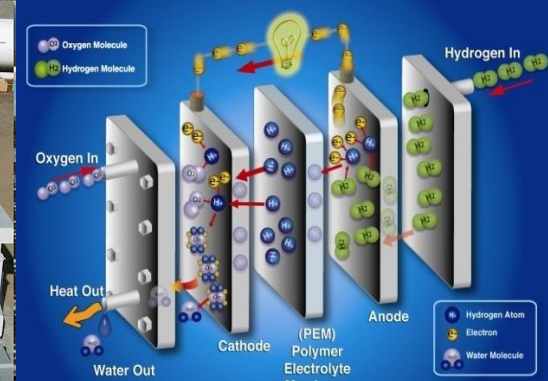


Hydrogen and Fuel Cell Activities

U.S. DEPARTMENT OF
ENERGY

Energy Efficiency &
Renewable Energy



5th International Conference on Polymer Batteries & Fuel Cells

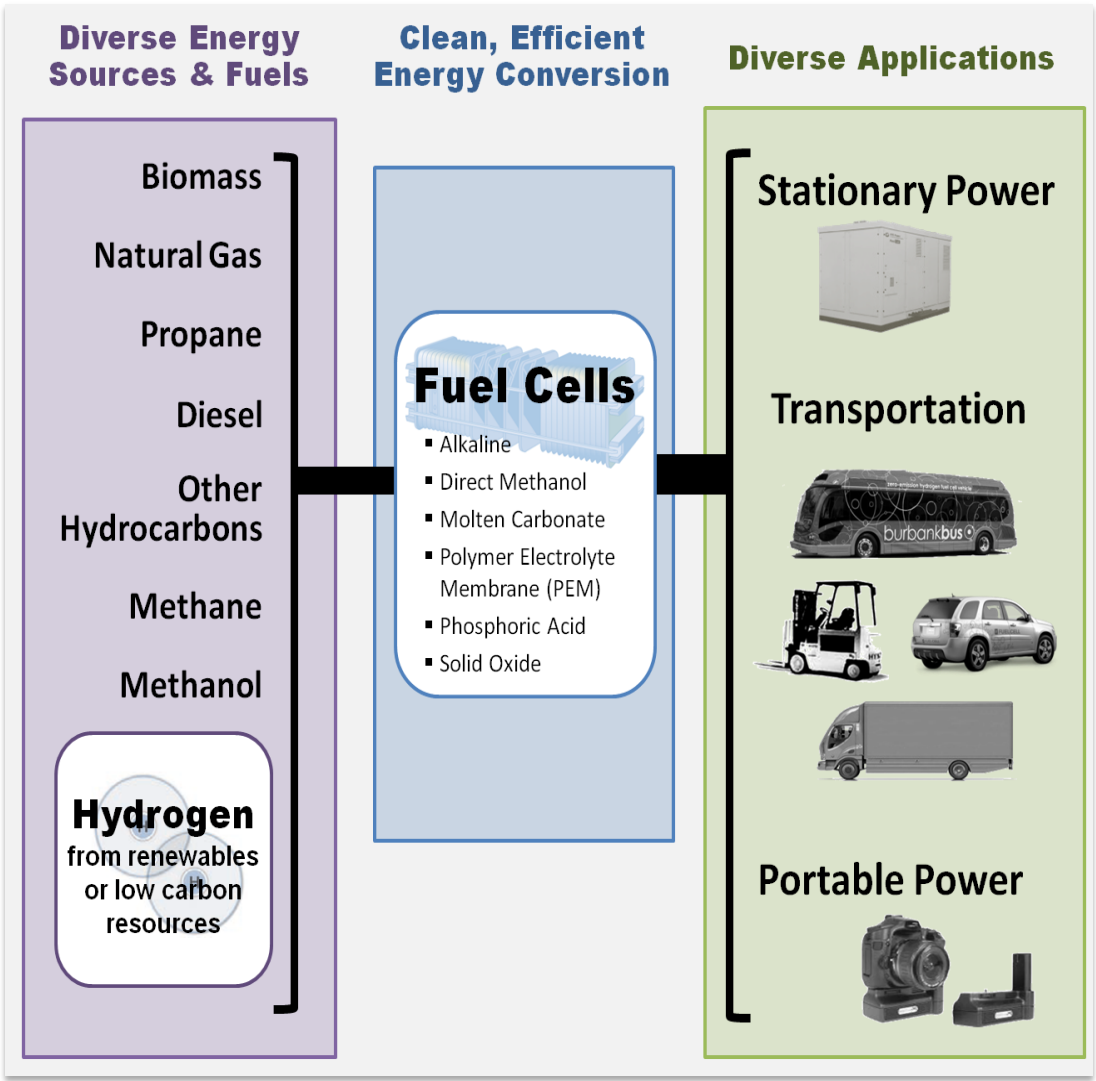
Argonne, Illinois

August 4, 2011

Dr. Sunita Satyapal

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

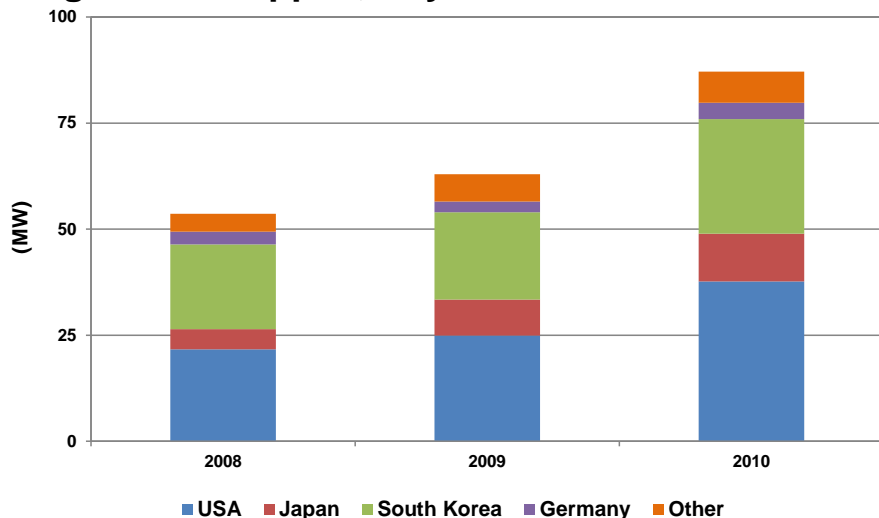
The Role of Fuel Cells



Key Benefits

- Very High Efficiency**
 - up to 60% (electrical)
 - up to 70% (electrical, hybrid fuel cell / turbine)
 - up to 85% (with CHP)
- Reduced CO₂ Emissions**
 - 35–50%+ reductions for CHP systems (>80% with biogas)
 - 55–90% reductions for light-duty vehicles
- Reduced Oil Use**
 - >95% reduction for FCEVs (vs. today's gasoline ICEVs)
 - >80% reduction for FCEVs (vs. advanced PHEVs)
- Reduced Air Pollution**
 - up to 90% reduction in criteria pollutants for CHP systems
- Fuel Flexibility**
 - **Clean fuels** — including biogas, methanol, H₂
 - **Hydrogen** — can be produced cleanly using sunlight or biomass directly, or through electrolysis, using renewable electricity
 - **Conventional fuels** — including natural gas, propane, diesel

Megawatts Shipped, Key Countries: 2008-2010



Fuel cell market continues to grow

- ~36% increase in global MWs shipped
- ~50% increase in US MWs shipped

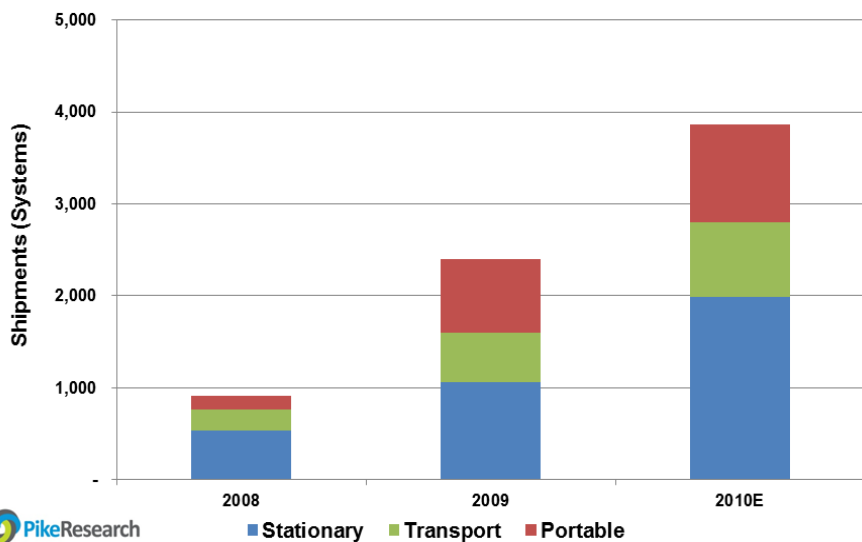
Various analyses project that the global fuel cell/hydrogen market could reach maturity over the next 10 to 20 years, producing revenues of:

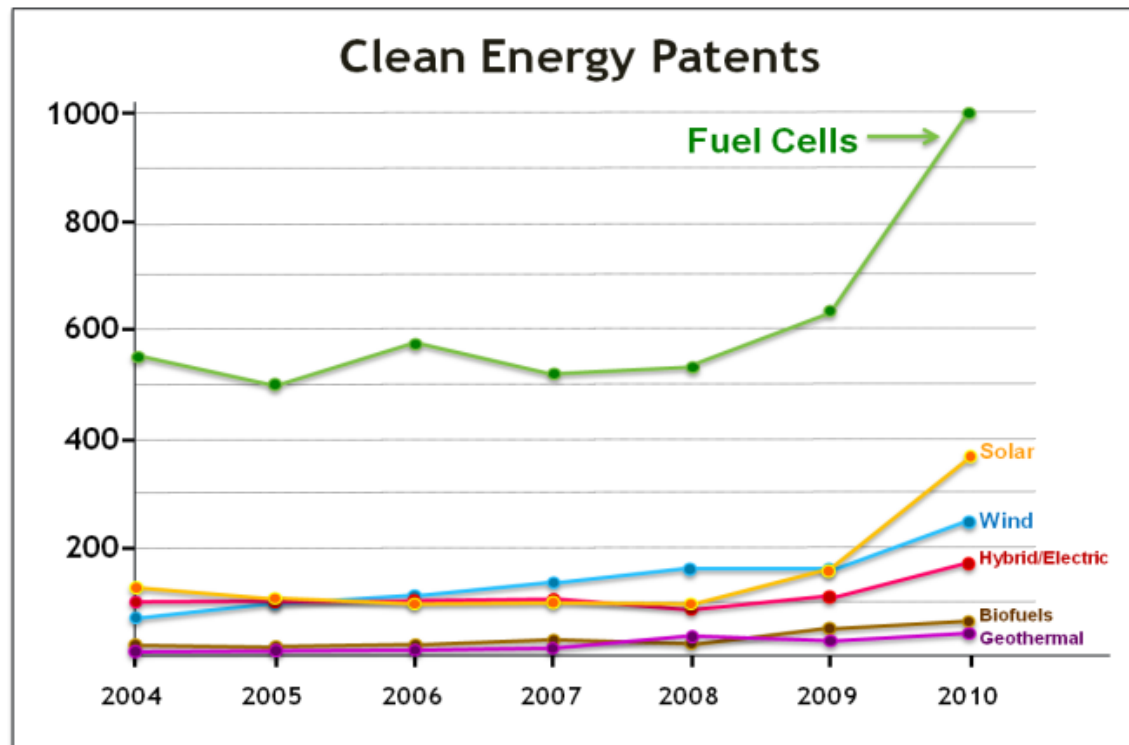
- \$14 – \$31 billion/year for stationary power
- \$11 billion/year for portable power
- \$18 – \$97 billion/year for transportation

Widespread market penetration of fuel cells could lead to:

- 180,000 new jobs in the US by 2020
- 675,000 jobs by 2035

North American Shipments by Application





Clean Energy Patent Growth Index^[1] shows that fuel cell patents lead in the clean energy field with nearly 1,000 fuel cell patents issued worldwide in 2010.

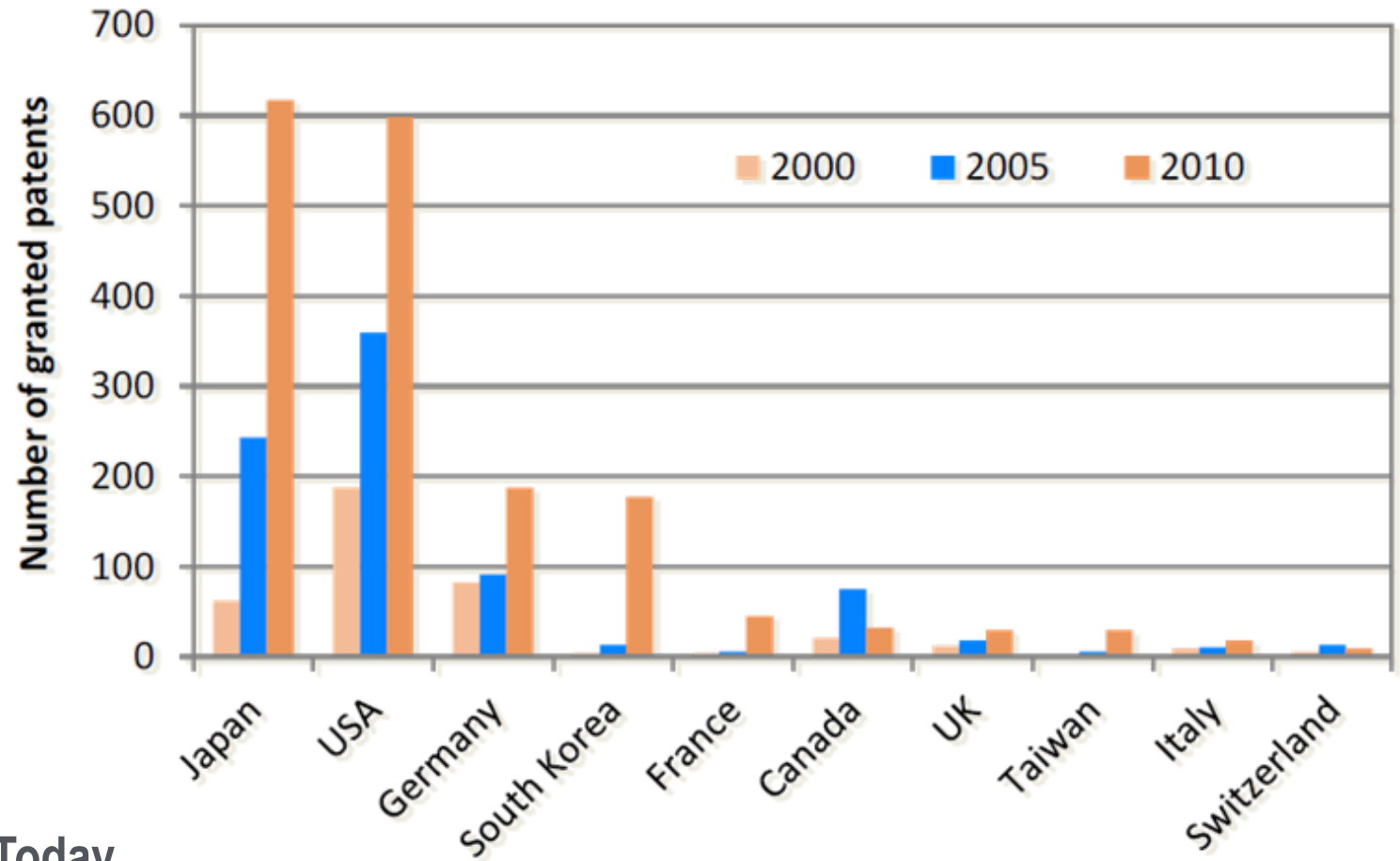
- 3x more than the second place holder, solar, which has just ~360 patents.
- Number of fuel cell patents grew > 57% in 2010.

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

Fuel Cell Patents per Country

Overall patents led by USA and Japan. Significant growth and acceleration of fuel cell patents by Japan to move ahead of the USA by 2010.

Annual granted fuel cell patents per country of origin (top ten)



FuelCell Today

Fuel Cells for Stationary Power, Auxiliary Power, and Specialty Vehicles

The largest markets for fuel cells today are in stationary power, portable power, auxiliary power units, and forklifts.

~75,000 fuel cells have been shipped worldwide.
>15,000 fuel cells shipped in 2009

Fuel cells can be a cost-competitive option for critical-load facilities, backup power, and forklifts.



Fuel Cells for Transportation

In the U.S., there are currently:

- > 200 fuel cell vehicles*
- ~ 20 active fuel cell buses*
- ~ 60 fueling stations*

Sept. 2009: Auto manufacturers from around the world signed a letter of understanding supporting fuel cell vehicles in anticipation of widespread commercialization, beginning in 2015.



Production & Delivery of Hydrogen

In the U.S., there are currently:

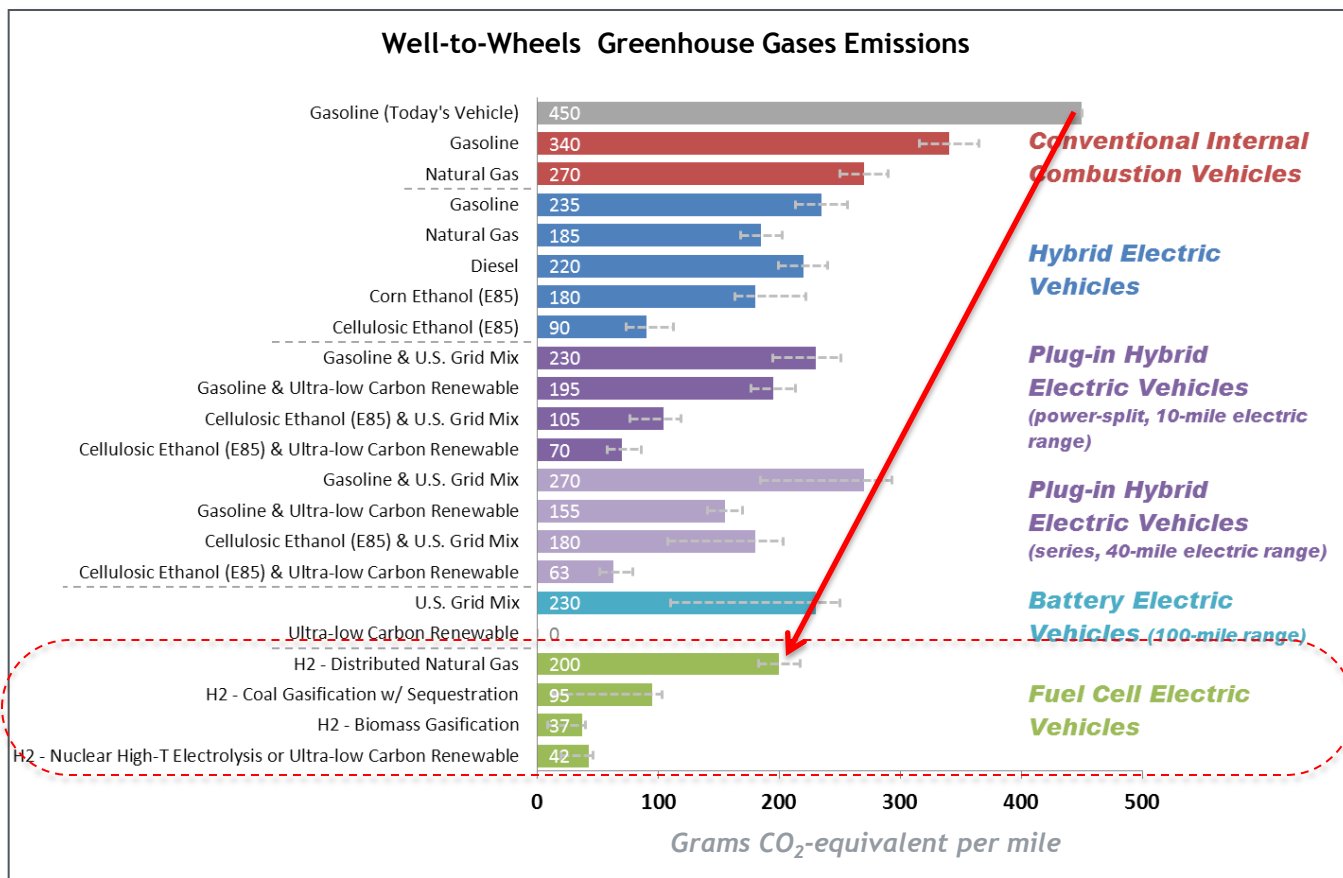
~9 million metric tons of H₂ produced annually
> 1200 miles of H₂ pipelines



Source: US DOE 09/2010

Well-to-Wheels CO₂ Analysis

Analysis by Argonne National Lab, DOE Vehicle Technologies Program, and FCT Program shows benefits from a portfolio of options



H₂ from Natural Gas

Even FCEVs fueled by H₂ from distributed NG can result in a **>50% reduction in GHG emissions** from today's vehicles.

Use of H₂ from NG decouples carbon from energy use—i.e., it allows carbon to be managed at point of production vs at the tailpipe.

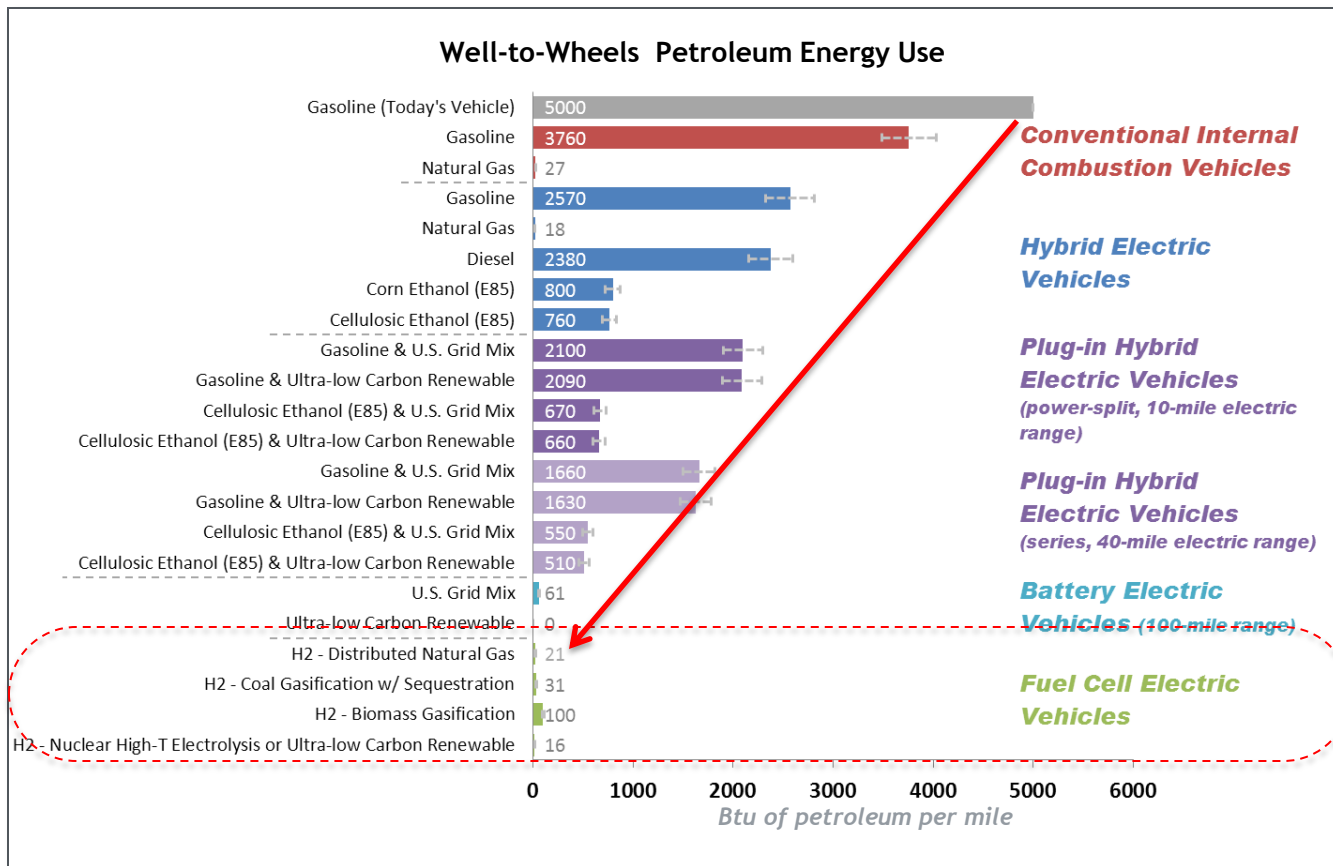
Even greater emissions reductions are possible as hydrogen from renewables enter the market.

Notes:

For a projected state of technologies in 2035-2045. Ultra-low carbon renewable electricity includes wind, solar, etc. Does not include the lifecycle effects of vehicle manufacturing and infrastructure construction/decommissioning.

Analysis & Assumptions at: http://hydrogen.energy.gov/pdfs/10001_well_to_wheels_gge_petroleum_use.pdf

Analysis by Argonne National Lab, DOE Vehicle Technologies Program, and FCT Program shows benefits from a portfolio of options.



H₂ from Natural Gas

FCEVs fueled by H₂ from distributed natural gas can almost completely eliminate petroleum use.

*1 million FCEVs would only increase current natural gas consumption by less than 0.2%**

** 1 million FCEVs would require ~1 billion cubic meters/year of NG; current NG consumption is about 600 billion cubic meters/yr*

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.

Analysis & Assumptions at: http://hydrogen.energy.gov/pdfs/10001_well_to_wheels_gge_petroleum_use.pdf

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.

Economic & Institutional Barriers

Safety, Codes & Standards Development

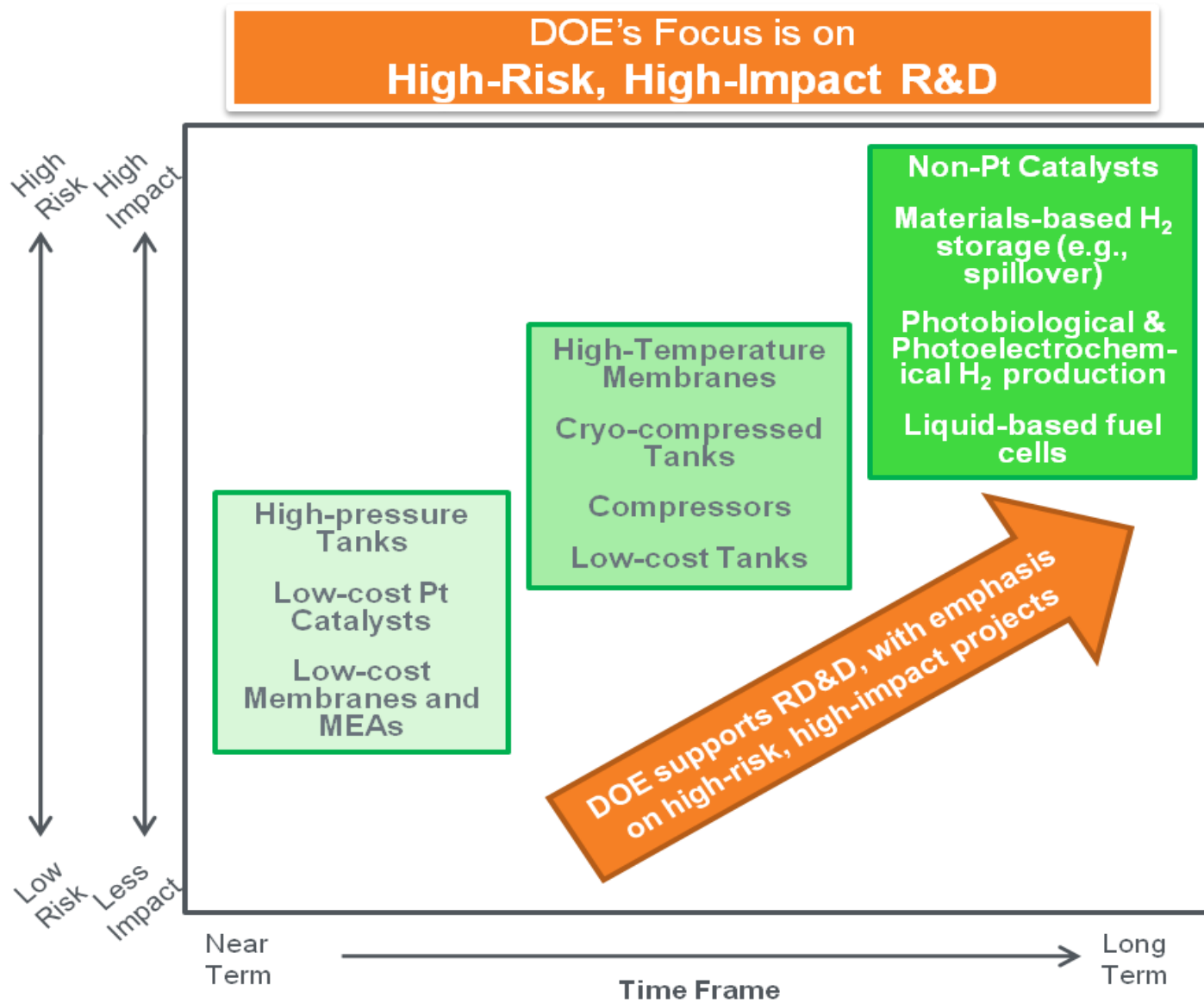
Domestic Manufacturing & Supplier Base

Public Awareness & Acceptance

Hydrogen Supply & Delivery Infrastructure

Market Transformation

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

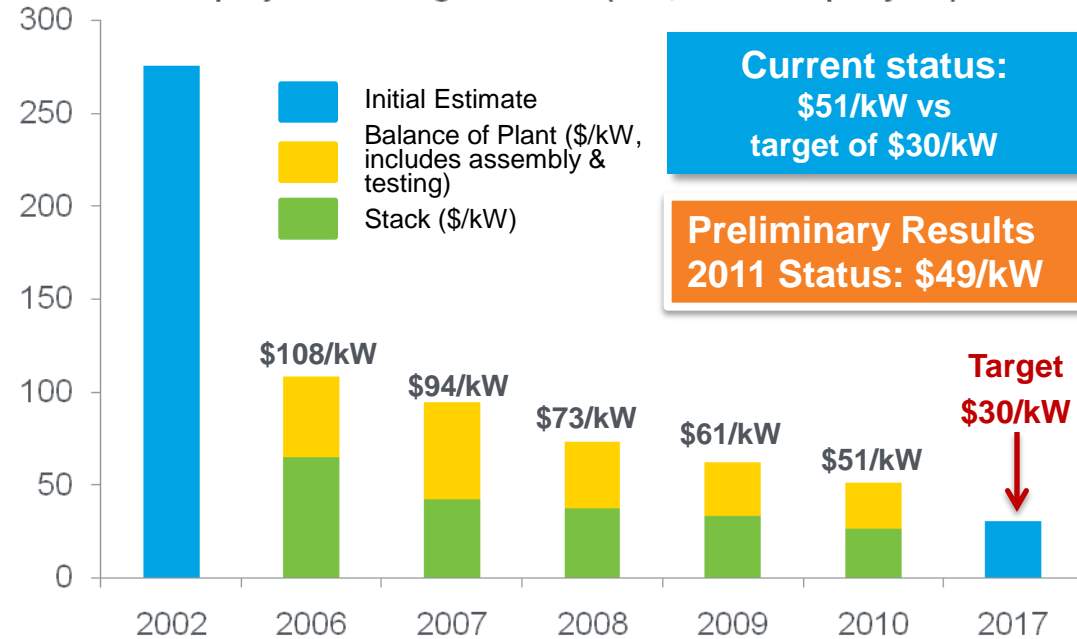


Projected high-volume cost of fuel cells has been reduced to \$51/kW (2010)*

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

Projected Transportation Fuel Cell System Cost

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



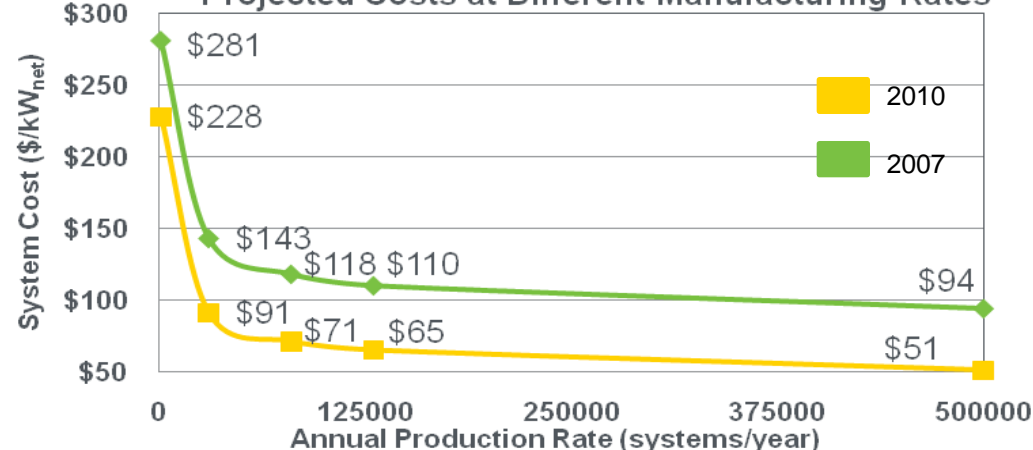
Current status:

\$51/kW vs target of \$30/kW

Preliminary Results 2011 Status: \$49/kW

Target \$30/kW

Projected Costs at Different Manufacturing Rates



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

**Panel found \$60 – \$80/kW to be a “valid estimate”:
http://hydrogenodev.nrel.gov/peer_reviews.html

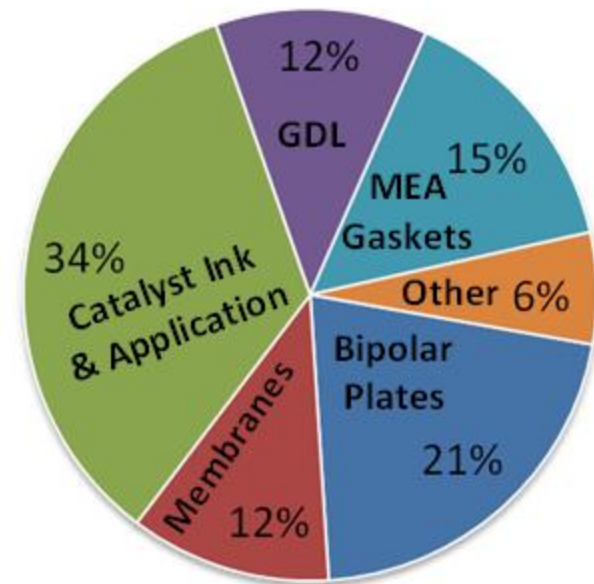
Challenges:

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

Four Strategies for Catalysts & Supports R&D:

- **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

Stack Cost - \$25/kW



DTI, 2010 analysis, scaled to high volume production of 500,000 units/yr

Used \$1100/Troy Ounce for Pt Cost

Fuel Cell Catalysts Technical Targets vs. Status

Electrocatalysts for Transportation Applications	Status ^a	Targets ^b
	2011	2017
Platinum group metal (PGM) total content (both electrodes)	0.19 g/kW	0.125 g/kW
PGM Total Loading	0.15 mg/cm ²	0.125 mg/cm ²
Loss in catalytic (mass) activity ^c	<40%	<40% loss of initial
Catalyst support loss ^d	<10% mass loss	< 10% mass loss
Mass activity ^e	0.24 A/mg Pt in MEA >0.44 A/mg Pt new alloy in RDE	0.44 A/mg PGM
Activity per volume of supported catalyst (non-PGM) ^f	60 A/cm ³ (measured) 160 A/cm ³ (extrapolated)	>300 A/cm ³

^a single cell status – will require scale-up

^b preliminary targets – approval pending

^c after 30,000 cycles from 0.6 – 1.0 V;

after 400 hours at 1.2 V

^d after 400 hours at 1.2 V

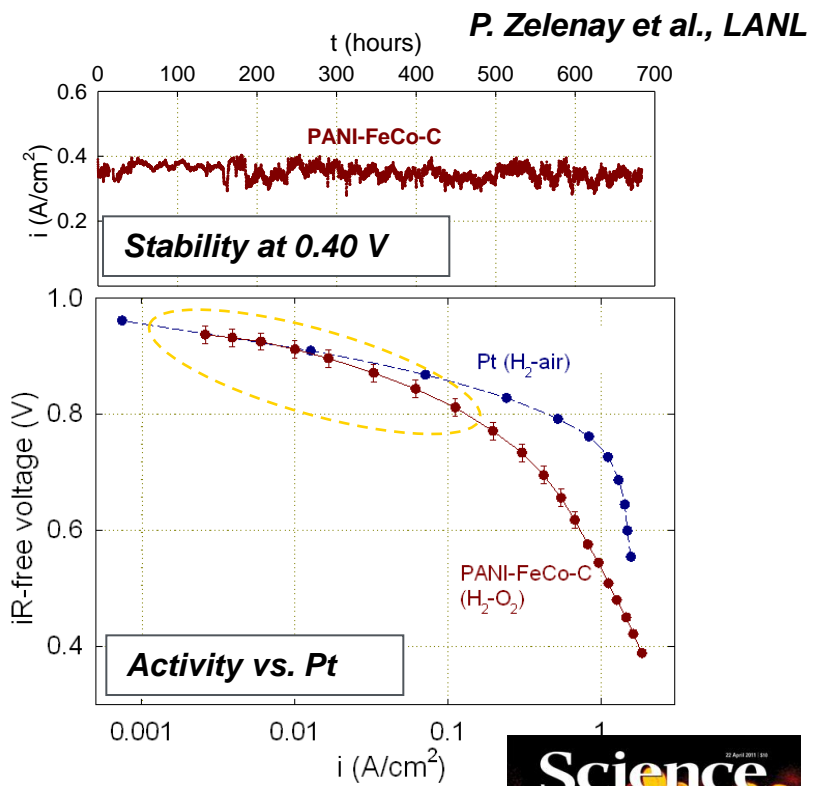
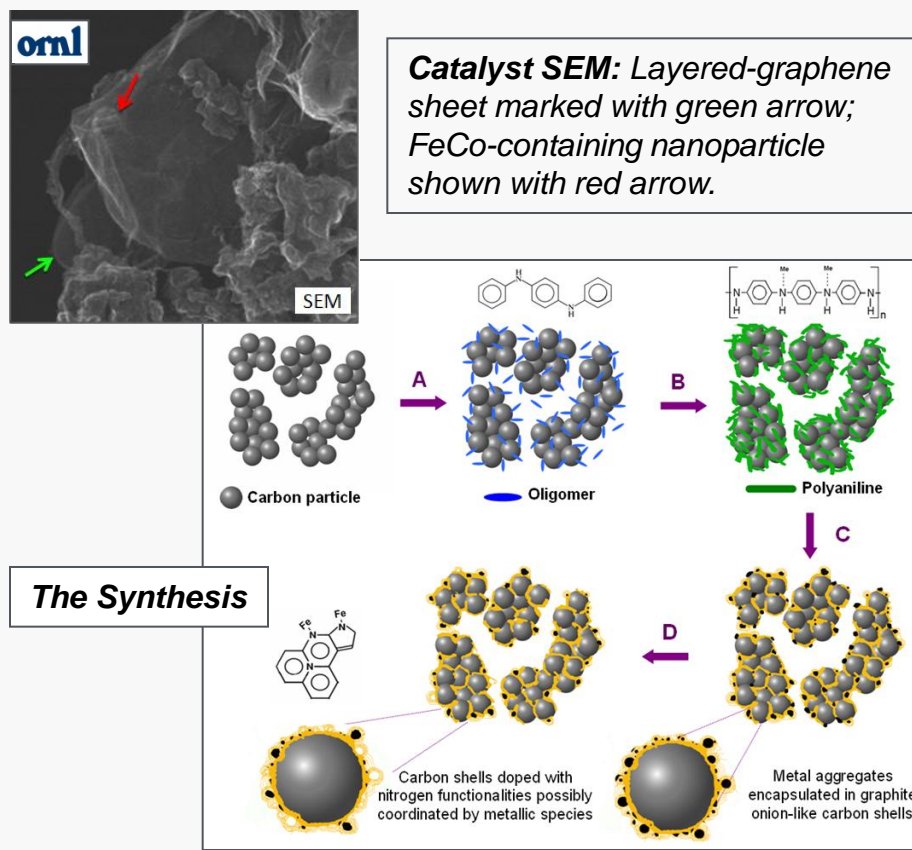
^e baseline @ 900mV_{IR-free}

^f baseline @ 800mV_{IR-free}

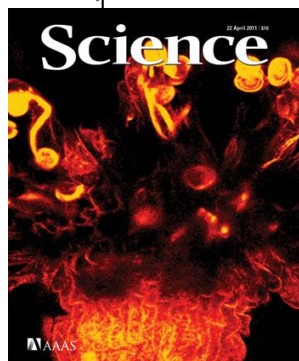
Update of Multiyear RD&D Plan in process

H	= High (significant challenge)	M	= Medium
M/H	= Medium/High	L	= Low (minimal challenge)

Catalysts: Non-PGM catalysts demonstrate activity approaching that of Pt



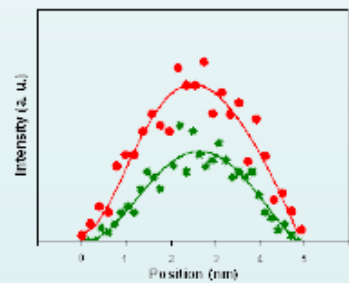
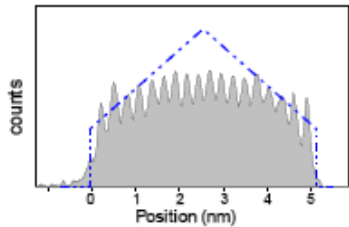
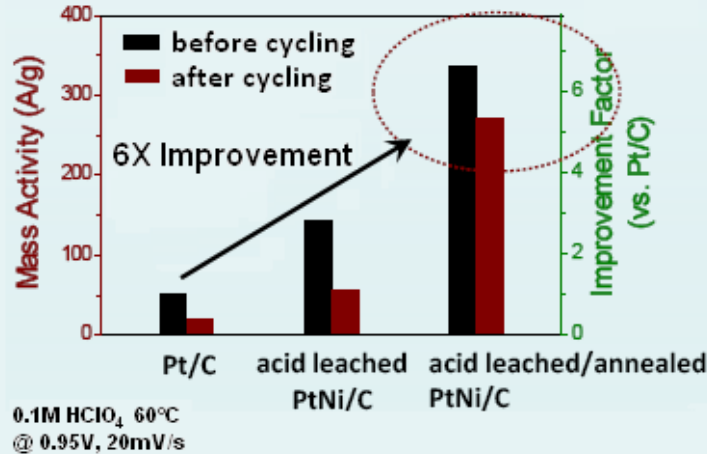
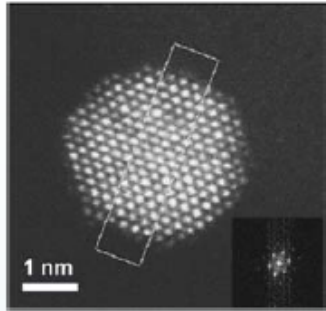
G. Wu, K. L. More, C. M. Johnston, P. Zelenay, *Science*, **332**, 443-7 (2011)



- High ORR activity reached with polyaniline-based and cyanamide-based catalysts
- Intrinsic activity getting close that of Pt, but electrode structure needs improvement

Catalysts: Nano-segregated binary and ternary catalysts demonstrate performance more than 6X that of platinum

Nanosegregated Binary (PtNi)

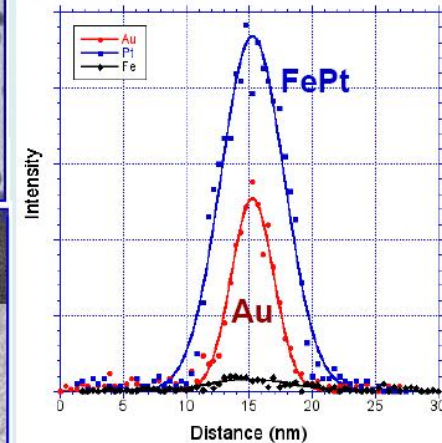
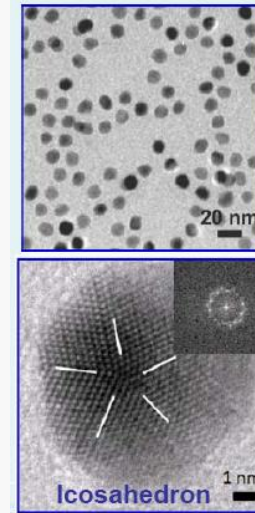


Multilayered Pt-skin surfaces confirmed for PtNi annealed NPs

Performance: Nanosegregated PtNi/C catalysts have ORR mass activity **~0.35 A/mg** in MEA testing – *approaching 0.44 A/mg target*

Durability: 3X improved retention of mass activity after 20,000 potential cycles compared to Pt/C

Nanosegregated Ternary (PtFeAu)



Performance: FePt(shell)/Au(core) demonstrates ORR mass activity more than 3X that of Pt/C

Durability: Maintains 80% of initial activity after 80,000 potential cycles (cf. less than 20% for Pt/C)

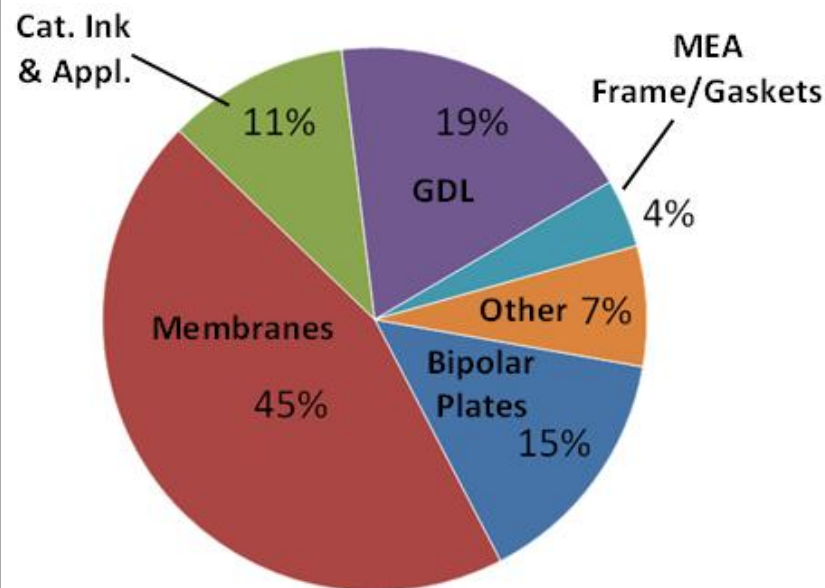
Challenges:

- **Membranes account for 45% of stack cost at low volume**
- **Limits on operating range**
- **Chemical and mechanical durability**

Membrane R&D:

- **High-Temperature, Low Humidity Conductivity**
 - Phase segregation (polymer & membrane)
 - Non-aqueous proton conductors
 - Hydrophilic additives
- **High Conductivity and Durability Across Operating Range with Cycling**
 - Mechanical support or membrane reinforcement
 - Chemical stabilization (additives, end-group capping)
 - Polymer structure (side chain length, grafting, cross-linking, backbone properties, blends, EW)
 - Processing parameters (temperature, solvents)
 - New materials

Stack Cost - \$144/kW



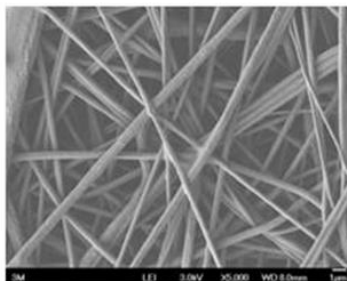
DTI, 2010 analysis, production of 1,000 units/yr

Fuel Cell Membrane Targets

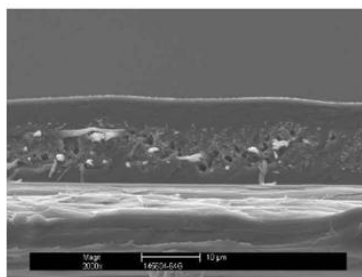
Characteristic	Units	2011	2017	Nafion®
		status	target	NRE211
Maximum oxygen crossover	mA/cm ²	<1	2	2.7
Maximum hydrogen crossover	mA/cm ²	<1.8	2	2.2
Area specific resistance at:				
Max operating temp and 40 – 80 kPa water partial pressure	ohm cm ²	0.023 (40 kPa) 0.012 (80 kPa)	0.02	0.186
80 C and water partial pressures from 25 - 45 kPa	ohm cm ²	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 cm ²	0.02 (3.8 kPa)	0.03	0.049
-20 C	ohm cm ²	0.1	0.2	0.179
Operating temperature	C	<120	≤120	120
Minimum electrical resistance	ohm cm ²		1000	
Cost	\$/m ²		20	
Durability				
Mechanical	Cycles w/<10 sccm crossover	>20,000	20,000	5,000
Chemical	hours	>2,300	500	

Innovative membranes demonstrate high conductivity at low RH

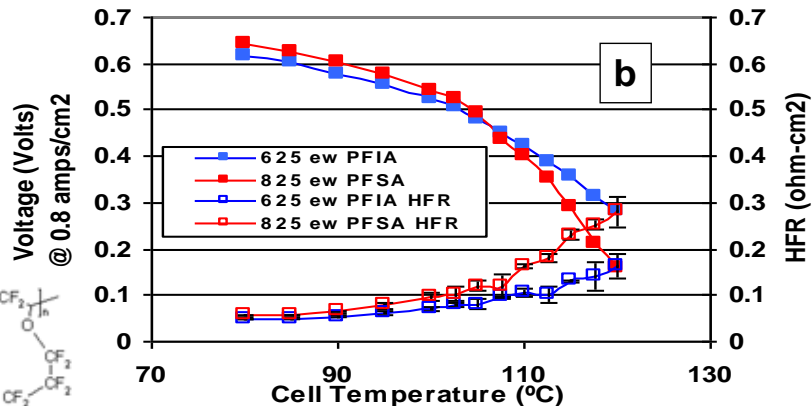
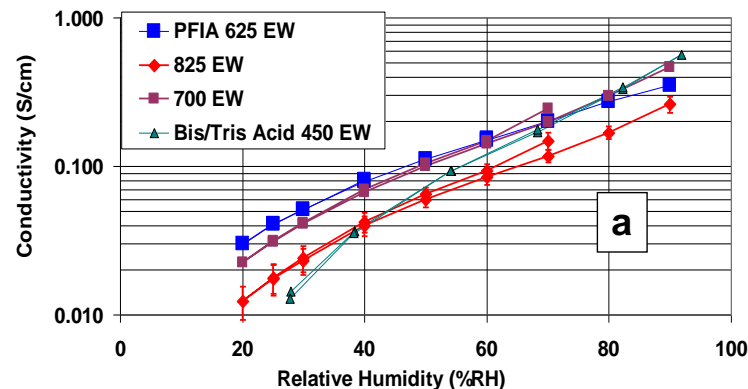
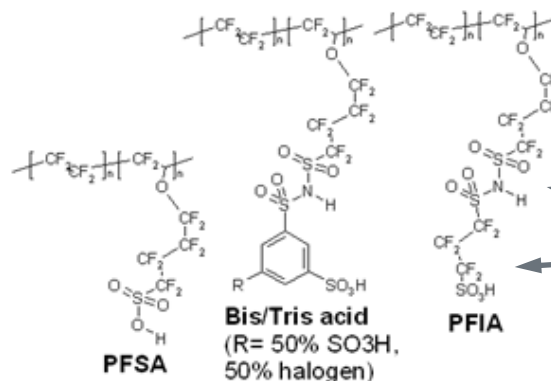
- PFIA membranes **meet most DOE targets** for performance and durability
- PFIA maintains high crystallinity at lower equivalent weight than PFSA → **better mechanical properties**
- High conductivity with PFIA under dry conditions: **0.087 S/cm @ 120 C, 25% RH**
- Supported and stabilized membranes are durable: **>2,300 hours chemical stability test; >20,000 RH cycles**



SEM Image of Nanofiber Support



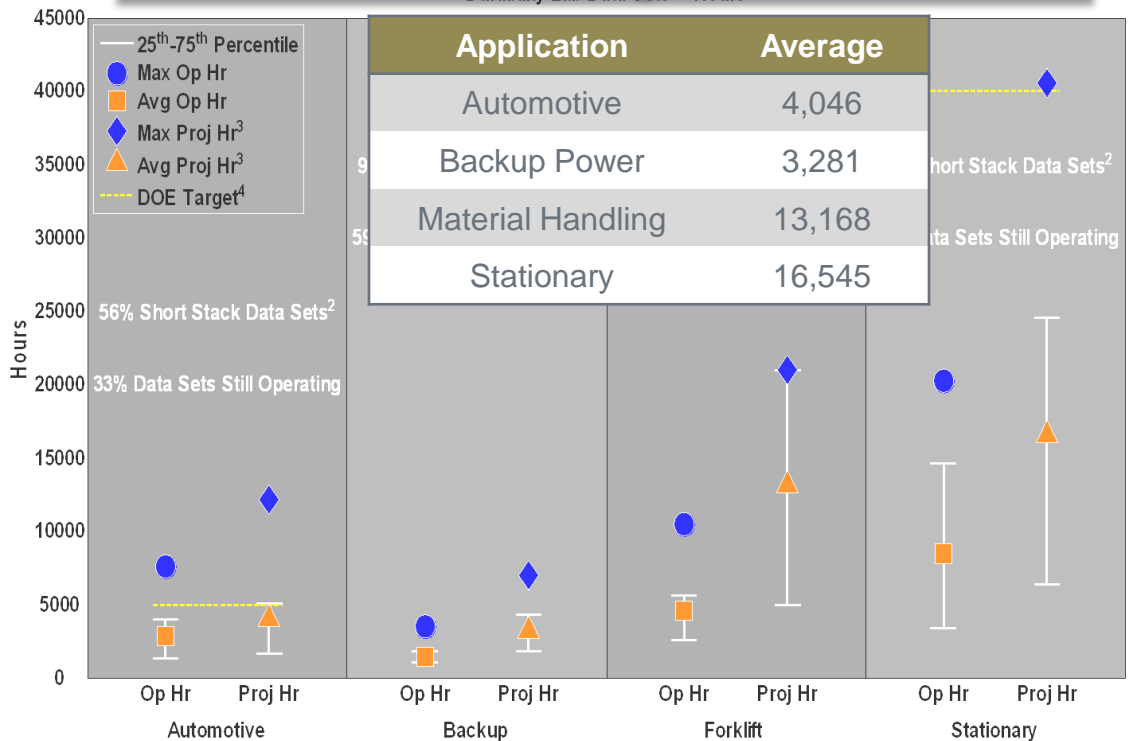
Freeze Fracture



Two superacid sites per side chain

S. Hamrock et al., 3M

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



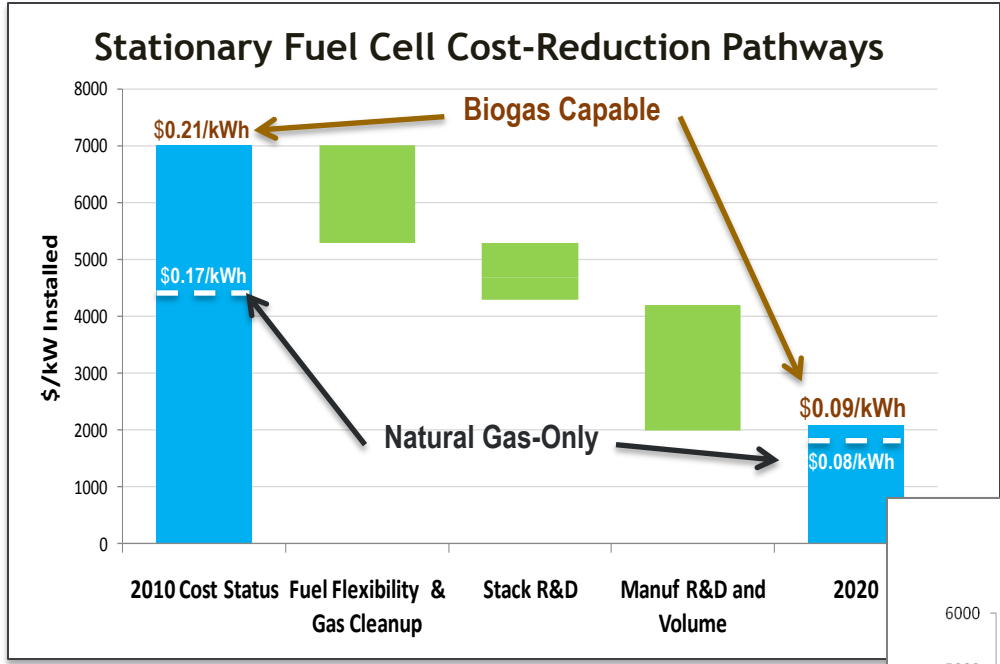
Tracking durability data from multiple companies (NREL)

Challenges – Continue to decrease cost and increase durability without compromising performance.

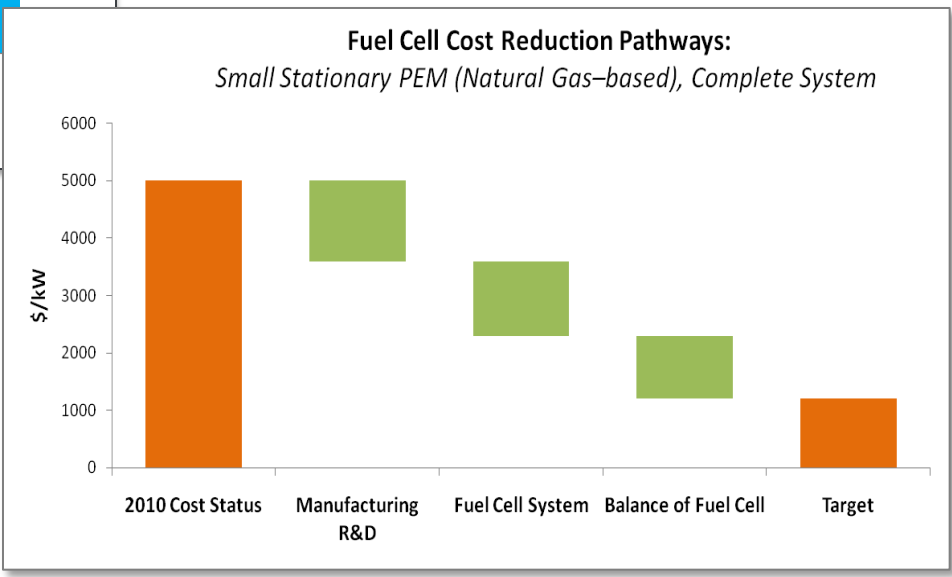
- **Catalysts**
 - Durability of low-PGM and non-PGM catalysts
 - Effects of impurities on low-PGM and non-PGM catalysts
 - Durability of catalyst supports
 - Water management with high-activity catalysts
 - Cost of PGM catalysts
- **Membranes**
 - Low RH performance
 - Durability of new membranes
 - Cost at low volumes
- **MEAs**
 - Low-temperature performance
 - Water management
 - High-current operation

Cost Reduction Roadmap for Stationary Fuel Cells (using biogas or natural gas)

Technology advancements, advanced manufacturing, and economies of scale are required to achieve necessary cost reductions.

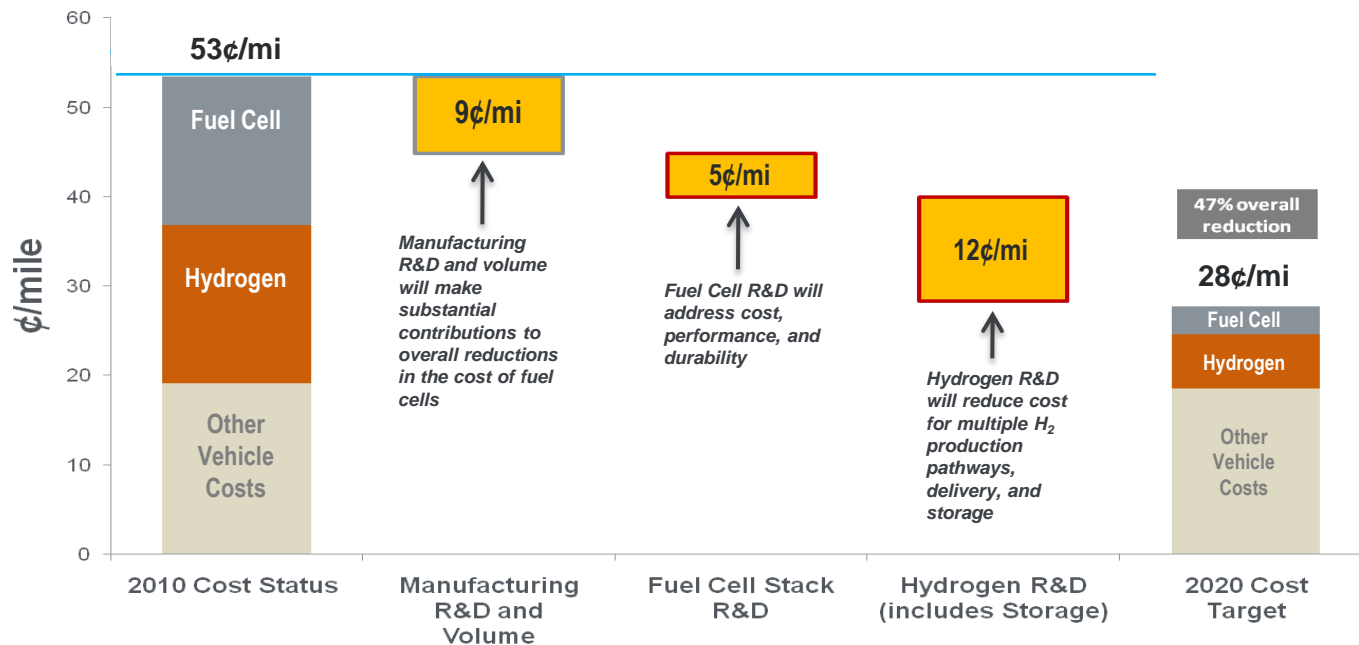


Biogas contains impurities that must be removed before it can be used in fuel cells. Gas cleanup equipment and operation result in costs beyond those associated with systems that use only natural gas.



We have pathways to reduce cost for all key components in lifecycle cost.

FCEV Lifecycle Cost Reduction Pathways



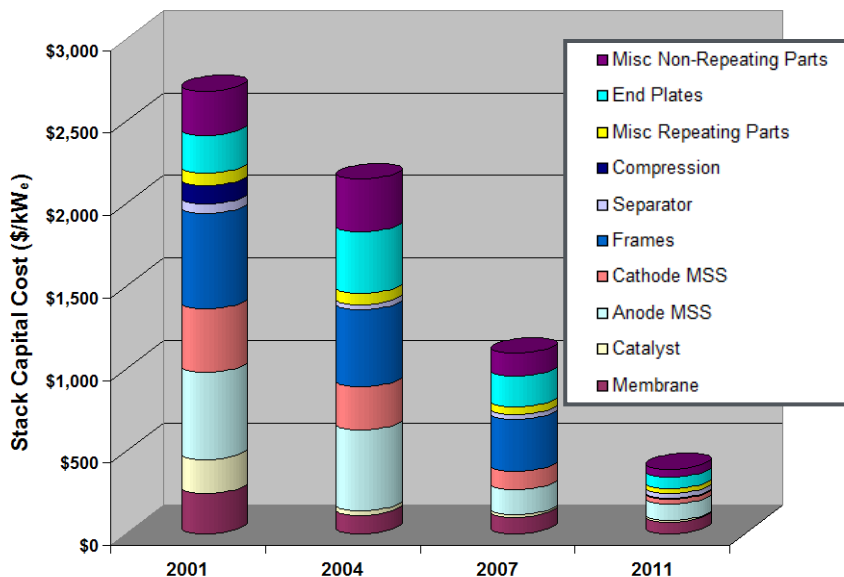
Assumptions

- Fuel cells
Cost: \$51/kW → \$30/kW
(low-volume cost is \$100/kW)
Durability: 75k → 150k miles
- Hydrogen Production
Cost: \$5.50/gge → \$3.00/gge
- On-board Hydrogen Storage
Cost: \$5,050 → \$1,100
- FCEV fuel economy
50 mpgge → ~60 mpgge
- Annual miles driven:
10,000 mi

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)

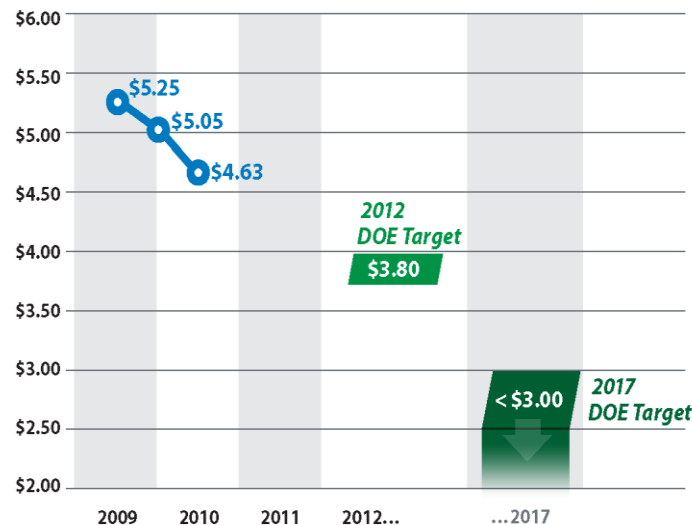


Photoelectrochemical Conversion (PEC):

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

Autothermal Reforming of Pyrolysis Oil

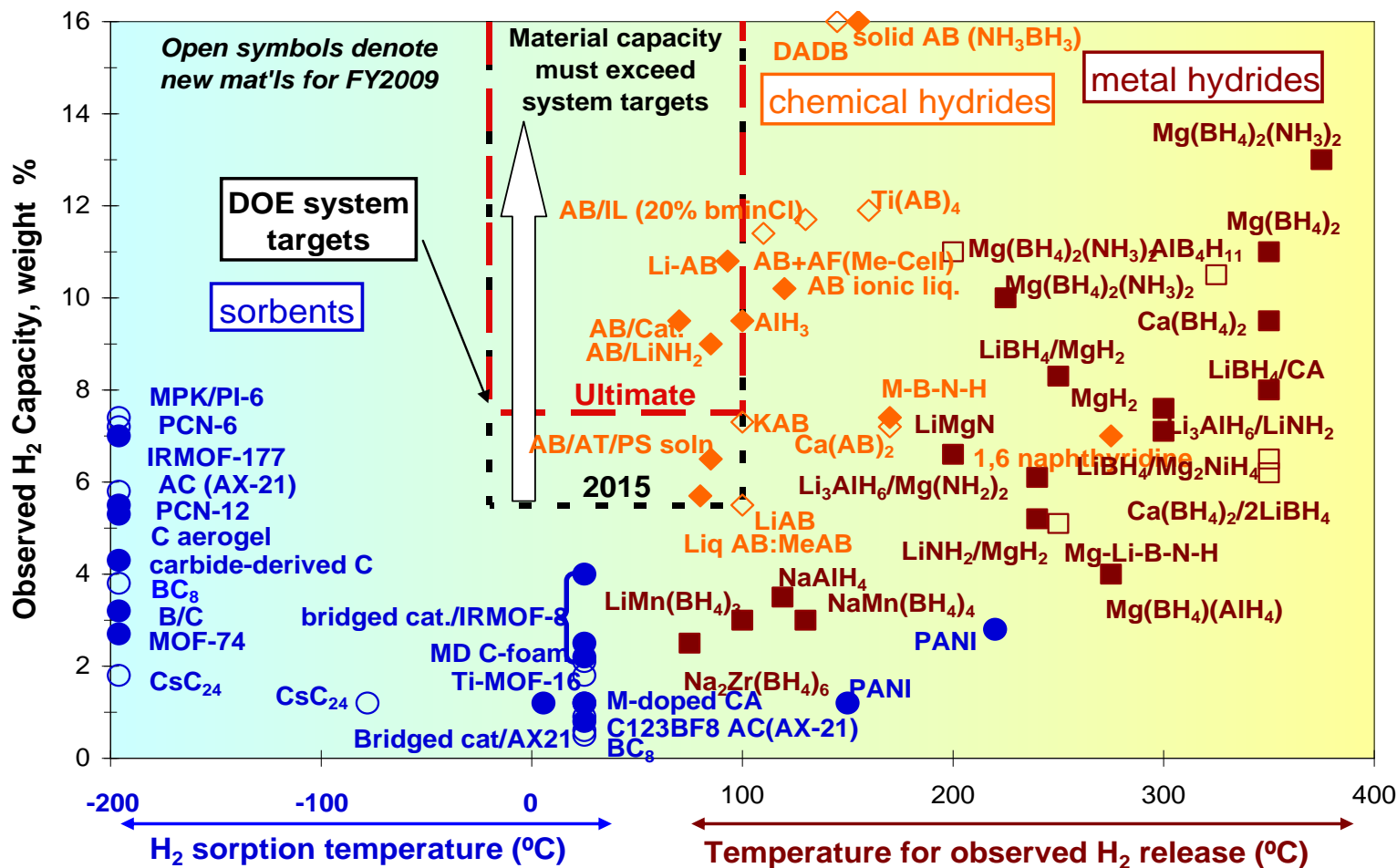
NREL's Distributed Production of H₂ from Bio-Derived Renewable Liquids \$/gge H₂ Delivered



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

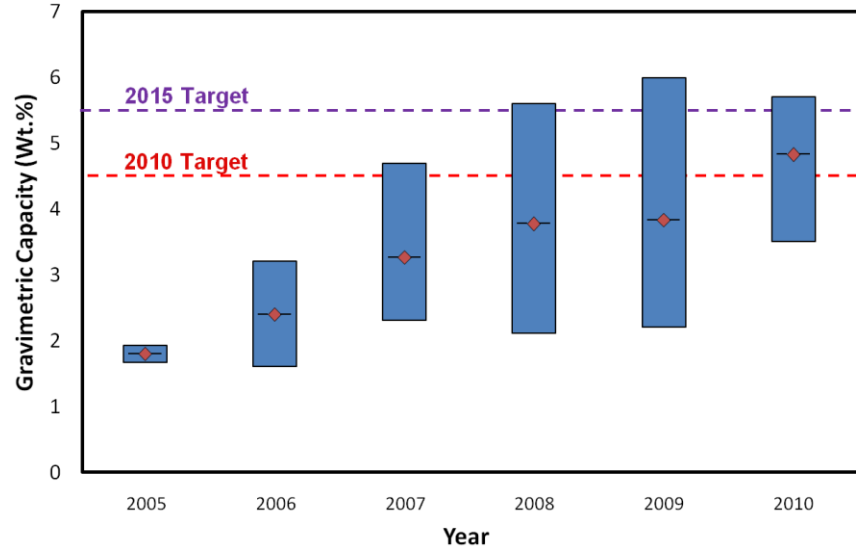
Tanks can achieve 430 mile range. Focus is on materials R&D but meeting all weight, volume, performance and cost requirements is still challenging.

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

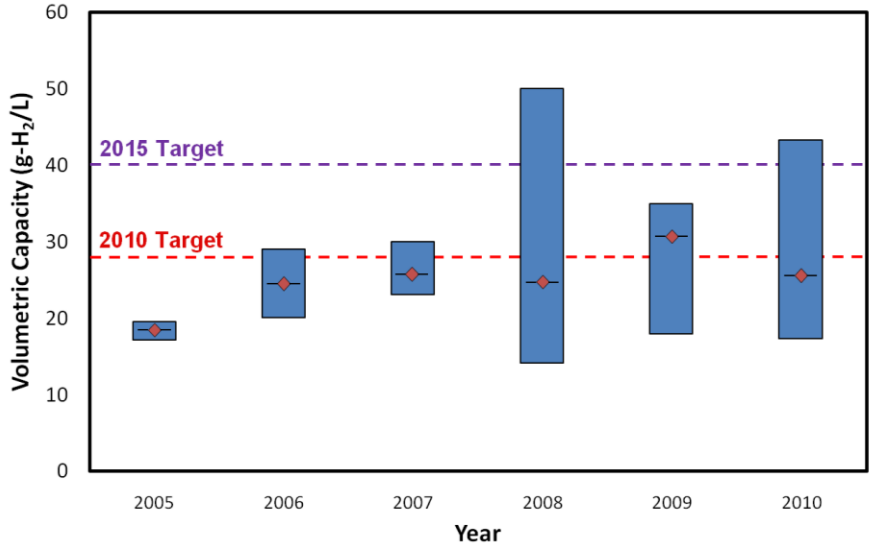


Projected Capacities for Complete 5.6-kg H₂ Storage Systems

Projected Ranges of System Gravimetric Storage Capacity
For Chemical, Metal Hydride, Sorbent and Physical Storage Technologies



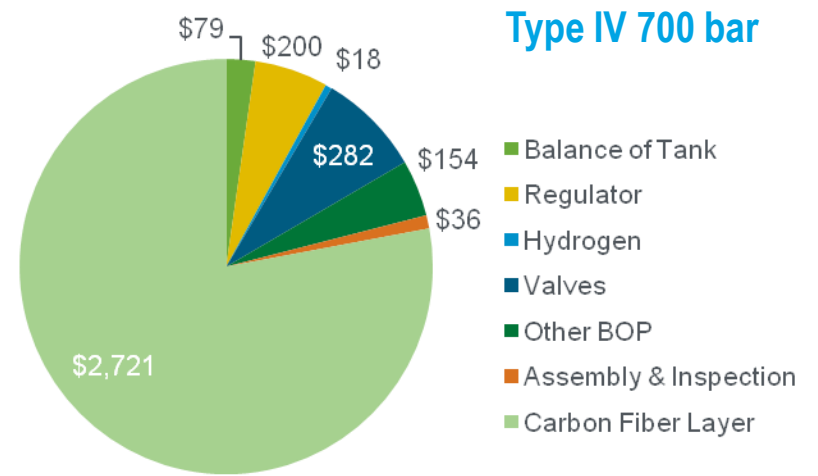
Projected Ranges of System Volumetric Storage Capacity
For Chemical, Metal Hydride, Sorbent and Physical Storage Technologies



Based on analysis using the best available data and information for each technology analyzed in the given year.

- **Assessed and updated targets as planned** — based on real-world experience with vehicles, weight and space allowances in vehicle platforms, and needs for market penetration
- **Developed and evaluated more than 400 material approaches experimentally and millions computationally**

Costs in the Carbon-Fiber Matrix



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)

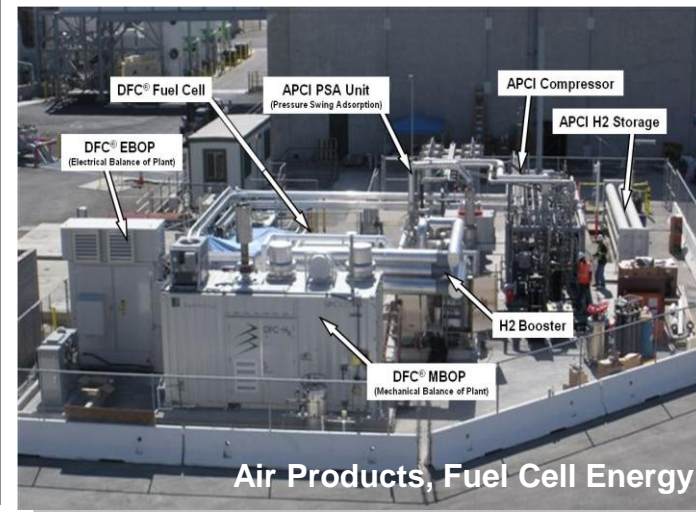
- H₂ fuel cell buses have a 42% to 139% better fuel economy when compared to diesel & CNG buses

Forklifts

- Over 45,000 refuelings at Defense Logistics Agency site

CHHP (Combined Heat, Hydrogen and Power)

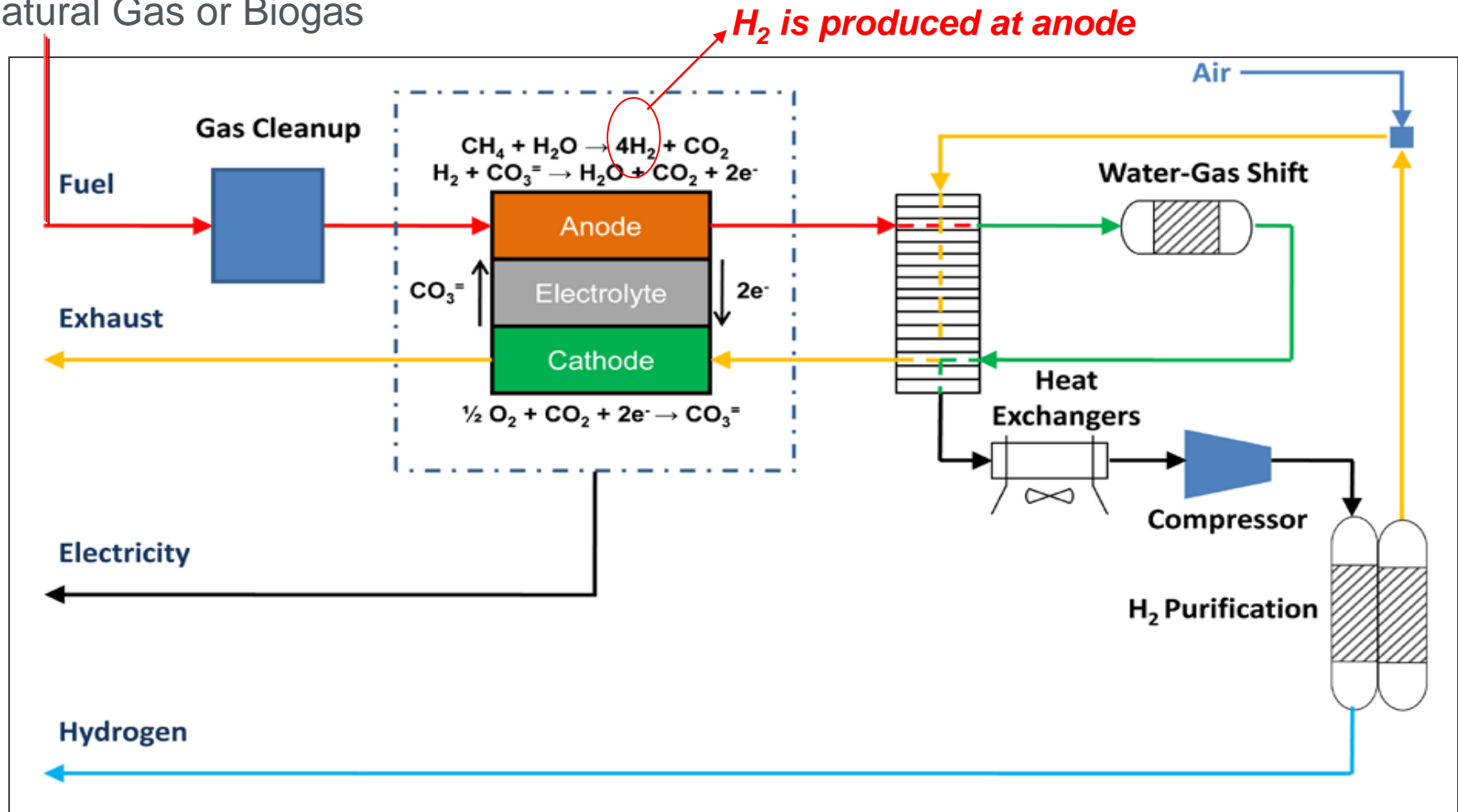
- Achieved 54% (hydrogen + power) efficiency of fuel cell when operating in hydrogen co-production mode
- 100 kg/day capacity, renewable hydrogen supply



Early Option for Hydrogen Infrastructure — Tri-generation (or “CHHP”)

High-temperature stationary fuel cells can co-produce hydrogen while providing power as well as heat for stationary applications . This offers an early supply of low-volumes of hydrogen without the need to commit to the capital cost of a dedicated fueling station.

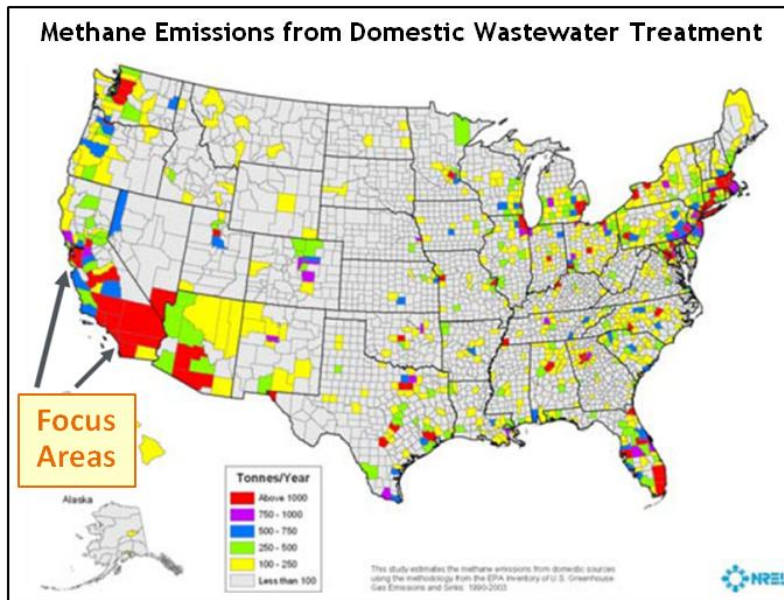
Natural Gas or Biogas



- *The majority of biogas resources are situated near large urban centers—ideally located near the major demand centers for hydrogen for FCEVs.*
- *Hydrogen can be produced from this renewable resource using existing steam-methane-reforming technology.*

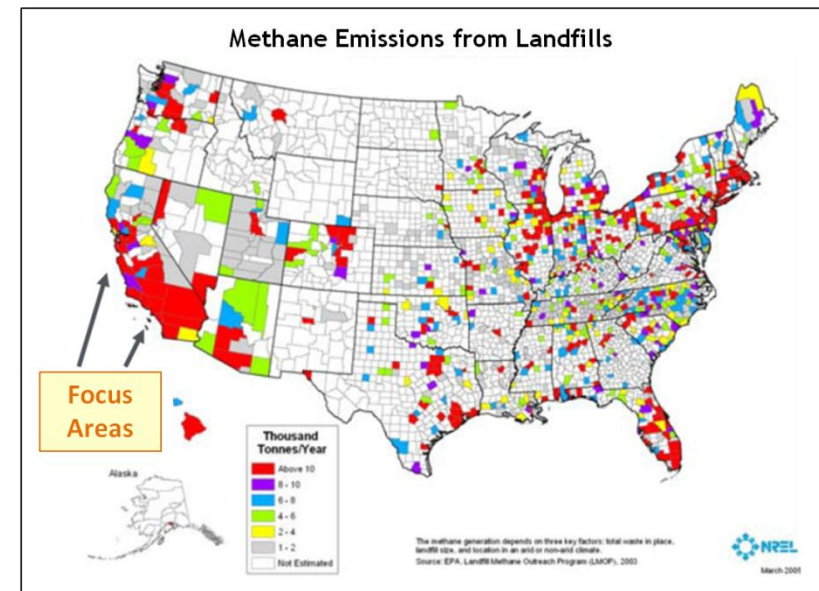
SOURCE: Wastewater Treatment, could provide enough H_2 to refuel 100,000 vehicles per day.

- 500,000 MT per year of methane is available from wastewater treatment plants in the U.S.
- ~50% of this resource could provide ~340,000 kg/day of hydrogen.

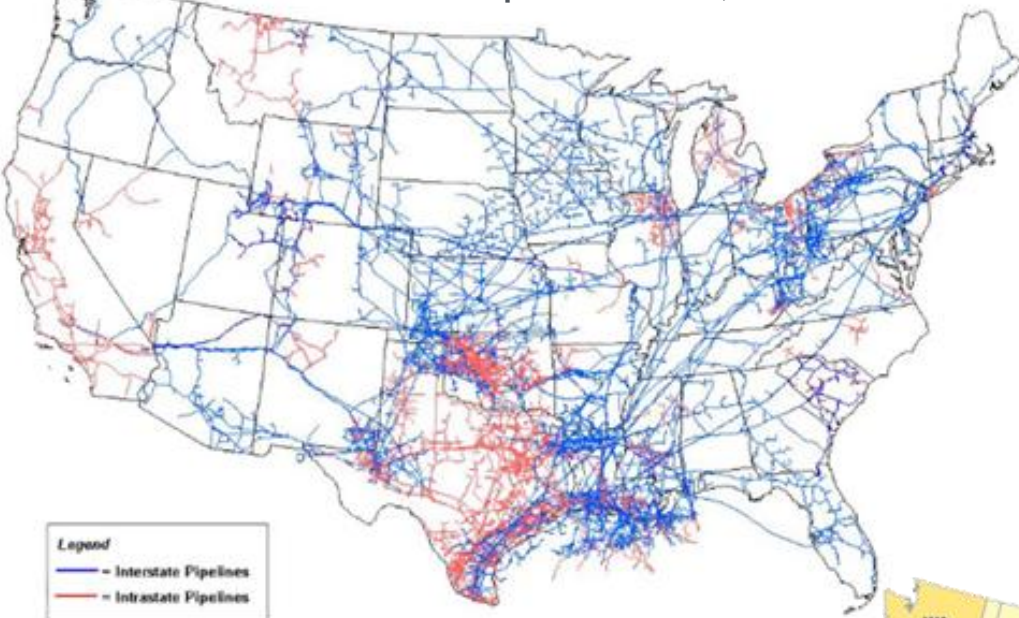


SOURCE: Landfills, could provide enough H_2 to refuel 2–3 million vehicles/day.

- 12.4 million MT per year of methane is available from landfills in the U.S.
- ~50% of this resource could provide ~8 million kg/day of hydrogen.



Natural Gas Pipeline Network, 2009



Legend
— Interstate Pipelines
— Intrastate Pipelines

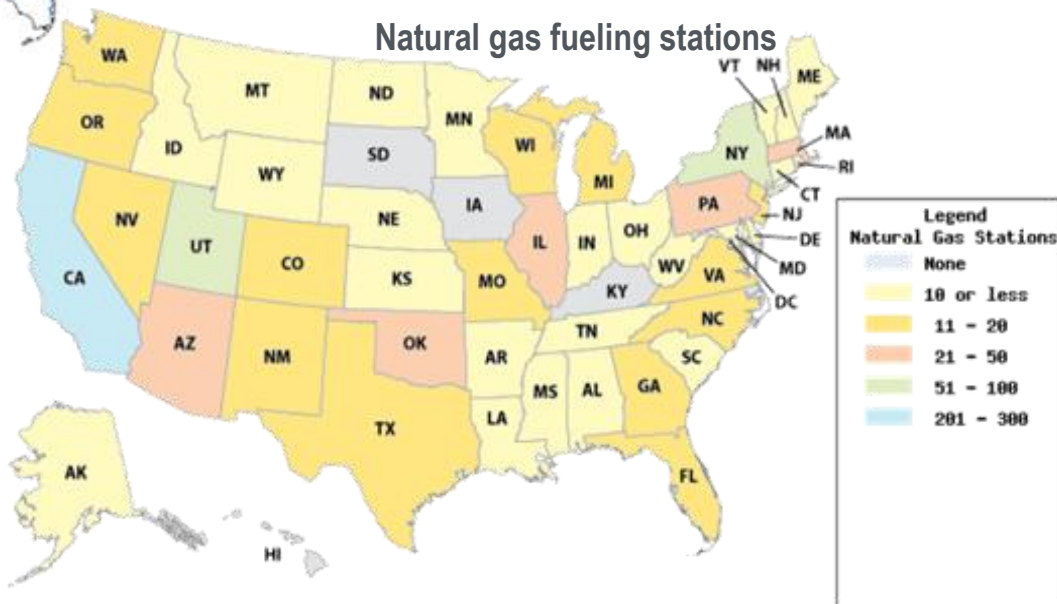
Source: Energy Information Administration, Office of Oil & Gas, Natural Gas Division, Gas Transportation Information System

> 300,000 miles of interstate and intrastate transmission pipelines

Options for hydrogen production

1. Distributed production from natural gas (long term renewables)
2. Co-produce hydrogen, heat, and power (tri-gen) with natural gas or biogas
3. Hydrogen from waste (industrial, wastewater, landfills)

Natural gas fueling stations



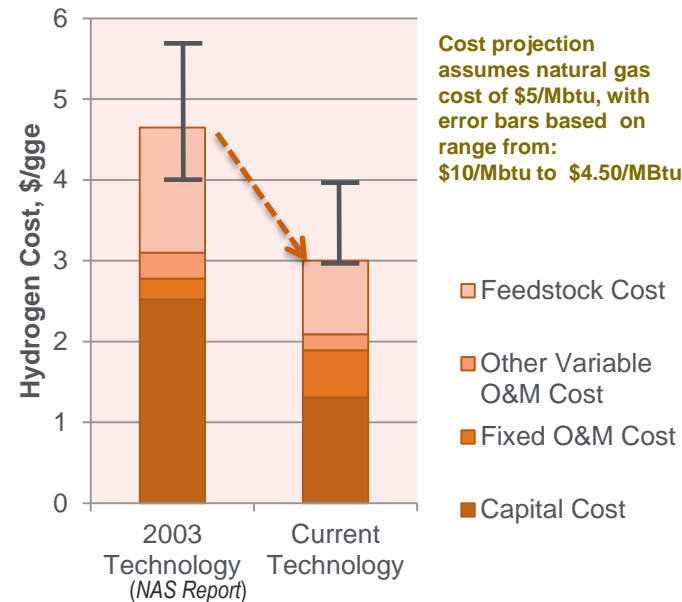
Hydrogen from Distributed Natural Gas — The Near-term Approach

DOE-funded efforts have reduced the cost of hydrogen produced from natural gas (at the fueling station) to \$3/gallon gasoline equivalent (gge), assuming high-volumes.

Program Success in Distributed NG Reforming:

- Completed R&D phase
- **Achieved high volume \$3/gge cost for H₂ dispensed at the station (validated by independent panel*)**
- Near-term option for commercialization has potential to reduce transportation sector GHG emissions by > 50%

Cost of H₂ Produced from Natural Gas—at the Station
(projected to high-volume, includes all station costs)



DNG reforming is an affordable option for a range of natural gas prices.

Challenge
Low volume cost is still too high

Progress & Plans in Renewable Hydrogen (all costs assume high-volume production**)

- **\$4.60 – \$5.70/gge** for distributed production (including all station costs) from electrolysis, pyrolysis oil reforming
- As low as **\$2.70/gge** for centralized production from renewables (high-volume production, at plant gate)
- **Direct solar conversion** — progress in several pathways (photoelectrochemical, biological, and thermochemical)
- **Renewable electrolysis** — **\$5/gge or less** if Sunshot and other DOE renewable targets are met (<\$4/gge with improvements in catalysts and membranes and corrosion-resistant and more-durable materials)

* Program Record #10001, www.hydrogen.energy.gov/program_records.html.

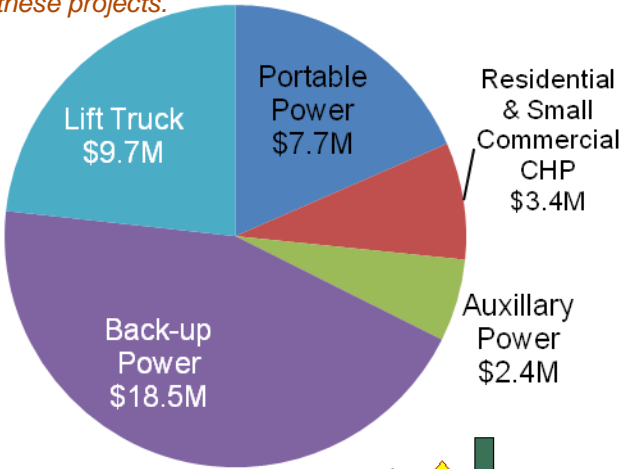
** Distributed costs assume station capacities of 1500 kg/day, with 500 stations built per year; costs for centralized production assume a range of production capacities, from 50,000 kg/day to 194,000 kg/day.

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

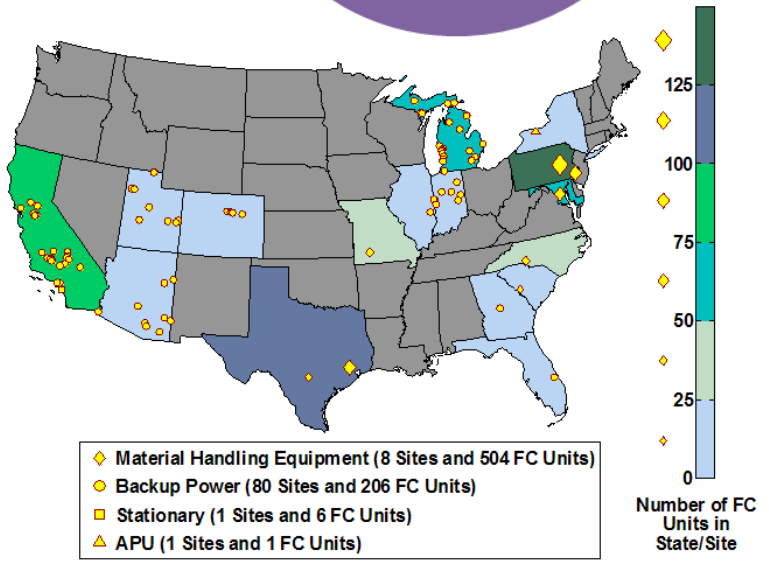
FROM the LABORATORY to DEPLOYMENT:

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.

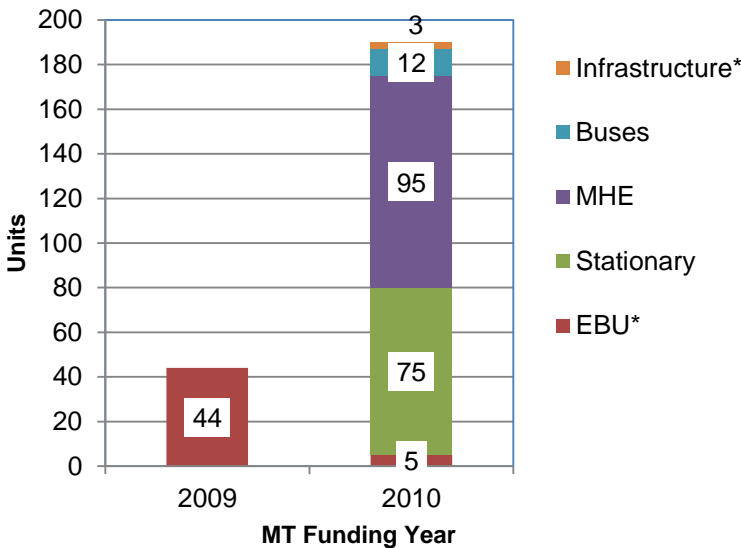


- Forklifts
 - FedEx Freight East, GENCO, Nuvera Fuel Cells, Sysco Houston
- Back-up Power
 - Plug Power, Inc., ReliOn, Inc., Sprint Nextel
- Portable Power
 - Jadoo Power, MTI MicroFuel Cells, Univ. of N. Florida
- Auxiliary Power
 - Delphi Automotive



ARRA JOBS STATUS (Apr 2011)
 ~46 jobs reported on Recovery.gov

Market Transformation Hydrogen and Fuel Cell Deployments*



\$3.6M in a cost-shared effort to install more than 230 kW in fuel cell backup power across 8 DOD installations, 1 NASA Research Center, and DOE National Lab.

Locations

- Cheyenne Mountain AFB (CO)
- Fort Hood (TX)
- Fort Bragg (NC)
- Aberdeen Proving Ground (MD)
- Picatinny Arsenal (NJ)
- U.S. Military Academy West Point (NY)
- U.S. Marine Corps (CA)
- Ohio National Guard (OH)
- NASA Ames (CA)
- Argonne National Laboratory (IL)

ERDC-CERL will manage the project with NREL collecting data for the first two years of the 5-year demonstration. LOGANEnergy will use fuel cells from four manufacturers: ReliOn, Alteryg, Idatech and Hydrogenics.

LOGANEnergy will manage three PEM fuel cell backup power units at Argonne National Laboratory.

- 6kW system by ReliOn
- 10kW system by Hydrogenics
- 15kW system by Alteryg

Projected installation date is December 2011.

The fuel cells will ensure the availability of electric power for critical applications during outages.



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!



ADDITIONAL DEPLOYMENTS



ARRA deployments

**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 2,600 operation hours.

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

Preliminary Analysis

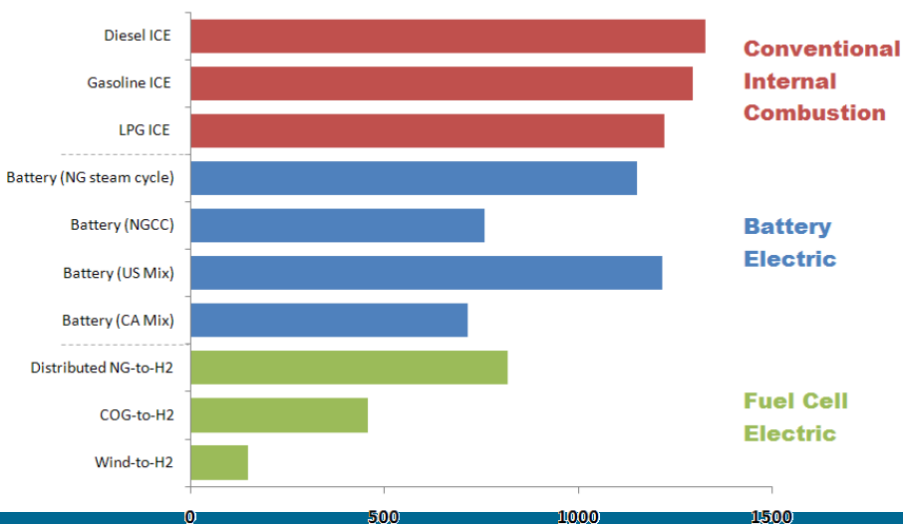
Compared to conventional forklifts, fuel cell forklifts have:

- 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

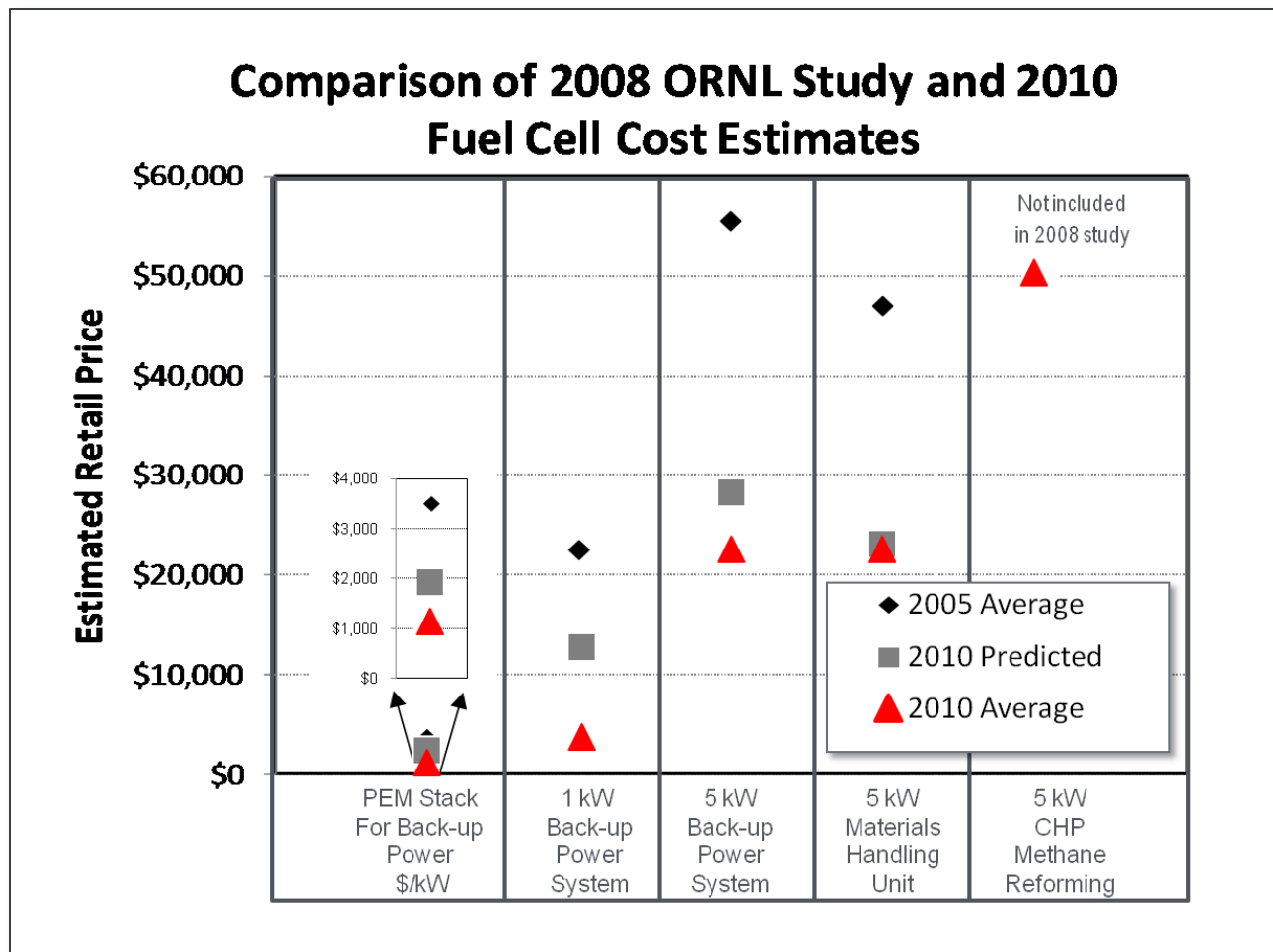
Fuel Cycle GHG Emissions for Forklifts
(g/kWh at the fork)



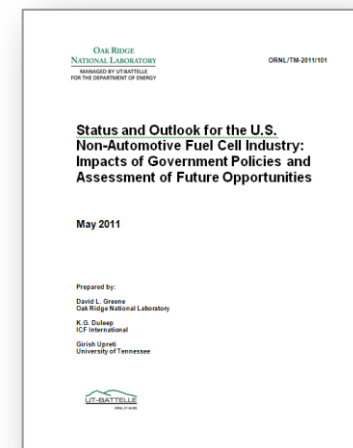
Published Fact Sheets & Case Studies



Deployments of fuel cells in early markets have reduced costs substantially.



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



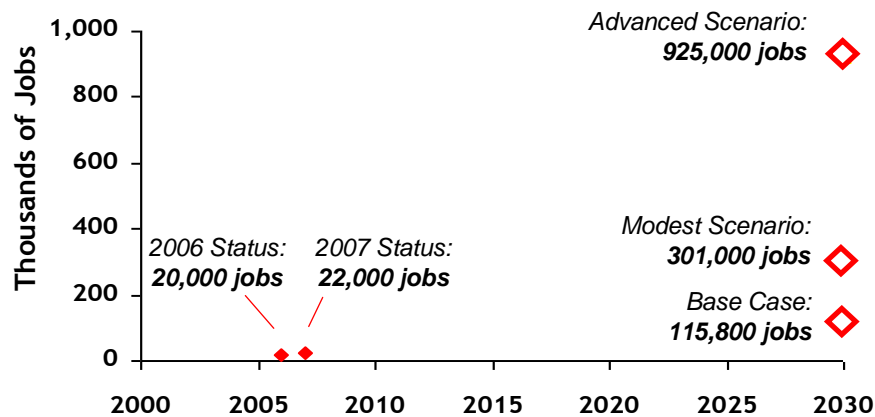
2005 and 2010 averages based on estimates supplied by OEMs. 2010 predicted assumed government procurements of 2,175 units per year, total for all market segments. Predictions assumed a progress ratio of 0.9 and scale elasticity of -0.2.

The fuel cell and hydrogen industries could generate substantial revenues and job growth.

Renewable Energy Industry Study*

- **Fuel cells are the third-fastest growing renewable energy industry** (after biomass & solar).
- Potential U.S. employment from fuel cell and hydrogen industries of **up to 925,000 jobs** (by 2030).
- Potential gross revenues up to **\$81 Billion/year** (by 2030).

Total Jobs Created by Hydrogen and Fuel Cell Industries
(includes direct and indirect employment)

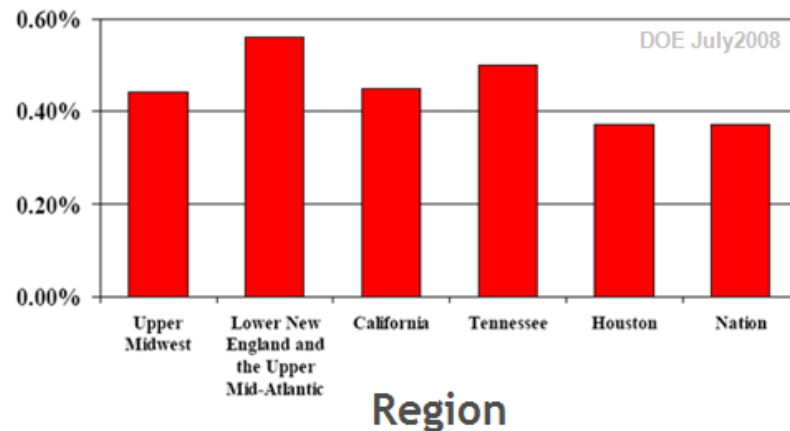


*Study Conducted by the American Solar Energy Society
www.ases.org/images/stories/ASES/pdfs/CO_Jobs_Final_Report_December2008.pdf

DOE Employment Study

- Projects net increase of **360,000 – 675,000 jobs**.
- Job gains would be distributed across up to 41 industries.
- Workforce skills would be mainly in the vehicle manufacturing and service sectors.

Employment Growth Due to Success of Fuel Cell & H₂ Technologies
(as percent of base-case employment in 2050)



www.hydrogen.energy.gov/pdfs/epact1820_employment_study.pdf

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

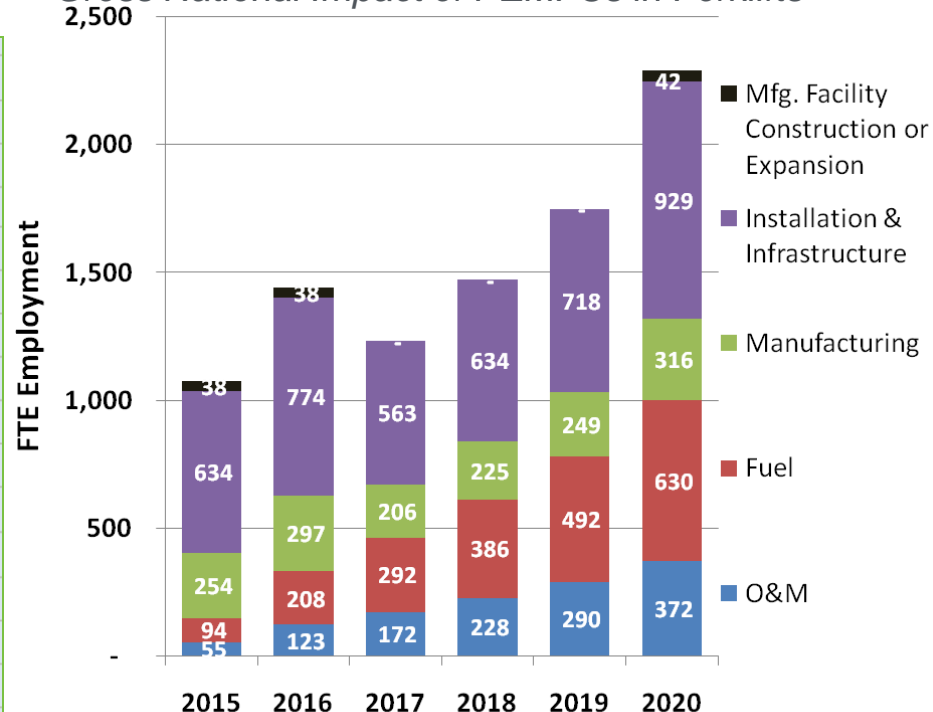
OPTIONAL USER INPUT FIELDS

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 Construction	10,000
Scale Elasticity	-0.2
Full Scale Production Capacity (kW/year)	25,000
Annual Growth Rate	2%
Average Annual Fuel Cell Price Frame (\$/kW)	\$1,098
Installation Cost (\$/kW)	TBD
Operations & Maintenance Cost (\$/kW, annual)	TBD

Will be available for beta testing (2011)

Preliminary Analysis

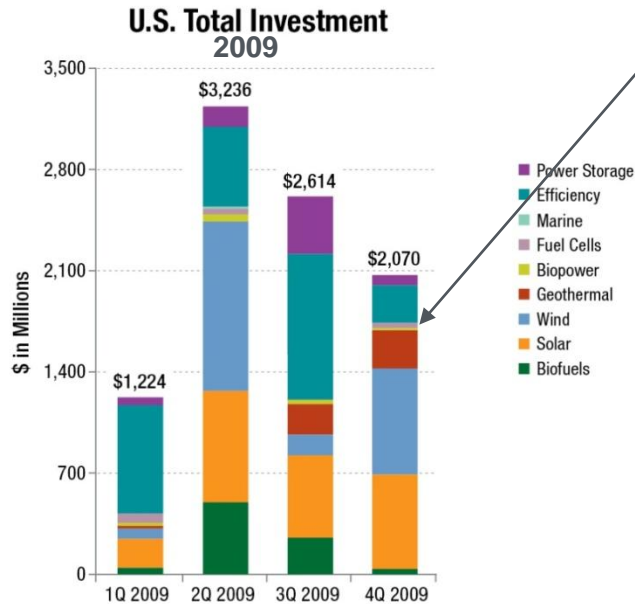
Gross National Impact of PEMFCs in Forklifts



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

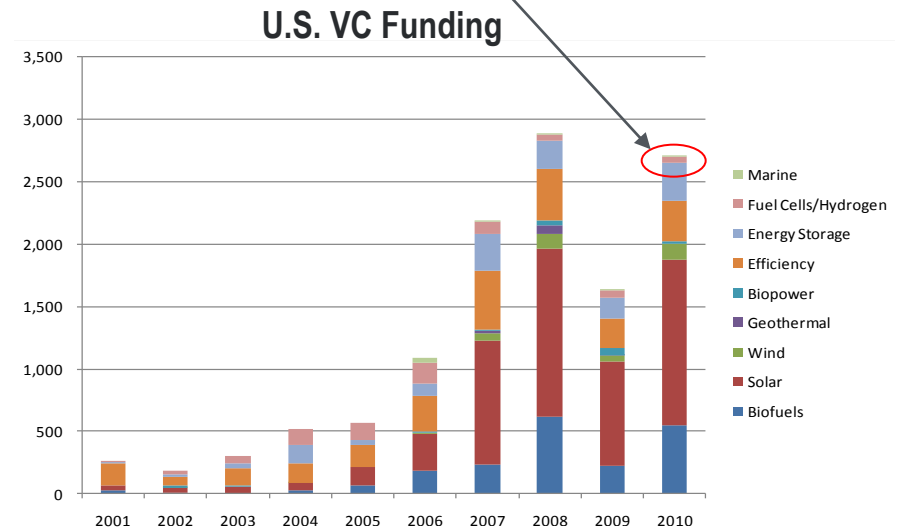
Technology/Market Assumptions:

- \$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.



Source: Bloomberg New Energy Finance; completed and disclosed deals only; includes VC/PE, public market activity, asset financing, and acquisition transactions.

DOE's funding is critical to the emerging fuel cell industry



Source: Bloomberg New Energy Finance, as of June 8th, 2011. Completed and disclosed deals only.

Fuel cell industry is less established than other clean energy industries—DOE funds have significant impact on the much smaller, emerging industries such as fuel cells.

* Source: www.cleandedge.com/reports/pdf/Trends2009.pdf

Portable Power Targets

		Portable Power Applications, Under 2W ¹		Portable Power Applications, 10-50 W ¹		Portable Power Applications, 100-250 W ¹	
	Units	2011 Status	2015 Target	2011 Status	2015 Target	2011 Status	2015 Target
Specific Power ²	W/kg	5	10	15	45	25	50
Power Density ²	W/L	7	13	20	55	30	70
Specific Energy ^{2,3}	Wh/kg	110	230	150	650	250	640
Energy Density ^{2,3}	Wh/L	150	300	200	800	300	900
Cost ⁴	\$/system	150	70	15	7	15	5
Durability ^{5,6}	hours	1500	5000	1500	5000	2000	5000
Mean Time Between Failures ^{6,7}	hours	500	5000	500	5000	500	5000

Assumptions and supporting information can be found here: http://hydrogenodev.nrel.gov/pdfs/11009_portable_fuel_cell_targets.pdf.

Revised FCT fuel cell APU targets published in 2010

	Units	Status	2013	2015	2020
Electrical efficiency at rated power ^[1]	%	25	30	35	40
Power density	W/L	17	30	35	40
Specific power	W/kg	20	35	40	45
Factory cost, stack plus required BOP ^[2]	\$/kW	750 ^[3]	700	600	500
Factory cost, system ^[4]	\$/kW	2000	1400	1200	1000
Transient response (10 to 90% rated power)	min	5	4	3	2
Start-up time from: 20 °C Standby conditions ^[5]	Min	50 50	45 20	45 10	30 5
Degradation with cycling ^[6]	%/1000 h	2.6	2	1.3	1
Operating lifetime ^{6, [7]}	h	3000	10,000	15,000	20,000
System availability	%	97	97.5	98	99

Assumptions and supporting information can be found here:
http://hydrogenodev.nrel.gov/pdfs/11009_portable_fuel_cell_targets.pdf.

APU targets were developed using:

- Comparison with incumbent technology (diesel ICE APUs)
- An RFI process to obtain input from stakeholders
- Direct discussion with developers

Example: 2020 power density target

Stakeholder recommendations:
20 – 55 W/L

Incumbent technology: 11 – 33
(mean 20) W/L

Final DOE 2020 target: 40 W/L – within range suggested by stakeholders and superior to incumbent technology

Targets developed with input from stakeholders and the research community
Cost and durability are the major challenges

Preliminary Technical Targets: 1 – 10 kW_e Residential Combined Heat and Power Fuel Cells Operating on Natural Gas^[1]

	Units	Status	2020 FCT Targets
Electrical energy efficiency at rated power ^[2]	%	34	45
CHP energy efficiency at rated power ^[3]	%	80	90
Cost ^[4]	\$/kW _e	750	500
Transient response time (from 10 - 90% rated power)	min	5	2
Start-up time from 20°C ambient temperature	min	60	20
System availability	%	97	99
Operating lifetime ^[5]	hours	6,000	60,000
Degradation with cycling	% / hours	<2/1000	0.3/1000

Assumptions and supporting information can be found here:
http://hydrogenoev.nrel.gov/pdfs/11009_portable_fuel_cell_targets.pdf.

2010 Independent Assessment of CHP Fuel Cell Status & Targets

- Confident that by 2015, LT-PEM & HT-PEM can achieve 40,000 hr
- 45% electrical efficiency (2020 target) for 1-10kW systems is feasible for HT-PEM, LT-PEM depends on improved catalysts & higher operating temps
- SOFC systems are likely to achieve DOE targets for electrical and CHP efficiencies. 90% CHP efficiency is likely to be attainable by SOFC systems.
- Confident that by 2020, LT-PEM & HT-PEM can achieve \$450-\$750/kW, while SOFC can achieve \$1000-2000/kW

Thank you

For more information, please contact

Sunita.Satyapal@ee.doe.gov