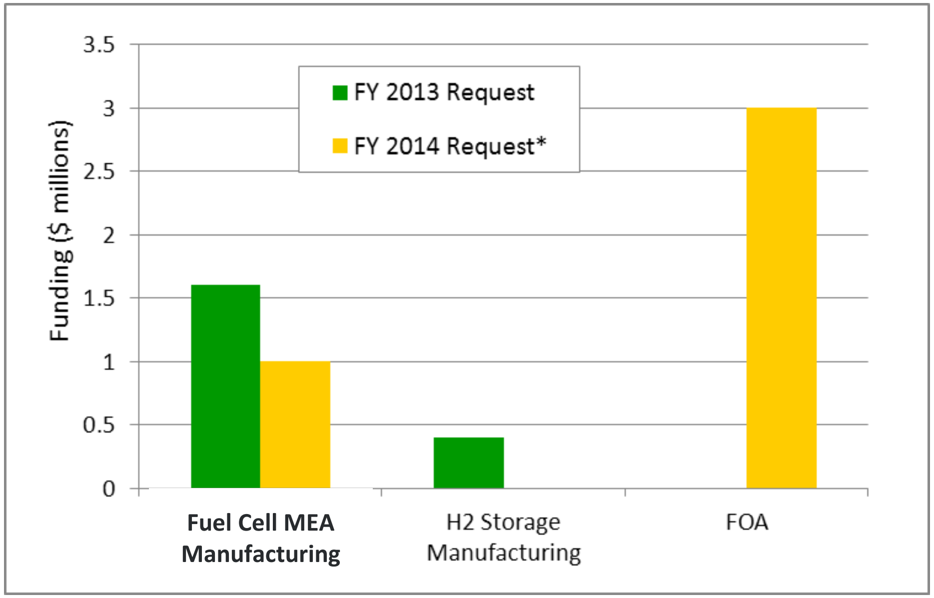
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Develop fabrication processes and technologies for fuel cell components to enable an automotive fuel cell cost of $30/kW in 2017

FY 2014 Request = $4.0M

FY 2013 Request = $2.0M

Manufacturing R&D Funding



* Subject to appropriations, project go/no go decisions and competitive selections. Exact amounts will be determined based on R&D progress in each area and the relative merit and applicability of projects competitively selected through planned funding opportunity announcements (FOAs).

EMPHASIS

- Continue core efforts on PEM fuel cells
  - Simplify roll-to-roll processing of MEAs by reducing the number of coating passes and direct coating of catalyst onto ionomer

Projects

- **MEA Manufacturing**
- **Detection of defects in catalyst coated membranes, gas diffusion electrodes, and solid oxide tube cells**

- Fund new projects (from FY 2013 funding opportunity announcement) based on results from hydrogen and fuel cell Manufacturing R&D workshop (subject to appropriations)

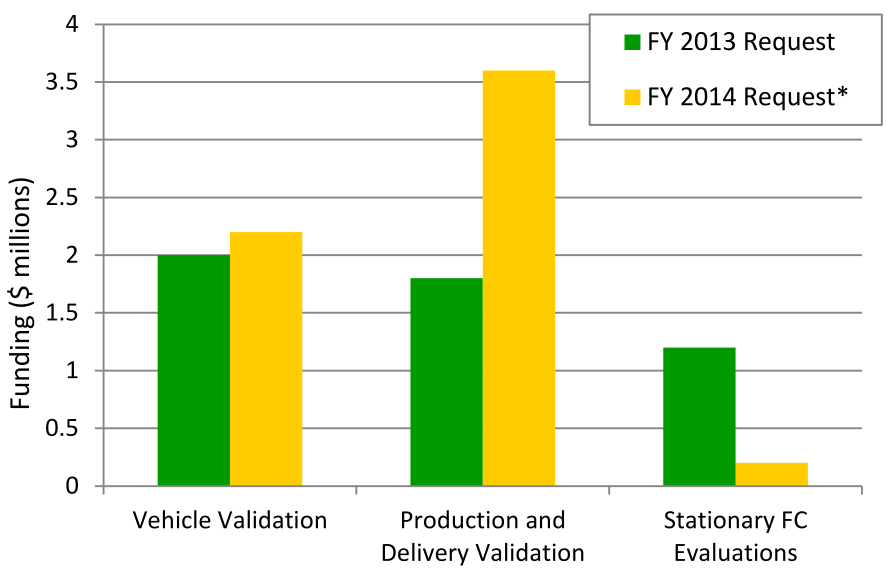
Technology Validation - Plans

Includes real-world data collection from FCEVs and H_2 stations, evaluation of innovative H_2 fueling and delivery components, and production and storage of hydrogen from renewable sources.

FY 2014 Request = $6.0M

FY 2013 Request = $5.0M

Technology Validation Funding



* Subject to appropriations, project go/no go decisions and competitive selections. Exact amounts will be determined based on R&D progress in each area and the relative merit and applicability of projects competitively selected through planned funding opportunity announcements (FOAs).

EMPHASIS

- Data collection, analysis and evaluation. (leverages equipment funded outside the Program) — *FY12–FY13 awards*
  - Light-duty vehicles, buses and hydrogen refueling stations. (Collaboration on buses with DOT)
  - Hydrogen Compressors and Advanced Refueling components
- Real-world demonstration / evaluations (small number of units for validation purposes) — *FY12–FY13 awards*
  - Stationary Hydrogen and Electricity Generation
  - High-Pressure Electrolyzers
  - Electrochemical Hydrogen Pump

Safety, Codes & Standards - Plans

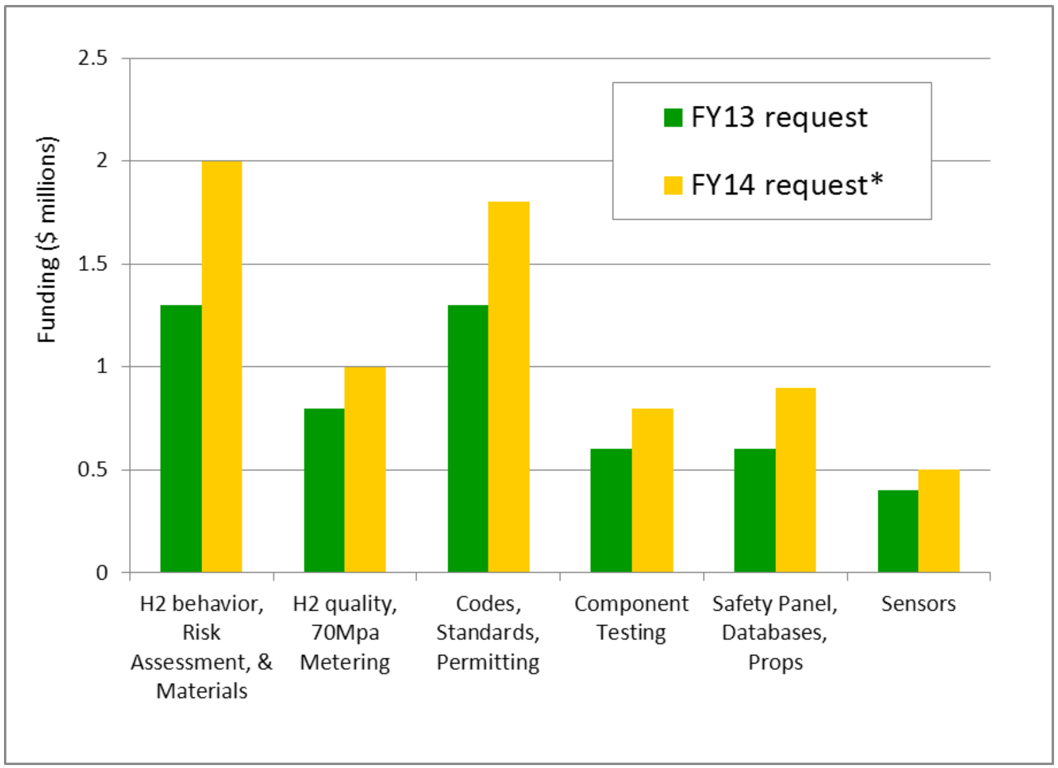
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Maintain critical Safety, Codes and Standards activities and leverage external efforts (states, industry, etc.)

FY 2014 Request = $7.0M

FY 2013 Request = $5.0M

Safety, Codes & Standards Funding



* Subject to appropriations, project go/no go decisions and competitive selections. Exact amounts will be determined based on R&D progress in each area and the relative merit and applicability of projects competitively selected through planned funding opportunity announcements (FOAs).

EMPHASIS

- Maintain core R&D to inform development and revisions of codes and standards
  - Validate performance data
  - Conduct risk assessments and establish protocols to identify and mitigate risk
  - Develop testing protocols for components and systems including high pressure vessels
  - Maintain efforts on materials compatibility, and hydrogen quality, measurement, and metering.
- Continue coordination and harmonization activities through international & domestic technical working groups.
- Continue coordination and dissemination of hydrogen safety information and safety panel activities.

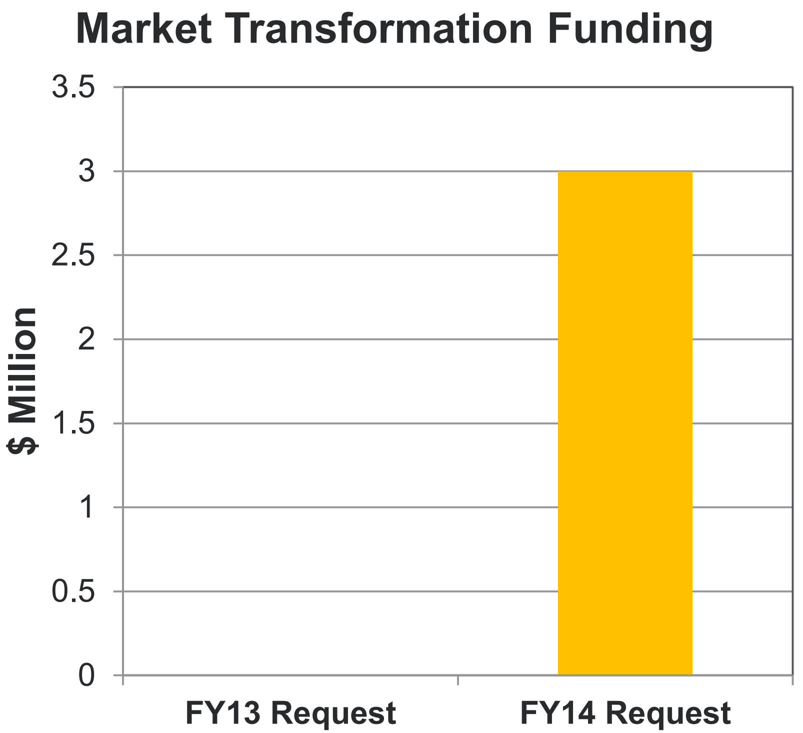
Market Transformation

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

Market Transformation focuses on supporting early market successes such as emergency backup power and specialty vehicle applications. The goal is to enable emerging markets to achieve economies of scale and reduce fuel cell life-cycle cost to be on a par with conventional technologies by 2020.

FY 2014 Request = $3M

FY 2013 Request = $0M



* Subject to appropriations, project go/no go decisions and competitive selections. Exact amounts will be determined based on R&D progress in each area and the relative merit and applicability of projects competitively selected through planned funding opportunity announcements (FOAs).

EMPHASIS

- Accelerate widespread commercialization of hydrogen and fuel cell technologies (e.g., next example similar to forklifts and telecom success stories)
- Fund cost-shared deployments and provide technical support to deployment efforts
- Complete assessment of early market fuel cell systems and provide feedback to program R&D areas
- Provide technical and financial assistance for government and other technology adopters such as for:
  - Distributed power
  - Auxiliary power for vehicles e.g., heavy duty trucks

*Preliminary estimates

EERE Budget: FY 2011 – FY 2014

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

Funding *($ in thousands)*				
Activity	**FY 2011 Allocation**	**FY 2012 Appropriation**	**FY 2013 *Request***	***FY 2014 Request***
Biomass and Biorefinery Systems	179,979	199,276	270,000	282,000
Building Technologies	207,310	219,204	310,000	300,000
Federal Energy Management Program	30,402	29,891	32,000	36,000
Geothermal Technology	36,992	37,862	65,000	60,000
Hydrogen and Fuel Cell Technologies	95,847	103,624*	80,000	100,000
Water Power	29,201	58,787	20,000	55,000
Advanced Manufacturing (formerly Industrial Technologies)	105,899	115,580	290,000	365,000
Solar Energy	259,556	288,951	310,000	356,500
Vehicle Technologies	293,151	328,807	420,000	575,000
Weatherization & Intergovernmental Activities	231,300	128,000	195,000	248,000
Wind Energy	78,834	93,254	95,000	144,000
Facilities & Infrastructure	51,000	26,311	26,400	46,000
Strategic Programs	32,000	25,000	58,900	36,000
Program Direction	170,000	165,000	164,700	185,000
Congressionally Directed Activities	228,803	292,135	0	0
RE-ENERGYSE	0	0	0	0
Adjustments	-29,750	-9,909	-69,667	-12,800
Total	**1,711,721**	**1,809,638**	**2,267,333**	**2,775,700**

* The FY 2012 and FY 2013 numbers shown on page 384 of the White House's FY 2014 Budget Request (www.whitehouse.gov/sites/default/files/omb/budget/fy2014/assets/doe.pdf) reflect $9.7 million that was carried over from FY 2012 to FY 2013 for obligation in FY 2013

A number of opportunities to leverage activities (e.g. Vehicle Technologies, Advanced Manufacturing)

Potential Collaborations: Vehicle Technologies

Fiscal Year 2014 Priority Activities

- **EV Everywhere Grand Challenge, $303.5M:** Make the U.S. the first country to provide a wide array of plug-in electric vehicle models that are as affordable and convenient as gasoline vehicles by 2022.
- **SuperTruck Initiative:** Develop and demonstrate technologies that improve heavy-duty, class 8 vehicle fuel economy by 50% (relative to a comparable 2009 vehicle) by increasing energy efficiency, reducing aerodynamic drag and weight, and hybridization.
- **Alternative Fuel Vehicle Community Partner Projects, $90M**: Accelerate the adoption of PEV's, natural gas vehicles, and other alternative fuels through highly-leveraged community partnerships to introduce alternative fuel and advanced vehicles at scale.
- **Grid Integration Initiative, $20M:** Coordinate with EERE's Building and Solar Energy Technologies Offices, to develop and advance the platform of technologies necessary to fully integrate PEVs and other clean energy technologies into the distribution system in a safe, reliable, and cost effective manner.
- **Vehicle Technologies Incubator, $30M:** Funding program to introduce potentially high-impact promising "off-road-map" new technologies and learning curves into the Vehicle Technologies portfolio.

(Dollars in Thousands)	FY 2012 Current	FY 2013 Request	FY 2013 Annualized CR*	FY 2014 Request
Batteries and Electric Drive Technology	117,740	210,000	—	240,200
Vehicle and Systems Simulation & Testing	47,198	57,000	—	70,000
Advanced Combustion Engine R&D	58,027	57,000	—	59,500
Materials Technology	40,830	50,000	—	59,500
Fuels and Lubricant Technologies	17,904	12,000	—	17,500
Outreach, Deployment and Analysis	39,267	34,000	—	126,300
NREL User Facility	0	0	—	2,000
Total, Vehicle Technologies	320,966	420,000	330,819	575,000

*FY 2013 amount shown reflect the P.L. 112 175 continuing resolution level annualized to a full year. These amounts are shown only at the "congressional control" level and above; below that level, a dash (-) is shown.

Potential Collaborations: Advanced Manufacturing

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

Fiscal Year 2014 Priority Activities

- **Next Generation Manufacturing R&D Projects:** Focused on transformational improvements in manufacturing which will strengthen the competitiveness of today's industry, grow the U.S. manufacturing base, and advance foundational technology opportunities for clean energy applications to grow a new clean energy industry.

- **Advanced Manufacturing R&D Facilities:** Clean Energy Manufacturing Innovation Institutes, Critical Materials Hub and the Manufacturing Demonstration Facility on additive manufacturing are all critical parts of accelerating advanced manufacturing.

- **Industrial Technical Assistance:** Provide technical assistance to improve industrial competitiveness and catalyze better energy management using international standards and other best practices, and assist with adoption of CHP.

(Dollars in Thousands)	FY 2012 Current	FY 2013 Request	FY 2013 Annualized CR*	FY 2014 Request
Next Generation Manufacturing R&D Projects	60,334	205,000	—	120,000
Advanced Manufacturing R&D Facilities	34,628	54,000	—	217,500
Industrial Technical Assistance	17,730	31,000	—	27,500
Total, Advanced Manufacturing	112,692	290,000	116,287	365,000
*FY 2013 amount shown reflect the P.L. 112 175 continuing resolution level annualized to a full year. These amounts are shown only at the "congressional control" level and above; below that level, a dash (-) is shown.				

Forecourt CSD Workshop

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

The workshop was held March 20th and 21st at Agonne National Laboratory out side Chicago, IL

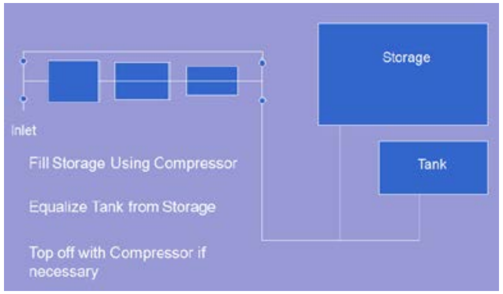
- ~30 experts from industry and public sector met to discuss the challenges to reducing the cost of hydrogen infrastructure at the forecourt and identify RD&D areas to address those challenges.
- Sessions organized into three topic areas, Compression, Storage, and Other and the top issues and activities from each session have been captured with a full report to follow during the AMR.

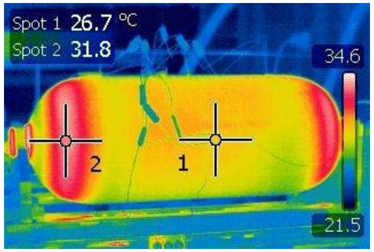
1.) Materials Research
- Dynamic seals
- Carbon fiber (cost and batch quality)
- Metallics

2.) Station Optimization Analysis
- Near, Mid and Long term markets
- Storage vs. Compression trade offs

3.) Metering, Quality & Performance Testing for Dispensing
- Meter accuracy
- Hydrogen quality measurement device
- Station dispensing test apparatus

4.) Data for codes and standards development
- Setback distances
- Tank cycle life

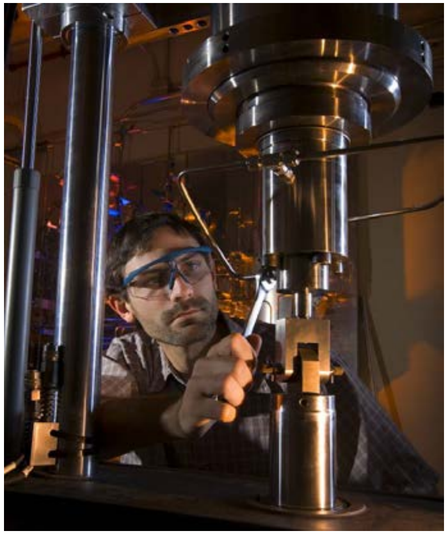




International meeting on Advancing Materials Testing in Hydrogen Gas

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

The workshop was held April 9th and 10th at Sandia National Laboratories in Livermore, CA



- There were 16 attendees representing 7 countries from Japan, France, S. Korea, UK, Finland, Canada, and the US.
- This meeting emphasized material testing in hydrogen gas, highlighting equipment, procedures, and safety.
- Goal: Give current laboratory operators an opportunity discuss information, ideas, challenges, and success stories.
- Each invited institution gave a presentation describing their test equipment, test procedures, safety features and limitations and challenges in there capabilities.

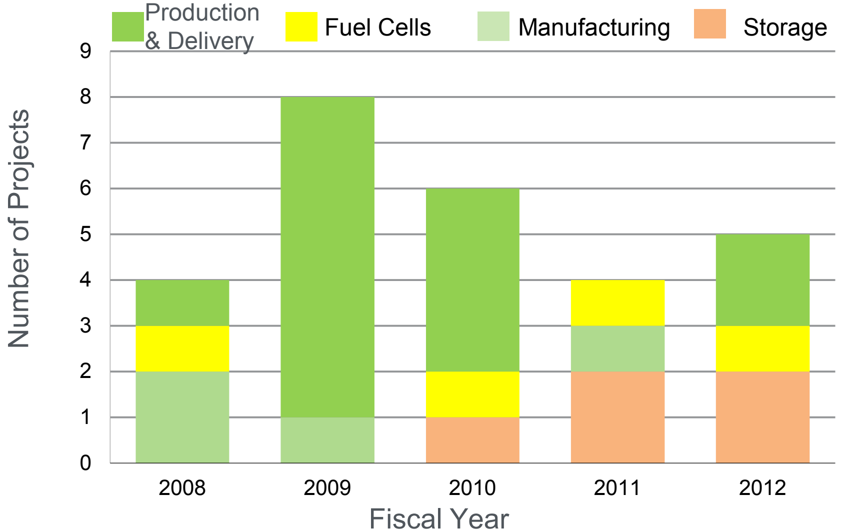
1.) Establish Technology Landscape
- Create catalogue of equipment design concepts, best practices, and safety features
- Determine test capability boundaries, environmental control, test durations and test rates materials test methods.
- Identify unanswered questions or gaps in existing testing capabilities

2.) Identify pathways and resources for development of capabilities
3.) Identify collaboration opportunities to address unanswered questions and enhance/develop capabilities

FCT Office Phase I SBIR (Small Business Innovation Research) Projects

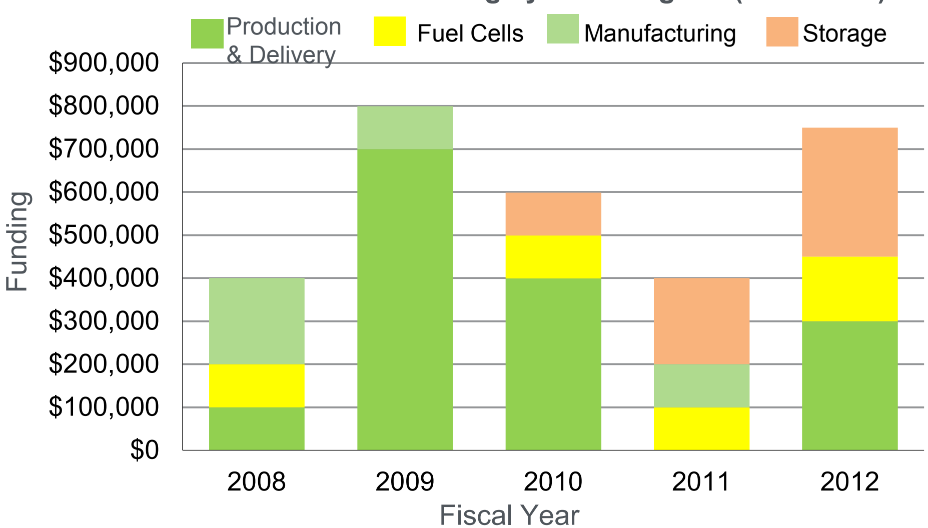
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Phase I SBIR Projects by Sub-Program (2008-2012)



Note: 6 Manufacturing Projects, 5 Fuel Cells Projects, 11 Production and Delivery Project, & 1 Storage Project from 2004 – 2007

Phase I SBIR Funding by Sub-Program (2008-2012)



Note: $0.6M for Manufacturing, $0.5M for Fuel Cells, $1.1M for Production & Delivery, & $0.1M for Storage from 2004 – 2007

Total of 50 Projects and $5.3 Million in Funding*

Production & Delivery:
- 25 Projects
- Hydrogen Production, Hydrogen Production Process Intensification, Hydrogen Compression & Liquefaction, Hydrogen Home Fueling Analysis & Hydrogen Dispensing

Storage:
- 6 Projects
- Advanced H_2 Storage Materials, Storage for Early Market Applications, Low Cost Compressed H_2 Storage Tank

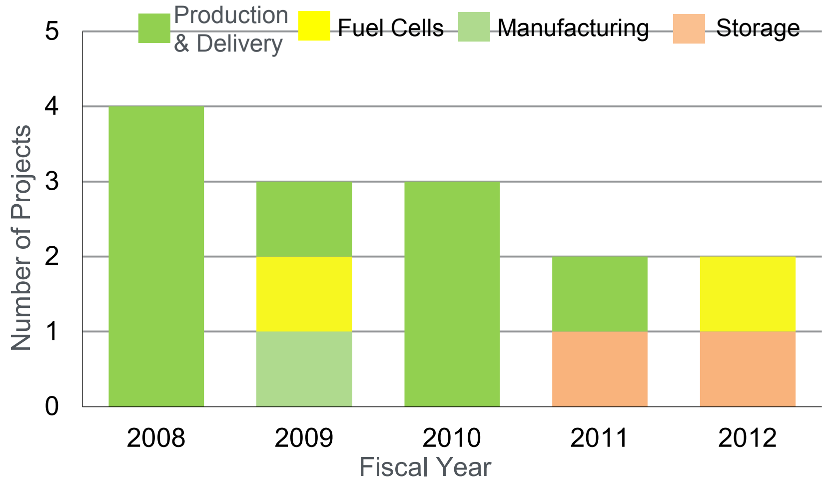
Fuel Cells:
- 9 Projects
- Fuel Cell Coolants & Membranes, Bio-Fueled Solid Oxide, Innovative Fuel cell Concepts & Balance of Plant, Stationary & Transportation Applications

Manufacturing:
- 10 Projects
- Hydrogen Production Equipment, Hydrogen Storage Containers, Proton Exchange Membrane (PEM) Fuel Cells & Bipolar Plates, Fuel Cell Range Extenders

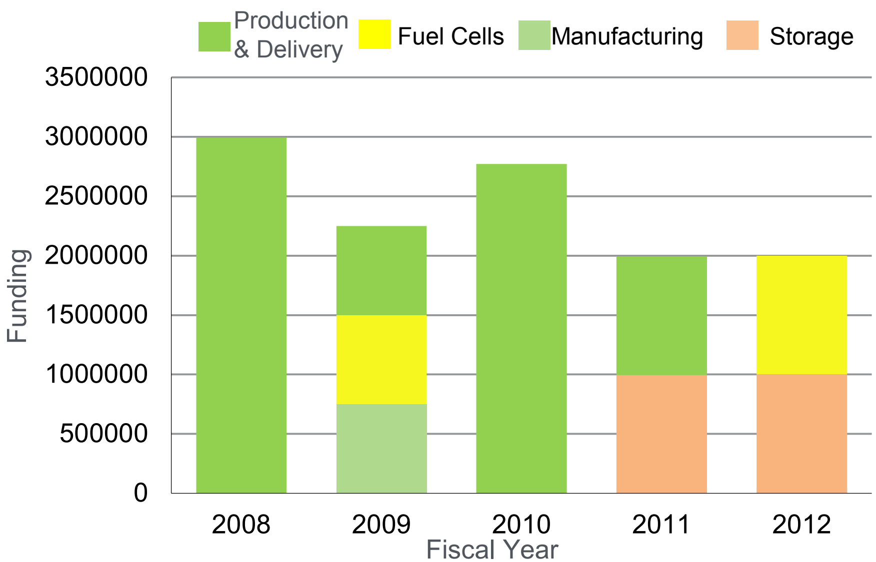
*Includes all SBIR Phase I Projects from 2004 to present

FCT Office Phase II SBIR Projects

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



Note: 2 Fuel Cells Projects, 2 Production & Delivery Projects, and 3 Manufacturing Projects from 2004 - 2007



Note: $1.5M for 2 Fuel Cells Projects, $2.2 M for 3 Manufacturing Projects, and $1.5M for 2 Production & Delivery Project from 2004 – 2007

Total of 21 Projects and $17.2 Million in

Production & Delivery

- Hydrogen Compression Technology
  - Mohawk Innovative Technology (2 projects), FuelCell Energy
- Hydrogen Production
  - Genesis Fueltech, Physical Optics Corporation, Synkera Technologies Inc., H_2 Pump, LLC, Proton Energy Systems, Giner Electrochemical Systems, LLC
- Hydrogen from Waste
  - Directed Technologies, Inc.
- Energy Storage for Intermittent Renewable Resources
  - Proton Energy Systems

Storage

- Hydrogen Storage for Early Market Applications
  - Hawaii Hydrogen Carriers
- Low Cost Compressed H2 Storage Tank
  - Applied Nanotech, Inc.

Fuel Cells

- Fuel Cell Systems Coolants and Membranes
  - Advanced Fluid Tech Inc., Dab Dynalene Heat Trans
- Dimensionally Stable High Performance Membrane
  - Giner Electrochemical Systems, Loc
- Bio-Fuel Solid Oxide Fuel Cell
  - Innovatek, Inc.
- Efficient and Lower Cost Fuel Cell Balance of Plant
  - Tetramer Technologies, LLC

Manufacturing

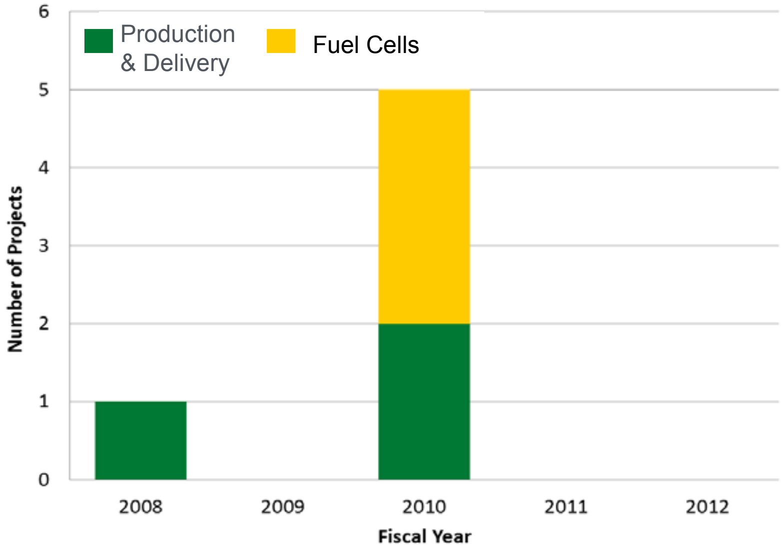
- Manufacturing of Hydrogen Storage Containers
  - Innosense, Loc
- Manufacturing of Proton Exchange Membrane (PEM) Fuel Cells
  - Nanotek Instruments, Inc., Scribner Assoc. Incorporated
- Manufacturing of Bipolar Plates
  - Faraday Technology, Inc.

*Includes all SBIR Phase II Projects from 2004 to present

FCT Office "Phase III" SBIR Projects

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

"Phase III" Projects by Sub-Program (2008 – 2012)



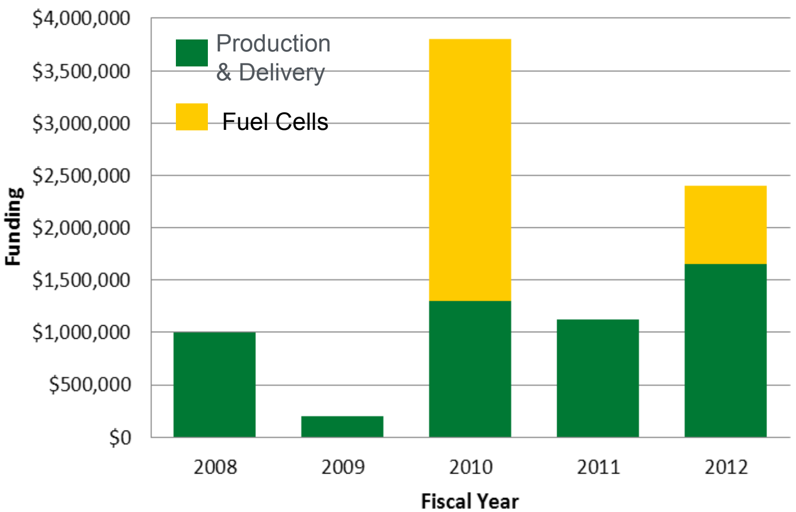
Production & Delivery

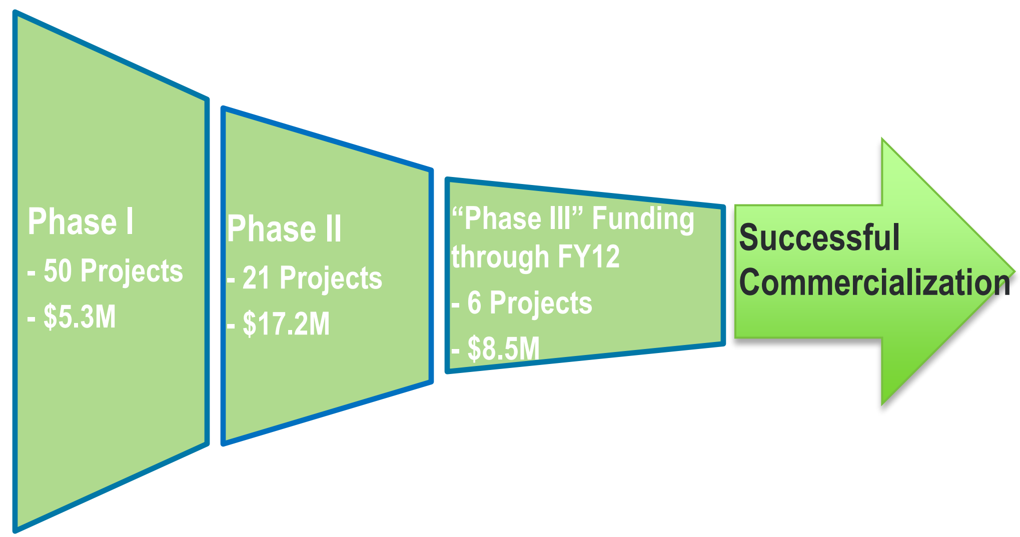
- Electrochemical Hydrogen Compression
  - FuelCell Energy, Inc.
- Centrifugal Hydrogen Compression
  - Mohawk Innovative Technology, Inc.
- Bio-Fueled Solid Oxide Fuel Cells
  - TDA Research, Inc.

Fuel Cells

- Advanced Materials for Fuel Cell Technologies
  - Dynalene Inc.
  - Giner Electrochemical Systems, Inc.
- Bio-Fuel Solid Oxide Fuel Cell
  - Innovatek, Inc.

"Phase III" Funding by Sub-Program (2008 – 2012)





Applied Programs Phase I FOA:

- Issued on 11/26/2012
- Applications due 2/5/2013
- Preliminary award notification date is May 2013
- FCT Program topics included: Hydrogen Dispenser Technologies

Basic Energy Science Phase I FOA:

- Included Fuel Cell Catalysis topic, with one award to Giner, Inc. for a project titled “Nanostructured Catalysts for Alkaline PEM Fuel Cells”

New elements: letter of intent required and increased emphasis on commercialization plan

Release 3 Phase II FOA:

- To be issued on July 15, 2013
- Applications due September 4, 2013
- Preliminary date of notice for award negotiation is November 2013

Computer Modeling Illustrates Cation Degradation Pathways for Fuel Cells

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

Scientific Achievement

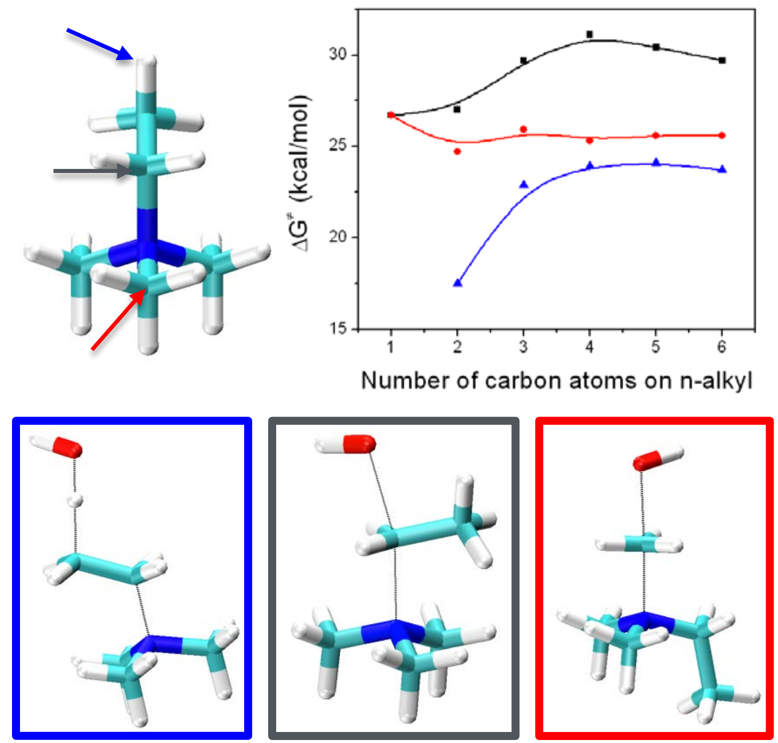
Computer modeling reveals cation degradation pathways for alkaline exchange membranes (AEMs).

Significance and Impact

Cation degradations insights obtained in this study will permit better performance and longer lifetime for alkaline membrane fuel cells (AMFCs).

Research Details

- AMFCs are new generation of full cells that can utilize non-precious catalysts, which can dramatically reduce the cost of fuel cells.
- In AMFCs, AEMs with tethered cations are used to allow hydroxide to transport between electrodes. However, the stability of cations under attack of hydroxide is a major issue for AMFCs.
- Density Functional Theory is used to investigate the degradation pathways for substituted trimethylammonium (TMA^+) cations used in AEMs.
- Hofmann elimination pathway is found to be the most vulnerable pathway and steric effect is suggested to make cations more stable.



Degradation pathways for alkyl-substituted TMA^+ cations: blue: Hofmann elimination pathway; **black**: S_N2 attack pathway on alkyl; **red**: S_N2 attack pathway on methyl. **Upper left panel**: reaction sites on ethyl-TMA^+ for these pathways; **upper right panel**: free energy barriers for alkyl-substituted TMA^+; and **lower panels**: transition states for ethyl-TMA^+.

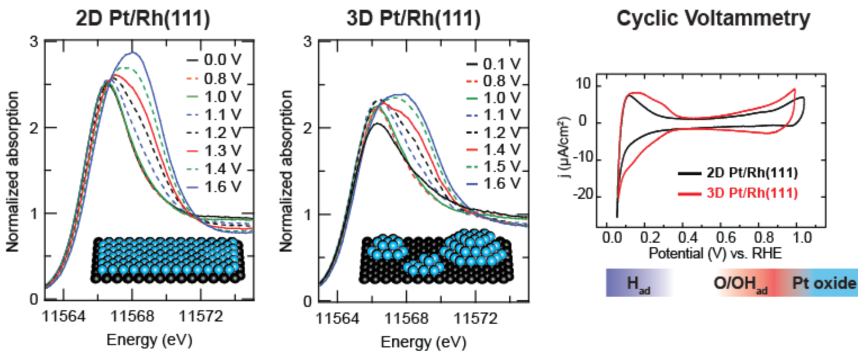
Long, H.; Kim, K.; Pivovar, B. S. (2012), *J. Phys. Chem. C,* 116 (17), 9419.

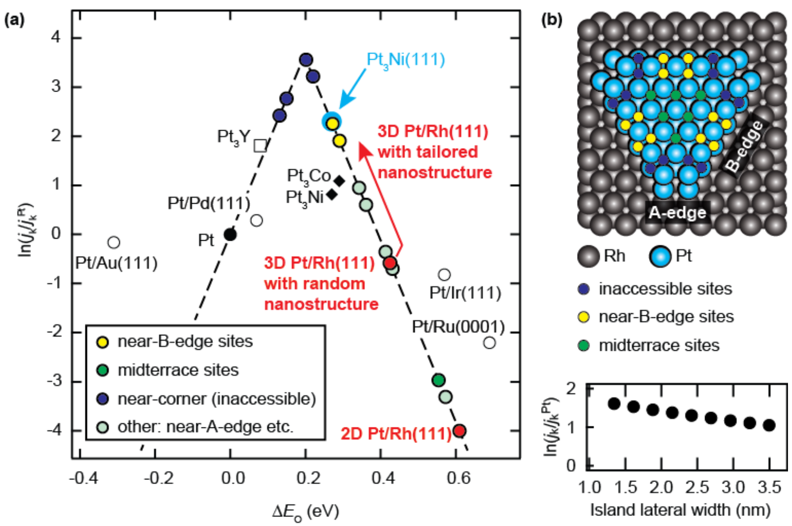
Work was performed at National Renewable Energy Laboratory

NREL NATIONAL RENEWABLE ENERGY LABORATORY

Balance of Nanostructure and Bimetallic Interactions in Pt Model Fuel Cell Catalysts

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





In situ HERFD XAS and cyclic voltammetry (top) of two different Pt/Rh(111) nanostructures showing different affinities to O_{ad}. Fuel cell volcano plot (bottom) with DFT-based prediction of site-specific ORR activities (a). Pt bilayer islands (b) with particularly high activity, due to their high number of most active sites.

Work was performed at SLAC National Accelerator Laboratory.

Scientific Achievement

Joint DFT and in situ XAS study reveals wide tunability of oxygen adsorption energy in bimetallic Pt/Rh nanostructures.

Significance and Impact

New design principle for fuel cell cathode catalyst with high activity and stability.

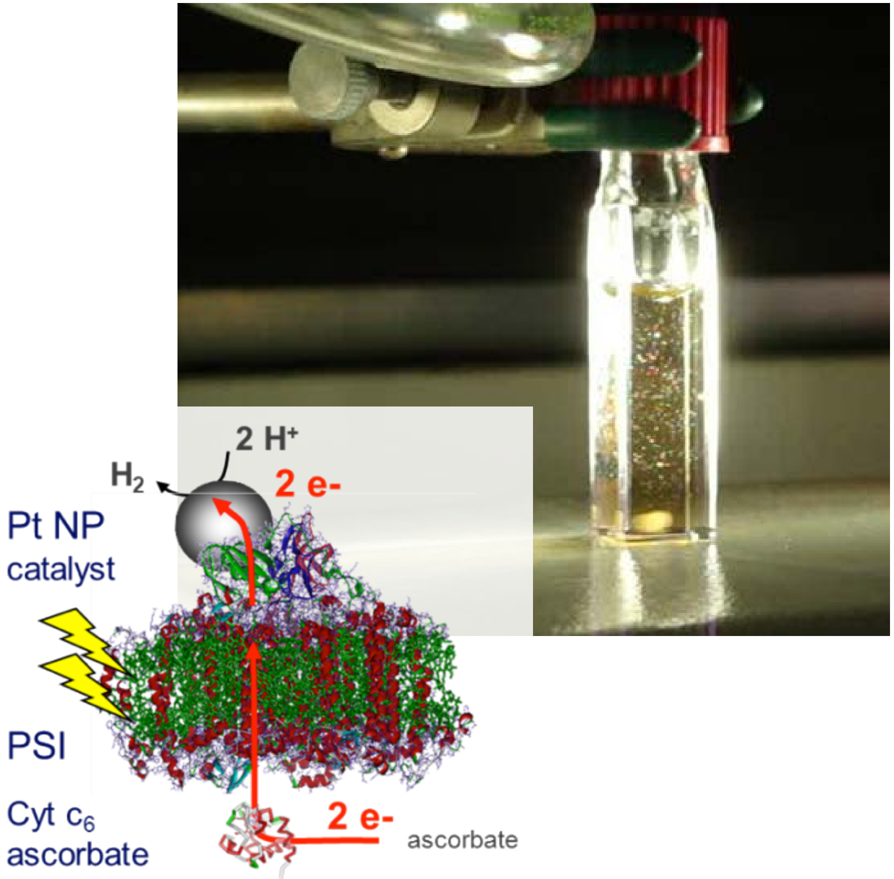
Research Details

- Bond strength of adsorbed oxygen atoms (O_{ad}) is tuning parameter for catalytic ORR activity, can be modified by mixing Pt with other metals
- Combination of HERFD XAS, EXAFS and DFT calculations reveals strong additional effect of local nanostructure on affinity of Pt to O_{ad}
- Pt/Rh(111) model system has poor ORR activity when Pt is in uniform single layer, but thicker Pt islands on Rh(111) can be up to 5x more active than pure Pt and much more durable than highly active Pt_3Ni or Pt_3Co

D. Friebel, V. Viswanathan, A. H. Larsen, D. J. Miller, H. Ogasawara, T. Anniyev, C. P. O'Grady, J. K. Nørskov, A. Nilsson, J. Am. Chem. Soc. 2012, 134, 9664-9671.

SLAC

Photocatalytic hydrogen production via a noncovalent biohybrid protein complex



Lisa Utschig, Argonne National Laboratory
J. Phys. Chem. Letts. (2011) 2: 236
C&E News January 31, 2011

- Using BES funding, researchers developed a Photosystem I (PSI) - platinum (Pt) nanoparticle hybrid system that photocatalytically generated hydrogen at a rate five times greater than the previous record-setting system.
- The study demonstrates that highly efficient photocatalysis of hydrogen can be obtained for a self-assembled, noncovalent complex between one of Nature's specialized energy converters, PSI, and Pt nanoparticles.
- The results suggest a new strategy for linking molecular catalysts to PSI that takes advantage of electrostatic-directed assembly to mimic acceptor protein binding.

Argonne NATIONAL LABORATORY

Chemical Sciences and Engineering Division

Platinum Monolayer Electro-Catalysts: Stationary and Automotive Fuel Cells

http://science.energy.gov/discovery-and-innovation/stor
New Catalyst Opens Way to...
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Discovery & Innovation

Stories of Discovery & Innovation
Brief Science Highlights
SBIR/STTR Highlights

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03.28.11

New Catalyst

A new highly stab
commercial use o

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Image courtesy of Broo... National Lab...
This high-angle annular d... field (HAADF) scanning transmission electron microscopy (STEM) imag... shows a bright shell on a... relatively darker nanopar... signifying the formation of a core/shell structure — a platinum monolayer shell on a palladium nanoparticle core.

...automotive applications and can be used extensively in electric cars if the technology can be made to work efficiently and economically. Developing these electrocatalysts is a big step in that direction."

The newly designed fuel cell catalysts are composed of a single layer of platinum over a palladium (or palladium-gold alloy) nanoparticle core. Their structural characterization was performed at Brookhaven's Center for Functional Nanomaterials and the National Synchrotron Light Source, both national scientific user facilities supported by the DOE Office of Science.

Fuel cells converts hydrogen and oxygen into water and, as part of the process, produce electricity. Hydrogen is oxidized when electrons are released and hydrogen ions are formed; the released electrons supply current for an electric motor. Oxygen is reduced by gaining electrons,

Enlarge Photo
Image courtesy of Brookhaven National Laboratory.
(From left) Brookhaven Lab chemists Kotaro Sasaki, Miomir Branko Vukmirovic, and

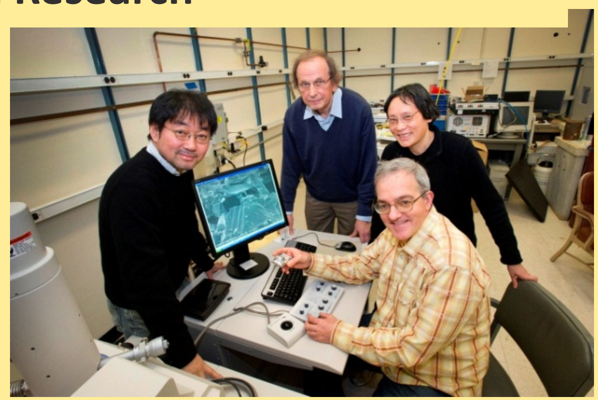
Manufacturing/ Commercialization

BNL-Toyota CRADA

Scale-up synthesis: **Pt-ML/Pd_9Au_1/C**

Brookhaven Lab Chemists Win R&D 100 Award for Fuel Cell Research

Radoslav Adzic
Kotaro Sasaki
Miomir Vukmirovic
Jia Wang



2012 R&D 100 50th ANNIVERSARY

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Science **315**, 220 (2007)

Fuel Cell Catalyst now commercially licensed