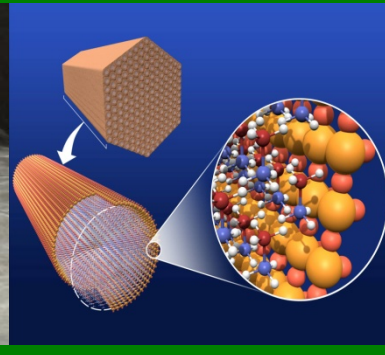
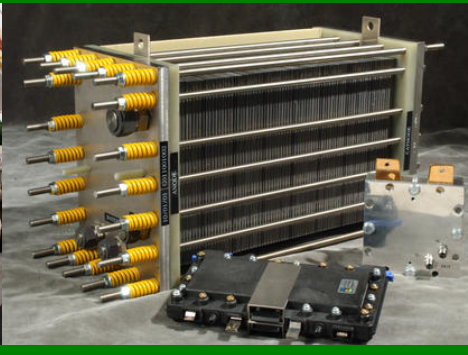




U.S. DEPARTMENT OF  
**ENERGY**



# Hydrogen & Fuel Cells Program Overview

*Dr. Sunita Satyapal  
Program Manager*

*2011 Annual Merit Review and Peer Evaluation Meeting*

*May 9, 2011*

# Hydrogen and Fuel Cells Key Goals

Enable widespread commercialization of hydrogen and fuel cell technologies:

- Early markets such as stationary power, lift trucks, and portable power
- Mid-term markets such as residential CHP systems, auxiliary power units, fleets and buses
- Long-term markets including mainstream transportation applications/light duty vehicles

## Diverse Energy Sources & Fuels

Biomass  
Natural Gas  
Propane  
Diesel  
Other Hydrocarbons  
Methane  
Methanol

**Hydrogen**  
from renewables  
or low carbon  
resources

## Clean, Efficient Energy Conversion

### Fuel Cells

- Alkaline
- Direct Methanol
- Molten Carbonate
- Polymer Electrolyte Membrane (PEM)
- Phosphoric Acid
- Solid Oxide

### Benefits

- **Efficiencies can be 60% (electrical) and 85% (with CHP)**
- **> 90% reduction in criteria pollutants**

## Diverse Applications

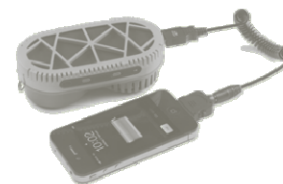
### Stationary Power



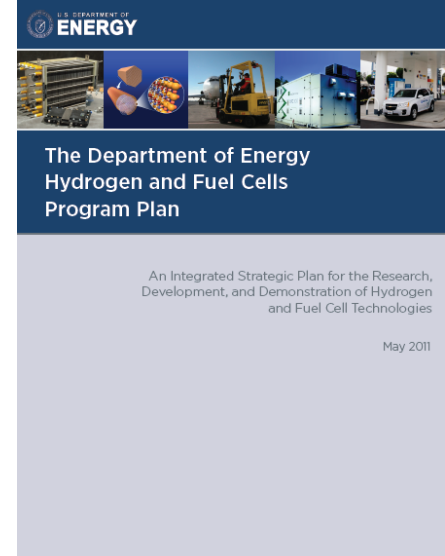
### Transportation



### Portable Power

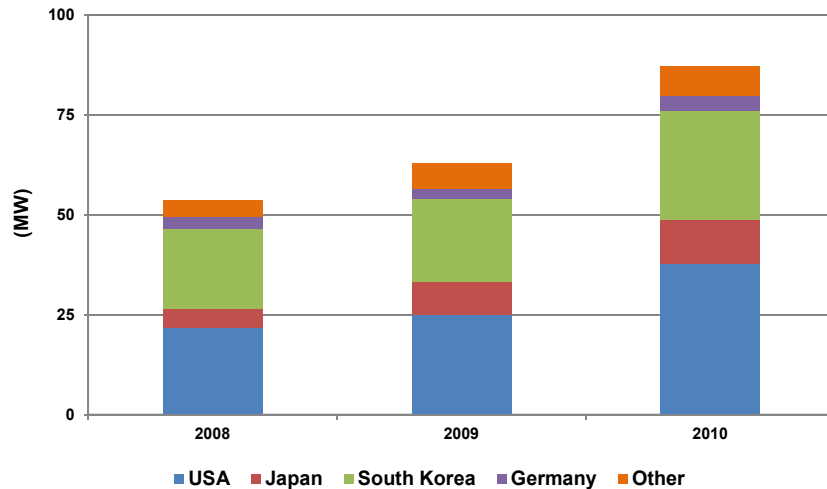


Updated  
Program Plan  
May 2011

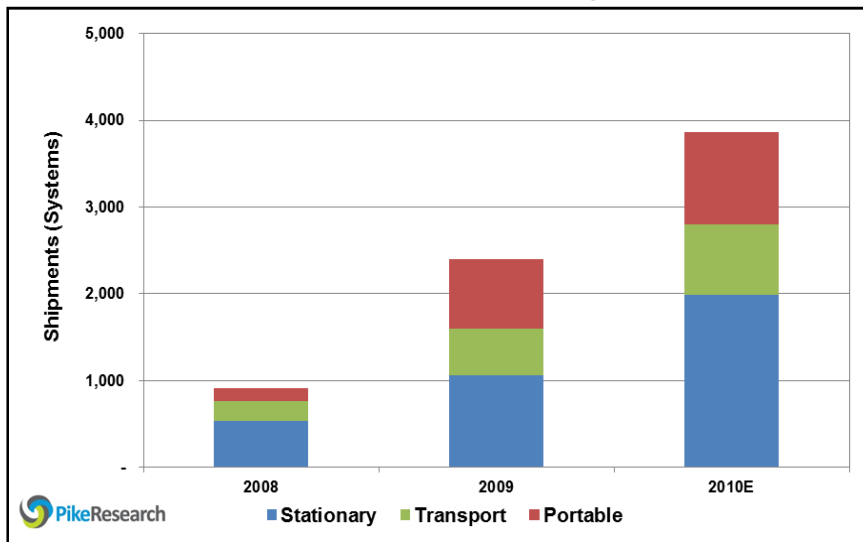


# Fuel Cell Market Overview

Megawatts Shipped, Key Countries: 2008-2010



North American Shipments by Application



Fuel cell market continues to grow

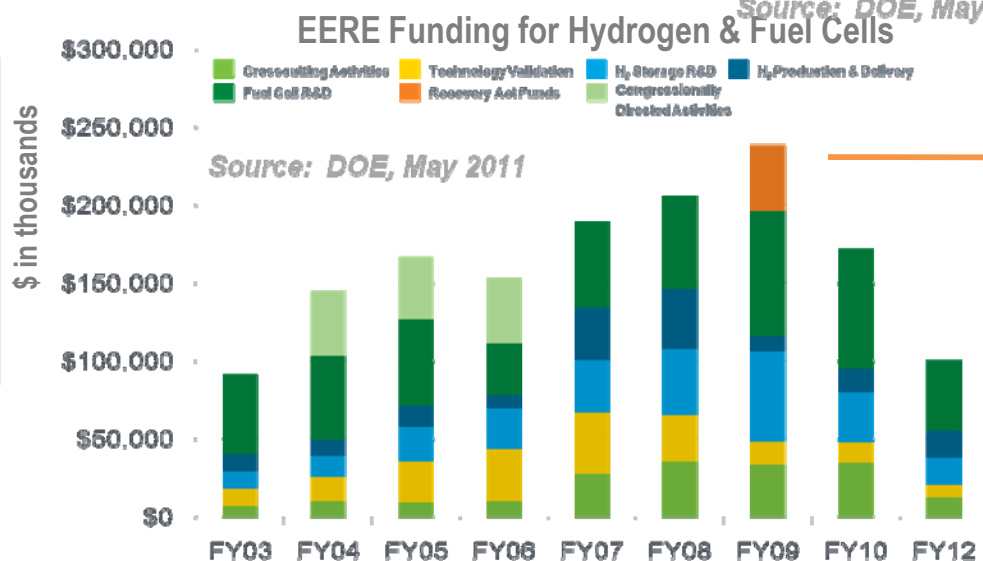
- ~36% increase in global MWs shipped
- ~50% increase in US MWs shipped
- Published several reports
  - The Business Case for Fuel Cells
  - State of the States: Fuel Cells in America
  - 2010 Fuel Cell Market Report



# Hydrogen & Fuel Cells - Budgets

EERE Funding (\$ in thousands)		
Key Activity	FY 2010	FY 2012 Request
<b>Fuel Cell Systems R&amp;D</b>	<b>75,609</b>	<b>45,450</b>
<b>Hydrogen Fuel R&amp;D</b>	<b>45,750</b>	<b>35,000</b>
<b>Technology Validation</b>	<b>13,005</b>	<b>8,000</b>
<b>Market Transformation</b>	<b>15,005</b>	<b>0</b>
<b>Safety, Codes &amp; Standards</b>	<b>8,653</b>	<b>7,000</b>
<b>Education</b>	<b>2,000</b>	<b>0</b>
<b>Systems Analysis</b>	<b>5,408</b>	<b>3,000</b>
<b>Manufacturing R&amp;D</b>	<b>4,867</b>	<b>2,000</b>
<b>Total</b>	<b>\$170,297</b>	<b>\$100,450</b>

Source: DOE, May 2011



~\$38 M/year  
for Basic  
Energy  
Sciences

Additional \$42 M  
under  
Recovery Act

<sup>1</sup> 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; Hydrogen Fuel R&D includes Hydrogen Production & Delivery and Hydrogen Storage R&D; No Market Transformation in FY 2012; FY 2009 Recovery Act funding of \$42M not shown in Table. FY 12 Includes SBIR/STTR funds<sup>4</sup>

# Key Challenges

*The Program has been addressing the key challenges facing the widespread commercialization of fuel cells.*

## Technology Barriers\*

### Fuel Cell Cost & Durability

Targets\*:

*Stationary Systems:* \$750 per kW,  
40,000-hr durability

*Vehicles:* \$30 per kW, 5,000-hr durability

### Hydrogen Cost

Target: \$2 – 4 /gge, (dispensed and untaxed)

### Hydrogen Storage Capacity

Target: > 300-mile range for vehicles—without compromising interior space or performance

### Technology Validation:

*Technologies must be demonstrated under real-world conditions.*

## Market Transformation

**Assisting the growth of early markets will help to overcome many barriers, including achieving significant cost reductions through economies of scale.**

## Economic & Institutional Barriers

Safety, Codes & Standards Development

Domestic Manufacturing & Supplier Base

Public Awareness & Acceptance

Hydrogen Supply & Delivery Infrastructure



# Progress – Fuel Cell R&D

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

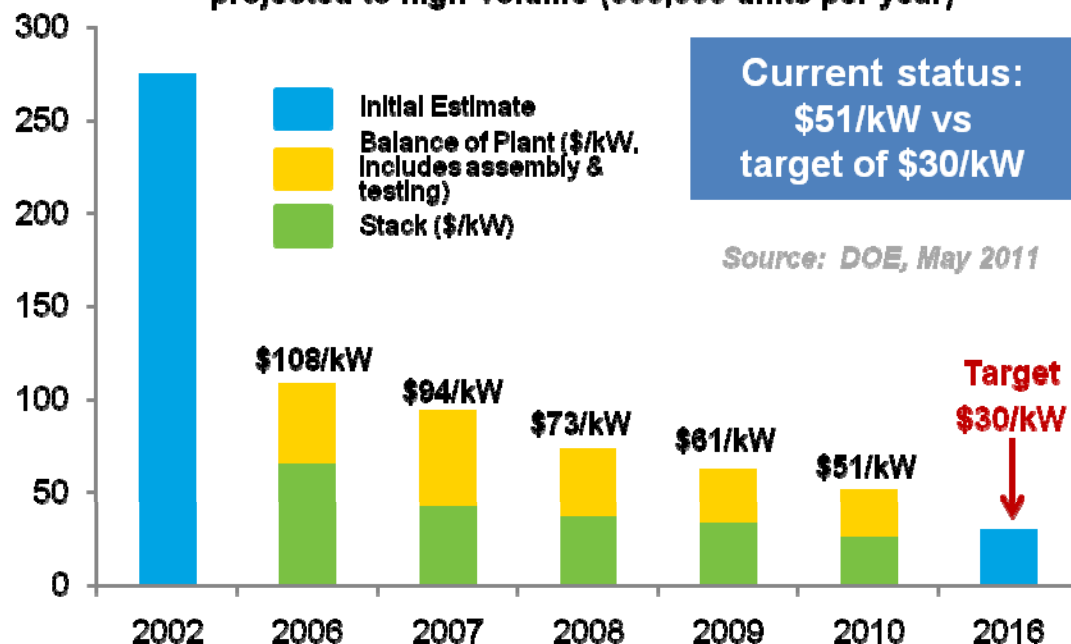
- **More than 30% reduction since 2008**
- **More than 80% reduction since 2002**

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

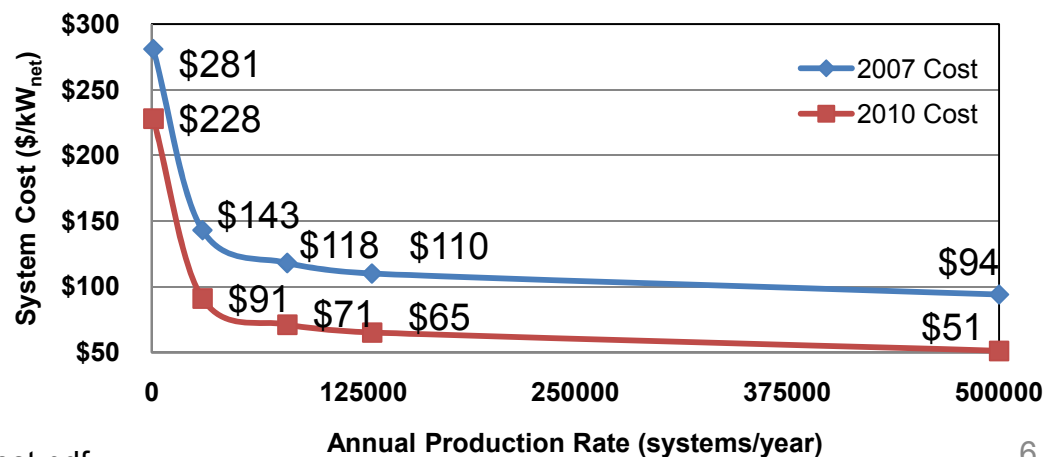
\*Based on projection to high-volume manufacturing (500,000 units/year).

\*\*Panel found \$60 – \$80/kW to be a “valid estimate” for 2008 [http://hydrogen.doedev.nrel.gov/peer\\_reviews.html](http://hydrogen.doedev.nrel.gov/peer_reviews.html)

**Projected Transportation Fuel Cell System Cost**  
-projected to high-volume (500,000 units per year)-



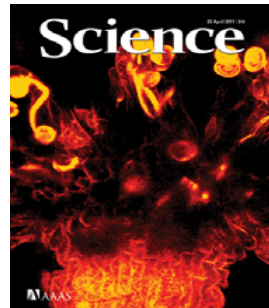
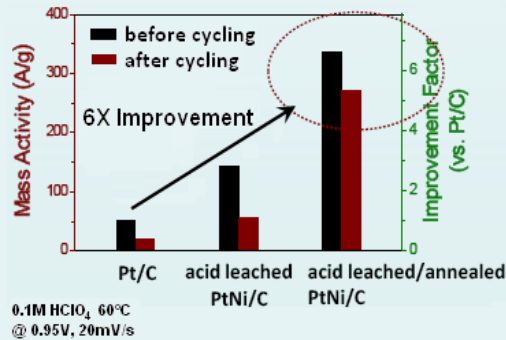
**Projected Costs at Different Manufacturing Rates**



# Progress – Fuel Cell R&D

Progress continues in low and zero Pt catalysts

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

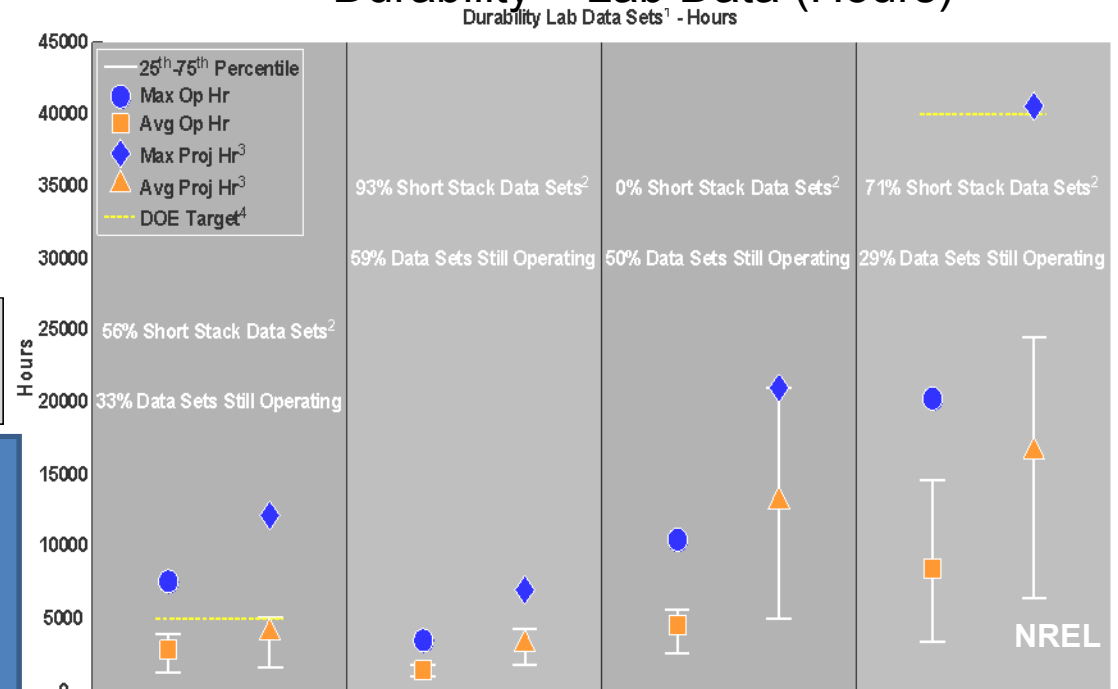


G. Wu, K. L. More, C. M. Johnston, P. Zelenay, *Science*, **332**, 443-7 (2011)

- 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!

## Durability – Lab Data (Hours)



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)

# Progress – Hydrogen Production & Delivery

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

### NEAR TERM:

#### Distributed Production

- ▲ Natural Gas Reforming
- ▲ Ethanol Reforming
- ▲ Electrolysis

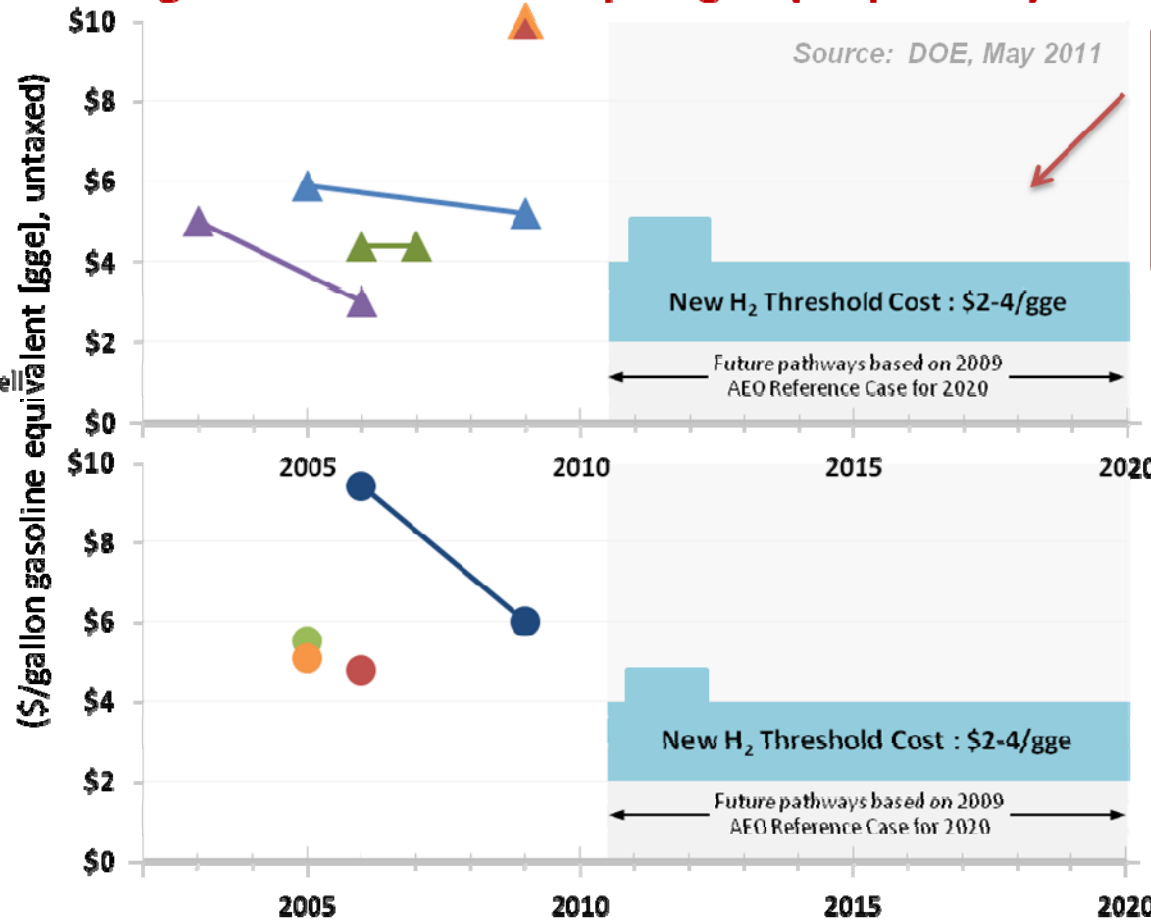
#### Low-volume (200 kg/day)

- ▲ Steam Methane Reforming
- ▲ H<sub>2</sub> from Combined Heat, Hydrogen, and Power Fuel Cell

### LONGER TERM:

#### Centralized Production

- Biomass Gasification
- Central Wind Electrolysis
- Coal Gasification with Sequestration
- Nuclear



H<sub>2</sub> 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.

Hydrogen Delivery: Projected an additional 33% improvement in tube trailer capacity in the last year due to optimized carbon composites vessel design (Lincoln Composites)

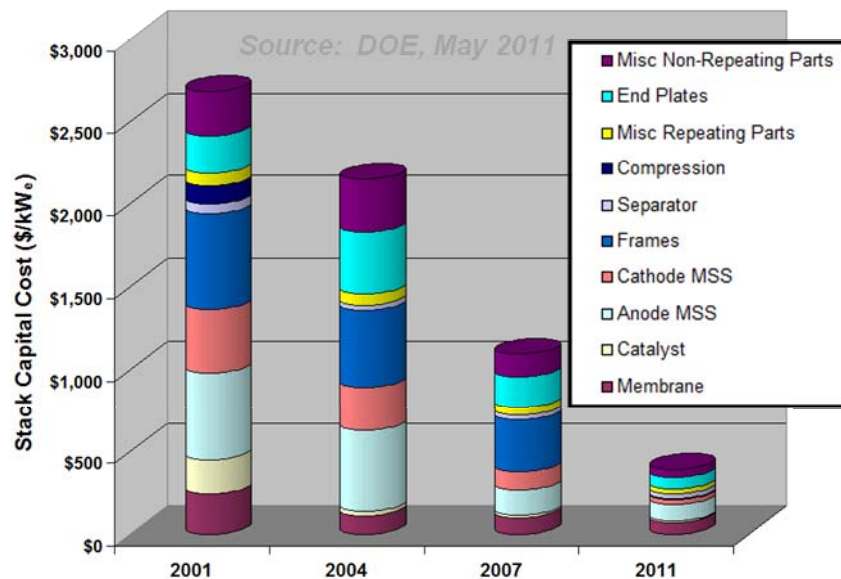


# Progress – Hydrogen Production

*Demonstrated continued progress in hydrogen cost reduction*

## Reduced electrolyzer cost by 80% since 2001

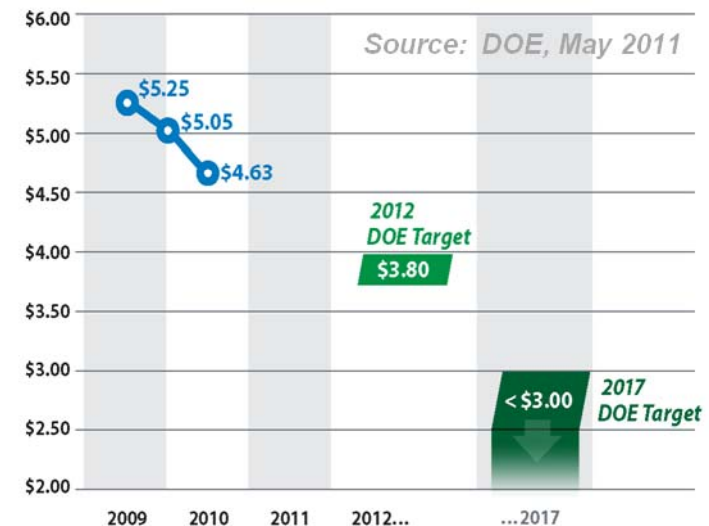
- 15% cost reduction in just the last year
- Projected high volume capital cost of \$350/kW (vs. 2012 target \$400/kW) (Proton, Giner)



## Autothermal Reforming of Pyrolysis Oil

NREL's Distributed Production of H<sub>2</sub> from Bio-Derived Renewable Liquids

\$/gge H<sub>2</sub> Delivered



## Photoelectrochemical Conversion (PEC):

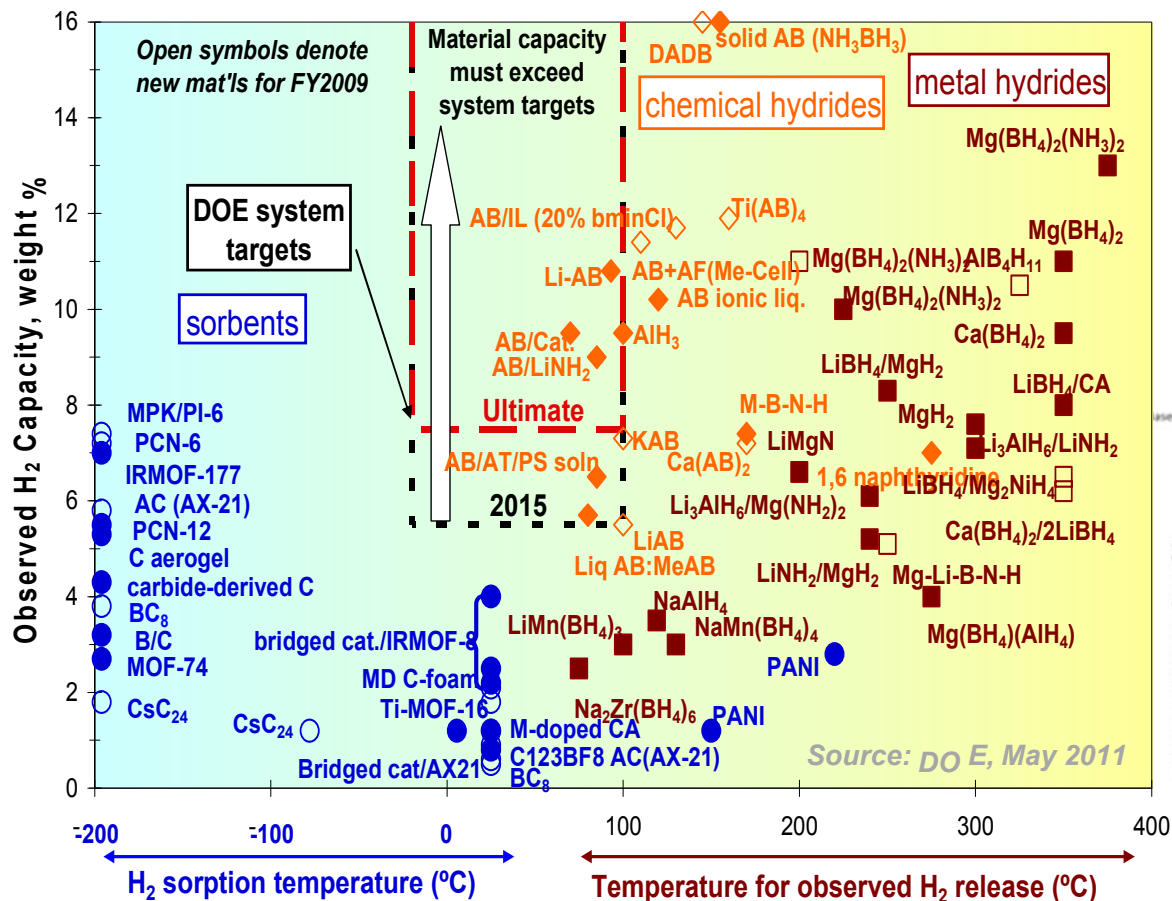
- Demonstrated potential to exceed 10% solar-to-hydrogen efficiency target
- >16% observed at lab scale (NREL)

- Increased hydrogen yield by 65%
- Reduced production cost to an estimated \$4.65/gge delivered

# Progress - Hydrogen Storage

Tanks can achieve 430 mile range. Focus is on materials R&D but meeting all weight, volume, performance and cost requirements is still challenging.

Developed > 420 new materials with potential to store hydrogen at low to moderate pressures



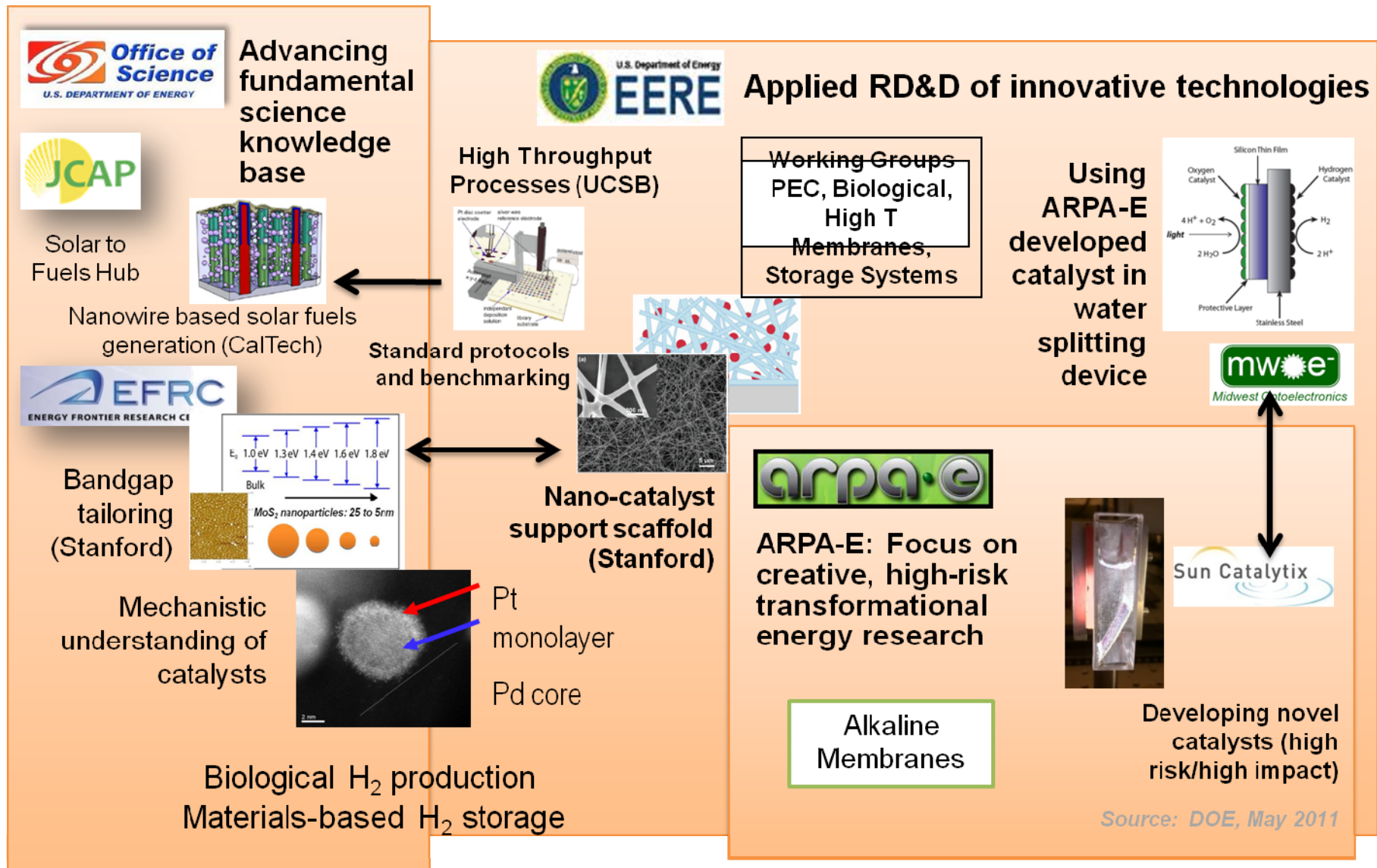
Projected Capacities for Complete 5.6-kg H<sub>2</sub> Storage Systems



- Validated cryosorbents achieving >8.5 wt.% H<sub>2</sub> storage (Texas A&M, SwRI)
- Identified potential pathways to reduce carbon fiber and tank cost

# Collaborations

## Examples of Cross-Office Collaborative Successes



*Demonstrations are essential for validating technologies in integrated systems*

## Real-world Validation

### Vehicles & Infrastructure

- 155 fuel cell vehicles and 24 hydrogen fueling stations
- Over 3 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)

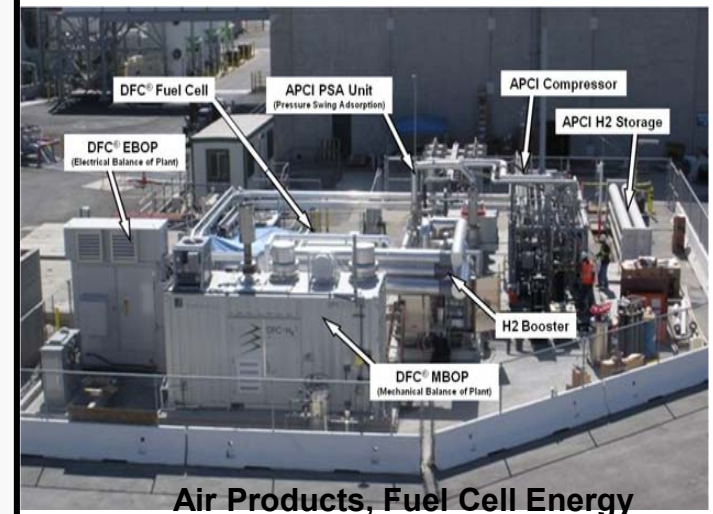
- H<sub>2</sub> fuel cell buses have a 42% to 139% better fuel economy when compared to diesel & CNG buses

### Forklifts

- Over 44,000 refuelings at Defense Logistics Agency site

### CHHP (Combined Heat, Hydrogen and Power)

- Achieved 54% (hydrogen + power) efficiency of fuel cell when operating in hydrogen co-production mode
- 100 kg/day capacity, renewable hydrogen supply

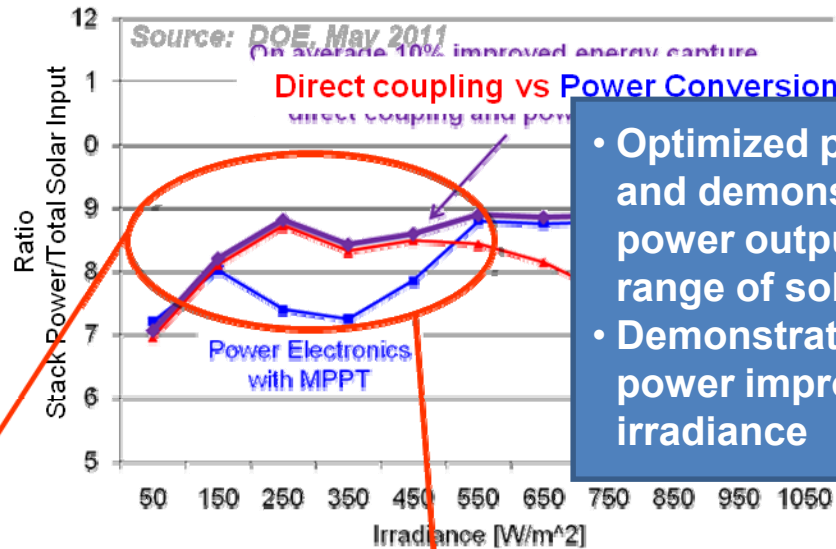




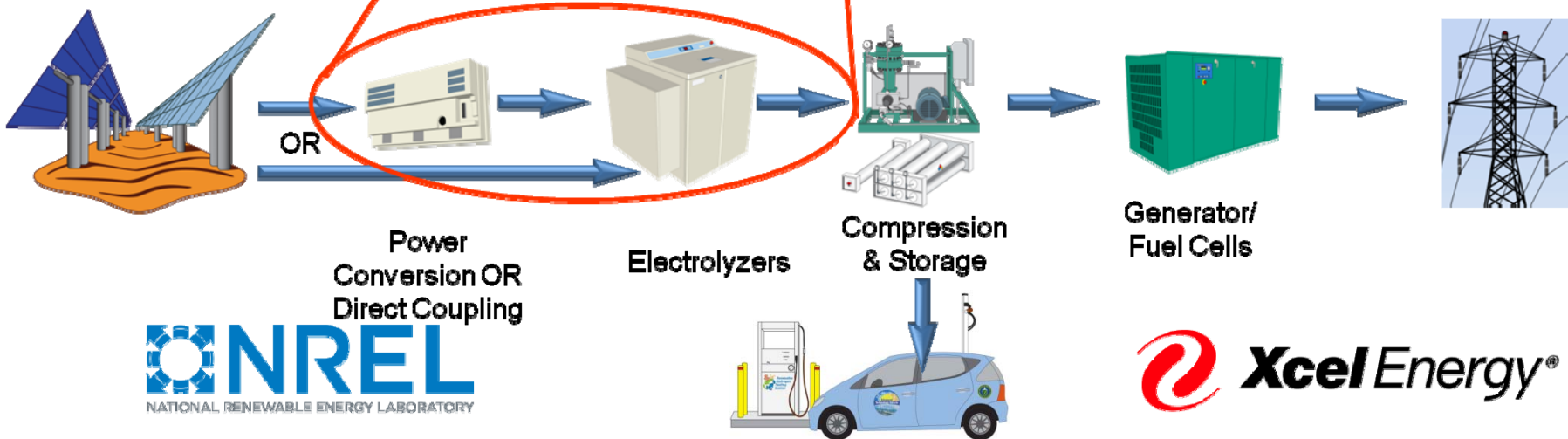
# Hydrogen & Fuel Cells for Energy Storage

*Improved efficiency of renewable H<sub>2</sub> production by matching the polarization curves of PV & electrolyzers to enable direct coupling.*

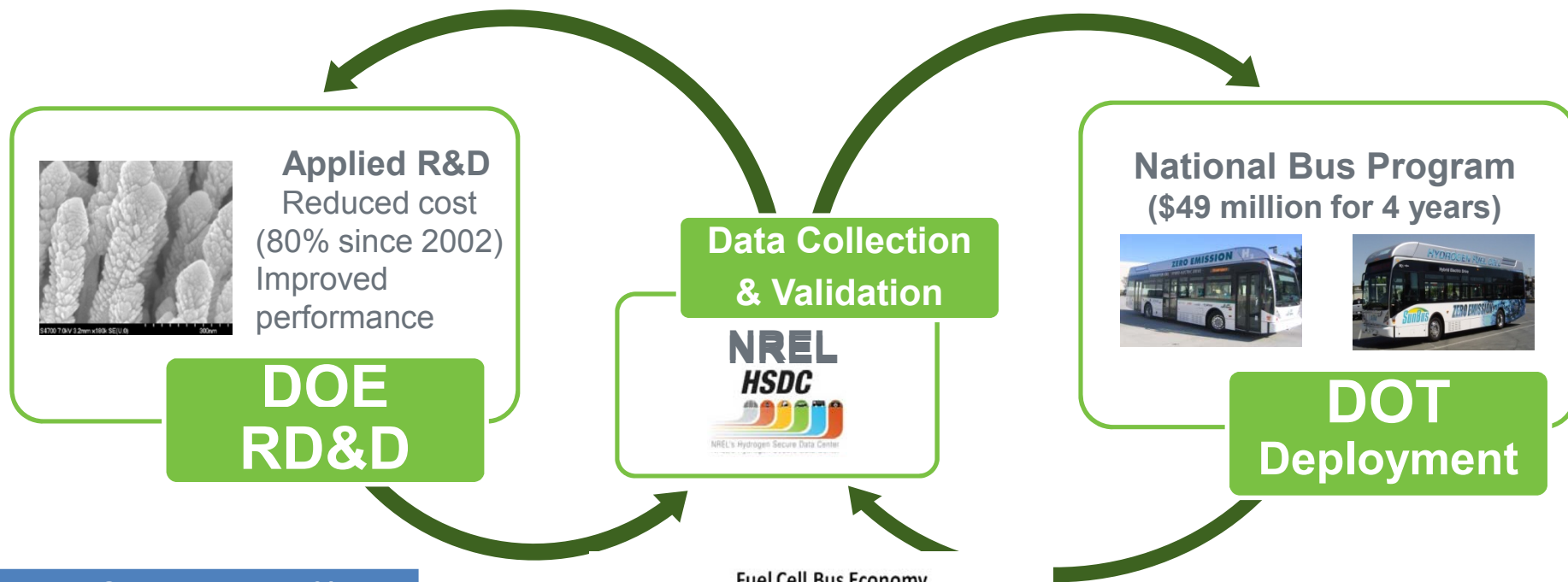
Expanded Facility to test multiple technologies (wind, solar, electrolyzers, fuel cells/ generators, plus H<sub>2</sub> refueling)



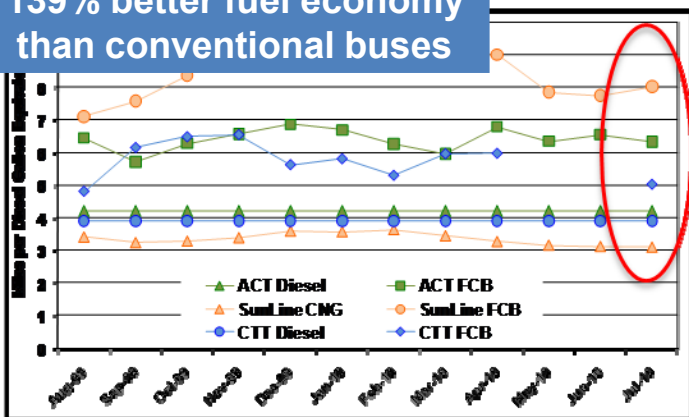
- Optimized power conversion and demonstrated consistent power output across larger range of solar input
- Demonstrated up to nearly 20% power improvement at low irradiance



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

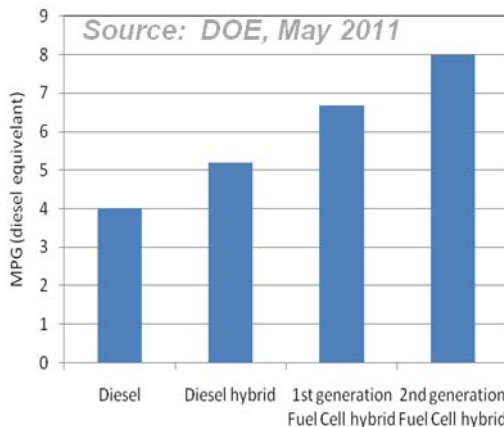


**Fuel Cell buses: 42% to 139% better fuel economy than conventional buses**



Source: DOE, May 2011

Fuel Cell Bus Economy



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 8,000 hr fuel cell durability



# DOD-DOE Memorandum of Understanding

*Strengthen coordination and partnerships between DOE and DOD.*

## Workshops Held

Waste-to-Energy

Aviation APUs

Shipboard APUs

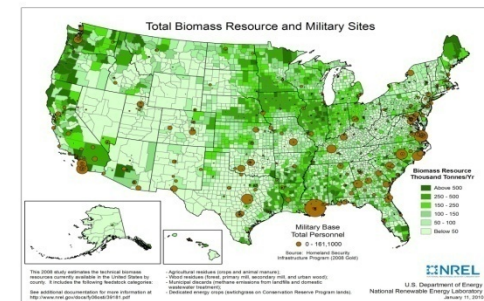
## Outcomes & Next Steps

DOD-DOE working group formed to identify opportunities.

Industry working group established

Bio/logistics fuels reforming

## Impact



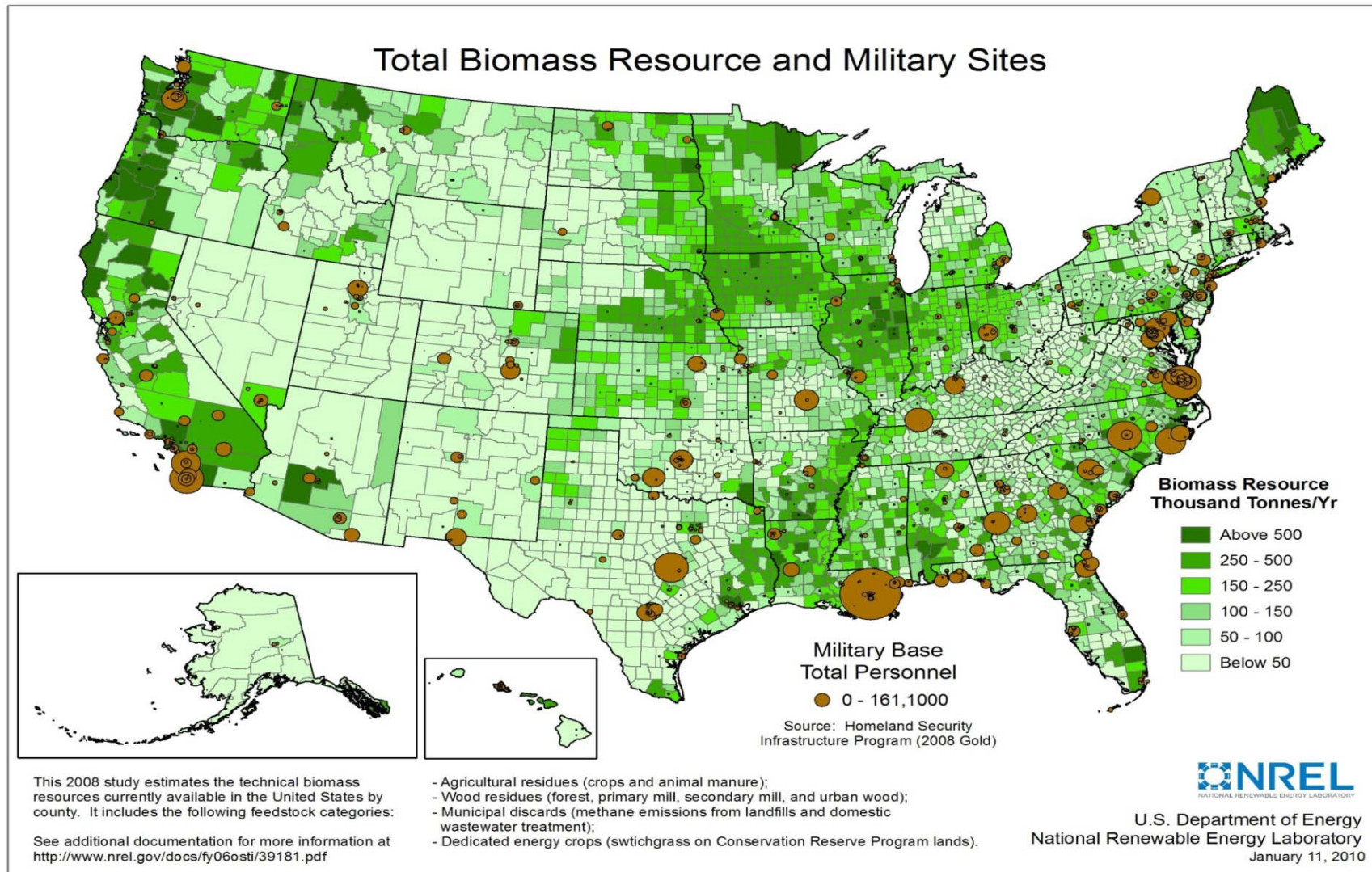
**634,000 million BTUs potential energy savings using waste-to-energy CHP<sup>2</sup>**

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

**Shipboard fuel cells capable of saving ~11,000-16,000 bbls/ship/yr<sup>2</sup>**

<sup>1</sup>FCHEA, <http://www.fchea.org/index.php?id=14>, <sup>2</sup> DOD Estimates

# Potential Resources near DOD Sites



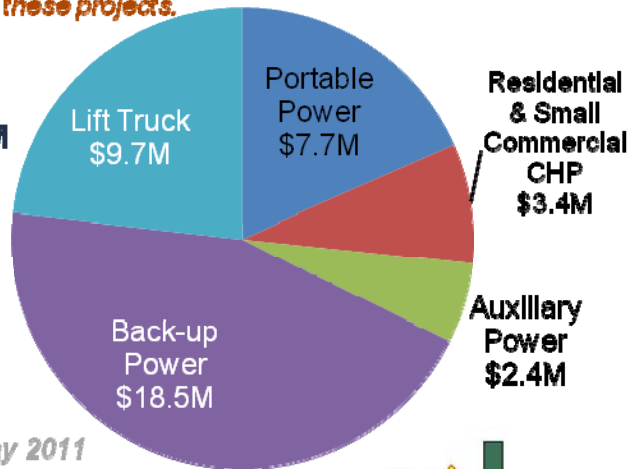
# Progress – Market Transformation & Recovery Act

Deployed more than 630 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 all of the fuel cell suppliers involved in these projects.

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



### Forklifts

- FedEX Freight East, GENCO, Nuvera Fuel Cells, Sysco Houston

### Back-up Power

- Plug Power, Inc., ReliOn, Inc., Sprint Nextel

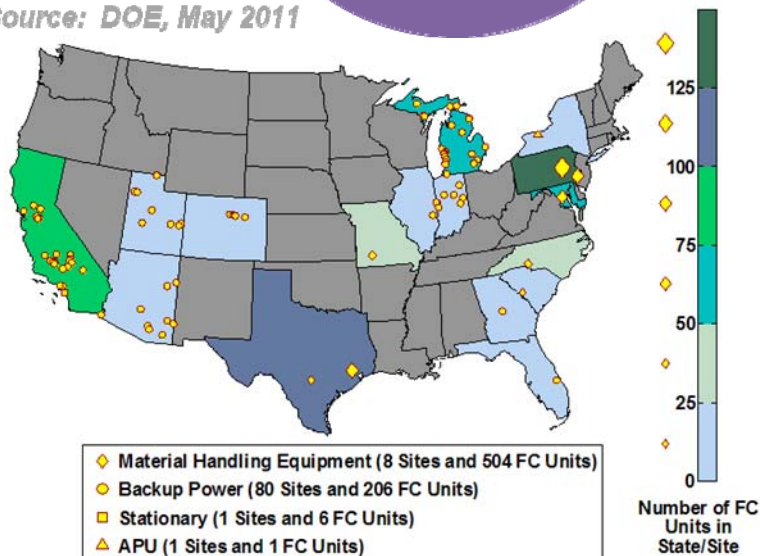
### Portable Power

- Jadoo Power, MTI MicroFuel Cells, Univ. of N. Florida

### Auxiliary Power

- Delphi Automotive

Source: DOE, May 2011

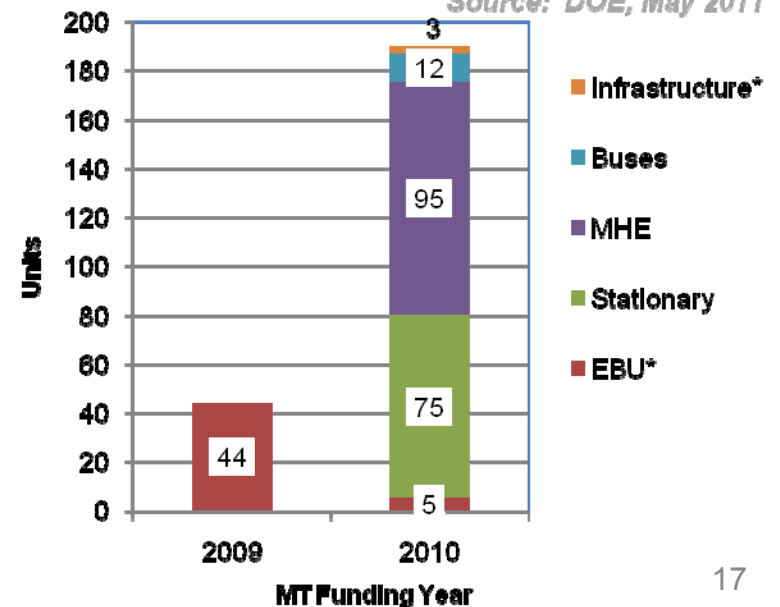


Source: DOE, May 2011

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

## Market Transformation Hydrogen and Fuel Cell Deployments\*

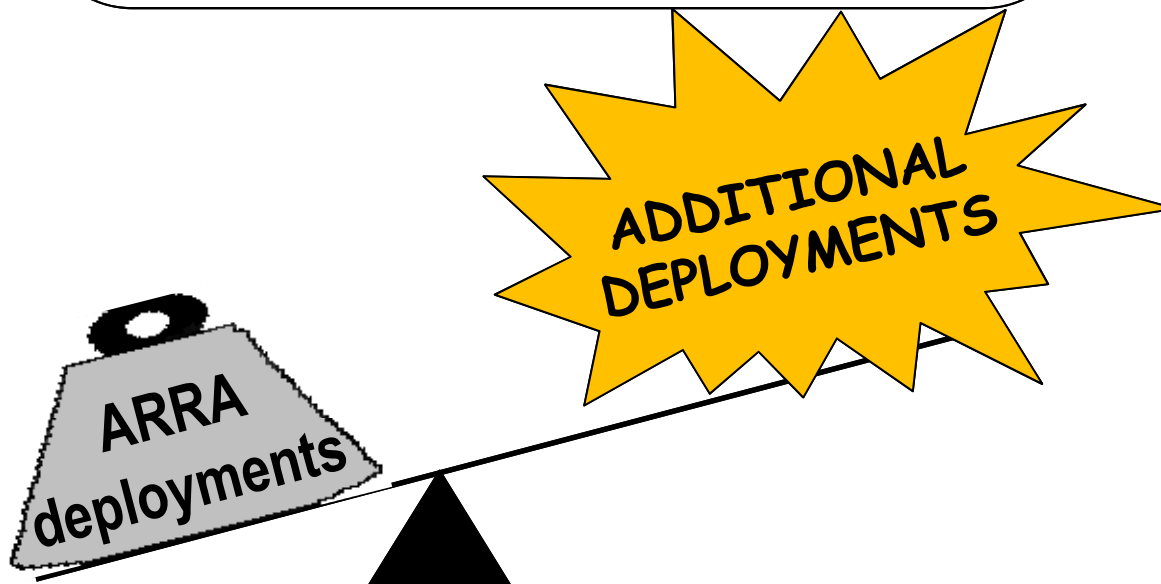
Source: DOE, May 2011



## Data Collection Snapshot (NREL)

ARRA Material Handling Equipment Data	As of 12/31/2010
Hydrogen Dispensed	> 18,500 kg
Hydrogen Fills	> 38,800
Hours Accumulated	> 307,400 hrs
Durability	~3,000 hrs*
Reliability	75% w/MTBF > 100 hrs

Additional fuel cell lift truck deployments taking place based on ARRA experience and lessons learned!



**MORE THAN 500  
ADDITIONAL FUEL CELL  
FORKLIFTS PLANNED**  
**E.g., Sysco, H-E-B  
Grocery, BMW**

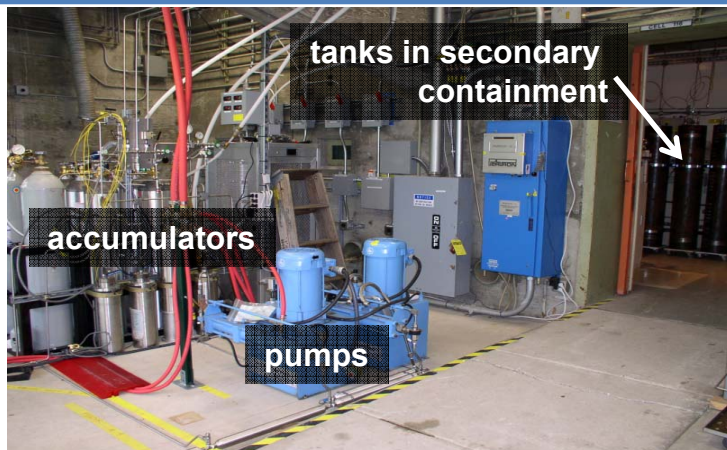
\*Average projected hours to 10% voltage drop of all the fleets with a max fleet project of more than 9,500 hours. 25% of systems have more than 2,300 operation hours and one fleet averages more than 2,6000 operation hours.



## Safety R&D and Codes & Standards

- Exceeded 34,000 hydrogen pressure cycles in steel storage tanks
- Quantified effect of barrier walls leading to potential for up to 50% reduction in separation distances
- Expanded web-based first responder training (17,000 visits)

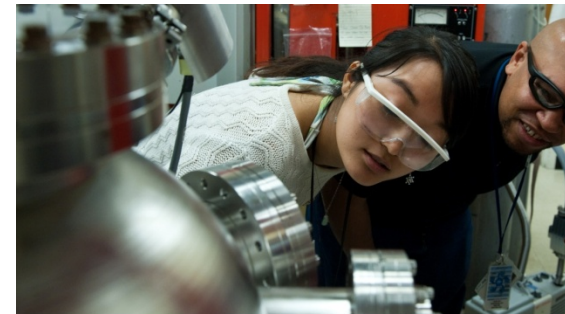
Tanks with engineered defects are projected to exceed expected life



Sandia National Lab

## Education and Outreach

- Developed and disseminated information to educate key stakeholders
- Reached > 8,500 teachers
- Measured up to 220% increase in knowledge level in 2 years



Postdoctoral fellowships in hydrogen and fuel cell research ▶

### Fuel Cell Technologies Post-doc Program

- Up to five positions available to conduct applied research at universities, national laboratories, and other research facilities
- **Applications are due June 30, 2011**

# Example - The Case for Fuel Cell Forklifts

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

## Preliminary Analysis

Compared to conventional forklifts, fuel cell forklifts have:

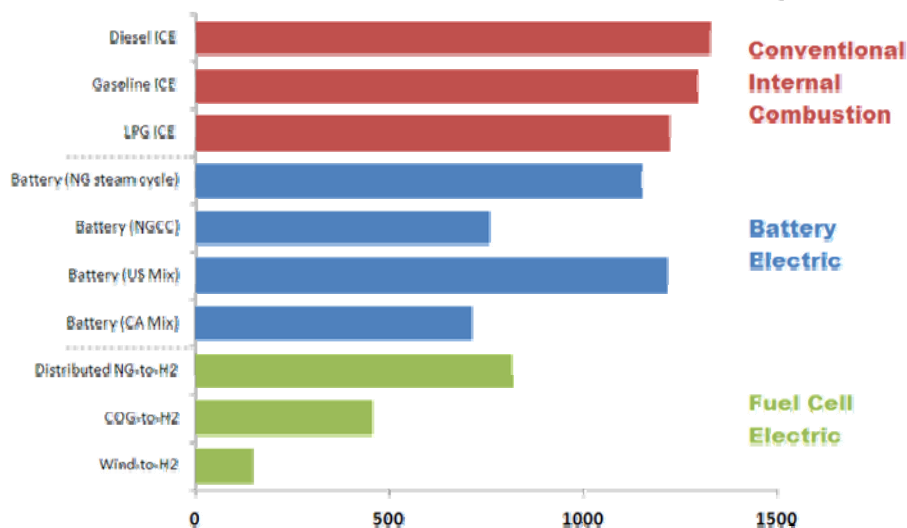
- 1.5 X lower maintenance cost
- 8 X lower refueling/recharging labor cost
- 2 X lower net present value of total system cost

## 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

Fuel Cycle GHG Emissions for Forklifts  
(g/kWh at the fork)

Source: DOE, May 2011



## Published Fact Sheets & Case Studies





# Employment Impacts of Early Markets

Developed user-friendly tool to calculate economic impacts

Select State or Region

Type of Fuel Cell

Application

Average Size of Manufactured Fuel Cell

Fuel Cells Manufactured by Year

Annual Fuel Cell Production (kW/year)

Time Frame (years)

Existing Fuel Cell Production Capacity (kW/year)

Additional Manufacturing Capacity to be Constructed (kW/year)

Sales Price (\$/kW)

Production Cost (\$/kW, initial)

Progress Ratio

Production Volume for Initial Cost

Scale Elasticity

Full Scale Production Level (kW/year)

Annual Rate of Technological Progress

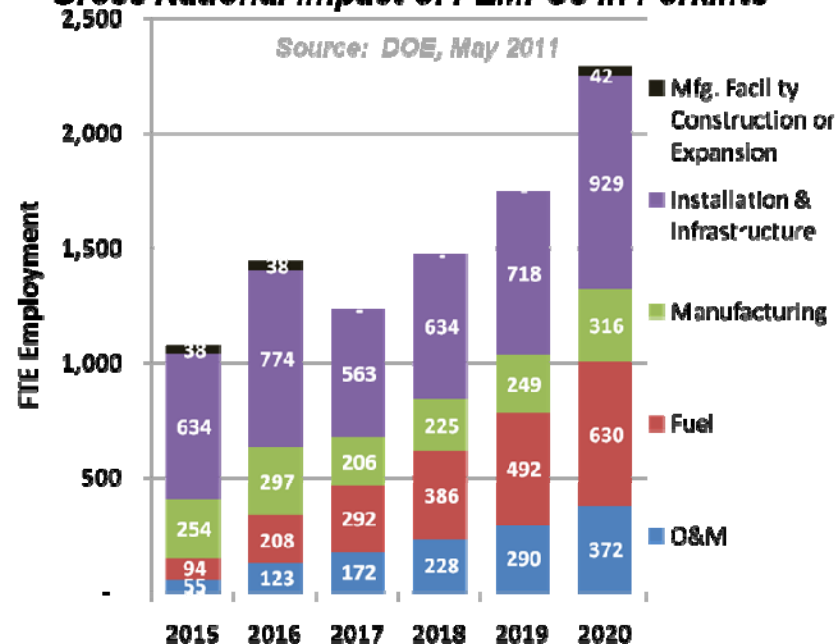
Average Production Cost Over Time Frame (\$/kW)

Installation Cost (\$/kW)

Operations & Maintenance Cost (\$/kW, annual)

Argonne National Lab/RCF

**Preliminary Analysis**  
**Gross National Impact of PEMFCs in Forklifts**

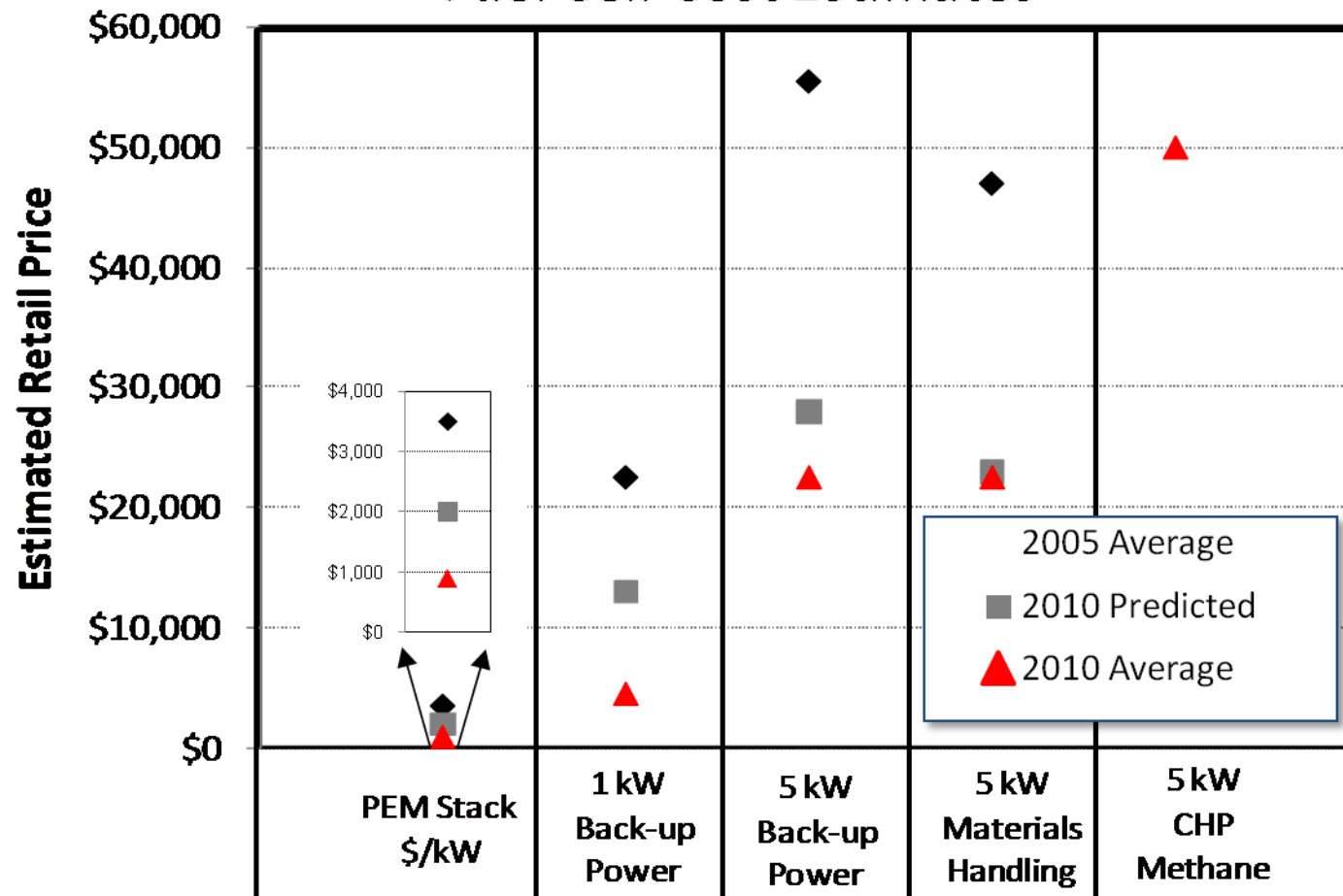


Includes *short-term jobs* (construction/expansion of mfg capacity, installation & infrastructure) & *on-going jobs* (manufacturing, O&M and fuel production & delivery)

- Average of 60 fuel cells/site, 250 site installations by 2020.
- Tax credit expires in 2016.

# Early Market Cost Reduction Analysis

## Comparison of 2008 ORNL Study and 2010 Fuel Cell Cost Estimates



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

Oak Ridge  
NATIONAL LABORATORY  
MANAGED BY UT-BATTELLE  
FOR THE DEPARTMENT OF ENERGY

ORNL/TM-2011/101

Status and Outlook for the U.S.  
Non-Automotive Fuel Cell Industry:  
Impacts of Government Policies and  
Assessment of Future Opportunities

May 2011

Prepared by:  
David L. Greene  
Oak Ridge National Laboratory  
K.S. Duleep  
CIC International  
Girish Upreti  
University of Tennessee



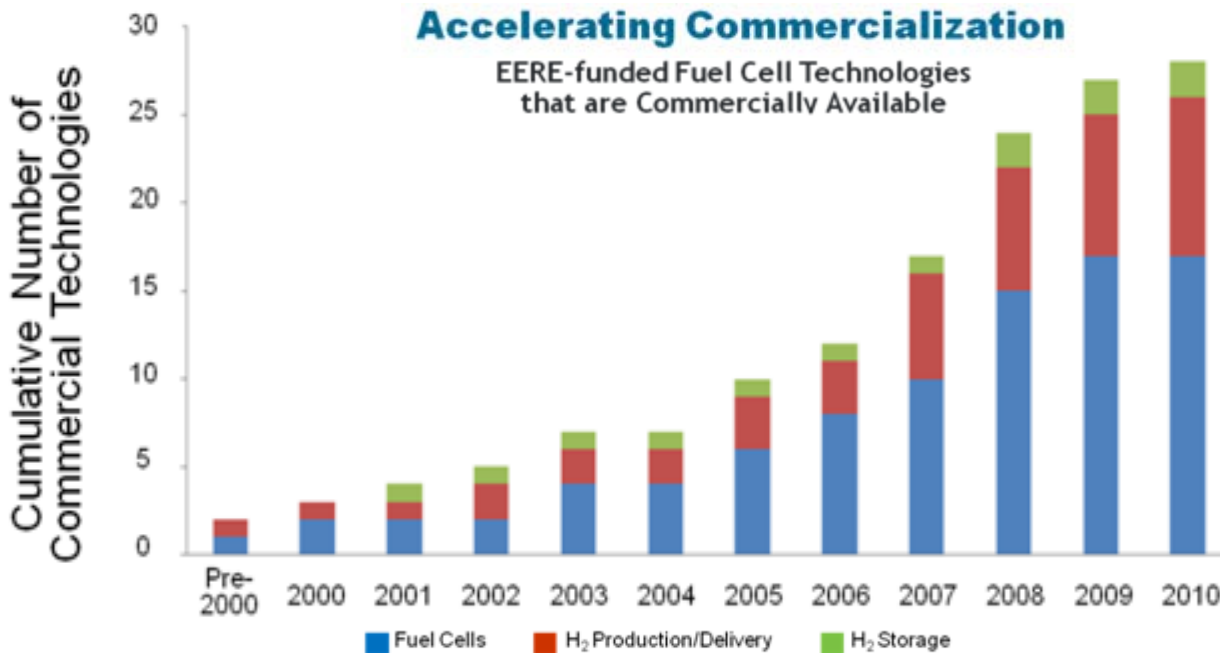
2005 and 2010 averages based on estimates supplied by OEMs. 2010 predicted assumed government procurements of 2,175 units per year, total for all market segments. Predictions assumed a progress ratio of 0.9 and scale elasticity of -0.2.

ORNL

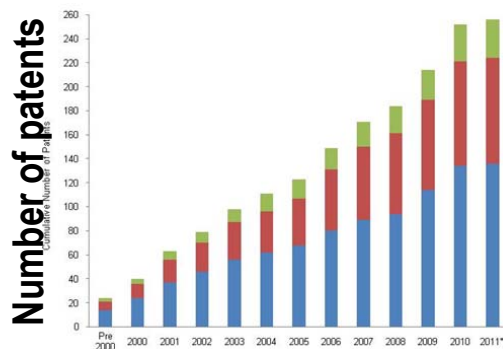
Source: DOE, May 2011

# Assessing Program Impact - Commercialization

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](http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/pathways_success_hfcit.pdf)



## 256 PATENTS resulting from EERE-funded R&D:

- 136 fuel cell
- 88 H<sub>2</sub> production & delivery
- 32 H<sub>2</sub> storage

**DuPont**

**Examples**

**BASF Catalysts**

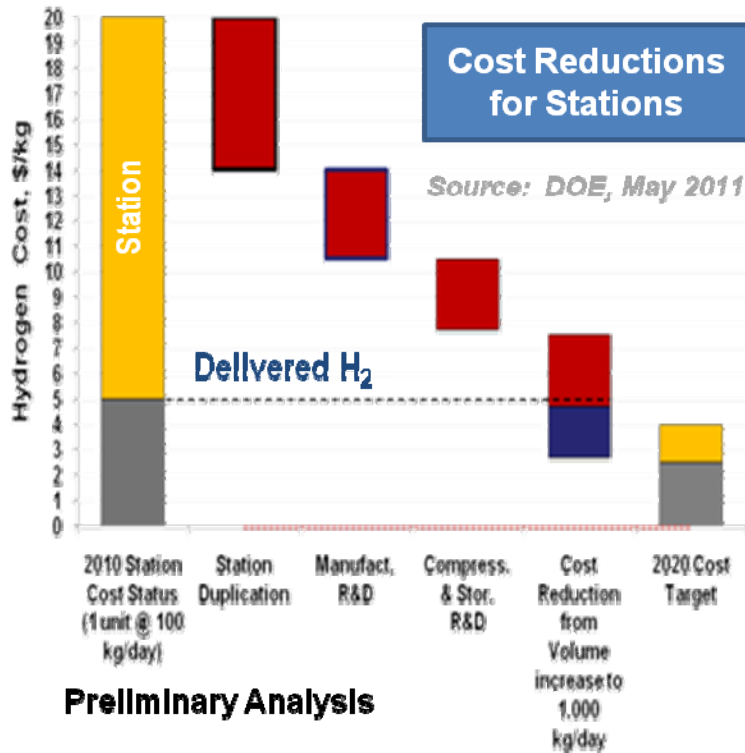
**Proton**

**3M**

**Quantum Technologies**

**Dynalene, Inc.**

# Additional Analysis - Hydrogen Infrastructure

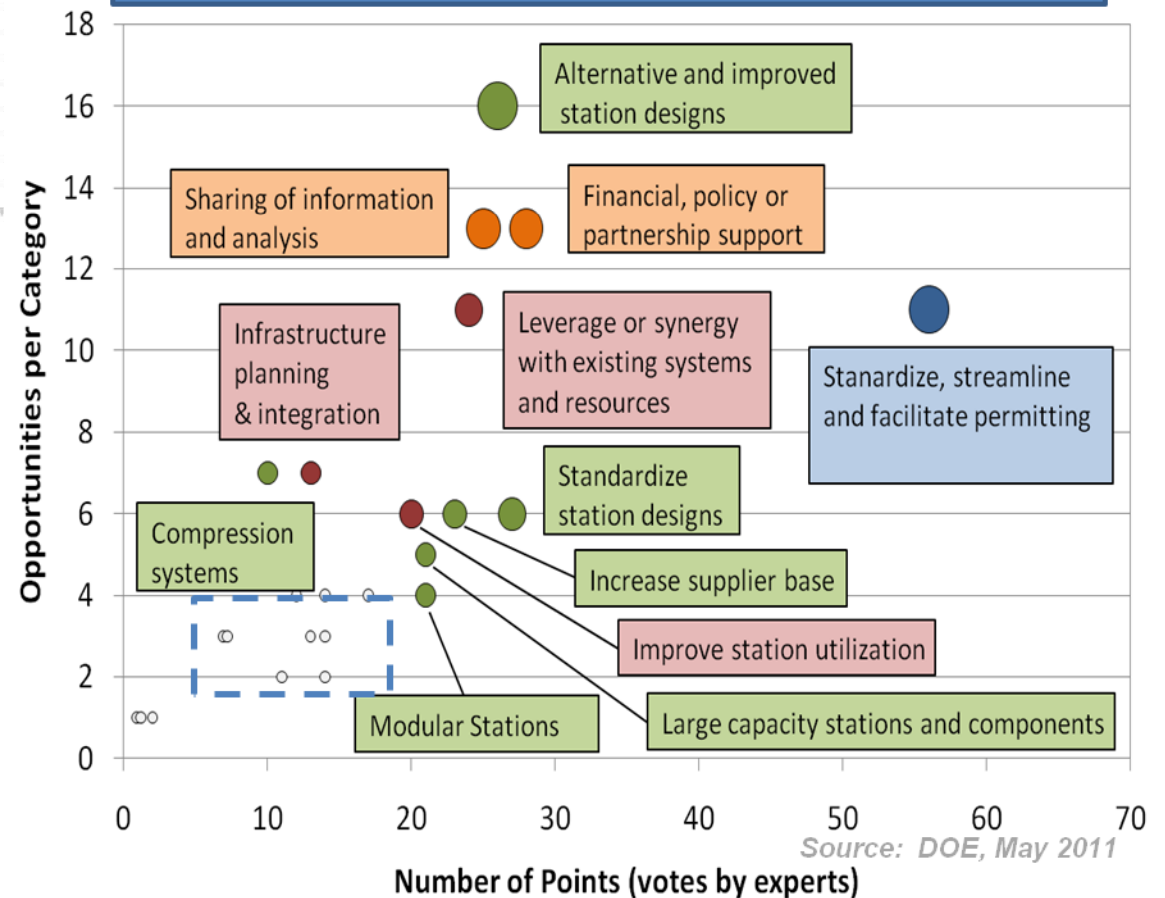


## Preliminary Analysis

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

Identified opportunities for reducing infrastructure cost. High-priority opportunities include station designs, streamlining/standardizing permitting process, and financial, policy and partnership support.

## Cost Reductions Opportunities Identified by Experts



## RFI: Tech. Validation

Closes June 1, 2011

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

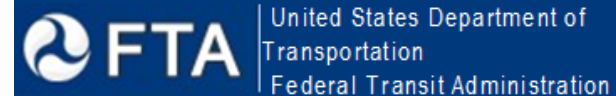
<http://www07.grants.gov/search/search.do?&mode=VIEW&oppld=84333>

## RFI: Bus Targets

Closes July 1, 2011

### Areas of Interest

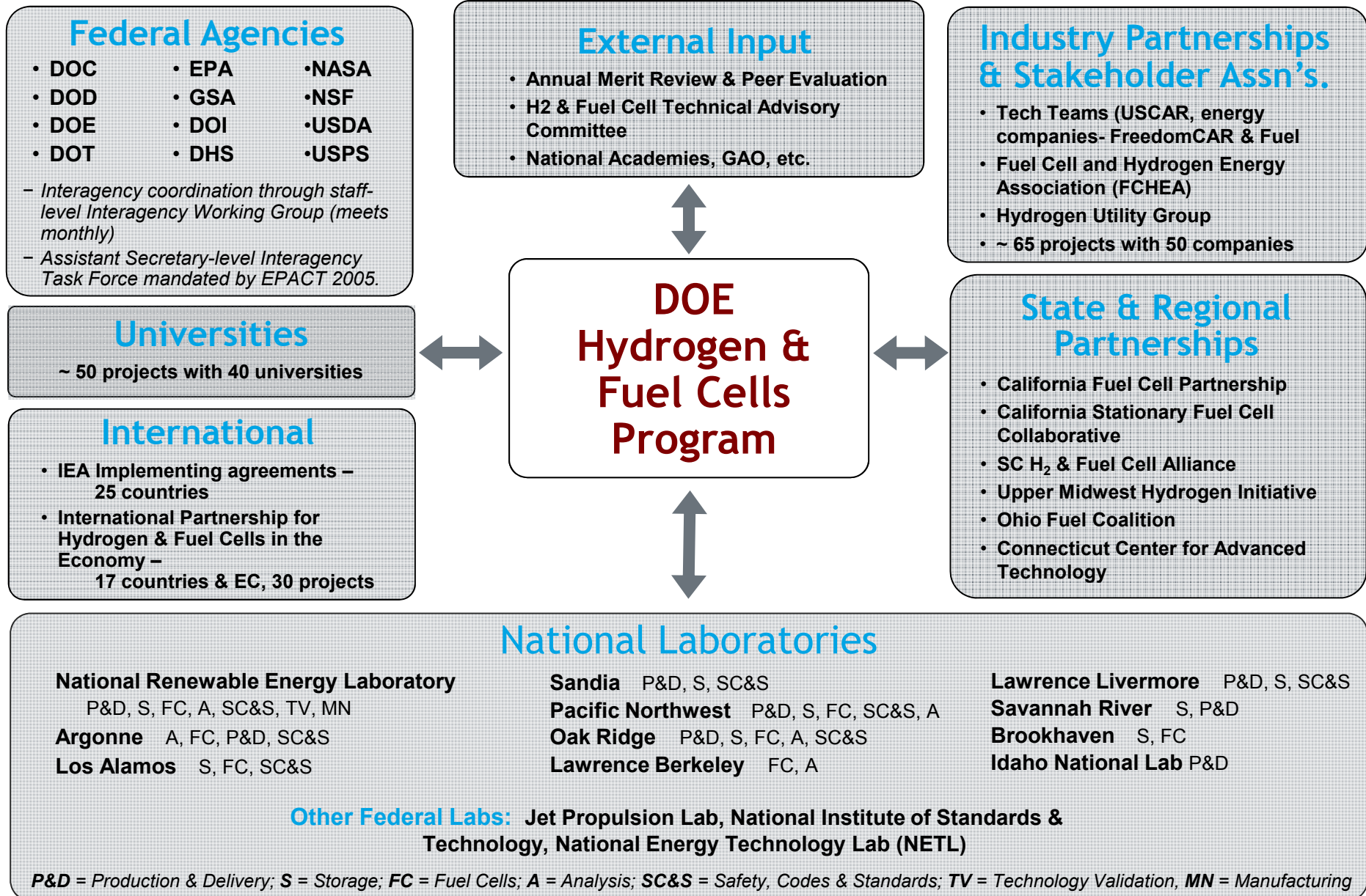
- Solicit feedback on performance, durability and cost targets for fuel cell transit buses
- Sponsored by



Questions may be addressed to:  
[DOEFCBUSRFI@go.doe.gov](mailto:DOEFCBUSRFI@go.doe.gov)



# Acknowledgements





# Thank you

## ***Presidential Awardees***

- ***Professor Susan Kauzlarich –UC Davis  
Presidential Award for Excellence in  
Science, Mathematics and Engineering  
Mentoring***
- ***Presidential Early Career Awards***
  - ***Dr. Jason Graetz –BNL***
  - ***Dr. Craig Brown – NIST***



Source: US DOE 2010



**For more information, please contact  
Sunita Satyapal  
Program Manager**

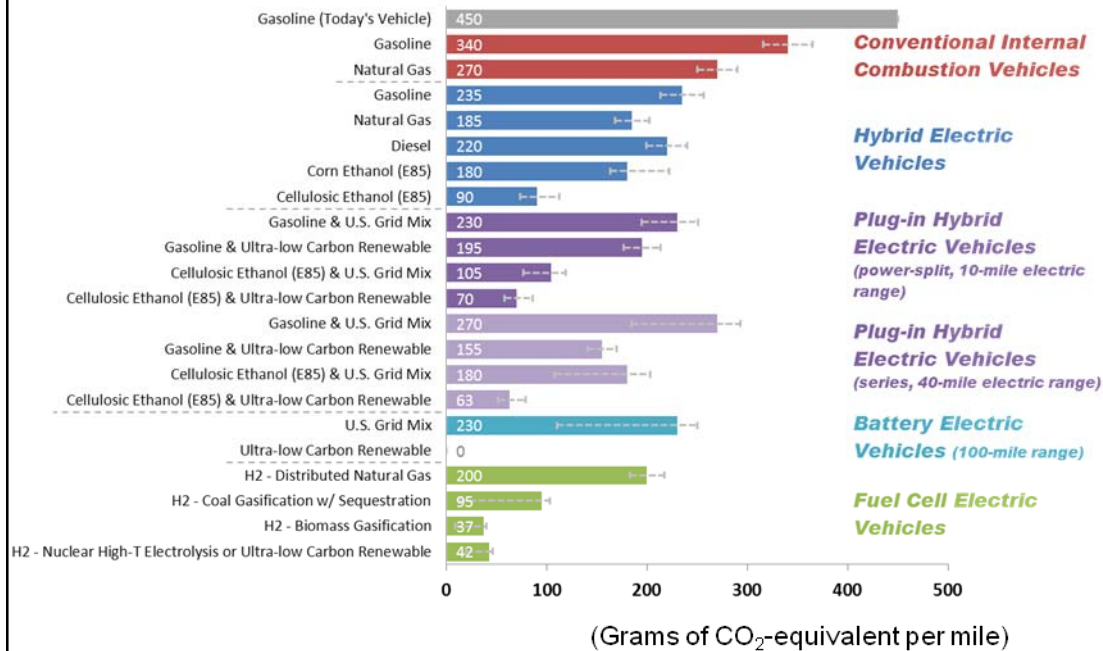
**[Sunita.Satyapal@ee.doe.gov](mailto:Sunita.Satyapal@ee.doe.gov)**

**[Hydrogenandfuelcells.energy.gov](http://Hydrogenandfuelcells.energy.gov)**

**[Hydrogen.energy.gov](http://Hydrogen.energy.gov)**

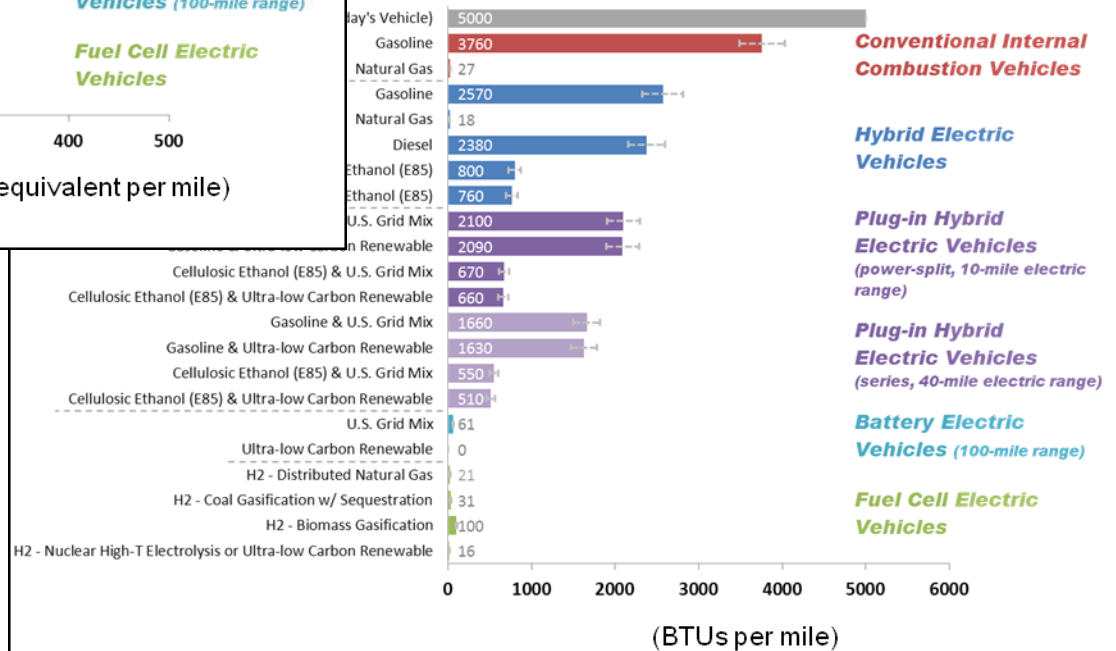
# Additional Information

Well-to-Wheels Greenhouse Gases Emissions Future Mid-Size Car  
(Grams of CO<sub>2</sub>-equivalent per mile)



Analysis includes portfolio of transportation technologies and latest models and updates to well-to-wheels assumptions

Well-to-Wheels Petroleum Energy Use for Future Mid-Size Car  
(BTUs per mile)



Source: DOE, May 2011

Source: DOE, May 2011

Analysis & Assumptions at:  
[http://hydrogen.energy.gov/pdfs/10001\\_well\\_to\\_wheels\\_gge\\_petroleum\\_use.pdf](http://hydrogen.energy.gov/pdfs/10001_well_to_wheels_gge_petroleum_use.pdf)

**Notes:**

For a projected state of technologies in 2035-2045.  
Ultra-low carbon renewable electricity includes wind, solar, etc.  
Does not include the life-cycle effects of vehicle manufacturing and infrastructure construction/decommissioning.  
Global warming potential of primary fuels excluded.

# Key Participants – Hydrogen Production

## Analysis & Testing

- ORNL
- TIAX
- PNNL
- UH
- SNL
- ANL

## Bio-derived Liquids

- ANL
- PNNL
- NREL

## Electrolysis

- Giner Electrochemical
- Avalence
- Proton Energy
- ORNL
- NREL

## Membranes

- Media and Process Technology
- ASU
- Pall Corporation
- ORNL

## Biomass Gasification

- UTRC
- GTI
- NETL

## Solar High Temperature Thermochemical H<sub>2</sub> Production

- SNL
- ANL
- SAIC
- U of CO, Boulder

## Photoelectrochemical H<sub>2</sub> Production

- LANL
- LLNL
- Midwest Optoelectronics
- MV Systems
- Stanford University
- NREL

## Biological H<sub>2</sub> Production

- UC Berkeley
- J. Craig Venter
- NREL



## Analysis

- ANL
- NREL
- PNNL

## Carriers

- Air Products
- PNNL

## Forecourt Compression/Storage

- AC Transit
- Fuel Cell Energy
- NASA
- ORNL

## H<sub>2</sub> Liquefaction & Delivery

- Gas Equipment Engineering Corporation
- Linde Corporation
- LLNL
- Praxair
- Prometheus Energy

## Pipelines & Pipeline Compression

- ANL
- Concepts NREC
- DOT
- I2CNER
- MITI
- NASA
- NIST
- ORNL
- Secat
- SNL
- SRNL
- University of Illinois

## Sub-program Review

- BP
- Chevron
- Exxon-Mobil

# Key Participants – Hydrogen Storage

## Metal Hydrides

- HRL Laboratories
- UTRC
- CalTech
- Stanford
- Pittsburgh/Ga. Tech
- Hawaii/UNB
- Illinois
- Ohio State
- Nevada-Reno
- Utah
- Northwestern
- Brookhaven
- NIST
- Jet Propulsion Lab
- Oak Ridge
- Savannah River
- Sandia

## Hydrogen Sorbents

- Air Products
- CalTech
- Duke U.
- Texas A&M
- Michigan
- North Carolina
- Penn State
- Rice
- Missouri-Columbia
- UCLA
- Northwestern
- Argonne
- Oak Ridge
- Lawrence Livermore
- NIST
- NREL

## Chemical Hydrogen Storage Materials

- Dow
- U.S. Borax
- Penn State
- Alabama
- California-Davis
- Missouri-Columbia
- Pennsylvania
- Oregon
- Washington
- Los Alamos
- Pacific Northwest
- Idaho

## System Engineering

- Ford
- General Motors
- Lincoln Composites
- UTRC
- Hawaii Hydrogen Carriers
- Oregon State
- CalTech
- L'Université du Québec à Trois-Rivières
- Savannah River
- Jet Propulsion Lab
- Los Alamos
- NREL
- Pacific Northwest

## Testing, Analysis, Physical Storage and Novel Concepts

- |                                |                                 |                      |                  |
|--------------------------------|---------------------------------|----------------------|------------------|
| • Air Products and Chemicals   | • Hydrogen Education Foundation | • Argonne            | • NREL           |
| • UTRC                         | • Southwest Research Institute  | • Savannah River     | • Purdue         |
| • Gas Technology Institute     | • SUNY – Syracuse               | • Lawrence Livermore | • U. of Arkansas |
| • Hawaii Hydrogen Carriers     | • UC Berkeley                   | • Sandia             | • GM             |
| • H2 Technology Consulting LLC | • UC Santa Barbara; UNLV        | • Oak Ridge          | • TIAX           |
|                                | • Quantum Technologies          | • Pacific Northwest  | • SiGNa          |

# Key Participants – Fuel Cells

## Testing and Technical Assessments

- LANL
- Directed Technologies
- TIAX
- NREL
- ANL
- ORNL
- NIST

## Bipolar Plates

- TreadStone Technologies
- ORNL
- ANL

## Catalysts & Supports

- BNL
- PNNL
- 3M
- UTC
- LBNL
- ANL
- LANL
- General Motors
- Northeastern University
- University of South Carolina
- Illinois Institute of Technology
- NREL

## Durability

- Ballard
- LANL
- Plug Power
- UTC
- ANL
- Nuvera Fuel Cells
- University of Connecticut

## Membranes

- Giner Electrochemical Systems
- Oak Ridge National Laboratory
- FuelCell Energy
- University of Central Florida
- 3M
- Vanderbilt University
- Colorado School of Mines
- Case Western Reserve University
- LANL
- Sandia National Laboratory
- Ion Power
- University of Southern Mississippi
- Kettering University

## Balance of Plant

- W. L. Gore & Associates
- Stark State College
- Dynalene

## Portable Power

- Arkema Inc.
- University of North Florida
- LANL
- NREL

## Stationary Power

- Intelligent Energy
- Acumentrics
- Versa Power Systems
- UTC
- University of Akron
- Colorado School of Mines
- Stark State College

## Transport

- SNL
- LBNL
- Nuvera Fuel Cells
- Giner Electrochemical Systems
- General Motors
- Rochester IT
- LANL
- CFD

## Impurities and Fuel Processors

- NREL
- University of Connecticut
- Clemson University
- University of Hawaii
- DuPont
- Rolls Royce

## MANUFACTURING R&D

### Electrode Deposition

- BASF

### High Pressure Storage

- Quantum
- PNNL

### MEA Manufacturing

- ORNL
- RPI
- Gore

### GDL Fabrication

- Ballard Material Products

### Testing of FC Stacks

- UltraCell
- PNNL
- LLNL

### Measurement of FC Stacks

- NIST
- NREL
- LBNL

## EDUCATION

### State & Local Government Projects

- Virginia Clean Cities
- Technology Transition Corporation
- Houston Advanced Research Center
- South Carolina Hydrogen and Fuel Cell Alliance
- Clean Energy States Alliance
- Connecticut Center for Advanced Technology, Inc.
- Ohio Fuel Cell Coalition

### Middle Schools & High Schools

- National Energy Education Development Project
- UC-Berkeley Lawrence Hall of Science

### University Projects

- Humboldt State Univ.
- University of Central Florida/UNC-Charlotte
- Cal State-LA
- Michigan Tech (MTU)
- Univ. of North Dakota
- Hydrogen Education Foundation

### Early Adopters

- Carolina Tractor

### Analysis

- Argonne National Lab
- RCF Consulting

## Safety, Codes & Standards

- LANL
- LLNL
- NASA
- NIST
- NREL
- PNNL
- ORNL
- SNL
- U.S. Dept. of Commerce
- U.S. Dept. of Transportation
- Regulatory Logic

Acknowledgements: SCS works with many other international and domestic stakeholders, including auto OEMs, energy providers, governmental agencies, NGOs, CDOs, and SDOs.

## Technology Validation

- Air Products & Chemicals, Inc.
- CA Fuel Cell Partnership
- Daimler
- General Motors Corp.
- Mercedes Benz North America
- NREL
- Shell Hydrogen

## Systems Analysis

- ANL
- LANL
- LLNL
- NREL
- ORNL
- PNNL
- RCF Economic & Financial Consulting, Inc.
- SNL
- UC Davis



## Industry

- Boeing
- BMW
- Excel Energy
- First Energy
- Ford Motor
- GM
- HELCO
- Price Choppers
- Walmart

## Other Federal Agencies

- Army - CERL
- Environmental Protection Agency
- Federal Aviation Administration
- Federal Transit Administration Navy - ONR
- Defense Logistics Agency - TARDEC
- NASA
- U.S. Department of Transportation
- U.S. Department of Defense
- U.S. Department of Interior - National Park Service
- U.S. Department of Commerce

## Federal Labs

- ANL
- LANL
- LLNL
- NREL
- ORNL
- SNL

## State Governments

- California
- Connecticut
- Hawaii
- New York
- South Carolina

## NGOs

- American Gas Association
- Electric Power Research Institute  
Fuel Cell and Hydrogen Energy  
Association
- Green Communities
- US Clean Heat and Power  
Association

## Data Collection & Analysis

- NREL

## Fuel Cell Developers

- Alteryg
- Delphi
- Jadoo Power
- MTI MicroFuel Cells
- Nuvera Fuel Cells
- Plug Power, Inc.
- ReliOn, Inc.
- University of North Florida

## Fuel Cell End-Users

- AT&T
- City of Folsom, CA
- Coca Cola
- Fort Irwin
- GENCO
- H-E-B
- Kimberly Clark
- NASCAR
- PG&E
- Sempra Energy customers
- Sprint Nextel
- Sysco Houston
- Sysco Philadelphia
- University of California - Irvine
- Warner Robins Air Force Base
- Wegmans
- Whole Foods Market

## Hydrogen Providers

- Air Products & Chemicals, Inc.
- Linde
- Nuvera Fuel Cells