FUEL CELL TECHNOLOGIES PROGRAM

HTAC Meeting

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

Overview of Hydrogen & Fuel Cell Activities

June 14, 2011

Sunita Satyapal

U.S. Department of Energy
Fuel Cell Technologies Program
Program Manager

Agenda

- Overview
  - Update on progress, key activities and announcements
- Budget Update
  - FY 2011 and FY 2012
- Additional Information & Next Steps
  - Blue Ribbon Panel
  - Input on H-Prize
  - Infrastructure

Fuel Cell Market Overview

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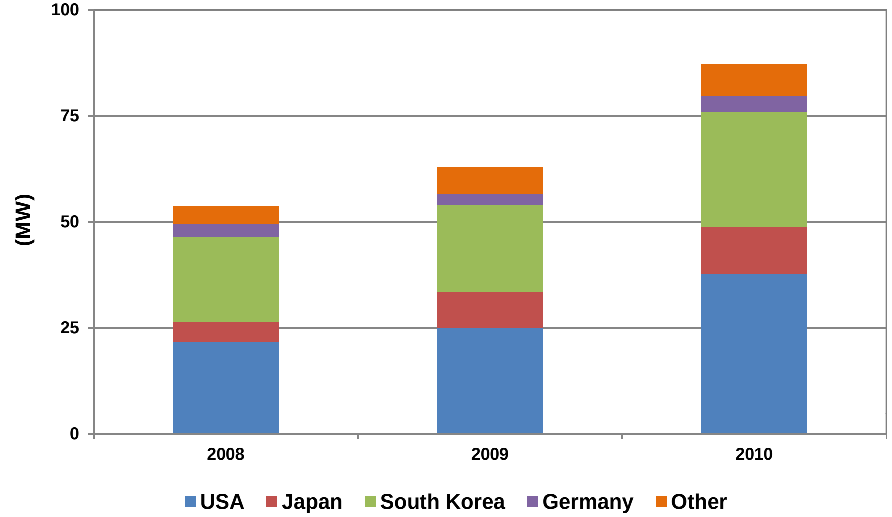
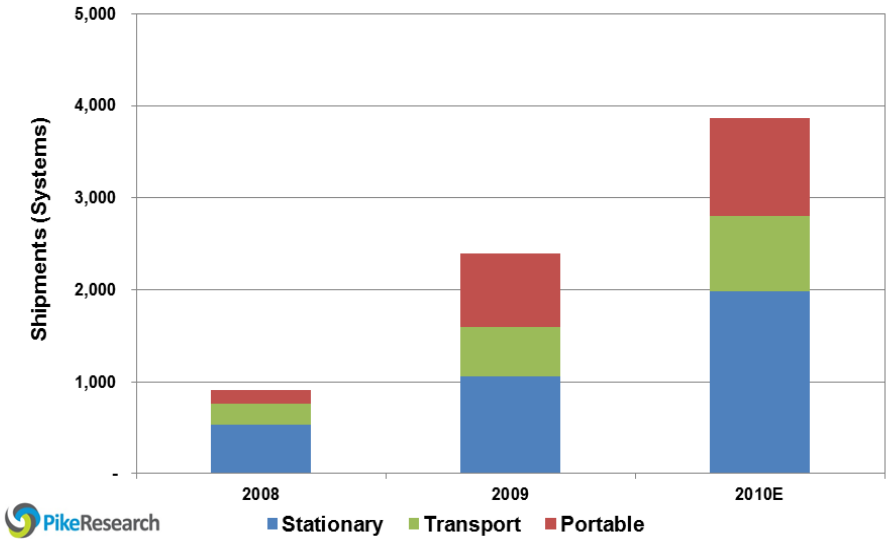
Megawatts Shipped, Key Countries: 2008-2010



North American Shipments by Application



Fuel cell market continues to grow
- ~36% increase in global MWs shipped
- ~50% increase in US MWs shipped

Global fuel cell/hydrogen market could reach maturity over the next 10 to 20 years, producing revenues of:
- $14 – $31 billion/year for stationary power
- $11 billion/year for portable power
- $18 – $97 billion/year for transportation

http://www.fuelcells.org/BusinessCaseforFuelCells.pdf, http://www.fuelcells.org/StateoftheStates.pdf
http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/program_plan2010.pdf

FuelCells2000, Pike Research, Fuel Cell Today, ANL

Patents Reflect Emerging Industry

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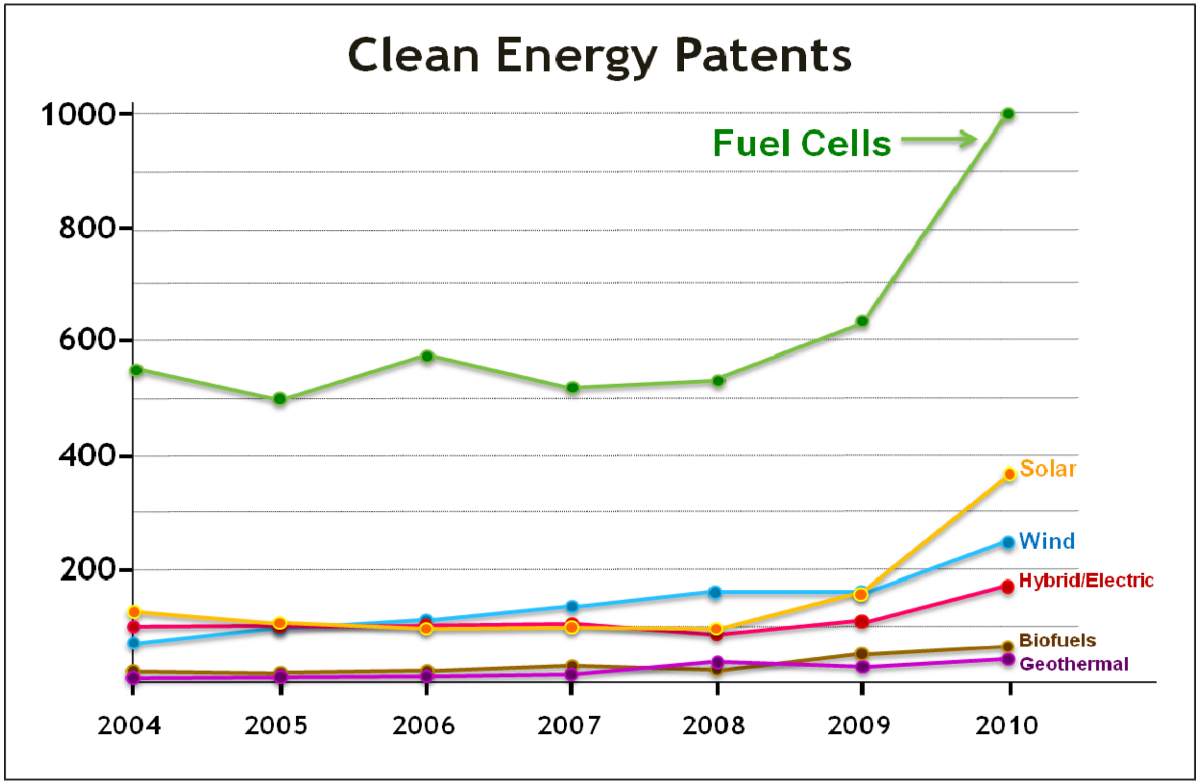

Source: Clean Energy Patent Growth Index[1]

- Fuel cell patents lead in the clean energy field (since 2002), with nearly 1,000 fuel cell patents worldwide in 2010.
  - 3X more than the second place holder, solar, with just ~360 patents.
  - Number of fuel cell patents grew > 57 % in 2010.

[1] http://cepgi.typepad.com/heslin_rothenberg_farley_/

Federal Role in Fuel Cells: RD&D to Deployments

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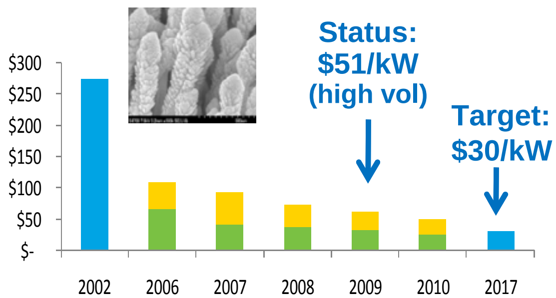
DOE R&D

- ***Reduces cost and improves performance***

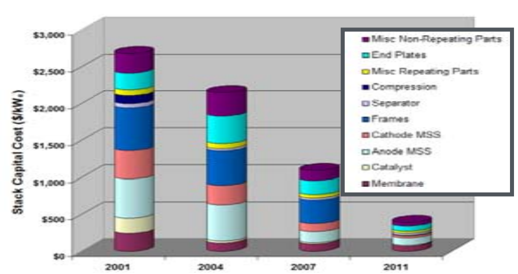
Examples:

Transportation Fuel Cell System Cost

- projected to high-volume (500,000 units per year) -



→ Reduced cost of fuel cells 30% since 2008, 80% since 2001



→ Reduced cost of electrolyzer stacks 60% since 2007

DOE Demonstrations & Technology Validation

- ***Validate advanced technologies under real-world conditions***
- ***Feedback guides R&D***

Examples—validated:

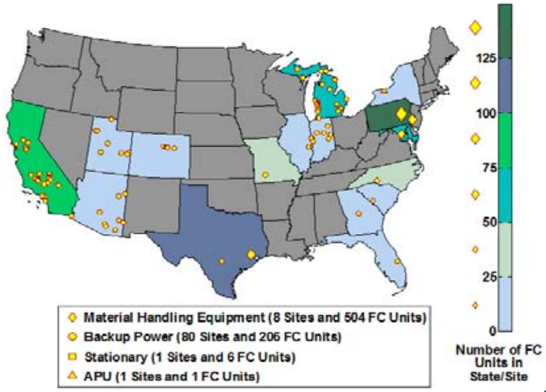
- ***59% efficiency***
- ***254 mile range (independently validated 430-mile range)***
- ***75,000-mi durability***

Program also includes enabling activities such as codes & standards, analysis, and education.

Deployments

- ***DOE Loan Guarantees (TBD)***
- ***DOE Recovery Act Projects***
- ***Government Early Adoption (DoD, FAA, California, etc.)***
- ***Tax Credits: 1603, 48C***

Recovery Act & Market Transformation Deployments



> 1,000 fuel cell deployments in ~ 2 years

Fuel Cells- Sensitivity Analysis Example

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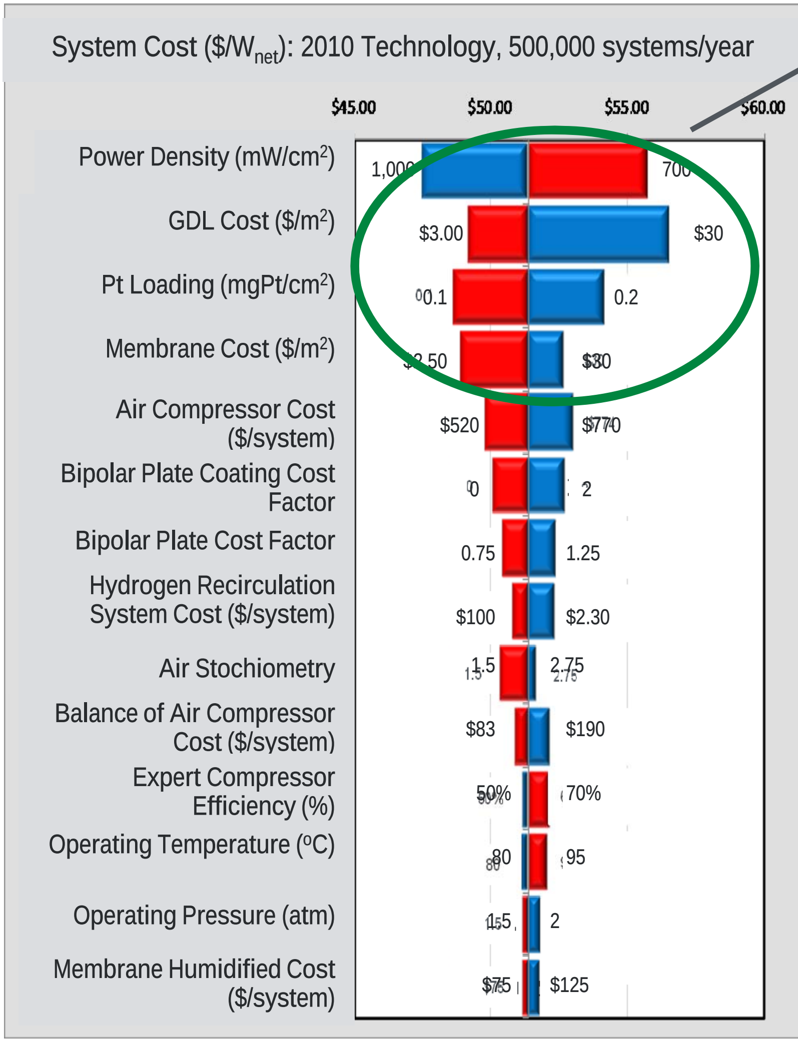
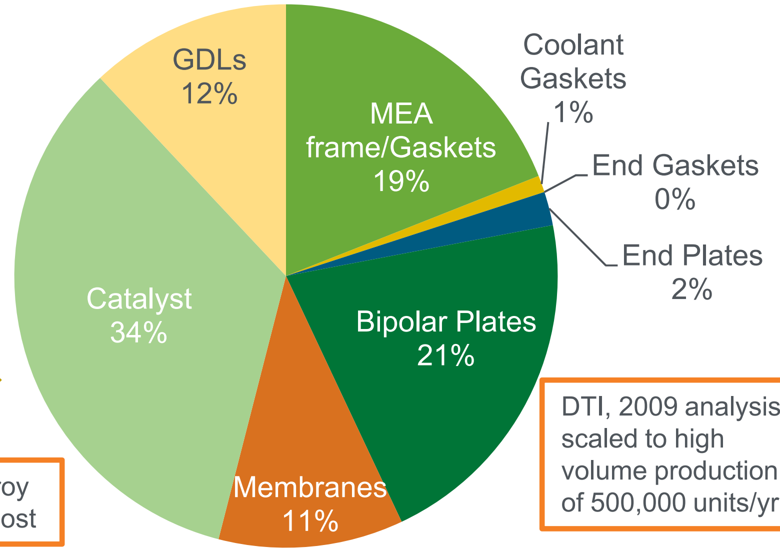
Challenges:

- Platinum (Pt) cost is ~34% of total stack cost
- Catalyst durability needs improvement



Key Focus Areas for R&D

Stack Cost - $26/kW



Used $1100/Troy Ounce for Pt Cost

DTI, 2009 analysis, scaled to high volume production of 500,000 units/yr

Strategies to Address Challenges - Examples

- Lower PGM Content
  - Improved Pt catalyst utilization and durability
- Pt Alloys
  - Pt-based alloys with comparable performance to Pt and cost less
- Novel Support Structures
  - Non-carbon supports and alternative carbon structures
- Non-PGM catalysts
  - Non-precious metal catalysts with improved performance and durability

Progress – Fuel Cell R&D

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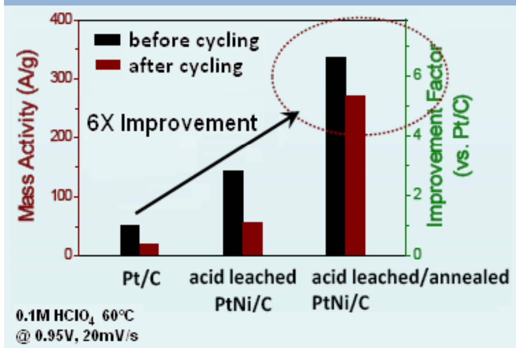
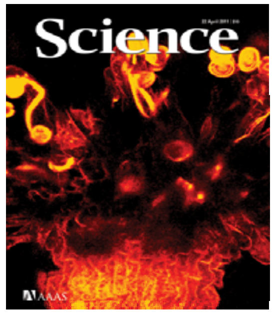
Progress continues in low and zero Pt catalysts





G. Wu, K. L. More, C. M. Johnston, P. Zelenay, *Science*, **332**, 443-7 (2011)

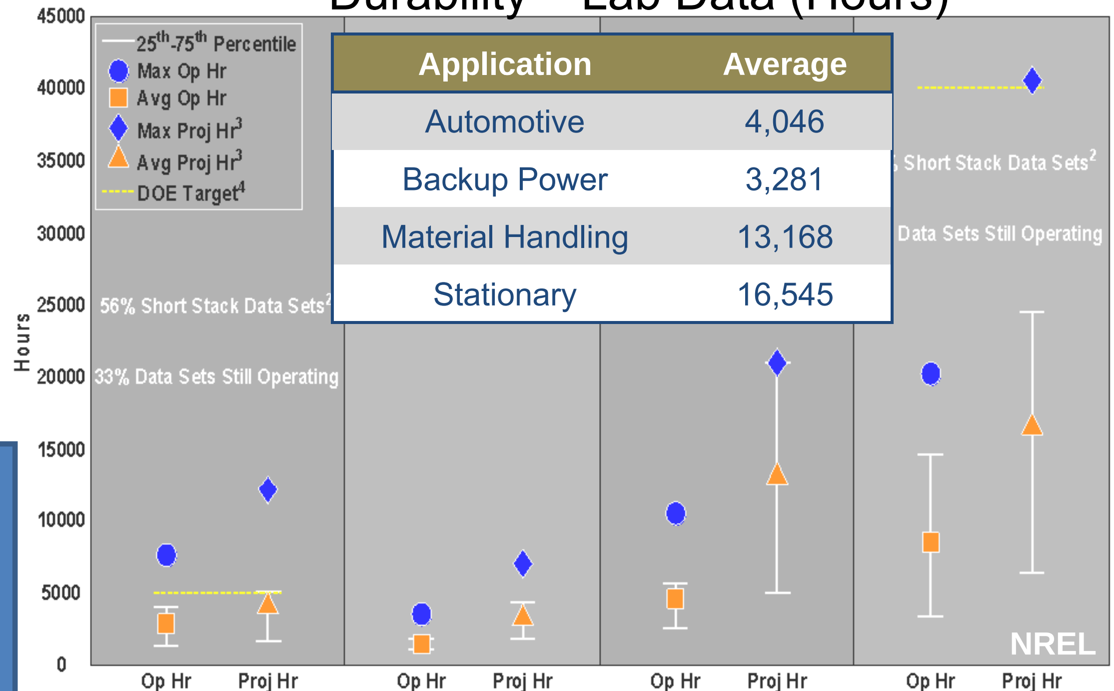
- **Developed and demonstrated non PGM catalysts (polyaniline/ cyanamide-based catalysts)**
- **Demonstrated more than 6X the performance of Pt using nanosegregated binary and ternary Pt alloy catalysts**

R. Adzic honored as Brookhaven Natl Lab Inventor of the Year for his work on fuel cell catalysis!

LANL, ORNL, ANL, BNL

Tracking durability for diverse applications. Maximum projected durability exceeds some DOE targets.

Durability – Lab Data (Hours)



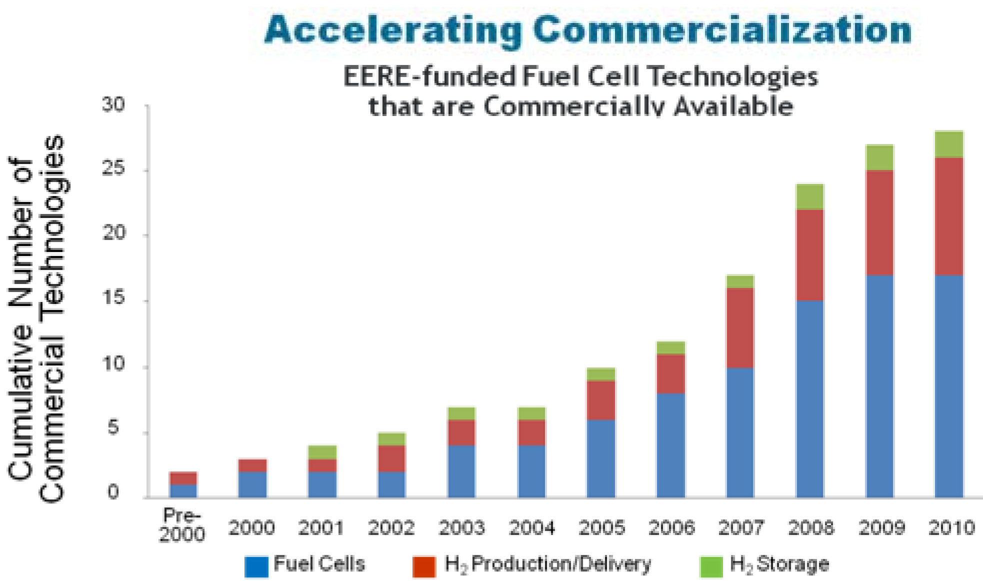
Application	Average
Automotive	4,046
Backup Power	3,281
Material Handling	13,168
Stationary	16,545

Tracking durability data from multiple companies (NREL)

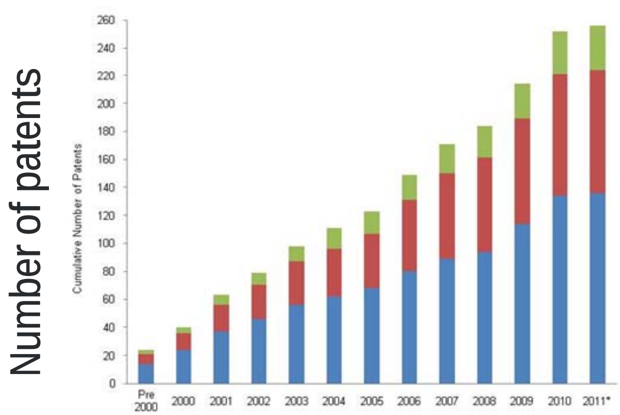
- **Demonstrated >10,000 hours for SOFCs (Acumentrics)**
- **Achieved 10,000 simulated start/stop cycles with new catalyst, greatly exceeding target (3M)**

Assessing the Program - Impact
Commercializing Technologies

DOE funding directly led to ~30 hydrogen and fuel cell technologies in the market.



Source: Pacific Northwest National Laboratory
http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/pathways_success_hfcit.pdf

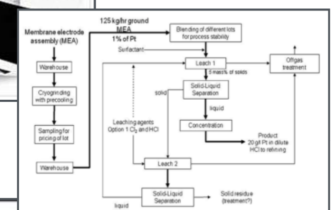


256 PATENTS resulting from EERE-funded R&D:
- 136 fuel cell
- 88 H_2 production and delivery
- 32 H_2 storage

Examples

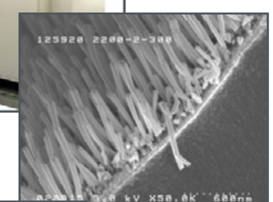
DuPont

BASF Catalysts LLC

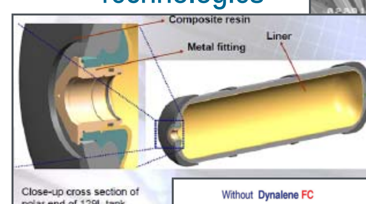


Proton Energy Systems

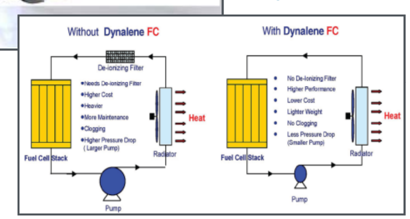
3M



Quantum Technologies



Dyanlene, Inc.



Employment Impacts of Early Markets

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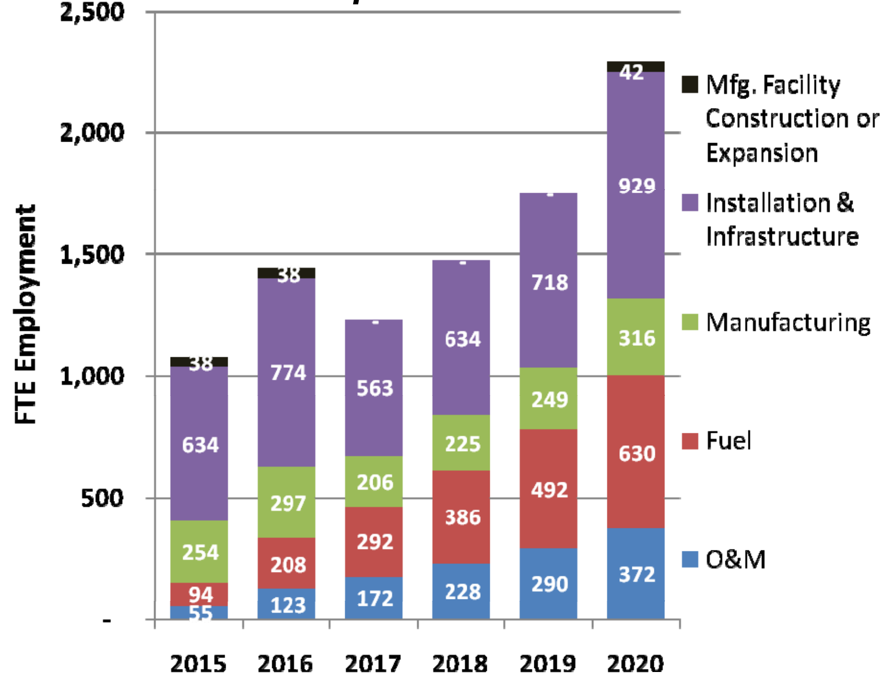
Developed user-friendly tool to calculate economic impacts

REQUIRED USER INPUT FIELDS	
Select State or Region	NE
Type of Fuel Cell	PEMFC
Application	Stationary - Backup
Average Size of Manufactured Fuel Cell	5
Fuel Cells Manufactured by Year	2000
Annual Fuel Cell Production (kW/year)	10,000
Time Frame (years)	5

OPTIONAL USER INPUT FIELDS	
Existing Fuel Cell Production Capacity (kW/year)	0
Additional Manufacturing Capacity to be Constructed (kW/year)	10,000
Sales Price ($/kW)	$2,000
Production Cost ($/kW, initial)	$1,301
Progress Ratio	0.97
Production Volume for Initial Cost	10,000
Scale Elasticity	-0.2
Full Scale Production Level (kW/year)	25,000
Annual Rate of Technological Progress	2%
Average Production Cost Over Time Frame ($/kW)	$1,098
Installation Cost ($/kW)	TBD
Operations & Maintenance Cost ($/kW, annual)	TBD

Argonne National Lab/RCF

Preliminary Analysis
Gross National Impact of PEMFCs in Forklifts



Includes ***short-term jobs*** (construction/ expansion of mfg capacity, installation & infrastructure) & ***on-going jobs*** (manufacturing, O&M and fuel production & delivery)

Technology/Market Assumptions:

- $1,300/kW initial mfg cost (*Battelle*), $4,200/kW retail price.
- Shipments reach 3,300 annually by 2020 *(Greene et. al.)* out of ~100,000.
- 15,000 FC forklifts in operation by 2020 (<2 percent of Class 1-3 forklifts).
- Average of 60 fuel cells/site, 250 site installations by 2020.
- Tax credit expires in 2016.

Early Market Cost Reduction Analysis

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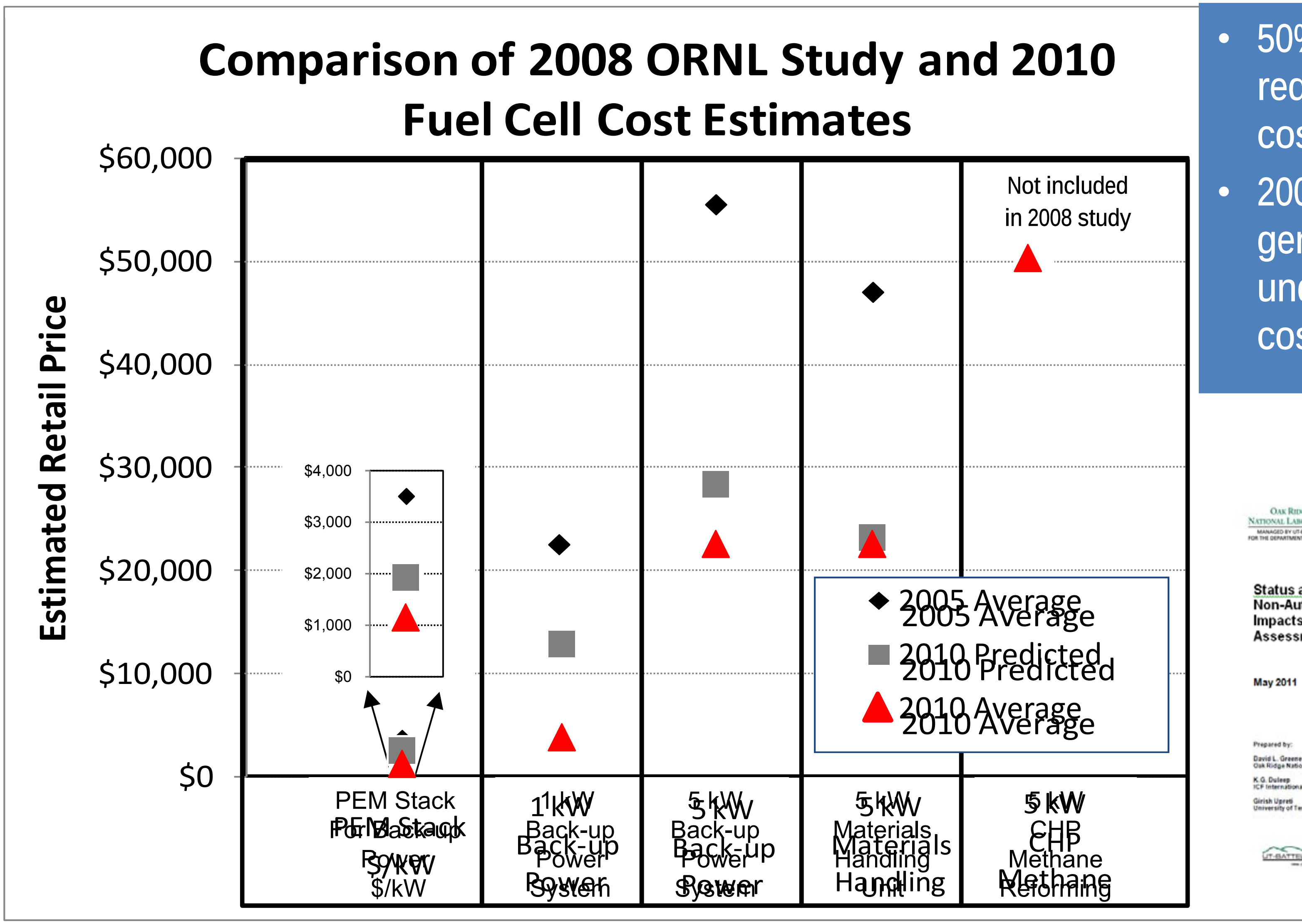
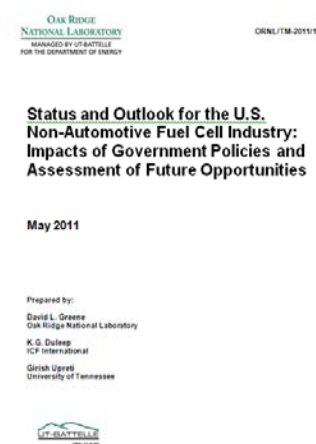


- 50% or greater reduction in costs
- 2008 model generally underestimated cost reductions



2005 and 2010 averages based on estimates supplied by OEMs. 2010 predicted assumed government procurements of 2,175 units per year, total for all market segments. Predictions assumed a progress ratio of 0.9 and scale elasticity of -0.2.

ORNL

DOE has launched an initiative to stimulate energy innovation, by licensing federal patents to start-up companies at reduced rates.

Opportunity for start-up businesses to utilize pioneering technology in federal patents at reduced cost with streamlined processing.

$1,000 licensing available on 15,000 patents held by 17 national labs from May 2 to December 15, 2011

- Businesses must identify a technology of interest and submit a business plan by **December 15, 2011.**
- Upfront fees are $1,000 and other license terms will be negotiated on a case by case basis.
- DOE will standardize process to reduce time and cost.
- 3rd Annual ARPA-E Energy Innovation Summit in 2012 will showcase successful entrepreneurs.

Visit DOE's Energy Innovation Portal
> 60 hydrogen and fuel cell technologies available
http://techportal.eere.energy.gov/category.do/categoryID=5

DOE is making it easier for companies to conduct collaborative R&D at national labs, reducing the upfront payment from covering the first 90 days of research to 60 days.

IPHE Update

Germany is the Chair and Secretariat for IPHE through at least November 2012

Last Meeting:

- May 13 14, 2011 Vancouver, BC, Canada
- Key Decisions:
  - IPHE will host a high-level stakeholder roundtable meeting in November 2011
  - Develop a Policy Paper that provides a baseline accounting of existing policies in IPHE countries that promote the incorporation of H2 and FCs into the market. (U.S. Lead)
  - IPHE will host a workshop in 2012 on hydrogen as a renewable energy storage medium. The workshop planning committee includes France, Canada, EC, Germany, Korea, Japan, NZ, and U.S.
  - Collaborating with the IEA Hydrogen Implementing Agreement on the Task 30 Global Hydrogen Systems Analysis. Key non-IEA HIA members such as China will provide data for the global analysis.

Stakeholder Roundtable Information

- ✓ November 17, 2011 in Berlin, Germany
- ✓ Designed to bring together senior IPHE government and senior private sector representatives
- ✓ Goal: To gain insights from key H2 and FC stakeholders regarding the current status of the technology, the progress made to date, and the remaining commercialization challenges.
- ✓ IPHE will use the outcomes from this workshop in its determination of whether to continue IPHE after its initial 10 year term (Nov. 2013), and how to focus the activities of IPHE if it is continued.

EERE H_2 & Fuel Cells Budgets

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Funding *($ in thousands)*

Key Activity	FY 2009[4]	FY 2010	FY 2011 Appropriation	FY 2012 Request
Fuel Cell Systems R&D[1]	**-**	**75,609**	**43,000**	**45,450**
Fuel Cell Stack Component R&D	61,133			
Transportation Systems R&D	6,435			-
Distributed Energy Systems R&D	9,750			-
Fuel Processor R&D	2,750			-
Hydrogen Fuel R&D[2]	**-**	**45,750**	**33,000**	**35,000**
Hydrogen Production & Delivery R&D	10,000			-
Hydrogen Storage R&D	57,823			-
Technology Validation	**14,789[5]**	**13,005**	**9,000**	**8,000**
Market Transformation[3]	**4,747**	**15,005**		**-**
Early Markets	4,747	15,005		-
Safety, Codes & Standards	12,238[5]	8,653	**7,000**	**7,000**
Education	4,200[5]	2,000		-
Systems Analysis	**7,520**	**5,408**	**3,000**	**3,000**
Manufacturing R&D	**4,480**	**4,867**	**3,000**	**2,000**
Total	**$195,865**	**$170,297**	**98,000**	**$100,450[6]**

[1] Fuel Cell Systems R &D includes Fuel Cell Stack Component R&D, Transportation Systems R&D, Distributed Energy Systems R&D, and Fuel Processor R&D [2] Hydrogen Fuel R&D includes Hydrogen Production & Delivery R&D and Hydrogen Storage R&D [3] No Market Transformation in FY 2012. [4] FY 2009 Recovery Act funding of $42.967M not shown in table [5] Under Vehicle Technologies Budget in FY 2009 [6] Includes SBIR/STTR funds to be transferred to the Science Appropriation; all prior years shown exclude this funding

EERE Budget: *FY09 – FY12*

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Funding *($ in thousands)*				
Activity	**FY 2009**	**FY 2010**	***FY 2011 Appropriation***	**FY 2012 *Request***
Biomass and Biorefinery Systems	214,245	216,225	182,695	340,500
Building Technologies	138,113	219,046	210,500	470,700
Federal Energy Management Program	22,000	32,000	30,402	33,072
Geothermal Technology	43,322	43,120	38,003	101,535
Hydrogen Technology	164,638	0	0	0
Hydrogen and Fuel Cell Technologies	0	170,297	98,000	100,450
Water Power	39,082	48,669	30,000	38,500
Industrial Technologies	88,196	94,270	108,241	319,784
Solar Energy	172,414	243,396	263,500	457,000
Vehicle Technologies	267,143	304,223	300,000	588,003
Weatherization & Intergovernmental Activities	516,000**	270,000	231,300	393,798
Wind Energy	54,370	79,011	80,000	126,859
Facilities & Infrastructure	76,000	19,000	51,000	26,407
Strategic Programs	18,157	45,000	32,000	53,204
Program Direction	127,620	140,000	170,000	176,605
Congressionally Directed Activities	228,803	292,135	0	0
RE-ENERGYSE	0	0	0	0
Adjustments	-13,238	0	-30,000	-26,364
Total	**$2,156,865**	**2,216,392**	**1,795,641**	**3,200,053**

* SBIR/STTR funding transferred in FY 2009 was $19,327,840 for the SBIR program and $2,347,160 for the STTR program.

** Includes $250.0 million in emergency funding for the Weatherization Assistance Grants program provided by P.L. 111-6, "The Continuing Appropriations Resolution, 2009."

Collaborations

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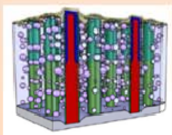
Examples of Cross-Office Collaborative Successes

Office of Science U.S. DEPARTMENT OF ENERGY

Advancing fundamental science knowledge base

JCAP

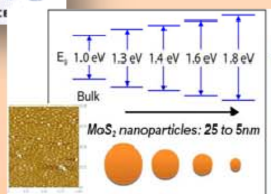
Solar to Fuels Hub



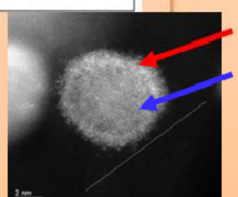
Nanowire based solar fuels generation (CalTech)

EFRC ENERGY FRONTIER RESEARCH CE

Bandgap tailoring (Stanford)



Mechanistic understanding of catalysts



Pt monolayer

Pd core

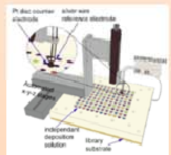
Biological H_2 production

Materials-based H_2 storage

U.S. Department of Energy EERE

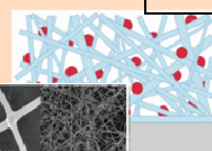
Applied RD&D of innovative technologies

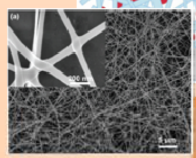
High Throughput Processes (UCSB)



Standard protocols and benchmarking

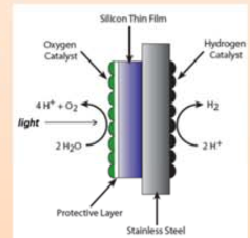
Working Groups PEC, Biological, High T Membranes, Storage Systems





Nano-catalyst support scaffold (Stanford)

Using ARPA-E developed catalyst in water splitting device



mwoe Midwest Optoelectronics

arpa·e

ARPA-E: Focus on creative, high-risk transformational energy research

Alkaline Membranes

Sun Catalytix

Developing novel catalysts (high risk/high impact)

Blue Ribbon Panel: H_2 Production

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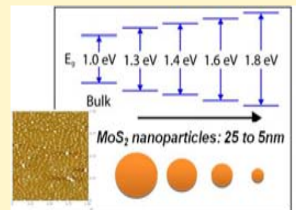
Provide guidance to DOE FCT Program on technical focus areas for H_2 production and coordination with other agencies and offices to optimize effectiveness of the H_2 Production Portfolio

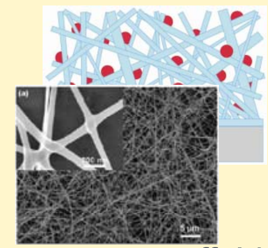
Going Forward

1. HTAC agrees to form Panel
2. HTAC/Chair selects a member to lead efforts
3. DOE/HTAC defines purpose and focus of Panel
4. Identify size of panel and potential members (Industry, Lab, University)
5. Set Dates/Location (1-1.75 day)
6. Invite panel members
7. Provide recommendations to DOE

Examples of Current Collaborations

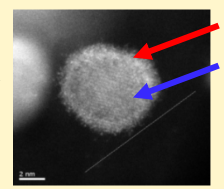


Bandgap tailoring



Nano-catalyst support scaffold (Stanford)

Mechanistic understanding of catalysts



Pt monolayer

Pd core

*HTAC may choose to reconvene the panel in a year to two to assess program

H-Prize

$1 Million for Breakthrough Advances in Materials for Hydrogen Storage

Prize Requirements:

- Gravimetric capacity:
  - >7.5 weight % releasable H_2:
  - Reversible H_2 between -40 to 85ºC and 1.5-150 bar
- Volumetric capacity:
  - > 70 g/liter total releasable H_2
- Charging kinetics:
  - $\geq 4 \times 10^{-4}$ g of H_2 per g of material per second
  - Measured at inlet H_2 gas temperature between -40 to 85ºC
  - Inlet H_2 pressure ≤ 150 bar
- Discharge kinetics:
  - $\geq 2 \times 10^{-5}$ g of H_2 per g of material per second
  - Measured at temperature between -40 to 85ºC
  - Oulet H_2 pressure ≥ 1.5 bar
- Cycle life:
  - 100 cycles: maintain reversible capacity ≥ 95% of the gravimetric capacity target.

Initial Interest Deadline:
February 15, 2010
20 teams registered with Hydrogen Education Foundation.

Data for Review Deadline:
November 15, 2010
Two submissions received by deadline for review by independent panel

No Winner Announced – difficult prize requirements not yet met

Potential for new H-Prize in Production & Delivery areas. For more information, visit http://hydrogenprize.org/

Announcements

RFI: Tech. Validation

Closed

Areas of Interest

- Innovative concepts for:
  - Stationary fuel cell systems for residential and commercial applications
  - Combined-heat-hydrogen-and-power (CHHP) co-production fuel cell systems
- Technology Validation projects for other markets

For more information:

http://www1.eere.energy.gov/hydrogenandfuelcells/news_detail.html?news_id=16873

http://www07.grants.gov/search/search.do?&mode=VIEW&oppId=84333

RFI: Bus Targets

Closes July 1, 2011

Areas of Interest

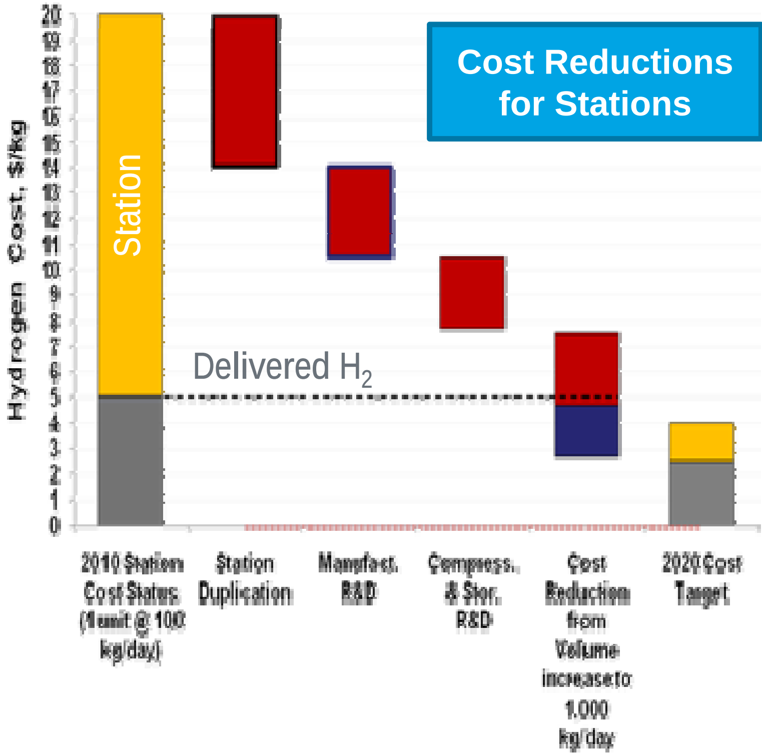
- Solicit feedback on performance, durability and cost targets for fuel cell transit buses
- Sponsored by

U.S. DEPARTMENT OF ENERGY

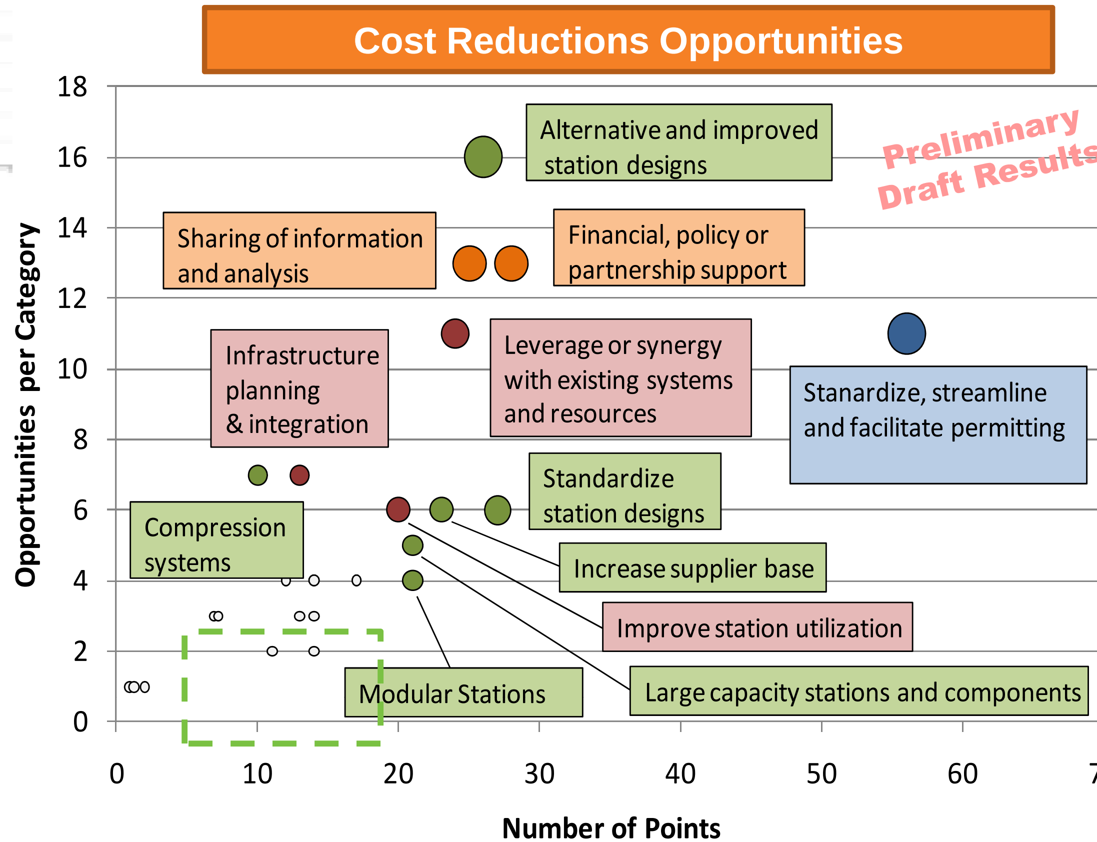
FTA United States Department of Transportation Federal Transit Administration

Questions may be addressed to:
DOEFCBUSRFI@go.doe.gov

Progress – Infrastructure



Clear opportunities for reducing the cost of infrastructure. High-priority opportunities include station designs, streamlining of the permitting process, and financial, policy and partnership support. Cost calculator developed.



1. Cost reduction from station duplication will require ~120 stations and was based on 3% reduction for a doubling of capacity.
2. Cost of hydrogen delivered to station is ~$5/kg.
3. Station cost reductions based on ANL Hydrogen Delivery Systems Analysis Model (HDSAM).
4. The current station cost is based on costs from the current California state funded stations. The capital cost for the station is $2.5 million.

Next Steps

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

- Enabling market penetration
  - Interagency Task Force, economies of scale, codes & standards, education, end user forum, etc.
- Portfolio optimization
  - RD&D under constrained budget scenario
  - Strategies for addressing early markets as well as sustaining long term goals, leveraging resources
- Infrastructure
  - Strategies for early markets as well as transportation
  - Fostering innovation for H2 production (e.g. point/local sources, energy storage, prize, blue ribbon panel)
  - Natural gas infrastructure workshop

Future: Interaction with ERAC (EERE Advisory Committee)

- Fuel Cell Technologies Program Opportunities Available
  - Conduct applied research at universities, national laboratories, and other research facilities
  - Up to five positions are available in the areas of hydrogen production, hydrogen delivery, hydrogen storage, and fuel cells
    - ❑ Applications are due June 30, 2011
    - ❑ Winners will be announced mid-August
    - ❑ Fellows will begin in mid-November 2011

eere.energy.gov/education/postdoctoral_fellowships/

Postdoctoral fellowships in hydrogen and fuel cell research ▸

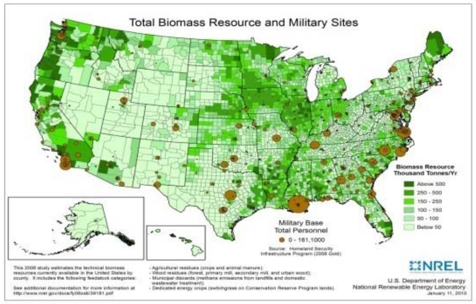
Additional Information

Sunita.Satyapal@ee.doe.gov

www.hydrogenandfuelcells.energy.gov

DOD-DOE Memorandum of Understanding

Strengthen coordination and partnerships between DOE and DOD

Workshops Held	Outcomes & Next Steps	Impact
Waste-to-Energy	DOD-DOE working group formed to identify opportunities.	
Aviation APUs	Industry working group established	
Shipboard APUs	Bio/logistics fuels reforming	

634,000 million BTUs potential energy savings using waste-to-energy CHP[2]

Potentially reduce NOx emissions by **~900-2,200 tons/yr** for aircraft & **1,200-2,000 tons/yr** for GSE[2]

Shipboard fuel cells capable of saving **~11,000-16,000 bbls/ship/yr**[2]

 Source: US DOE 6/22/2011 [1]FCHEA, http://www.fchea.org/index.php?id=14, [2] DOD Estimates

The Case for Fuel Cell Forklifts

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

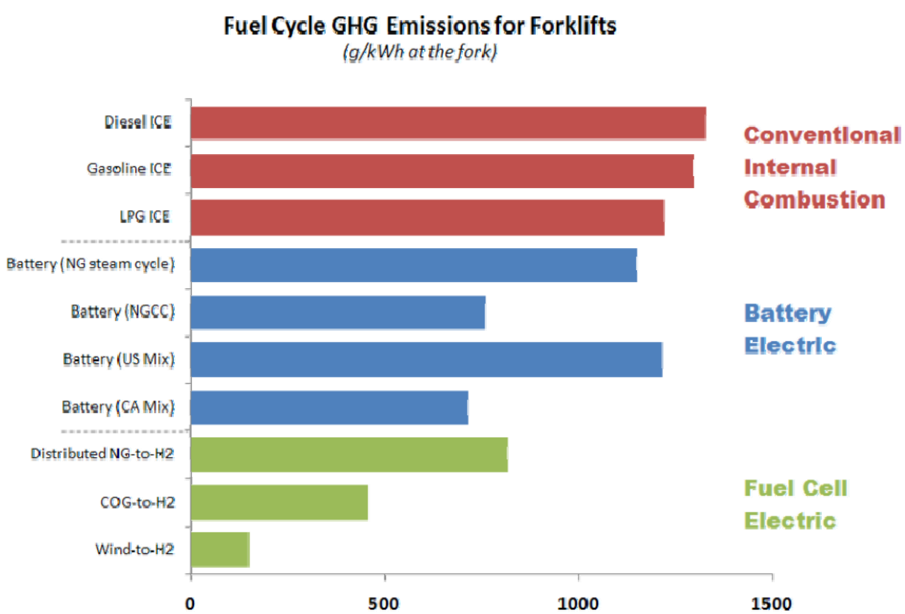
Fuel cell forklifts offer several advantages compared to conventional fork lift technology

Compared to conventional forklifts, fuel cell forklifts have:

- 1.5 times lower maintenance cost
- 8 times lower refueling/recharging labor cost
- 2 times lower net present value of total system cost

Preliminary Analysis: Comparison of PEM Fuel Cell- and Battery-Powered Forklifts

Time for Refueling/ Changing Batteries	4-8 min/day	45-60 min/day (for battery change-outs) 8 hours (for battery recharging & cooling)
Labor Cost of Refueling/Recharging	$1,100/year	$8,750/year
NPV of Capital Costs	$12,600 ($18,000 w/o incentives)	$14,000
NPV of O&M Costs (including fuel)	$52,000	$128,000



Hydrogen and fuel cells can offer substantial reductions in greenhouse gas emissions for forklifts can provide significant environmental and economic benefits to the end-user

Progress – Technology Validation

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

Demonstrations are essential for validating technologies in integrated systems

RECENT PROGRESS

Vehicles & Infrastructure

- 155 fuel cell vehicles and 24 hydrogen fueling stations
- Over 3.0 million miles traveled
- Over 131 thousand total vehicle hours driven
- 2,500 hours (nearly 75K miles) durability
- Fuel cell efficiency 53-59%
- Vehicle Range: ~196 – 254 miles (430 miles on separate FCEV)

Buses (with DOT)

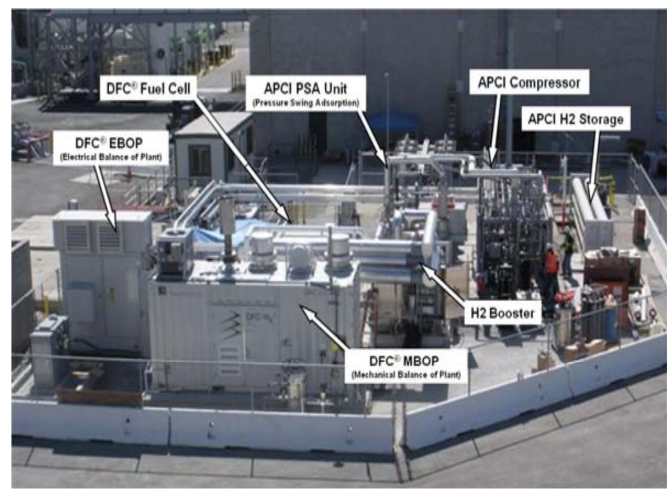
- H_2 fuel cell buses have a 42% to 139% better fuel economy when compared to diesel & CNG buses

Forklifts

- Over 44,000 refuelings at Defense Logistics Agency site

CHHP

- Achieved 54% (hydrogen + power) efficiency of unit when operating in hydrogen coproduction mode
- 100 kg/day capacity, renewable hydrogen supply



Progress – Market Transformation & Recovery Act

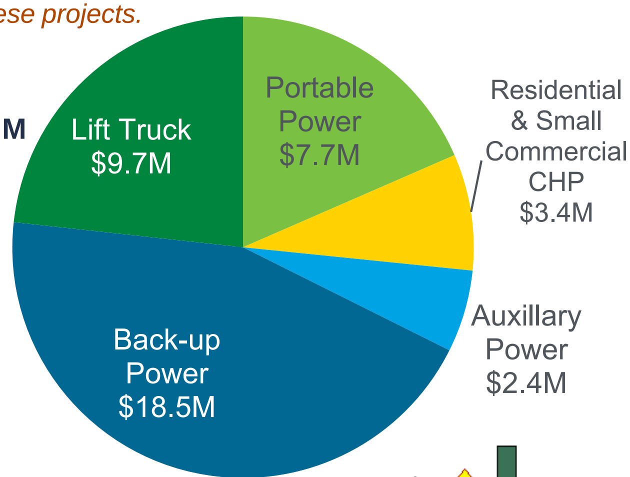
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Deployed more than 480 fuel cells to date for use in forklifts and backup power at several companies including Sprint, AT&T, FedEX, Kimberly Clark, and Whole Foods

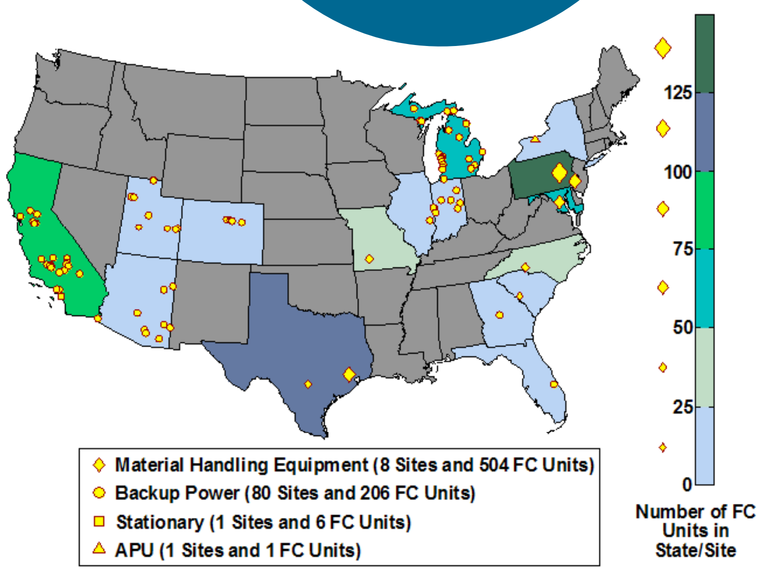
FROM the LABORATORY to DEPLOYMENT:

DOE funding has supported R&D by <u>all</u> of the fuel cell suppliers involved in these projects.

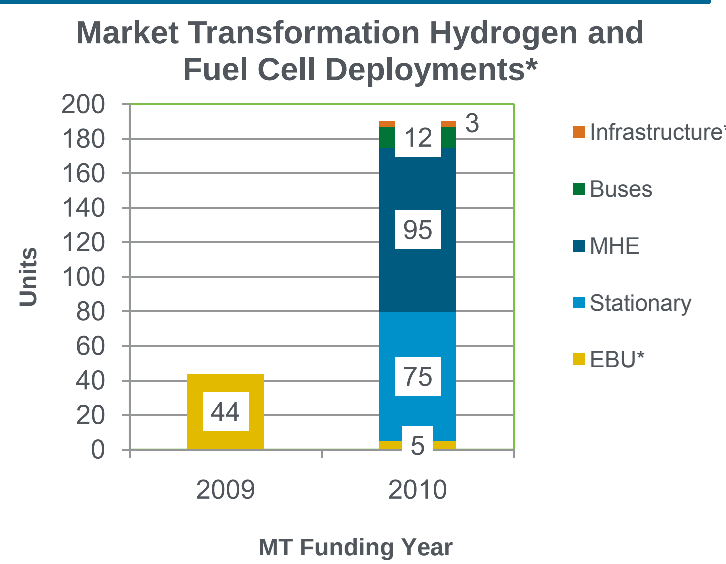
DOE: $42 M
Cost-share: $54 M
Total: $96 M.



- **Lift trucks**
  - FedEX Freight East, GENCO, Nuvera Fuel Cells, Sysco Houston
- **Back-up Power**
  - Plug Power, Inc., ReliOn, Inc., Sprint Nextel
- **Portable Power**
  - Jadoo Power, MTI MicroFuel Cells, University of North Florida
- **Auxiliary Power**
  - Delphi Automotive



JOBS STATUS
(Jan 2011)
~50 jobs reported on Recovery.gov

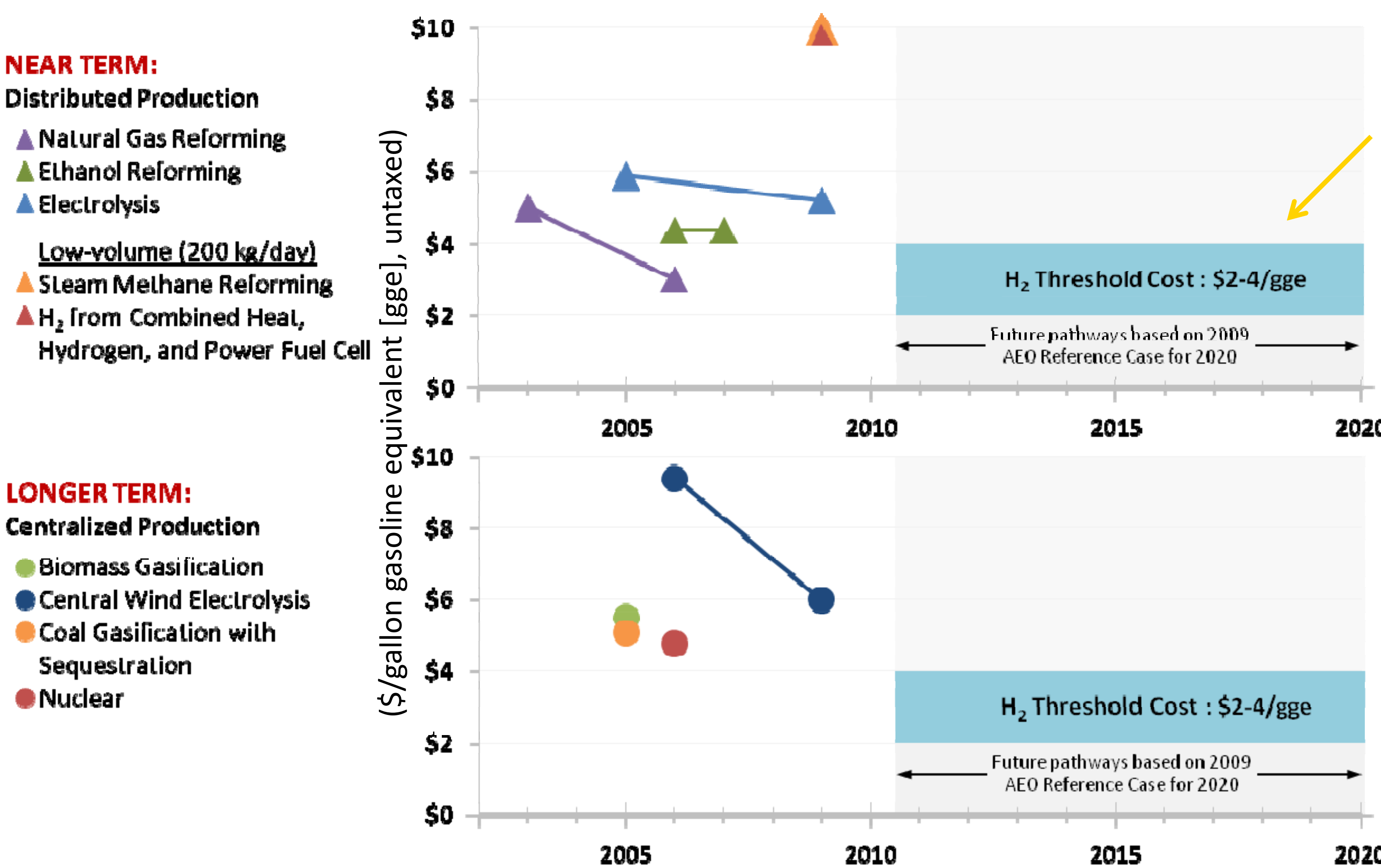


Progress – Hydrogen Production

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

High volume projected costs for hydrogen production technologies continue to decrease. Low volume/early market costs are still high. Hydrogen cost range reassessed – includes gasoline cost volatility and range of vehicle assumptions.

Projected High-Volume Cost of Hydrogen (Dispensed)—Status



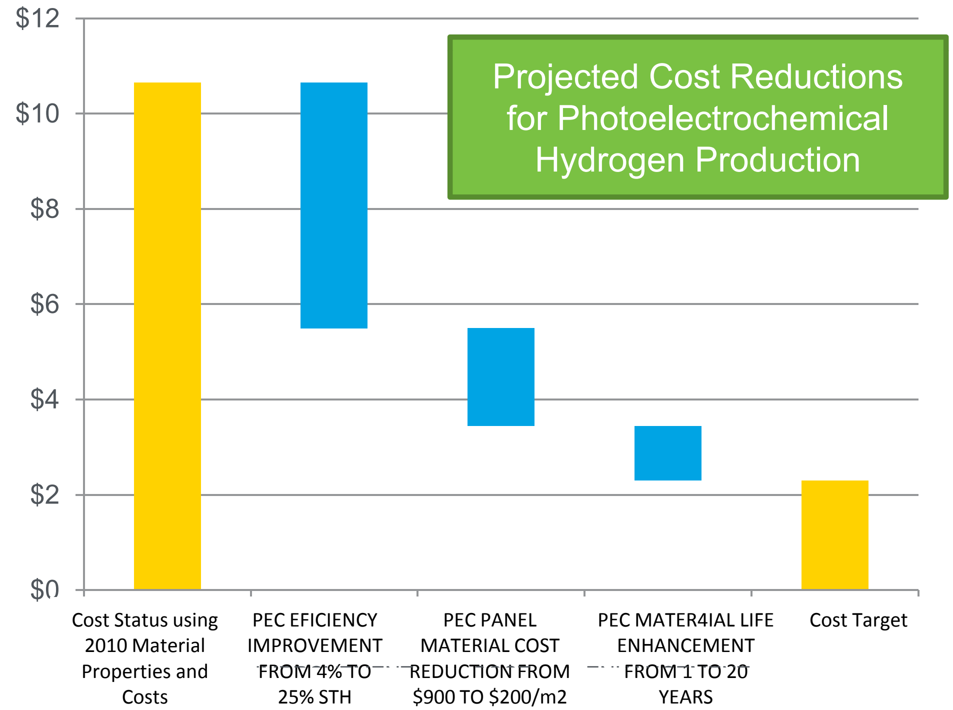
H_2 threshold cost being updated from $2-$3/gge

Notes:

Data points are being updated to the 2009 AEO reference case.

The 2010 Technology Validation results show a cost range of $8-$10/gge for a 1,500 kg/day distributed natural gas and $10-$13/gge for a 1,500 kg/day distributed electrolysis hydrogen station.

Waterfall Charts- Preliminary PEC Analysis



$/kg H2 cost sensitivities for [long-, mid-, near-term] materials targets (based on DTI PEC Technoeconomic Boundary Level Analysis: Type 4 System)

Approaches:

MATERIAL EFFICIENCY: Increase PEC efficiency from 4% (baseline) to 25%.

Focus on novel integrated thin film device structures (e.g., with metal oxides) with multi-junction absorber layers for 1.8-2.2 V and enhanced surface catalysis for efficiency enhancements toward the 25% target

MATERIAL COST: Decrease PEC panel material cost from $900/m^2 to $200/m^2.

Focus on material and processing/fabrication cost reductions, e.g. breakthrough self-assembling semiconductor synthesis approaches (instead of vapor deposition, etc.)

MATERIAL LIFETIME: Increase life from 1 to 20 yrs.

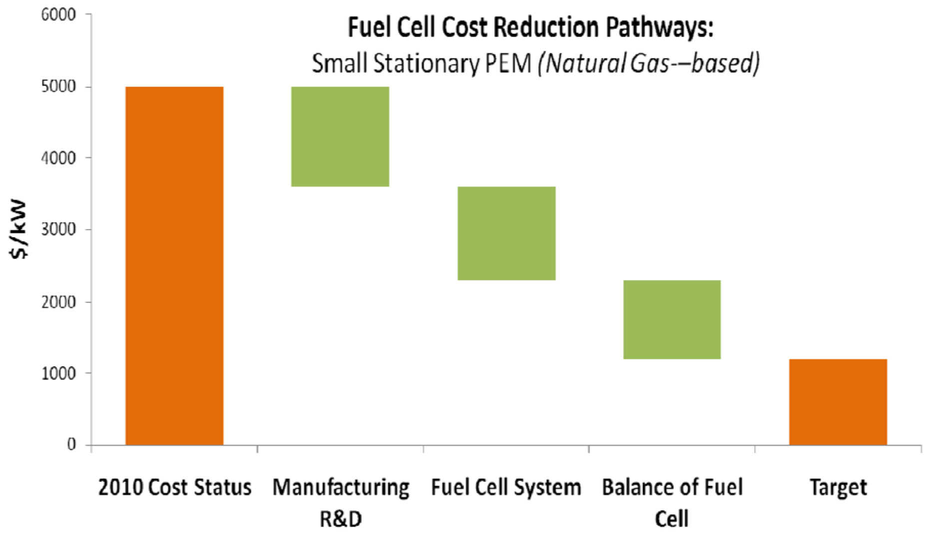
Focus on advanced surface modification strategies to enhance catalysis and mitigate corrosion of the crystalline material systems currently capable of >18% solar-to-hydrogen conversion

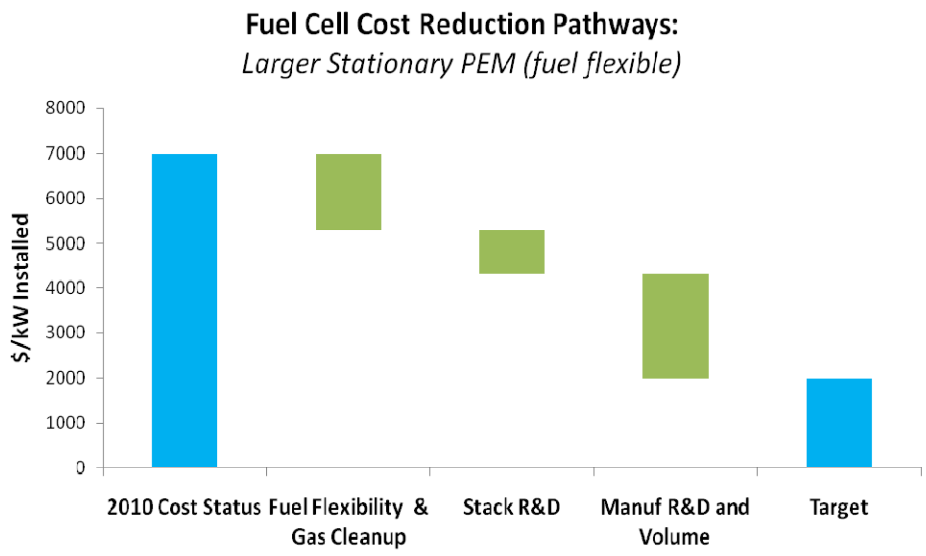
OTHER NEW IDEAS:

Disruptive technologies incorporating nano-structured semiconductor, catalyst and membrane components with the potential for high efficiency and durability using low-cost synthesis routes (e.g. work with EFRC/Solar Hub on approaches such as nanoparticle MoS_2 in porous scaffold)

Cost Reduction Analyses

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





Progress – Fuel Cells

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

Reduced the projected high-volume cost of fuel cells to $51/kW (2010)*

- ***More than 30% reduction since 2008***
- ***More than 80% reduction since 2002***

Ballard has demonstrated advanced gas diffusion layer manufacturing processes that have reduced cost by >50% and increased manufacturing capacity by 4X since 2008

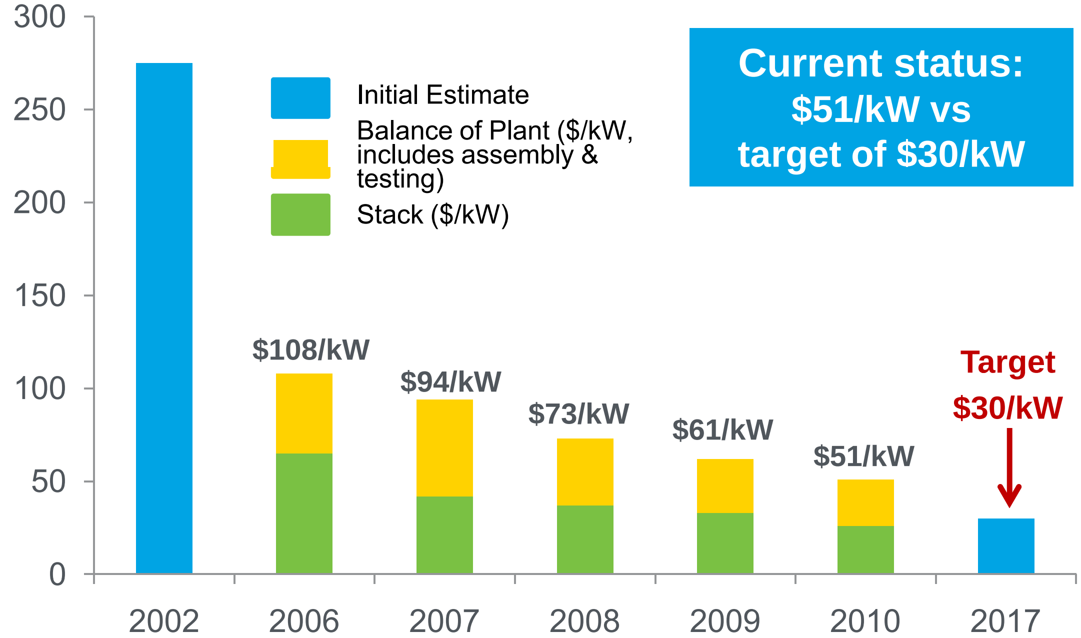
Based on projection to high-volume manufacturing (500,000 units/year).

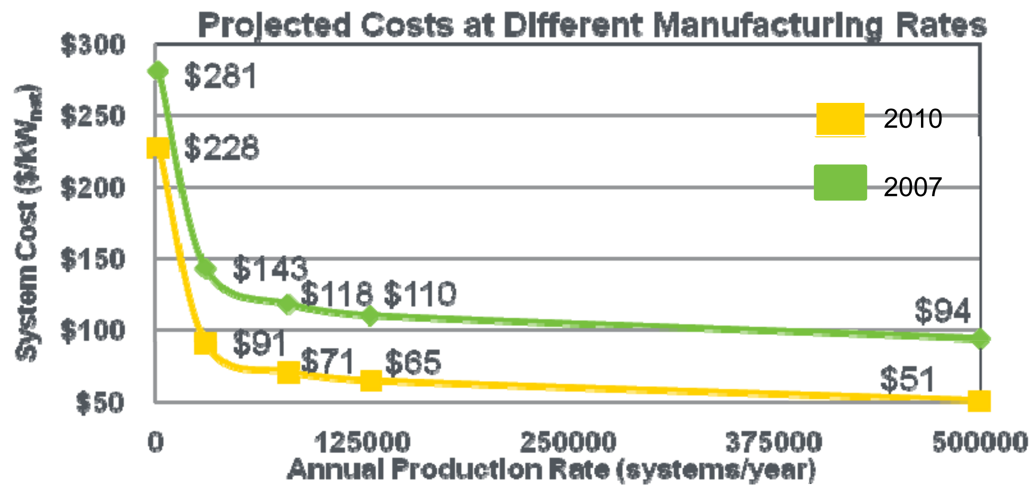
*****Panel found $60 – $80/kW to be a "valid estimate": http://hydrogendoedev.nrel.gov/peer_reviews.html***

http://www.hydrogen.energy.gov/pdfs/10004_fuel_cell_cost.pdf

Projected Transportation Fuel Cell System Cost

-projected to high-volume (500,000 units per year)-



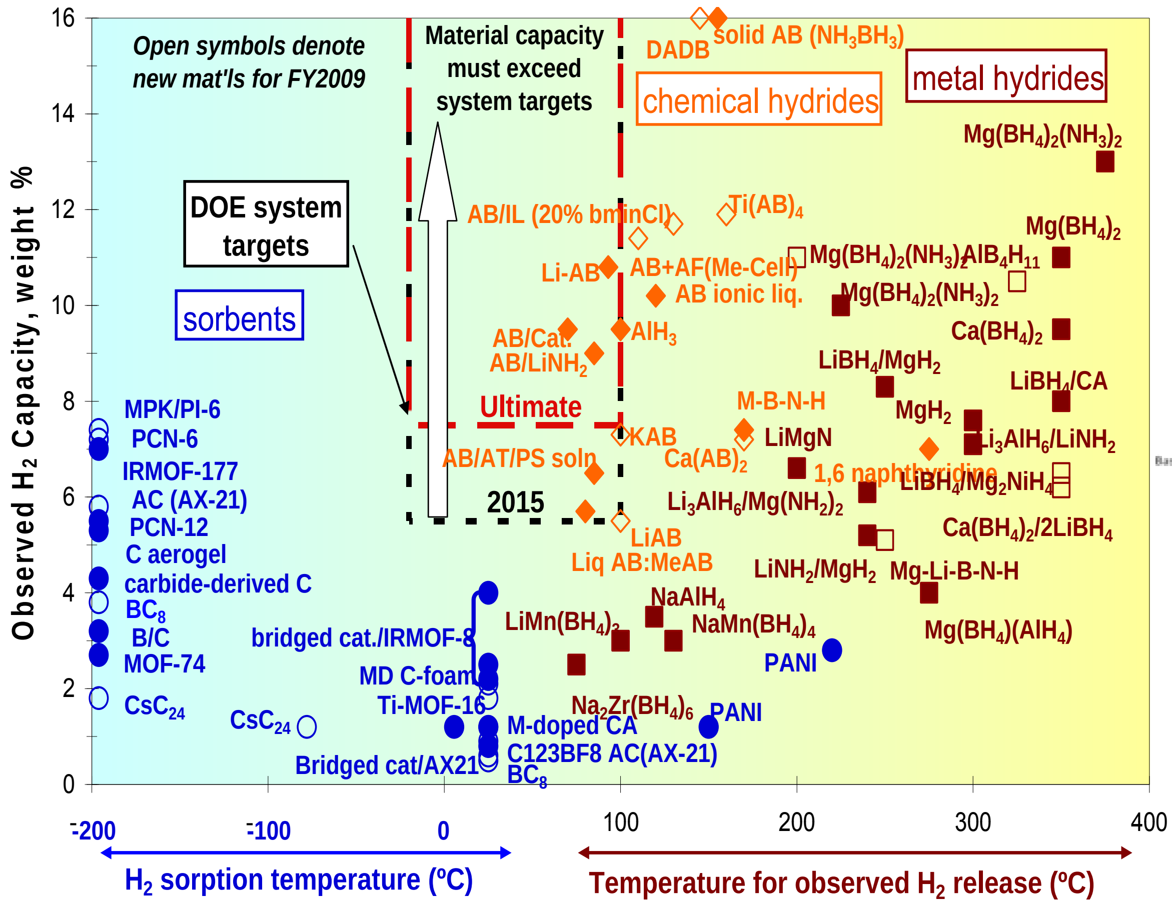


H_2 Storage R&D

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

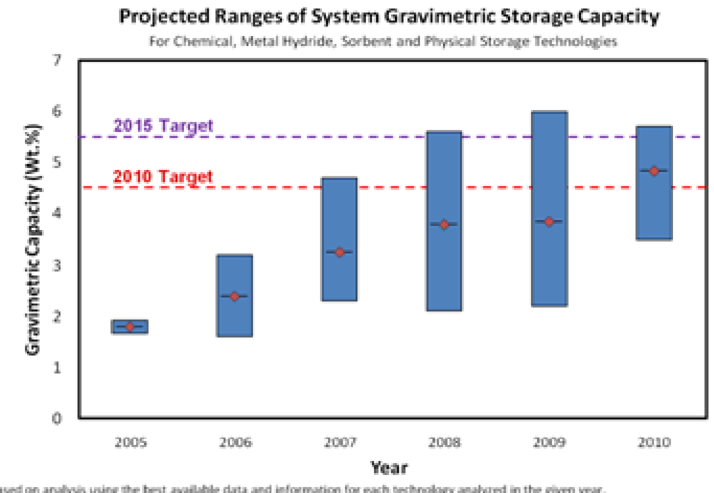
Significant progress has been made but meeting all weight, volume, performance and cost requirements is still challenging.

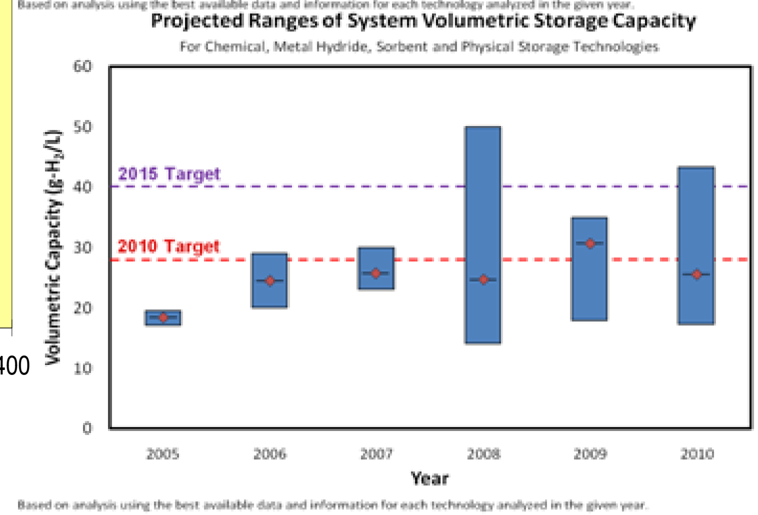
Validated 430 mile range with compressed gas*



*prior accomplishment

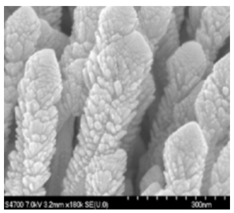
Projected Capacities for Complete 5.6-kg H_2 Storage Systems





DOE – DOT Collaborations

DOE and DOT support the development and deployment of fuel cell technology



Developed low Pt approach
Reduced cost by >30% since 2008, 80% since 2002

DOE RD&D

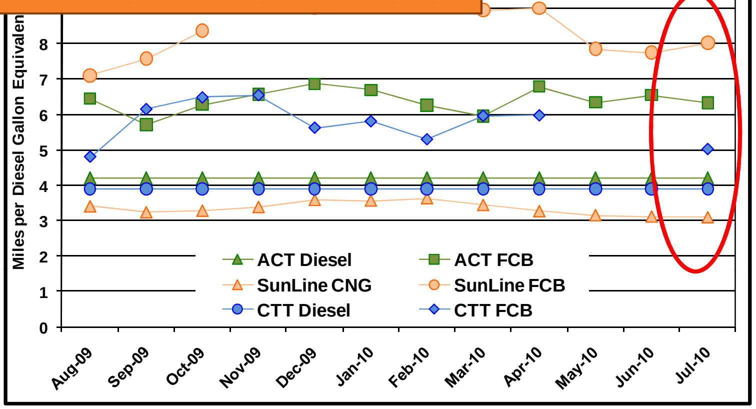
Data Collection & Validation

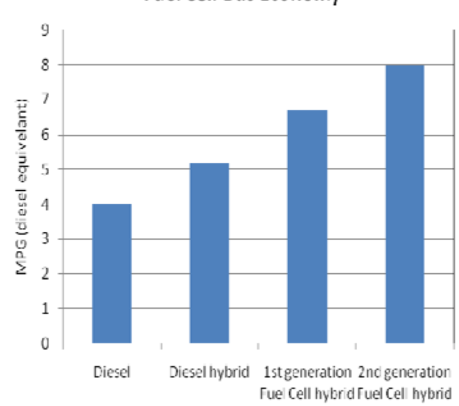
NREL HSDC

National Bus Program
($49 million for 4 years)

DOT Deployment

Fuel Cell buses: 39% to 141% better fuel economy than conventional buses





Projections based on the typical diesel baseline of 4 mpg in an average transit duty cycle

Accomplishments

Demonstrated:

- Doubled fuel economies (8 mpg, >2X compared to diesel buses)
- 41% increase in average miles between roadcall with new fuel cell system (~8,500 MBRC)
- Demonstrated more than 7,000 hr fuel cell durability

DOE Collaboration Opportunities

Fuel Cell Technologies Program

Program	Program Key Focus
Buildings ($471M)	Develop and scale up deployment of technologies, tools, and standards for making residential and commercial buildings more energy-efficient, affordable, and better performing.
Industrial Technologies ($320M)	Research and develop advanced manufacturing and materials technologies and accelerate industrial adoption of energy efficient and clean energy technologies. Help U.S. producers to become global leader in production of clean energy technologies.
Solar ($457M) (e.g. EFRC)	"Sun Shot" – Enable grid parity before the end of the decade by achieving $1/W installed price for PV (without subsidies). Develop new innovative materials and thermal storage to enable CSP to compete with intermediate and baseload power markets.
Biomass ($331M)	Develop and transform domestic biomass resources into biofuels, bioproducts, & biopower: 1) Complete steps to achieve a modeled cost of less than $2/gal (by volume) of cellulosic ethanol in 2012 and progress towards $3/gal for renewable hydrocarbon fuels by 2017 (both in 2007$), 2) Collaborate with Office of Sc. to develop synthetic-biology tools to enhance national capability in biomanufacturing, 3) validate 15 M gallons of annual advanced biofuel production capacity,4) Provide incentive for advanced biofuel production via a reserve auction.
Vehicle Technologies ($588M)	Strategic research, development and deployment activities supporting the goal of 1 M electric drive vehicles on U.S. roads by 2015.
FEMP ($33M) - Federal facilities - EO 13514	Facilitates the Federal Government's implementation of sound, cost effective energy management and investment practices resulting in lifecycle saving of over 52 trillion Btus. Increased funding for technical assistance will support Federal cost and GHG reduction efforts by developing guidance, technical assistance and GHG reporting protocols.
ARPA-E ($550M) **Innovative concepts**	Focuses exclusively on high risk, high payoff concepts - technologies promising genuine transformation in the ways we generate, store and utilize energy.