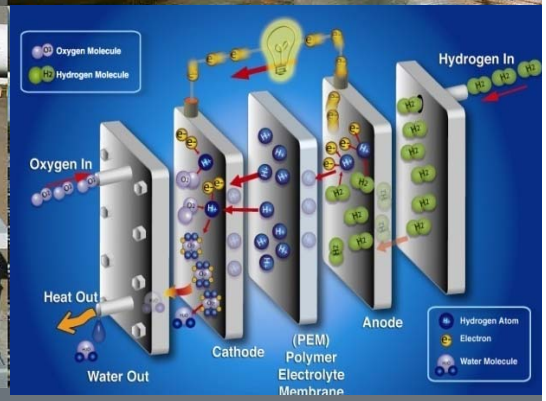
Fuel Cell Technologies Overview

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



States Energy Advisory Board (STEAB)
Washington, DC
3/14/2012

Dr. Sunita Satyapal

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

Outline

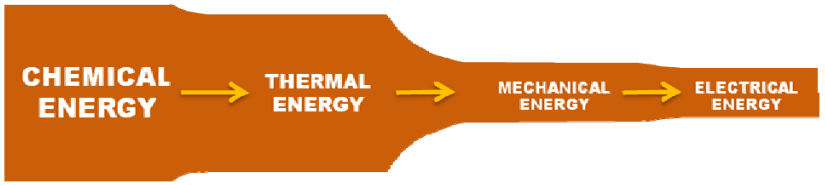
- Introduction
  - Technology and Market Overview
- DOE Program Overview
  - Mission & Structure
  - R&D Progress
  - Demonstration & Deployments
- State Activities
  - Examples of potential opportunities

Fuel cells convert chemical energy directly to electrical energy — with very high efficiency — and without criteria pollutant emissions.

Combustion Engines — convert chemical energy into thermal energy and mechanical energy, and then into electrical energy.

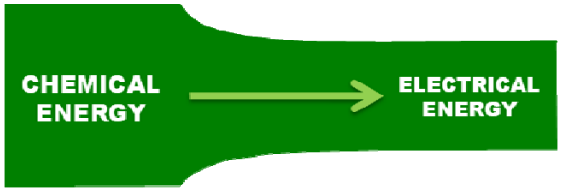
Fuel cells — convert chemical energy directly into electrical energy, bypassing inefficiencies associated with thermal energy conversion. Available energy is equal to the Gibbs free energy.

Energy Conversion in Combustion Engines

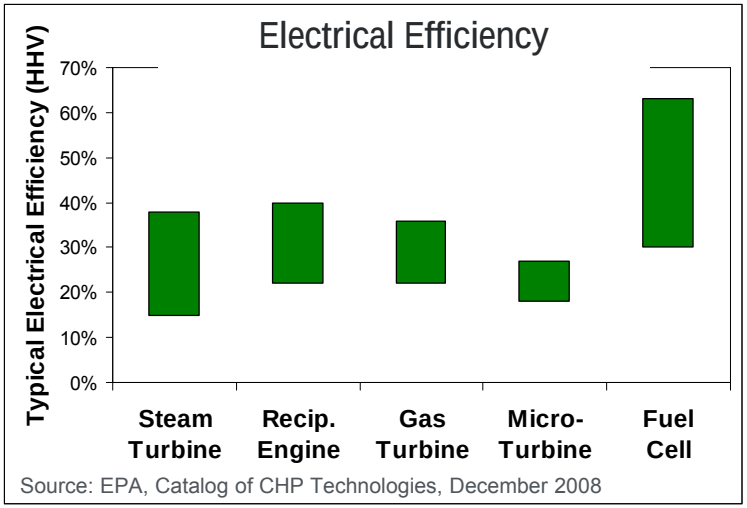


15 – 40% efficiency

Energy Conversion Fuel Cells

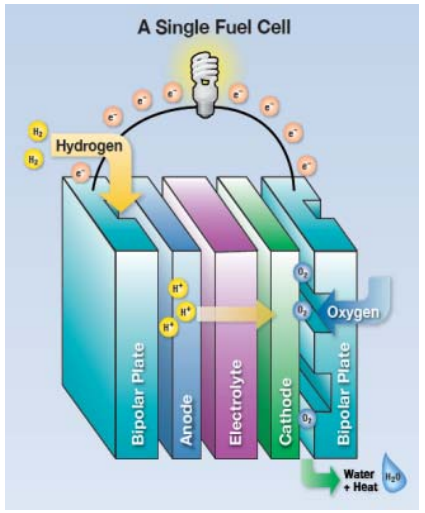


60%+ efficiency possible



Source: EPA, Catalog of CHP Technologies, December 2008

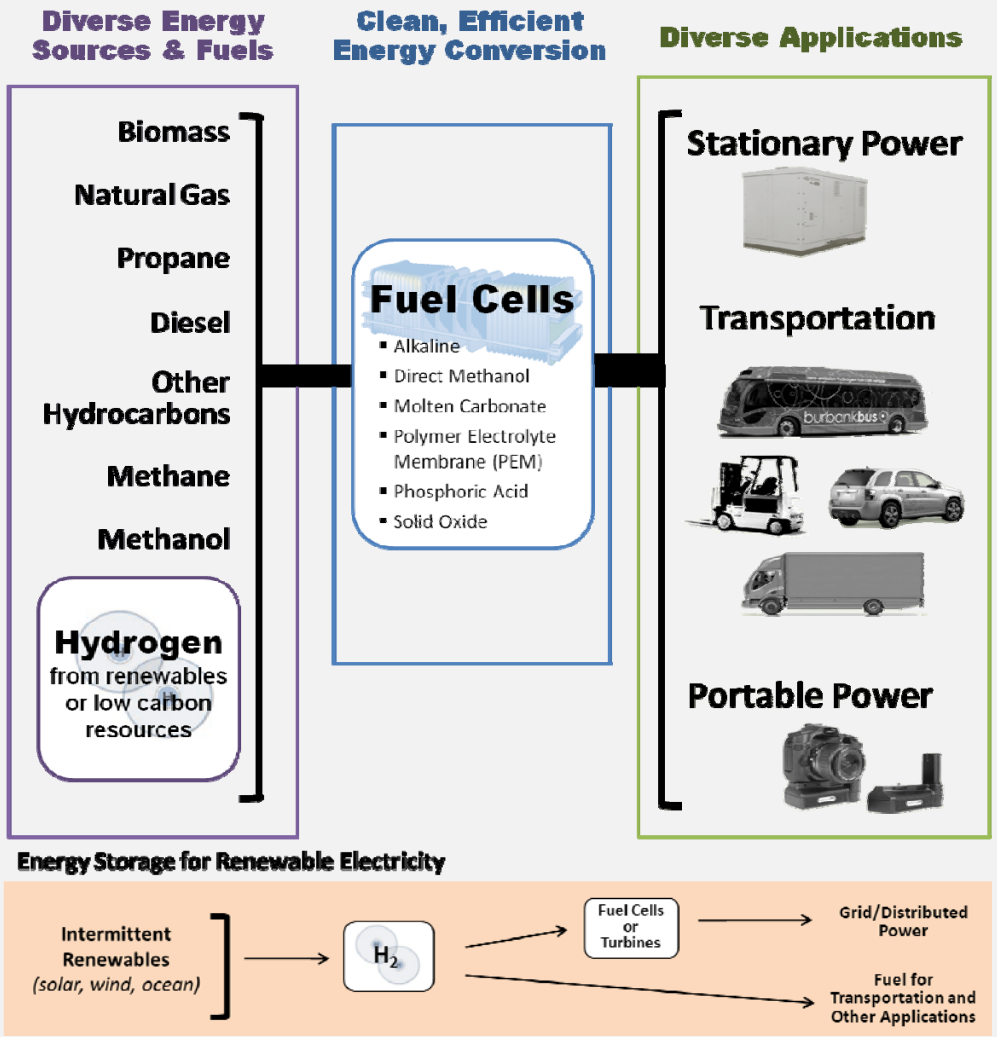
Fuel cells convert chemical energy directly into electrical energy, bypassing inefficiencies associated with thermal energy conversion



Fuel Cells: *Benefits & Market Potential*

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

The Role of Fuel Cells



Key Benefits

Very High Efficiency
- **> 60%** *(electrical)*
- **> 70%** *(electrical, hybrid fuel cell / turbine)*
- **> 80%** *(with CHP)*

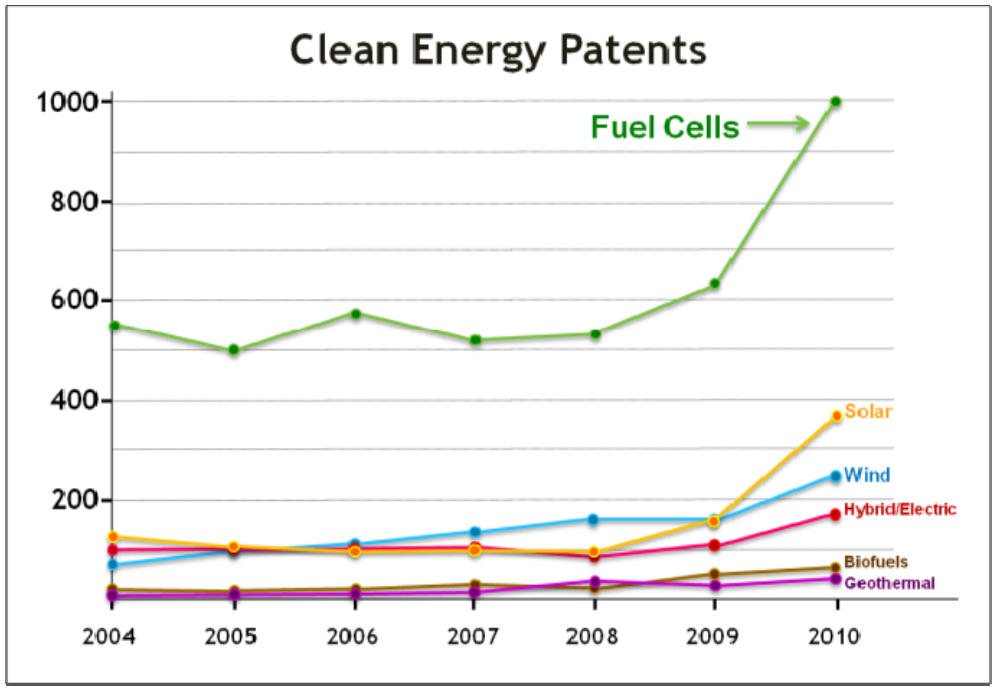
Reduced CO_2 Emissions
- **35–50%+ reductions** *for CHP systems (>80% with biogas)*
- **55–90% reductions** *for light-duty vehicles*

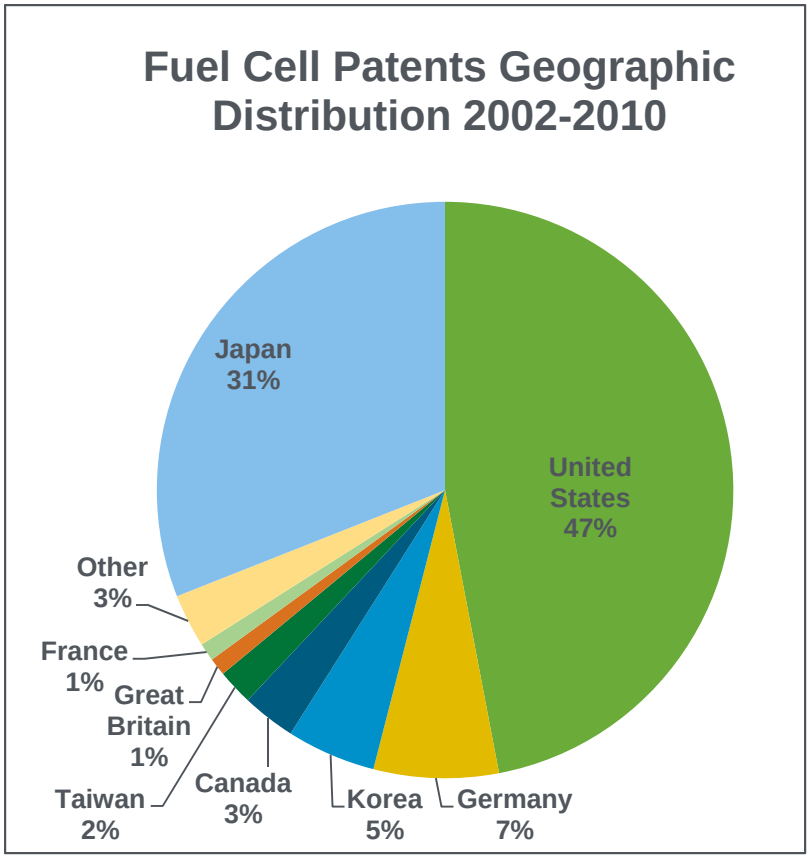
Reduced Oil Use
- **>95% reduction** *for FCEVs (vs. today's gasoline ICEVs)*
- **>80% reduction** *for FCEVs (vs. advanced PHEVs)*

Reduced Air Pollution
- **up to 90% reduction in criteria pollutants** *for CHP systems*

Fuel Flexibility
- **Clean fuels** — *including biogas, methanol, H_2*
- **Hydrogen** — *can be produced cleanly using sunlight or biomass directly, or through electrolysis, using renewable electricity*
- **Conventional fuels** — *including natural gas, propane, diesel*

Fuel Cells – An Emerging Industry





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

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} 2010 Year in Review from http://cepgi.typepad.com/heslin_rothenberg_farley_/

Worldwide Investment & Interest Are *Strong and Growing*

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

Interest in fuel cells and hydrogen is global, with more than $1 billion in public investment in RD&D annually, and 17 members of the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE).

Activity by Key Global Players

Germany: >$1.2 Billion in funding '07 – '16); plans for 1000 hydrogen stations; >22,000 small fuel cells shipped.

Japan: ~$1.0 Billion in funding ('08 – '12); plans for 2 million FCEVs and 1000 H2 stations by 2025; 100 stations by 2015; 15,000 residential fuel cells deployed

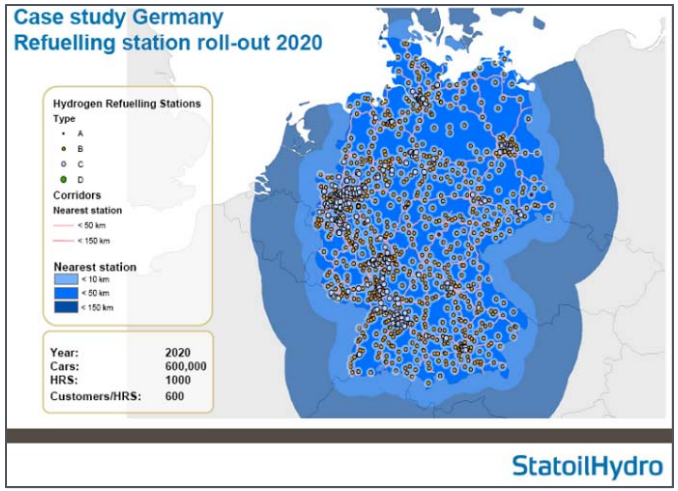
European Union: >$1.2 Billion in funding ('08–'13)

South Korea: ~$590 M ('04-'11); plans to produce 20% of world shipments and create 560,000 jobs in Korea

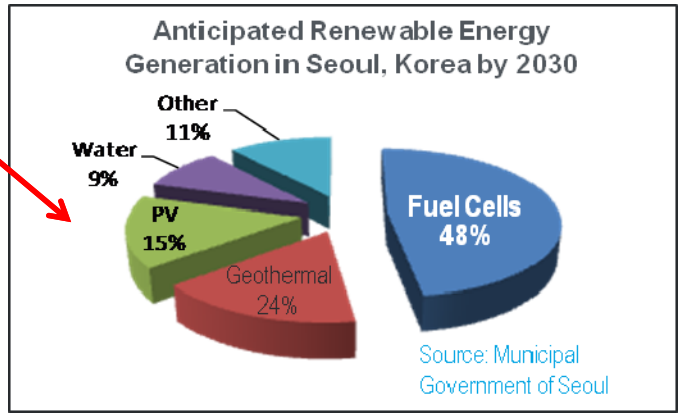
China: Thousands of small units deployed; 70 FCEVs, buses, 100 FC shuttles at World Expo and Olympics

Source: DOE 2010

Germany ***and*** *Japan* ***have formed industry led consortia to enable 1,000 stations (each)***



South Korea: ***recently purchased >100 MW of fuel cells*** *from two U.S. companies — FuelCell Energy and UTC Power.*



Pike Research

Worldwide Commitment to FCEVs

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

The world's leading automakers have committed to develop FCEVs. Germany and Japan have announced plans to expand the hydrogen infrastructure.

Major Auto Manufacturers' Activities and Plans for FCEVs

Toyota
- 2010-2013: U.S. demo fleet of 100 vehicles
- 2015: Target for large-scale commercialization
- "FCHV-adv" can achieve 431-mile range and 68 mpgge

Honda
- Clarity FCX named "World Green Car of the Year"; EPA certified 72mpgge; leasing up to 200 vehicles
- 2015: Target for large-scale commercialization

Daimler
- Small-series production of FCEVs began in 2009
- Plans for tens of thousands of FCEVs per year in 2015 – 2017 and hundreds of thousands a few years after
- In partnership with Linde to develop fueling stations.
- ***Recently moved up commercialization plans to 2014***

General Motors
- 115 vehicles in demonstration fleet
- 2012: Technology readiness goal for FC powertrain
- 2015: Target for commercialization

Hyundai-Kia
- 2012-2013: 2000 FCEVs/year
- 2015: 10,000 FCEVs/year
- "Borrego" FCEV has achieved >340-mile range.

Volkswagen
- Expanded demo fleet to 24 FCEVs in CA
- Recently reconfirmed commitment to FCEVs

SAIC (China)
- Partnering with GM to build 10 fuel cell vehicles in 2010

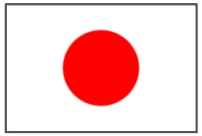
Ford
- Alan Mulally, CEO, sees 2015 as the date that fuel cell cars will go on sale.

BMW
- BMW and GM plan to collaborate on the development of fuel cell technology

Based on publicly available information during 2011

H_2Mobility - evaluate the commercialization of H_2 infrastructure and FCEVs
- Public-private partnership between NOW and 9 industry stakeholders including:
  - Daimler, Linde, OMV, Shell, Total, Vattenfall, EnBW, Air Liquide, Air Products
- FCEV commercialization by 2015.

UKH_2Mobility will evaluate anticipated FCEV roll-out in 2014/2015
- 13 industry partners including:
  - Air Liquide, Air Products, Daimler, Hyundai, ITM Power , Johnson Matthew, Nissan, Scottish & Southern Energy, Tata Motors, The BOC Group, Toyota, Vauxhall Motors
- 3 UK government departments
- Government investment of £400 million to support development, demonstration, and deployment.

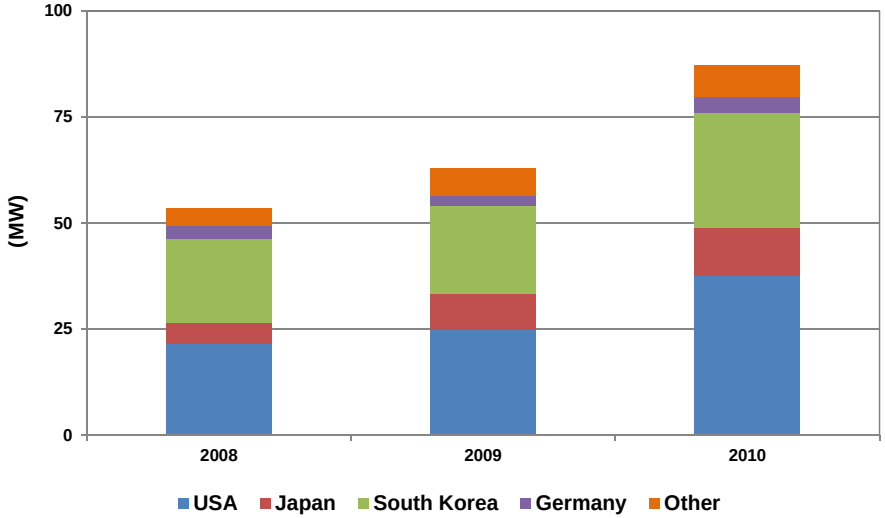


13 companies and Ministry of Transport announce plan to commercialize FCEVs by 2015
- 100 refueling stations in 4 metropolitan areas and connecting highways planned, 1,000 station in 2020, and 5,000 stations in 2030.

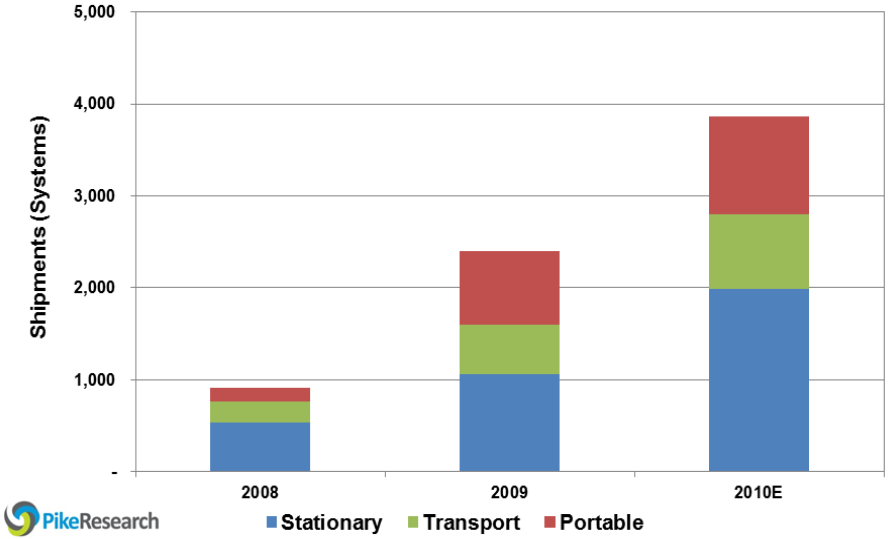
Fuel Cell Market Overview

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

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**

Widespread market penetration of fuel cells could lead to:
- **180,000 new jobs in the US by 2020**
- **675,000 jobs by 2035**

FuelCells2000, Pike Research, Fuel Cell Today, ANL

http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/program_plan2010.pdf

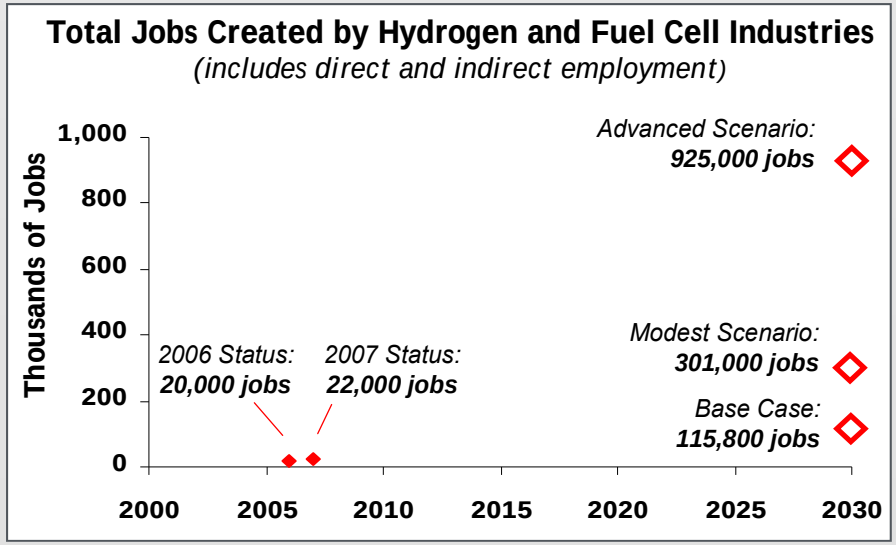
Fuel Cells - *The Economic Potential*

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

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

Renewable Energy Industry Study*

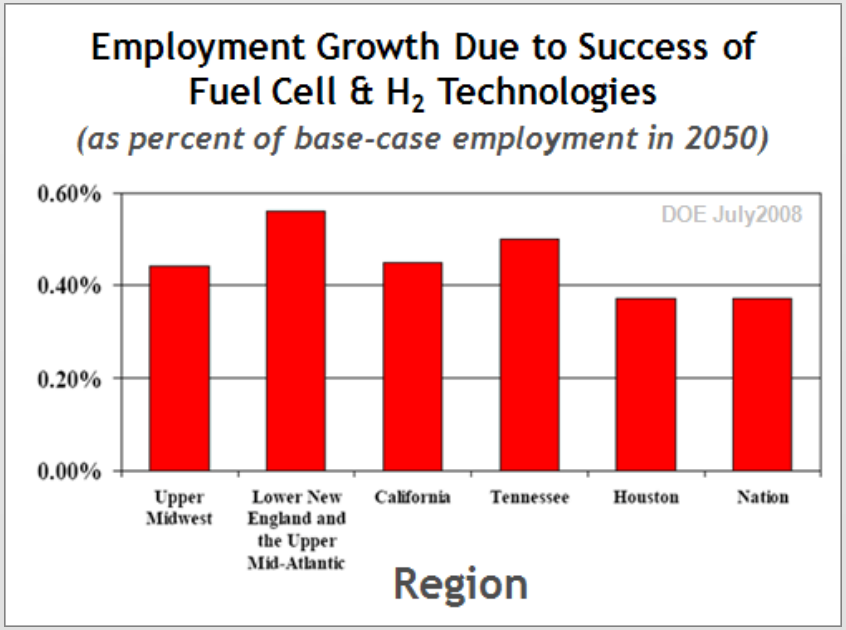
- **Fuel cells are the third-fastest growing renewable energy industry** (after biomass & solar).
- Potential U.S. employment from fuel cell and hydrogen industries of **up to 925,000 jobs** (by 2030).
- Potential gross revenues up to **$81 Billion/year** (by 2030).



*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.

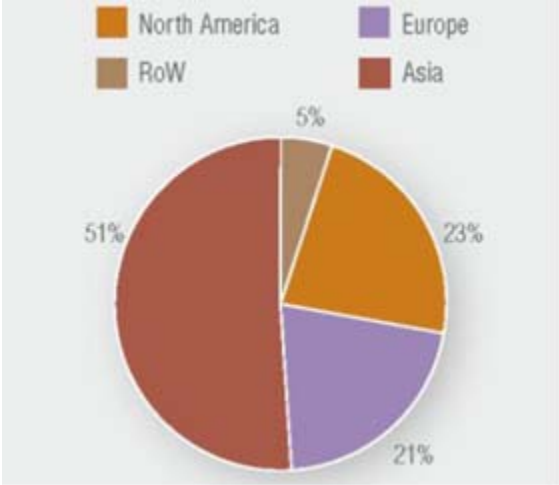


www.hydrogen.energy.gov/pdfs/epact1820_employment_study.pdf

Patents and Job Creation

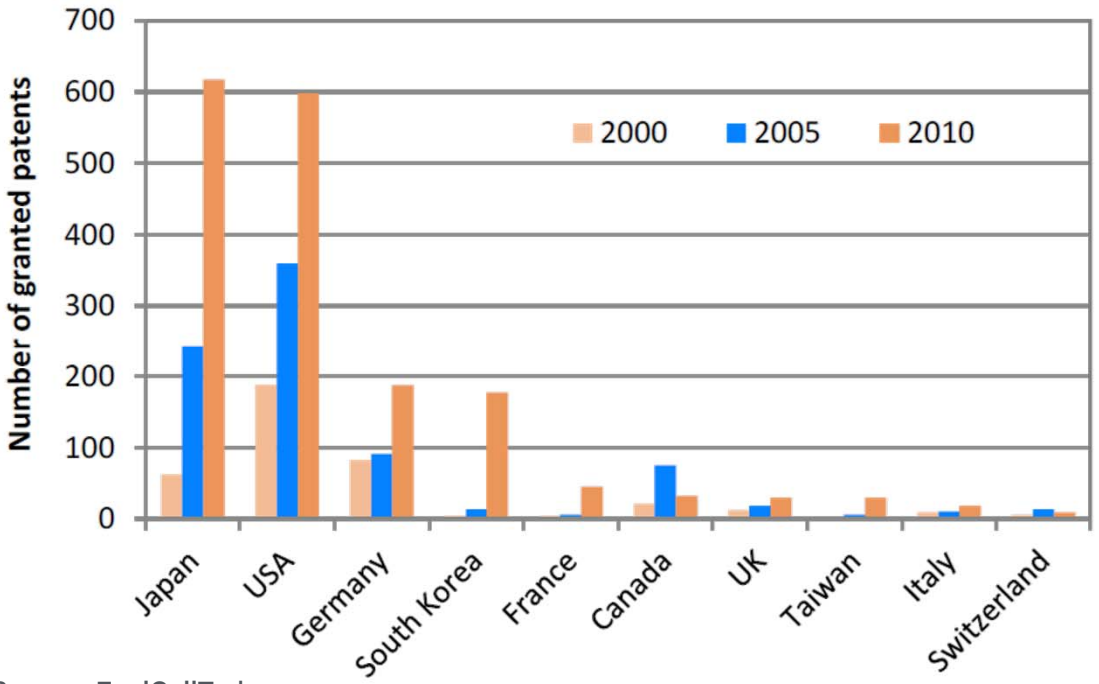
**Significant growth in number of patents filed by Japan, Korea, Germany, U.S.
Job creation projections show significant growth in Asia and Europe.**

Job Creation by Region of Production 2009-2019



Source: FuelCellToday

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



Source: FuelCellToday

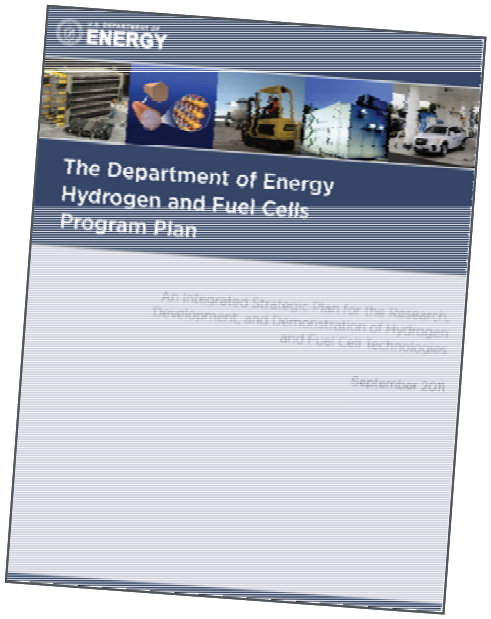
Program Mission

The mission of the Hydrogen and Fuel Cells Program is to enable the widespread commercialization of hydrogen and fuel cell technologies through:

- **basic** and **applied research**
- **technology development** and **demonstration**
- Addressing **institutional** and **market challenges**

Key Goals: Develop hydrogen and fuel cell technologies for:

1. **Early markets** *(e.g., stationary power, forklifts, portable power)*
2. **Mid-term markets** *(e.g., residential CHP, auxiliary power, buses and fleet vehicles)*
3. **Longer-term markets, 2015-2020** *(including mainstream transportation, with focus on passenger cars)*



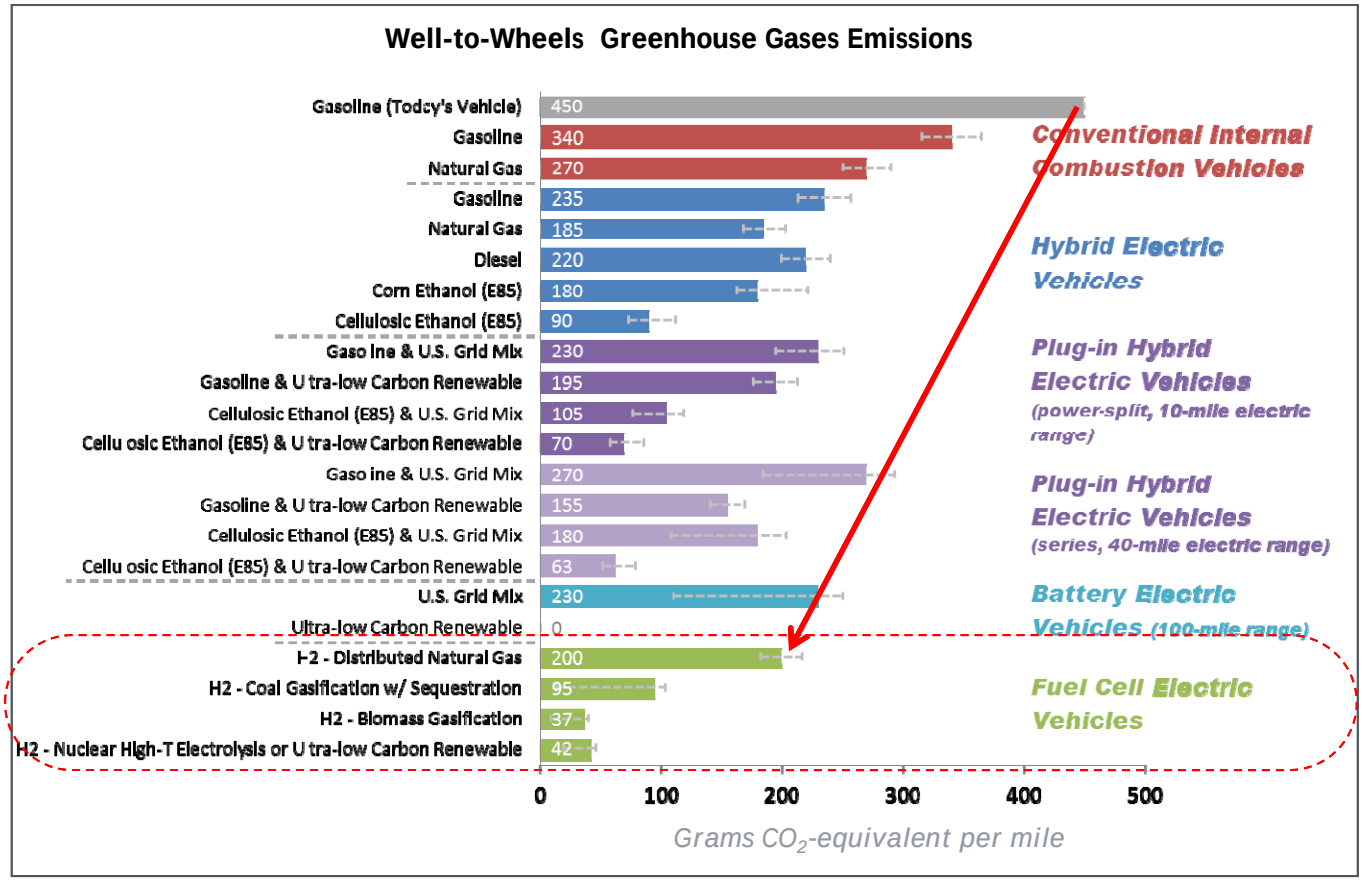
An integrated strategic plan for the research, development, and demonstration activities of DOE's Hydrogen and Fuel Cells Program

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

Well-to-Wheels CO_2 Analysis

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

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



H_2 from Natural Gas

Even FCEVs fueled by H_2 from distributed NG can result in a >50% reduction in GHG emissions **from today's vehicles.**

Use of H_2 from NG decouples carbon from energy use—i.e., it allows carbon to be managed at point of production vs at the tailpipe.

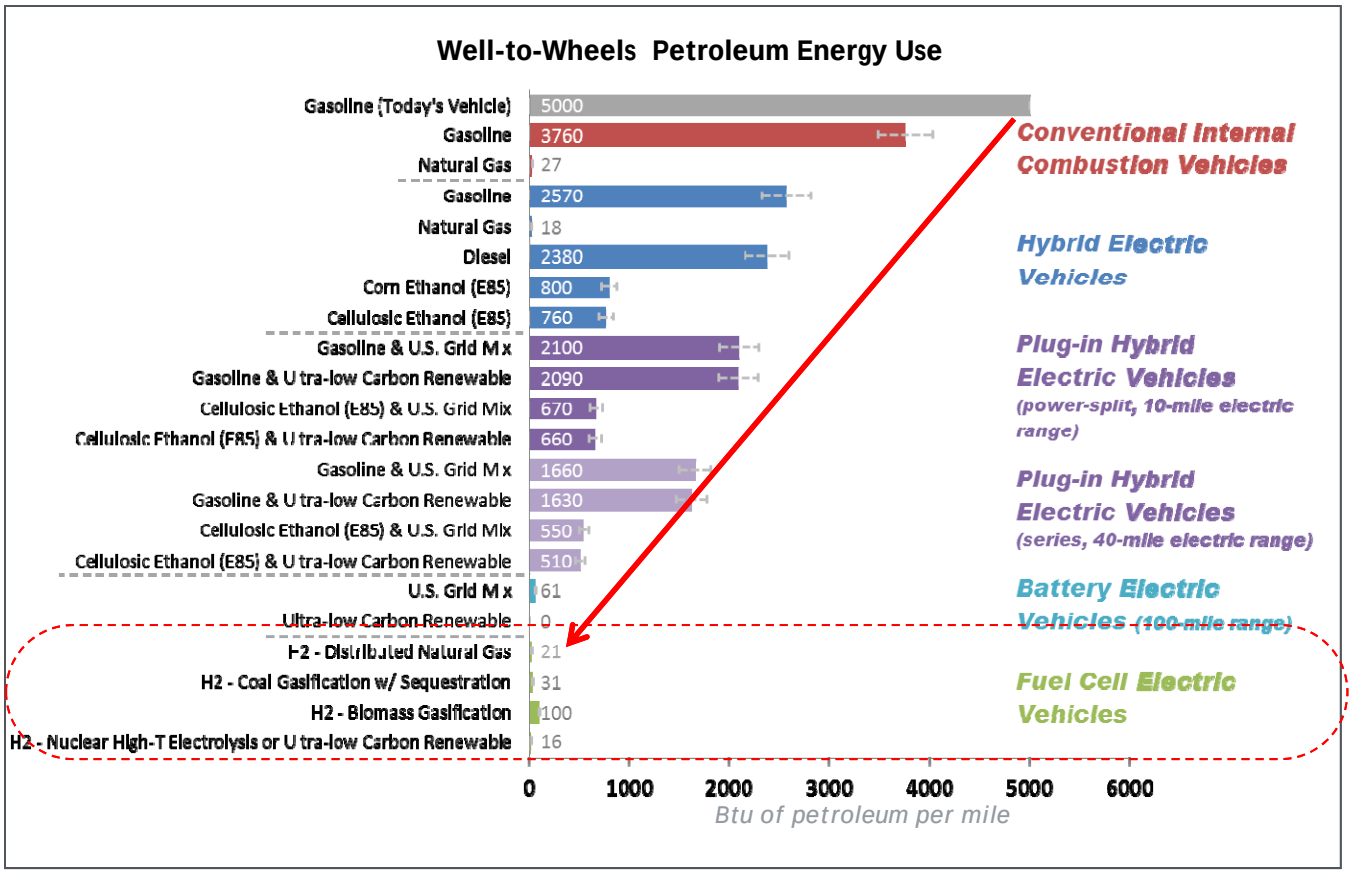
Even greater emissions reductions are possible as hydrogen from renewables enter the market.

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

Well-to-Wheels Petroleum Analysis

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

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

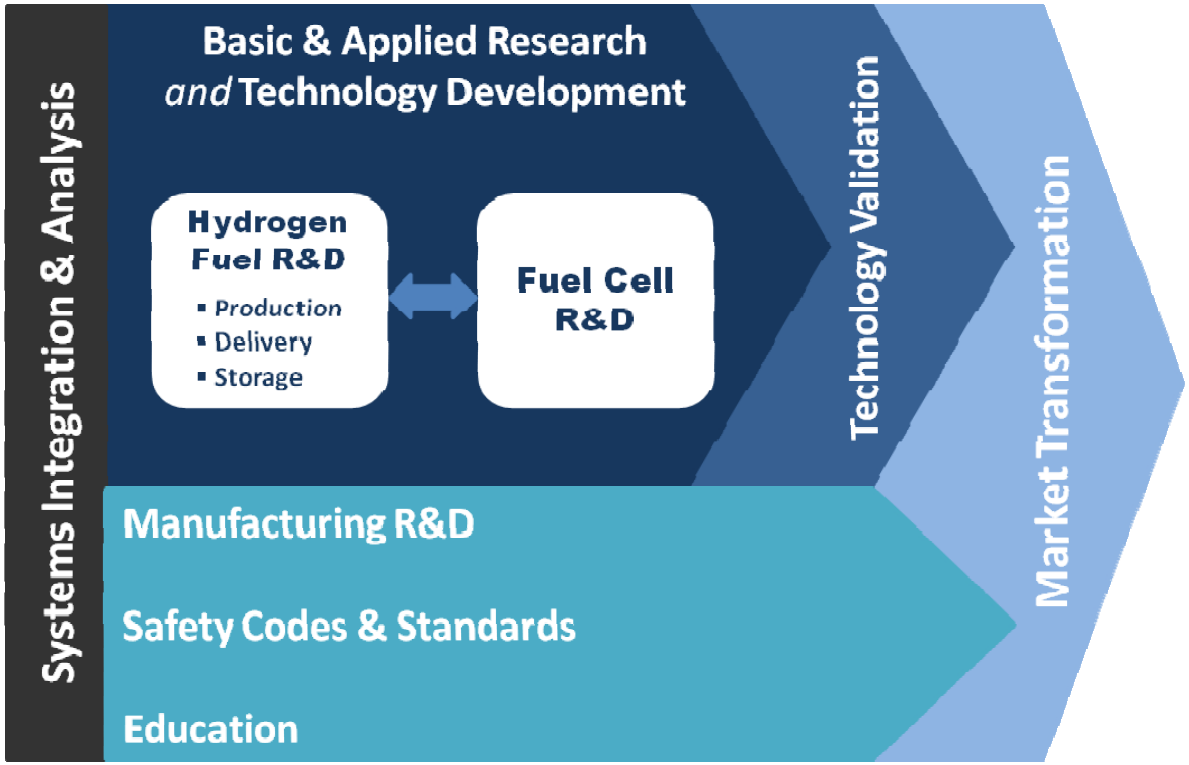


H_2 from Natural Gas

FCEVs fueled by H_2 from distributed natural gas can almost completely eliminate petroleum use.

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

DOE Program Structure



Nearly 300 projects currently funded

at companies, national labs, and universities/institutes

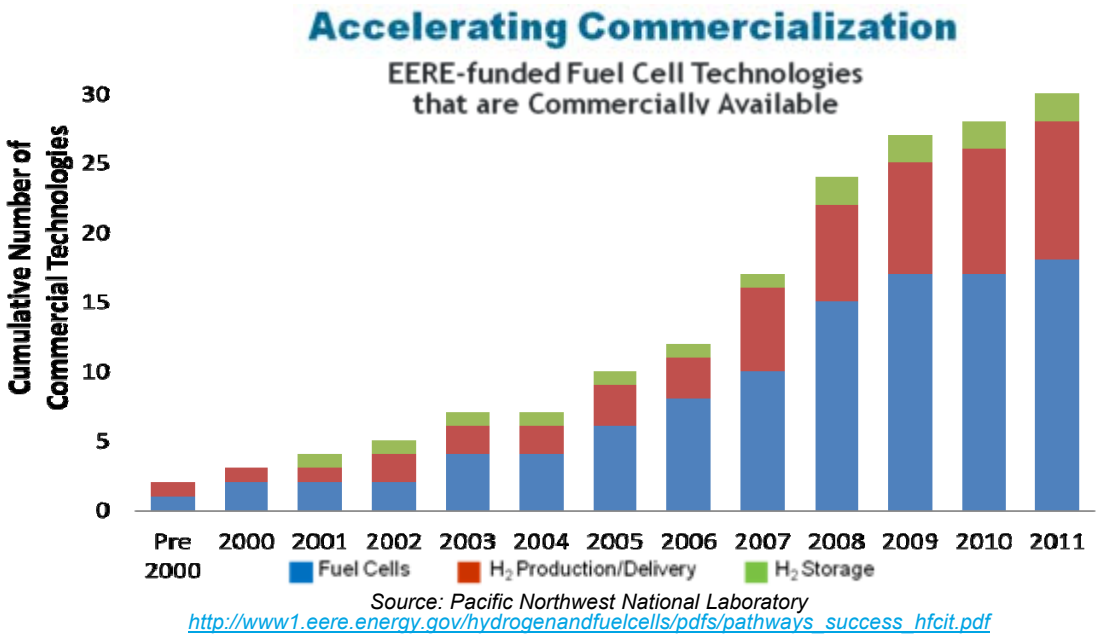
FY12 EERE H_2 and Fuel Cells Budget: $104M

Assessing the Impact of DOE Funding

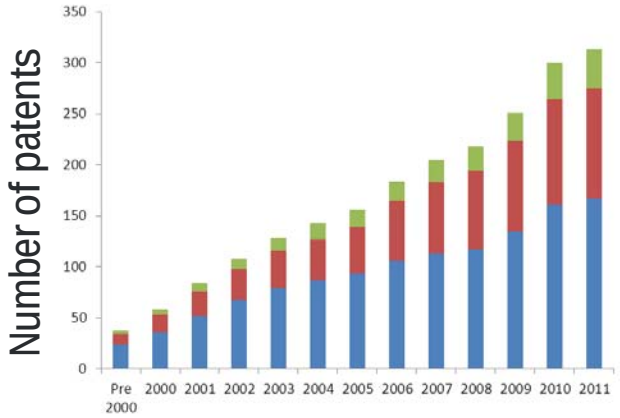
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

DOE funding has led led to 313 patents, ~30 commercial technologies and >60 emerging technologies.

DOE's Impact: ~$70M in funding for specific projects was tracked – and found to have led to nearly $200M in industry investment and revenues.



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



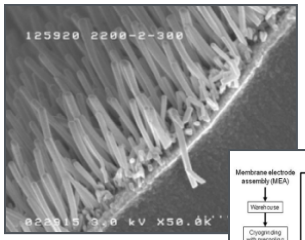
>310 PATENTS resulting from EERE-funded R&D:

- *Includes technologies for hydrogen production and delivery, hydrogen storage, and fuel cells*

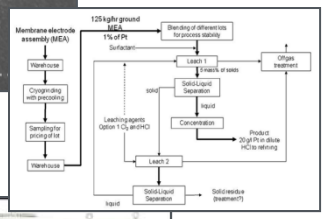
http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/pathways_2011.pdf

Examples

3M



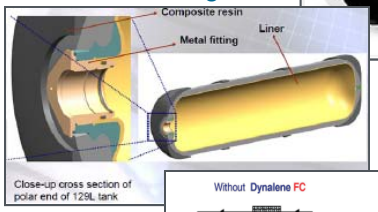
BASF Catalysts LLC



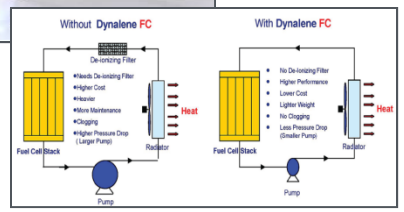
Proton Energy Systems

DuPont

Quantum Technologies



Dynalene, Inc.



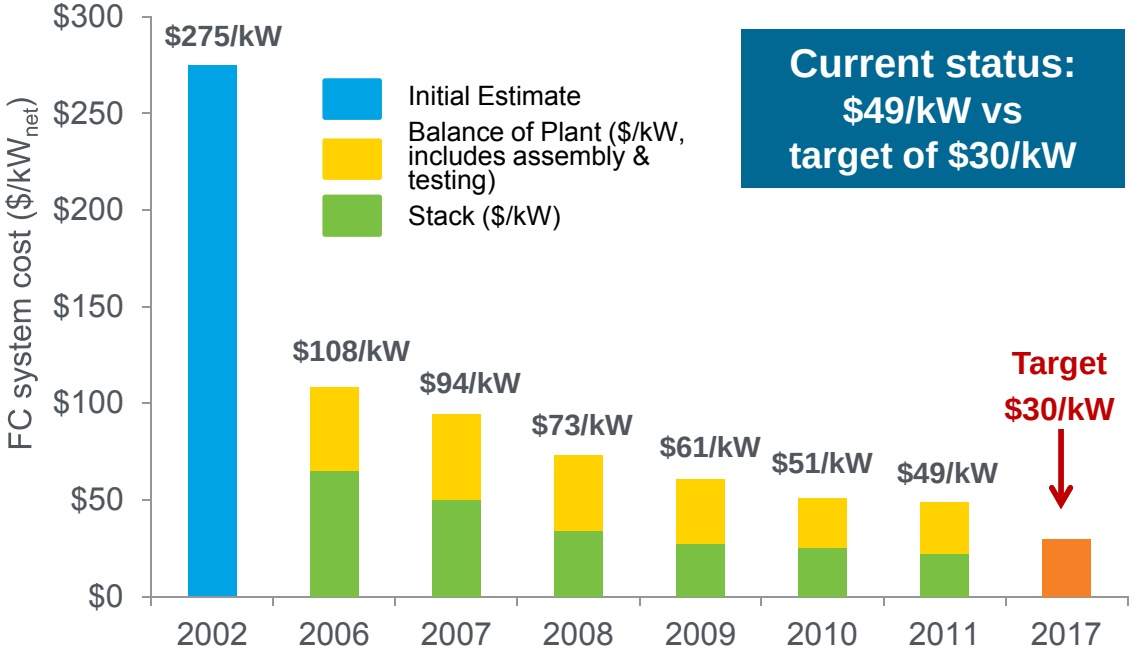
Progress – Fuel Cells

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

Projected high-volume cost of fuel cells has been reduced to $49/kW (2011)*

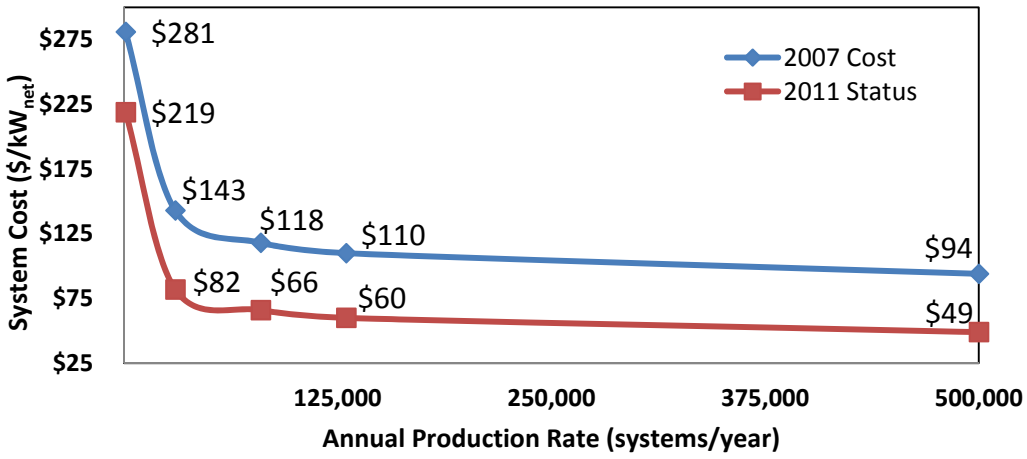
- ***More than 30% reduction since 2008***
- ***More than 80% reduction since 2002***

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



Current status: $49/kW vs target of $30/kW

Projected Costs at Different Manufacturing Rates



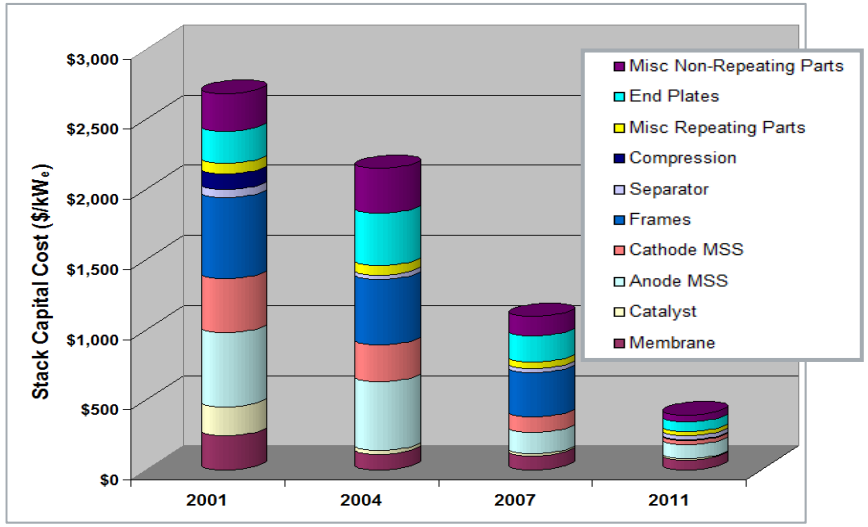
***Based on projection to high-volume manufacturing (500,000 units/year).** The projected cost status is based on an analysis of state-of-the-art components that have been developed and demonstrated through the DOE Program at the laboratory scale. Additional efforts would be needed for integration of components into a complete automotive system that meets durability requirements in real-world conditions.*

DOE Funded Accomplishments

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

Reduced cost of H_2 production (multiple pathways)

- Reduced electrolyzer stack costs by greater than 80% since 2001 through design optimization and manufacturing innovations (Giner Electrochemical Systems)



Projected High-Volume Cost of Hydrogen Production1 (Delivered2)—Status

Distributed Production (near term)

Electrolysis

Feedstock variability: $0.03 - $0.08 per kWh

Bio-Derived Liquids

Feedstock variability: $1.00 - $3.00 per gallon ethanol

Natural Gas Reforming

Feedstock variability: $4.00 - $10.00 per MMBtu

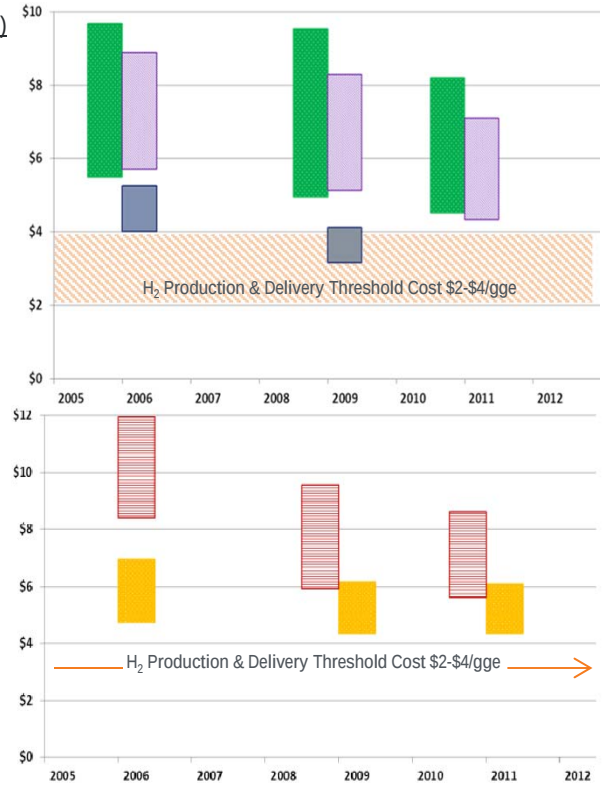
Central Production (longer term)

Electrolysis

Feedstock variability: $0.03 - $0.08 per kWh

Biomass Gasification

Feedstock variability: $40-$120 per dry short ton



- Compressed H_2 tanks can achieve >250 mile range
- Validated a vehicle that can achieve 430 mile range (with 700 bar Type IV tanks)
- Developed and evaluated more than 400 material approaches experimentally and millions computationally

Progress – Technology Validation

Demonstrations are essential for validating technologies in integrated systems.

Real-world Validation

Vehicles & Infrastructure

- >180 fuel cell vehicles and 25 hydrogen fueling stations
- Over 3.7 million miles traveled
- Over 146 thousand total vehicle hours driven
- 2,500 hours (nearly 75K miles) durability
- 5 minute refueling time (4 kg of hydrogen)
- 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 130,742 total refuelings since 2009

CHHP (Combined Heat, Hydrogen and Power)

- Demonstrated the world's first facility for co-producing hydrogen and power (with 54% efficiency)

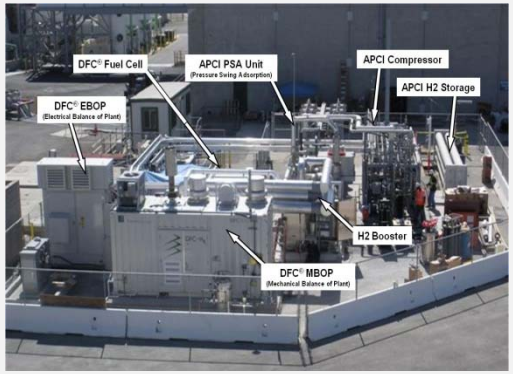
Technology Validation—Tri-Generation

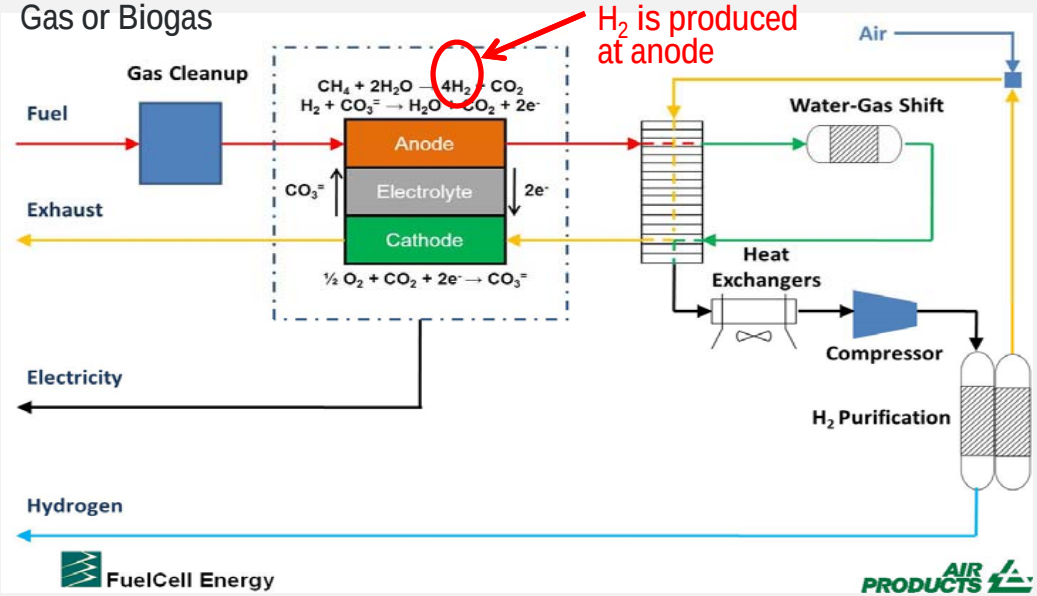
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

"Energy Department Applauds World's First Fuel Cell and Hydrogen Energy Station in Orange County" (Co-funded by DOE, CA and industry)

Demonstrated world's first Tri-generation station (CHHP with 54% efficiency)

-Anaerobic digestion of municipal wastewater-





Fountain Valley demonstration

- ~250 kW of electricity
- ~100 kg/day hydrogen capacity (350 and 700 bar), enough to fuel 25 to 50 vehicles.

Current Hydrogen Infrastructure

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

Current Status

- Over **9 million metrics tons** of hydrogen produced per year
- Over **1,200 miles** of hydrogen pipelines (CA, TX, LA, IL, and IN)
- There are more than **50 fueling stations** in the U.S.

There have been > 100,000 hydrogen refuelings in the U.S. — including FCEVs, forklifts, and other applications.

Existing Hydrogen Production Facilities

- ***Significant hydrogen supply infrastructure is already located near most major U.S. cities.***
- **Hydrogen can be delivered from central production facilities to fueling stations by liquid truck, tube trailer or new drop-tank system.**

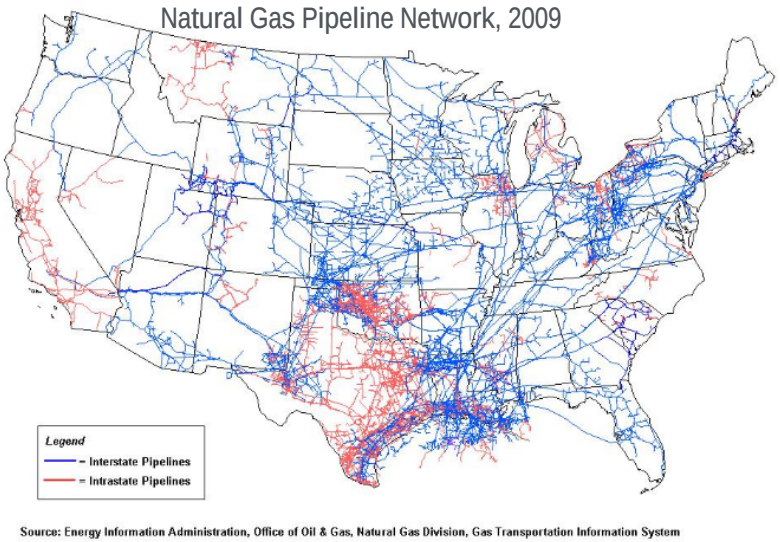
Options for Early Hydrogen Infrastructure

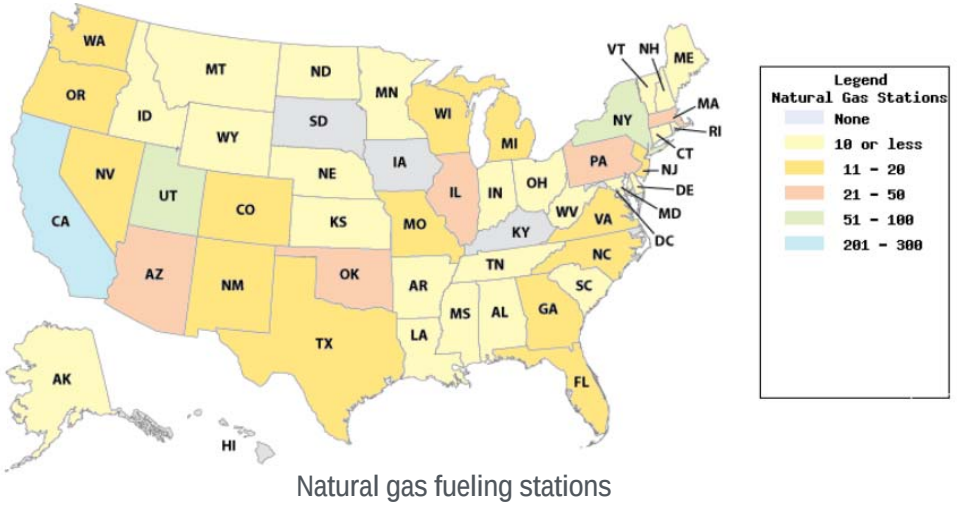
Two Main Options for Low-cost Early Infrastructure

1. **Hydrogen delivered from central site**
   - Low-volume stations (~200-300 kg/day) would cost <$1M and provide hydrogen for $7/gge *(e.g., high-pressure tube trailers, with pathway to $5/gge at 400–500 kg/day- comparable to ~$2.10/gallon gasoline untaxed)*
2. **Distributed production (e.g. natural gas, electrolysis)**

Other options

1. Co-produce H_2, heat and power (tri-gen) with natural gas or biogas
2. Hydrogen from waste (industrial, wastewater, landfills)





Natural gas fueling stations

Hydrogen and Fuel Cell Initiatives at the State Level

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

Several states—including California, Connecticut, Hawaii, Ohio, New York, and South Carolina—have major hydrogen and fuel cell programs underway.

California

FCEVs and Fuel Cell Buses

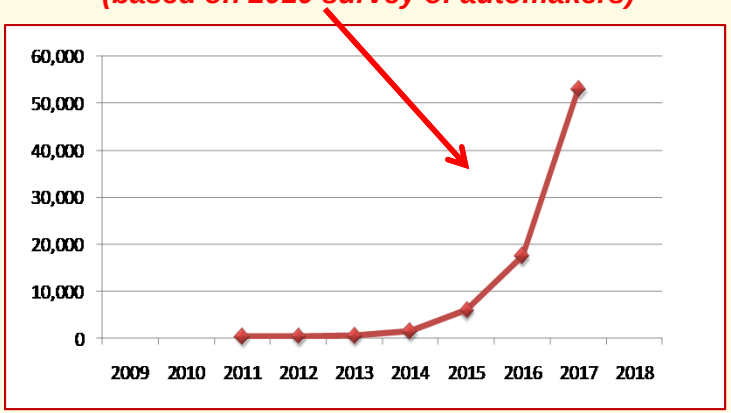
- **> 400 vehicles** in operation since 1999 — >160 currently operating
- **~3.9 million miles** driven
- **> 1 million passengers** on fuel cell buses

Investment in Hydrogen Stations

- **20 stations** — including planned/funded
- **~$34M invested** *(C.A.R.B. and C.E.C.)* — with ~$23M industry cost share
- **~$18M planned** for future solicitations

Industry's Plans for FCEV Sales in CA

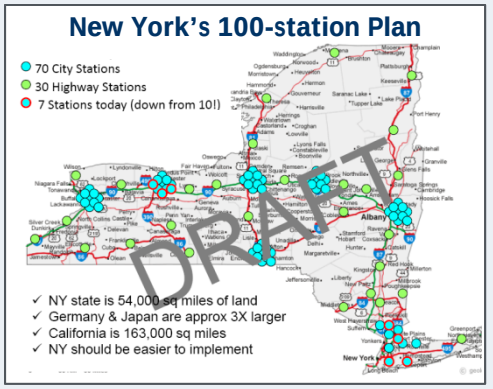
(based on 2010 survey of automakers)



New York

Plans 100 hydrogen stations (70 city, 30 highway) by 2020 to support minimum of 50,000 FCEVs — plan starts in 2015 with 1500 vehicles and 20 stations

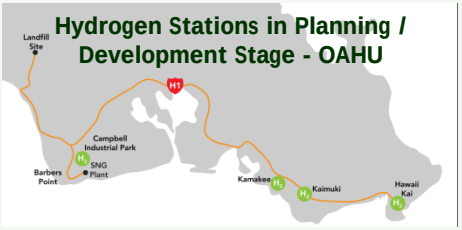
- Industry Investment: **Six auto companies plan total investment of nearly $3.0 Billion**
- State Investment: **NY developing plans to provide $50M to support infrastructure rollout while leveraging >$165M in Federal vehicle incentives for initial FCEV commercial deployment**



Hawaii

Agreement signed by 12 stakeholders—including GM, utilities, hydrogen providers, DOD, DOE—to establish hydrogen as a major part of the solution to Hawaii's energy challenges.

- 15 GM FCEVs **currently in demonstrations with military**
- Renewable hydrogen **(from geothermal and wind energy) will be used for buses**
- **Goals include** 20-25 stations **on Oahu by 2015 to support annual sales of up to** 5,000 FCEVs **in early years.**



Funding Opportunity Announcements

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

DOE Announces up to $6 Million to Collect Performance Data on Fuel Cell Electric Vehicles

This FOA will collect, analyze, and validate performance data from light-duty hydrogen fuel cell electric vehicles (FCEV) operating in real-world environments. Feedback will be provided to the DOE hydrogen and fuel cell R&D projects and industry partners to help determine what additional R&D is required to move the technology forward.

Responses Due: Monday, April, 30, 2012

DOE Announces up to $2 Million to Collect Data from Hydrogen Fueling Stations and Demonstrate Innovations in Hydrogen Infrastructure Technologies

Topic Area 1: Hydrogen Refueling Station Data Collection
Topic Area 2: Validation of Advanced Refueling Components
This FOA will test, demonstrate, and validate hydrogen refueling components and complete systems in real-world operating environments. Feedback will be provided to help determine what additional R&D is required to move the technology forward.

Responses Due: Friday, May 11, 2012

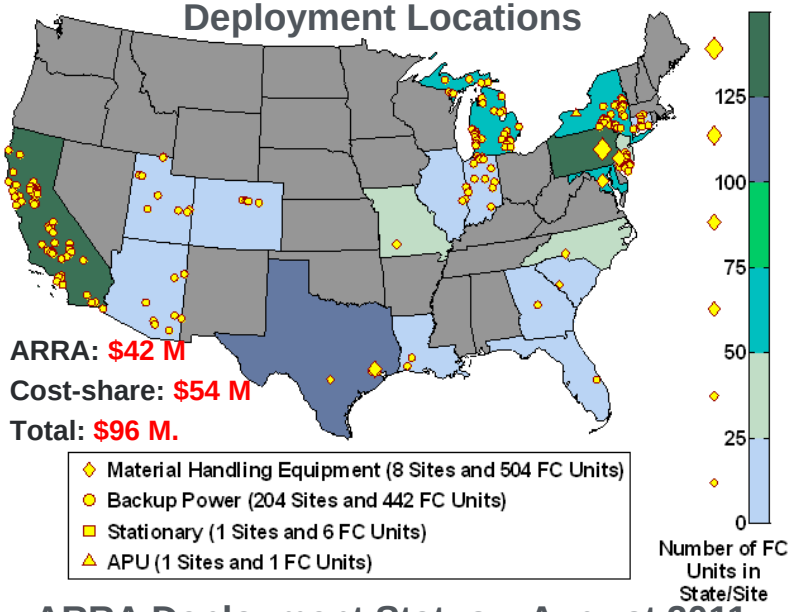
Plans include leveraging state activities (e.g. CA state funding for fueling stations)
FCT will not be funding infrastructure but can fund technology innovation that could be applicable to/enable infrastructure (e.g. innovative refueling/compression technologies)

Recovery Act and Market Transformation Spur Deployments

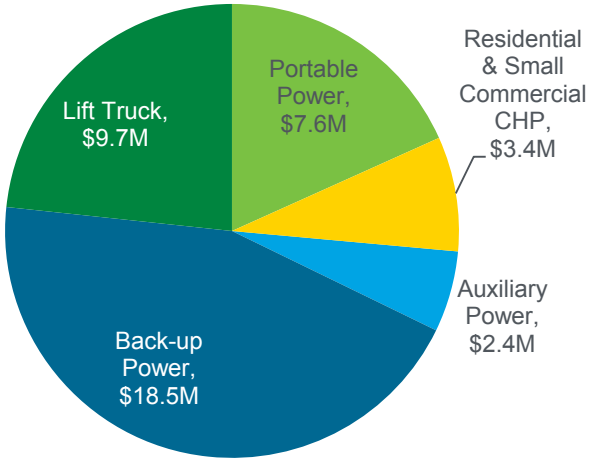
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Deployments help ensure continued technology utilization growth and catalyze market penetration while providing data and lessons learned.

Deployment Locations



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



ARRA Deployment Status – August 2011

Fuel Cell Application	Operational Fuel Cells	Total Fuel Cells Planned
Backup Power	371	539
Material Handling	467	504
Stationary	2	6
APU	0	4
Total	**840**	**> 1,000**

NREL ARRA Data Collection Snapshot

ARRA Material Handling Equipment Data	As of 9/30/2011
Hydrogen Dispensed	>51,500 kg
Hydrogen Fills	>88,000
Hours Accumulated	>380,000 hrs

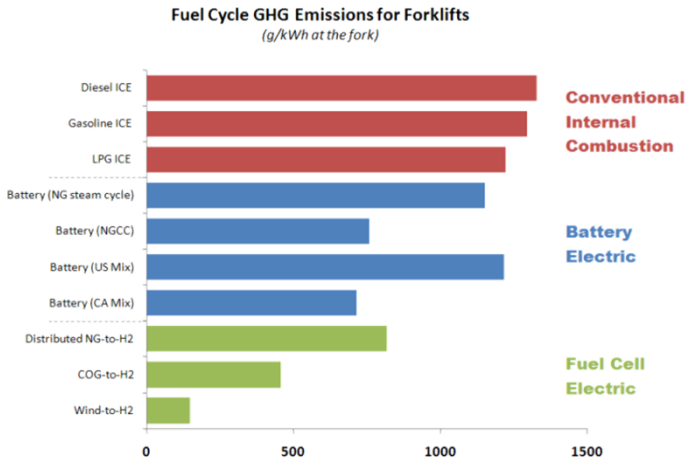
ARRA as Catalyst for Deployments

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

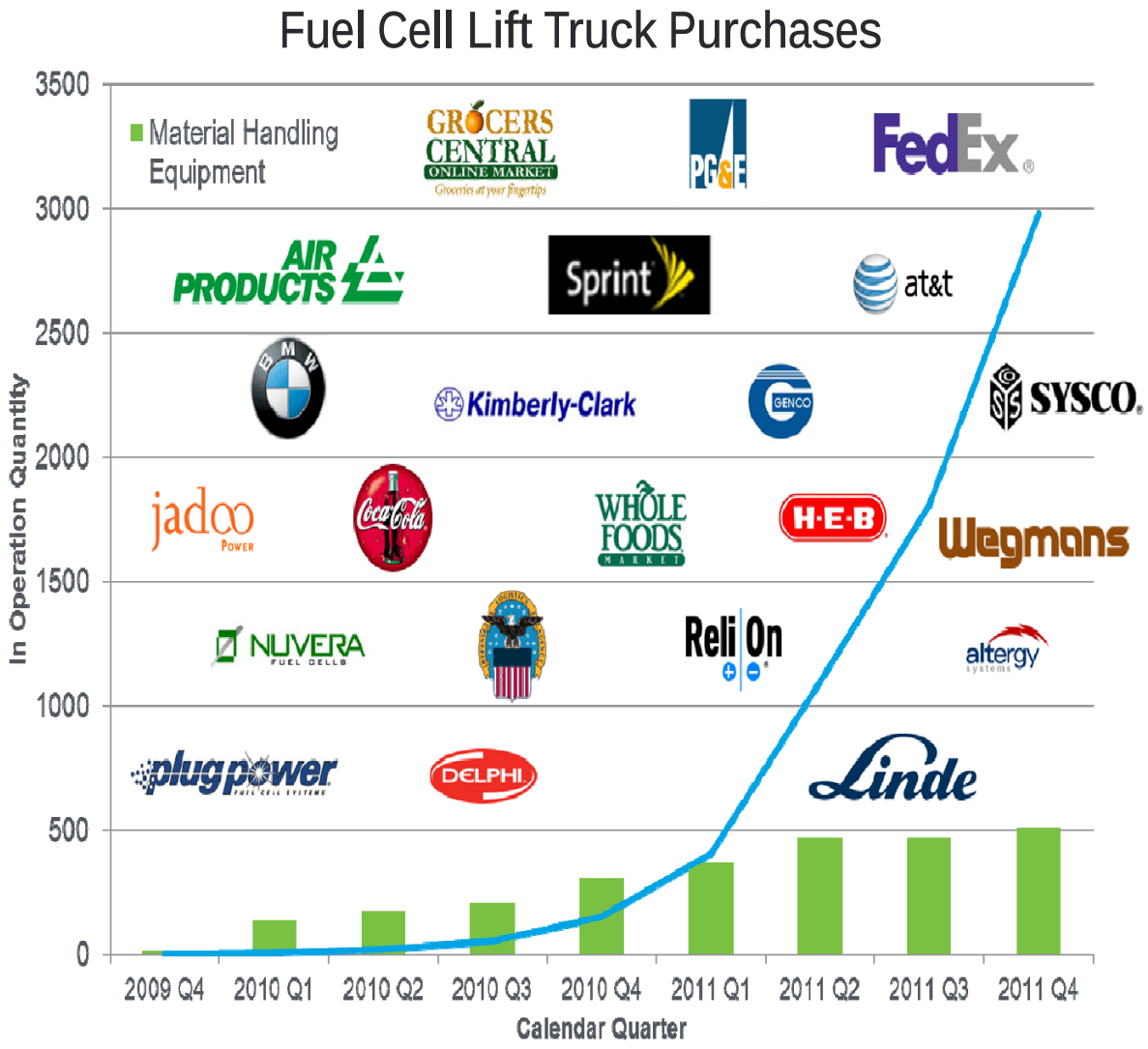
ARRA deployments of fuel cells for lift trucks (~400) led to industry purchases* of an estimated 3,000 additional fuel cell lift trucks with NO DOE funding

The Case for Forklifts*
Compared to conventional forklifts, fuel cell forklifts have:

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



*Preliminary Analysis



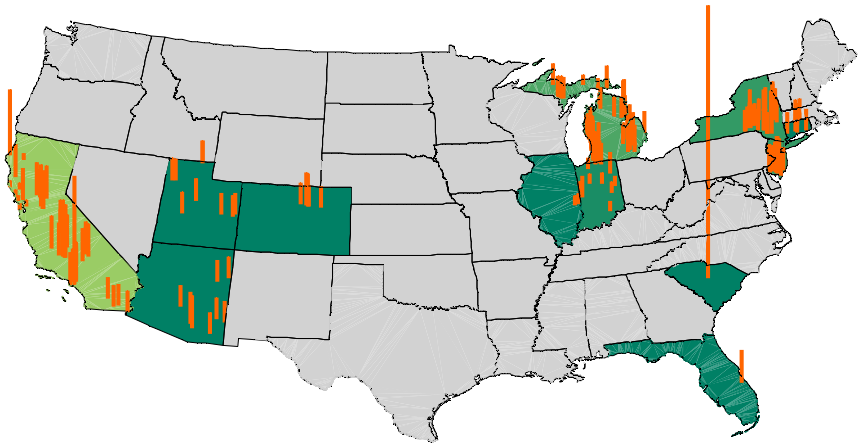
* Including deployed and on order

Backup Power Deployments

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

Nearly 900 kW deployed at ~200 sites

State	kW Capacity	Sites	State	kW Capacity	Sites
Arizona	40	9	Indiana	46	15
California	304	63	Michigan	148	36
Colorado	24	5	New Jersey	84	21
Connecticut	32	8	New York	116	29
Florida	6	1	South Carolina	50	1
Illinois	4	2	Utah	36	9
Totals	**kW Capacity**	**890**	**Totals**	**Sites**	**199**



Next Steps

- Quantify benefits
- Determine lessons learned and key areas for government support (if any)

Includes ARRA and DOE Interagency Agreement (IAA) Deployments

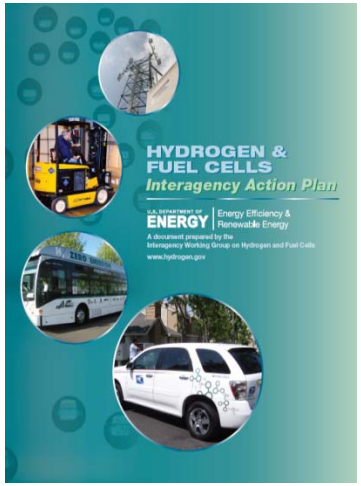
Tracked by NREL

DOE and Interagency Activities

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

Developed Interagency Action Plan—integrated plan for coordinating U.S. federal agency efforts hydrogen and fuel cells RDD&D

DOE will continue to lead Interagency Task Force and Working Group across 10 Agencies and identify opportunities to leverage funding and activities



December 2011

Goals

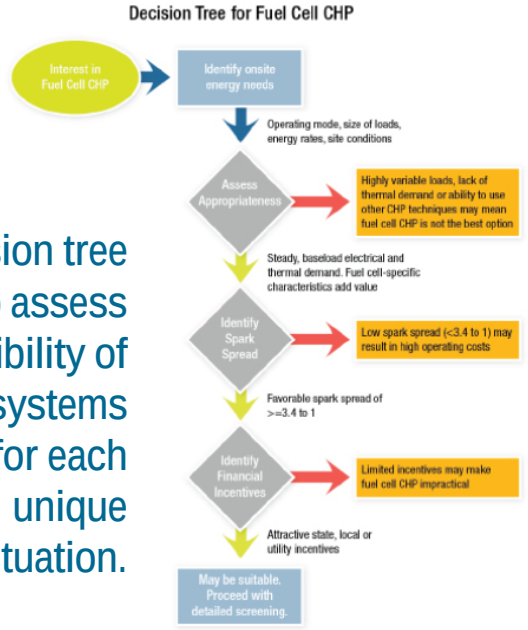
1. Strengthen and Accelerate Research and Development
2. Accelerate Development & Adoption of Codes, Standards & Safe Practices
3. Work with Industry to Validate Technologies under Real-World Conditions
4. Adopt Technologies in U.S. Government Operations
5. Track and Communicate Results

Future Focus Area: Increase demand through Federal deployments

Developed Procurement Guide (ORNL)

Provides clear guidance on CHP technology – its benefits, ideal usage, and financing options.

Decision tree to help assess feasibility of CHP systems for each unique situation.



State of the States

The Business Case for Fuel Cells: Why Top Companies are Purchasing Fuel Cells Today

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

34 companies profiled in the report, cumulatively, have ordered, installed or deployed:

- *more than 1,000 fuel cell forklifts;*
- *>250 fuel cells totaling 30+ MWs of stationary power;*
- *more than 240 fuel cell units at telecom sites.*

State of the States: Fuel Cells in America

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

Report analyzing the seven regions of the United States, compiling state activities supporting fuel cell and hydrogen policy, as well as installations and demonstrations in each state.

See report: http://www.fuelcells.org/StateoftheStates2011.pdf

Additional States to Watch

Hawaii - hydrogen station at Hickam Air Force Base, recently launched the Hawaii Hydrogen Initiative (H2I) with GM, starting a renewable hydrogen generation and refueling station with the Navy

Texas - Fuel cell forklift deployments by several major food distributors (e.g. HEB, Sysco)

Delaware - non-renewable fuel cells added to net metering, two fuel cell buses. home to major fuel cell component suppliers

Florida - Cleantech Industry Cluster includes fuel cells

Maryland - FuelWorks research center at University of Maryland, Whole Foods forklift fleet among country's largest

Emerging Market Opportunities for States

Hydrogen and fuel cell technologies can be utilized across a wide spectrum of industries for several different applications including:

- **Material Handling Equipment**
- **Backup power**
- **Combined-heat-and-power**

Major companies including FedEx, Coca-Cola, AT&T, Wegmans, and Whole Foods (among others) are utilizing fuel cell technology today.

High Profile CHP Installation Underscores Benefits

Freedom Tower to tap green fuel cell power:

Low emission fuel cells to provide onsite heat and power for landmark project

"New York's Freedom Tower, the skyscraper being constructed on the site of the World Trade Center, is to use fuel cells to power its heating and cooling systems.

UTC Power, the fuel cell division of engineering conglomerate United Technologies, announced that it has received orders from the ***New York Power Authority (NYPA)*** *for 12 fuel cells totaling 4.8MW of power to serve the Freedom Tower and three other new towers under construction at the site in Manhattan."*

Examples of CHP Deployments

The Food Industry is an emerging market for stationary fuel cells

Completed & Planned Deployments

- **Whole Foods**
- **Price Chopper**
- **SUPERVALU(Albertsons/Shaws)**
- **Ahold (Stop & Shop)**
- **Coca-Cola**
- **Gills Onions**
- **Pepperidge Farms**
- **Sierra Nevada Brewery**

Fuel cells provide significant environmental and efficiency benefits to a wide range of industries.

Case Study: First National Bank, Omaha

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

Increasing efficiency and availability with fuel cells at a banking center

Location	Omaha, NE
Date Installed	1999
Equipment	Four 200 kW fuel cells
Use	Primary and back-up power, heat and cooling for a three-level operations plant
Benefits	40-50% reduction in greenhouse gas emissions
Performance	• Availability: > 99.999% • Input to output fuel efficiency: 54%

System	Input to Output Fuel Efficiency	Calculated Emissions		Calculated Availability	20-year Life Cycle Cost
		CO_2	NO_x		
Utility	30%	4,207 Tons*	11 Tons	94.60%	$4.9 Million
UPS	25%	4,599 Tons*	12 Tons	99.999%	$8.6 Million
Fuel Cell	54%	2901 tons	Negligible	99.999995%	$8.1 Million

* Includes ESC steam production.

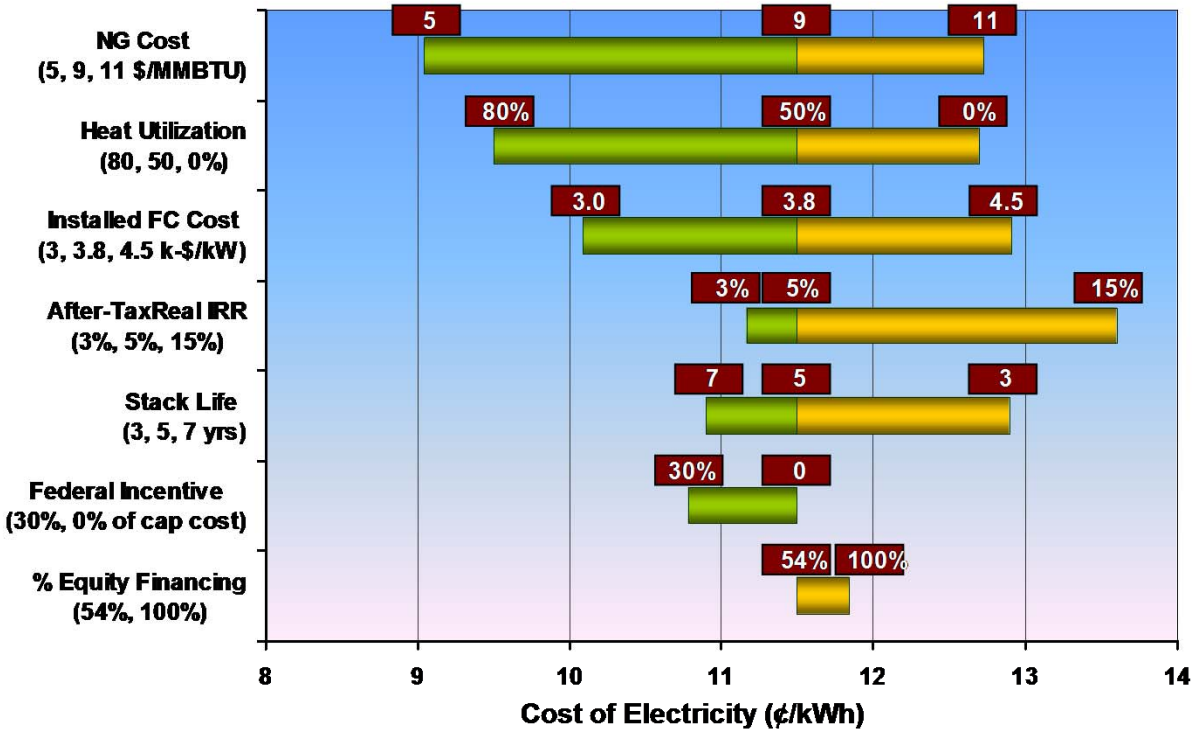
Contact: Dennis Hughes, 402-633-3926
dhughes@fnni.com

Stationary Fuel Cells – Cost analysis

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

Analysis efforts are underway, to provide information on potential costs and benefits of a variety of stationary fuel cell applications.

Example: Cost of Electricity from Commercial-Scale Stationary Fuel Cell



Performance Parameters

System Electric Efficiency	= 45% (LHV Basis)
System Total Efficiency	= 77% (LHV Basis)
System Size	= 1,400 kW
System Life	= 20 years
Capital cost	= $3.5 million
Installed cost	= $5.3 million

Financial Assumptions

Startup year	= 2010
Financing	= 54% equity
Interest rate	= 7%
Financing period	= 20 years
After-tax Real IRR	= 5%
Inflation rate	= 1.9%
Total tax rates	= 38.9%
Depreciation schedule	= 7 years (MACRS)
Payback period	= 11 years

Stack replacement cost distributed annually

Operation Assumptions

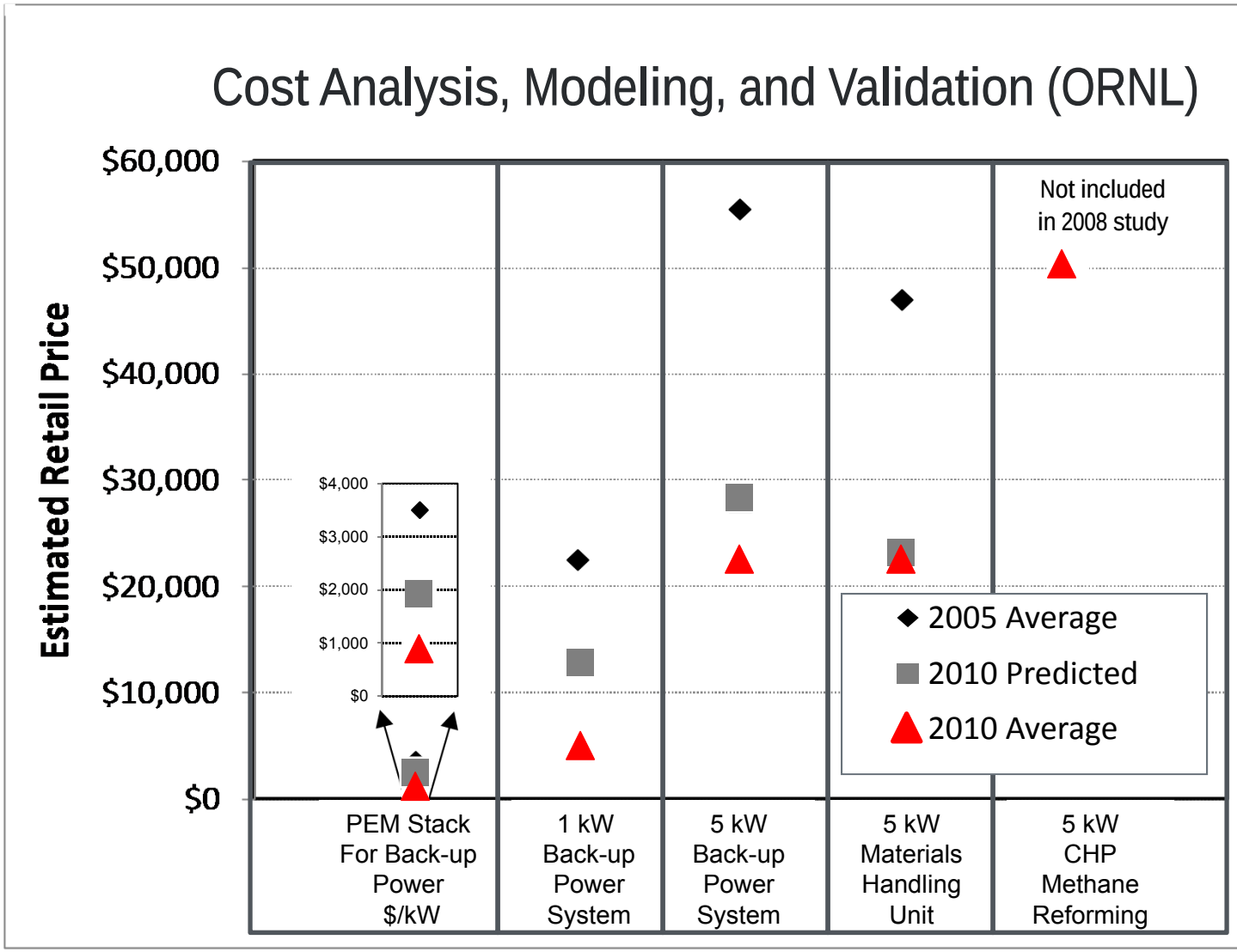
System utilization factor	= 95%
Restacking cost	= 30% of installed cap. cost
Heat value	= cost of displaced natural gas from 80% efficient device

Source: NREL Fuel Cell Power Model

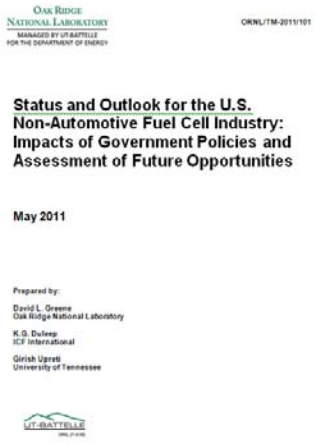
Example for MCFC 1.4 MW

Early Market Cost Reduction Analysis

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



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


Oak Ridge National Laboratory
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.G. Duleep
ICF International
Girish Upreti
University of Tennessee

UT-BATTELLE

http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/ornl_non_automotive_fuelcell.pdf

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

Jobs Tool Under Development for Employment Impacts of Early Markets

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

Tool will allow states to determine potential jobs from fuel cell manufacturing and related sectors.

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

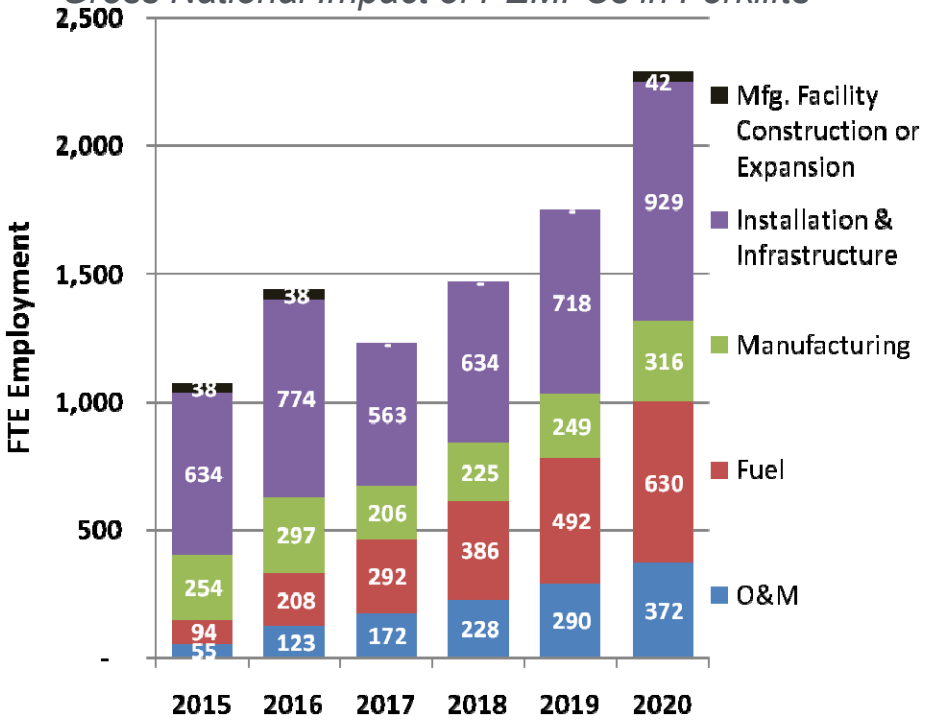
OPTIONAL USER INPUT FIELDS	
Existing Fuel Cell Production Capacity (kW/year)	0
Additional Manufacturing Capacity to be Constructed (kW/year)	10,000
Sales Price ($/kW)	$2,000
Production Cost ($/kW, initial)	$1,301
Progress Ratio	0.97
Production Volume for Initial C…	10,000
Scale Elasticity	-0.2
Full …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

Currently undergoing beta testing
Will be available ~ May 2012

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.

Recently Released States Reports

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

Northeast Hydrogen Fuel Cell Industry Status and Direction


NORTHEAST HYDROGEN FUEL CELL INDUSTRY
STATUS AND DIRECTION
2012

Joel M. Rinebold
Alexander C. Barton
Adam J. Brzozowski

The Connecticut Center for Advanced Technology, Inc.

Report by Joel M. Rinebold, Alexander C. Barton, and Adam J. Brzozwski

Connecticut Center for Advanced Technology, Inc.

Highlights potential for fuel cell industry in northeast US detailing relevant information on products and markets, employment, and system efficiency and cost.

See report:
http://dl.dropbox.com/u/53527617/NORTHEAST%20HYDROGEN%20FUEL%20CELL%20INDUSTRY%20STATUS%20AND%20DIRECTION%202012.pdf

State by state plans identifying fuel cell opportunities and potential implementation strategies (drafts in process)

Available for:
Connecticut
Massachusetts
Maine
New Hampshire
New Jersey
New York
Rhode Island
Vermont

Northeast Hydrogen Fuel Cell Cluster

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

Preliminary Analysis- Economic Impact Summary

	CT	NY	MA	ME	NH	RI	VT	NJ	Regional
Total Employment	2,529	1,728	964	18	45	32	16	111	**5,443**
Total Revenue / Investment in 2010 ($ million)	$496	$292	$171	$2.9	$8.7	$6.9	$3.3	$26.5	**$1,009**
Total Supply Chain Companies	599	183	322	28	25	19	5	8	**1189**

The Connecticut Center for Advance Technology, Inc.

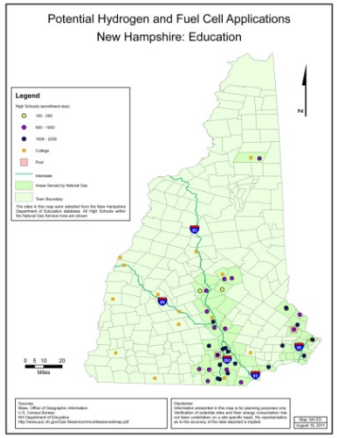
www.ccat.us

Northeast Hydrogen Fuel Cell Cluster

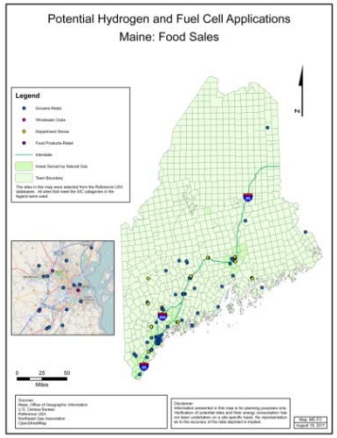
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Targets: Geographic Information System (GIS) Mapping

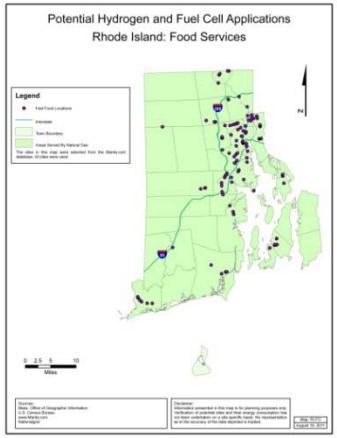
Education



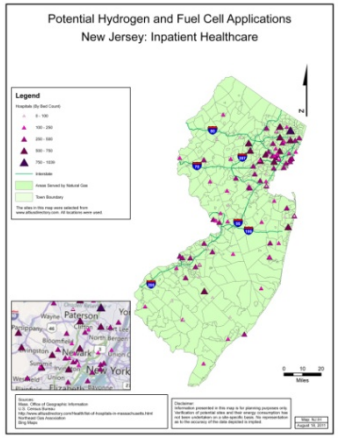
Food Sales



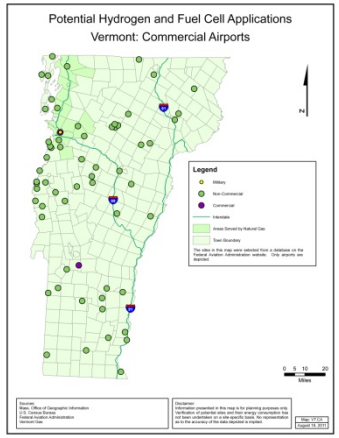
Food Services



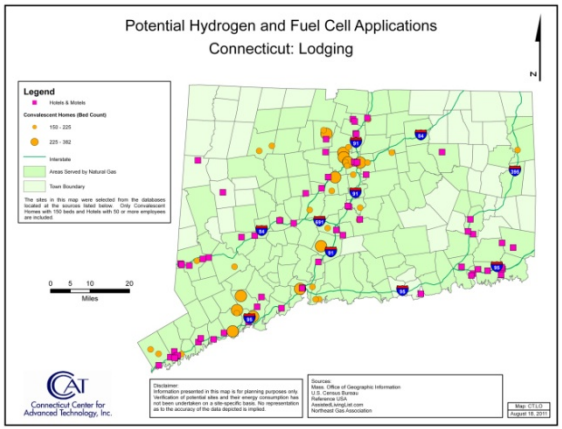
Inpatient Healthcare



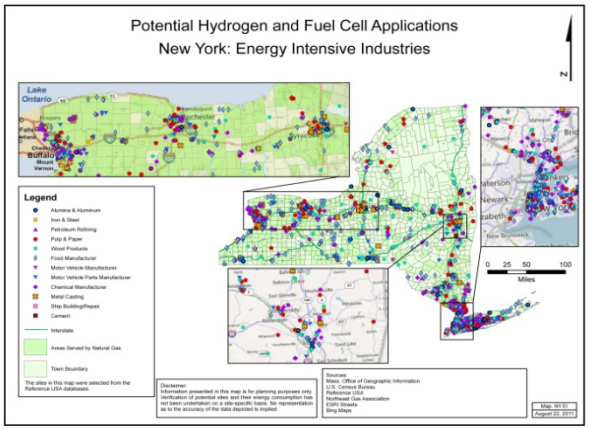
Airports (Military)



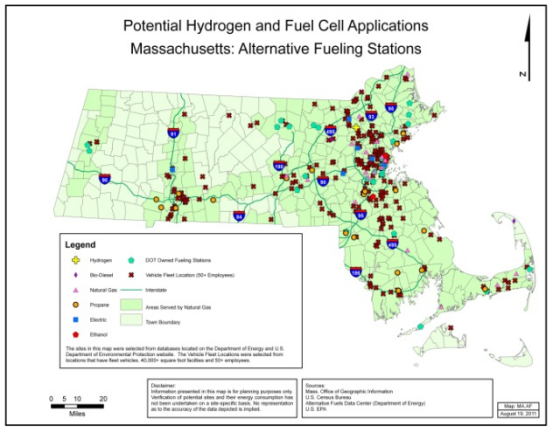
Lodging



Energy Intensive Industry



Alternative Fueling Stations



The Connecticut Center for Advance Technology, Inc.

www.ccat.us

Targets: Breakdown Example for 300 kW Stationary

Category	Total Sites	Potential Sites	MWs	MW-hrs per year	MW at 90% Capacity Factor	Aggregate Annual Thermal Output		CO2 emissions
						MMBTU	MWh	
Education	18,335	2,190	210.9	1,662,735.6	189.81	4,478,301.22	1,312,515.01	434,286.20
Food Sales	51,300	1,201	360.3	2,840,605.2	324.27	7,650,696.67	2,242,290.94	642,698.16
Food Services	64,600	387	116.1	915,332.4	104.49	2,465,295.26	722,536.71	219,715.25
Inpatient Healthcare	3,994	422	126.6	998,114.4	113.94	2,688,254.78	787,882.41	232,631.61
Lodging	8,033	884	265.2	2,090,836.8	238.68	5,631,320.45	1,650,445.62	484,156.44
Public Order & Safety	3,310	313	93.9	740,307.6	84.51	1,993,895.14	584,377.24	179,454.82
Energy Intensive Industries	4,758	429	128.7	1,014,670.8	115.83	2,732,846.69	800,951.55	223,655.68
Government Operated Buildings	1,255	90	27.0	212,868.0	24.30	573,324.48	168,031.79	49,990.87
Wireless Telecommunication Towers*	3,960	397		-	-	-	-	-
WWTPs	578	16	4.8	37,843.2	4.32	101,924.35	29,872.32	8,417.75
Landfills	213	14	4.2	33,112.8	3.78	89,183.81	26,138.28	7,327.39
Airports (w/ AASF)	842	50 (20)	16.2	127,720.8	14.58	343,994.69	100,819.08	31,414.59
Military	14	14	4.2	33,112.8	3.78	89,183.81	26,138.28	59,737.86
Ports	120	19	5.7	44,938.8	5.13	121,035.17	35,473.38	10,272.06
Total	**161,312**	**6,426**	**1,363.8**	**10,752,199.2**	**1,227.42**	**28,959,256.51**	**8,487,472.60**	**2,064,422.25**

* No Base Load

Northeast Hydrogen Fuel Cell Cluster

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

Policies and Incentives

	ME	NH	VT	MA	RI	CT	NY	NJ
Energy Policy								
Mandatory Renewable Portfolio Standard (RPS)	■	■		■	■	■	■	■
Fuel Cell Eligibility	■			*	*	■	■	*
Interconnection Standards (Includes Fuel Cells)		*	*	*	*	■	■	*
Net Metering (Includes Fuel Cells)	■	*	*	*	*	■	■	*
Public Benefits Fund (Includes Fuel Cells)	■		*	*	*	■	■	*
Renewable Greenhouse Gas Initiative (RGGI) Member	■	■	■	■	■	■	■	■
State Incentives for Fuel Cells								
Performance-Based	■				*	■	■	
State Grant Program	■		*	**	*	■	■	
State Loan Program	■		*		*	■		
State Rebate Program								*
Property Tax Incentive (Commercial)			*					*
Sales Tax Incentive			*				■	
Industry Recruitment/ Support				*		■		*
Property-Assessed Clean Energy (PACE) Financing	■			**			■	

■ All fuel cell types * Fuel cells using renewable fuels ** Renewable energy eligible technology to be locally determined ** eligible through Green Communities program

www.dsireusa.org

The Connecticut Center for Advance Technology, Inc.

www.ccat.us

Education Activities

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

Education: ***Based on prior year funds – projects are being completed***

ACTIVITIES

- **Increase acceptance and inclusion of technologies as a part of a clean energy portfolio**
- **Reduce "soft costs" associated with early adoption (e.g., insurance, permitting, uniform codes and standards)**
- **Increase general knowledge of the benefits multiple applications**
- **Increase awareness of broad range of applications—beyond light-duty vehicles and buses**

PROGRESS *(key examples)*

Educated over 23,000 first responders and code officials through introductory web-based courses and advanced hands-on training.

Continued to promote and deploy the "H2 Educate" middle-school learning module—reaching a total of more than 9,550 teachers in 35 states since the project was launched.

Conducted seminars and developed fact-sheets and case studies for end-users

Conducted more than 80 workshops to help state officials identify deployment opportunities

2011 Hydrogen Student Design Contest had 54 university teams registered from 19 countries, including seven of the top 20 engineering schools in the world.

Increased offering of university certificates and minors at universities (examples include: Michigan Tech, Univ. of NC at Charlotte)

Communication & Outreach

Published more than 70 news articles in FY 2011 (including blogs, progress alerts, and DOE FCT news alerts)

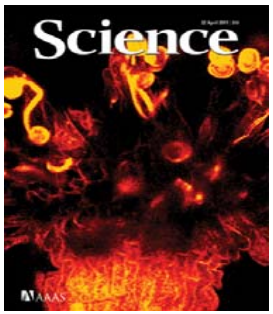
Communication and Outreach Activities include:

- Webinar Series:
  - Feb. 6 – National Hydrogen Learning Demonstration Status
  - Continuing series of informational webinars led by FCT and partners on various topics.
- News Items:
  - Energy Department Awards More Than $7 Million for Innovative Hydrogen Storage Technologies in Fuel Cell Electric Vehicles
  - DOE Launches Comprehensive Hydrogen Storage Materials Clearing House
- Monthly Newsletter

Blogs Published to Energy.gov website include:

- Fuel Cell Powers Up Festivities at Sec. Chu's Holiday Party
- Fuel Cell Lift Trucks: A Grocer's Best Friend

"These technologies are part of a broad portfolio that will create new American jobs, reduce carbon pollution, and increase our competitiveness in today's global clean energy economy."



Progress in low and zero Pt catalysts highlighted in Science

Hydrogen power lights at the 2011 Golden Globes

Hydrogen fuel cells providing critical backup power

DOE Monthly Newsletter

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

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

Fuel Cell Technologies Program

January 2012 Newsletter

Welcome to the inaugural issue of the Fuel Cell Technologies Program newsletter. This newsletter will be issued monthly to our Fuel Cell News subscribers and will include a recap of the previous month's news and events as well as a preview of upcoming activities.

In this issue:

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

In the News

DOE Releases Request for Information on Early Market Opportunities for Fuel Cell Technologies

The Department of Energy (DOE) has issued a Request for Information asking for stakeholder feedback on the commercial readiness of fuel cell and hydrogen technologies. Topics covered include: auxiliary power on board commercial, heavy duty road vehicles for refrigeration; fuel cell battery rechargers for all electric vehicles used for transporting freight or passengers; and technology deployment projects for other on or off road transportation markets. The deadline for responses is March 2, 2012.

Hydrogen and Fuel Cells Interagency Action Plan Released

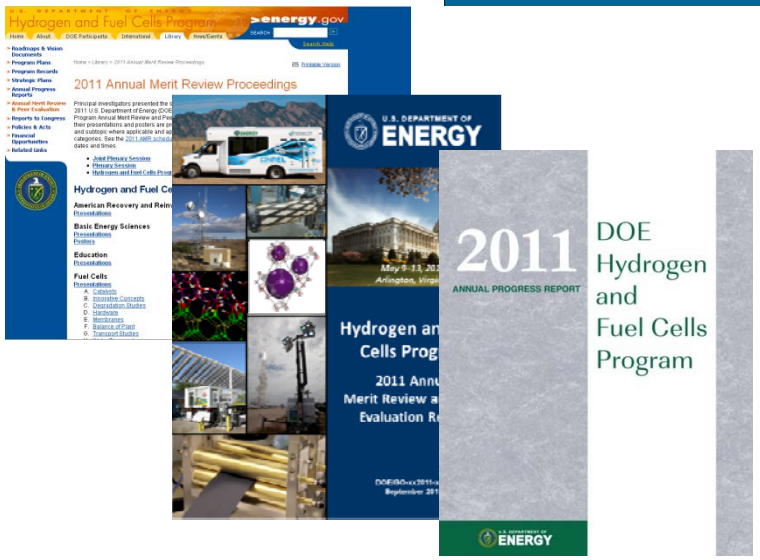
The Hydrogen and Fuel Cells Interagency Task Force and Interagency Working Group released their Interagency Action Plan (IAP) on January 30. The Hydrogen and Fuel Cells Interagency Action Plan guides collaborative federal agency efforts to research, develop, demonstrate, and deploy hydrogen and

Inaugural Newsletter for Program issued January 2012.

Subscribe

http://www1.eere.energy.gov/hydrogenandfuelcells/subscribe.html

Key Reports



The DOE Fuel Cell Technologies Program also funds the development and publication of key reports

The Business Case for Fuel Cells: Why Top Companies are Purchasing Fuel Cells Today

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

See report: http://www.fuelcells.org/BusinessCaseforFuelCells.pdf

State of the States: Fuel Cells in America

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

See report: ttp://www.fuelcells.org/StateoftheStates2011.pdf

2010 Fuel Cell Market Report

By Breakthrough Technologies Institute, Inc. http://www.btionline.org/

See report:

http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/2010_market_report.pdf

Annual Merit Review & Peer Evaluation Proceedings

Includes downloadable versions of all presentations at the Annual Merit Review

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

Annual Merit Review & Peer Evaluation Report

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

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

Annual Progress Report

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

www.hydrogen.energy.gov/annual_progress.html

Next Annual Review: May 14 18, 2012 Arlington, VA

http://annualmeritreview.energy.gov/

Acknowledgements

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

Federal Agencies

- DOC
- DOD
- DOE
- DOT
- EPA
- GSA
- DOI
- DHS
- NASA
- NSF
- USDA
- USPS

– *Interagency coordination through staff-level Interagency Working Group (meets monthly)*

– *Assistant Secretary-level Interagency Task Force mandated by EPACT 2005.*

External Input

- Annual Merit Review & Peer Evaluation
- H2 & Fuel Cell Technical Advisory Committee
- National Academies, GAO, etc.

Industry Partnerships & Stakeholder Assn's.

- Tech Teams (USCAR, energy companies- U.S. DRIVE)
- Fuel Cell and Hydrogen Energy Association (FCHEA)
- Hydrogen Utility Group
- ~ 65 projects with 50 companies

Universities

~ 50 projects with 40 universities

DOE Hydrogen & Fuel Cells Program

State & Regional Partnerships

- California Fuel Cell Partnership
- California Stationary Fuel Cell Collaborative
- SC H_2 & Fuel Cell Alliance
- Upper Midwest Hydrogen Initiative
- Ohio Fuel Coalition
- Connecticut Center for Advanced Technology

International

- IEA Implementing agreements – 25 countries
- International Partnership for Hydrogen & Fuel Cells in the Economy – 17 countries & EC, 30 projects

National Laboratories

National Renewable Energy Laboratory P&D, S, FC, A, SC&S, TV, MN
Argonne A, FC, P&D, SC&S
Los Alamos S, FC, SC&S
Sandia P&D, S, SC&S
Pacific Northwest P&D, S, FC, SC&S, A
Oak Ridge P&D, S, FC, A, SC&S
Lawrence Berkeley FC, A
Lawrence Livermore P&D, S, SC&S
Savannah River S, P&D
Brookhaven S, FC
Idaho National Lab P&D

Other Federal Labs: Jet Propulsion Lab, National Institute of Standards & Technology, National Energy Technology Lab (NETL)

P&D = Production & Delivery; S = Storage; FC = Fuel Cells; A = Analysis; SC&S = Safety, Codes & Standards; TV = Technology Validation, MN = Manufacturing

States and Coordination

Next Steps:

Coordination on

- Education & Outreach
- Policies & Incentives
- Codes & Standards
- Lessons Learned
- Accelerate Deployments

Solicit ideas (STEAB, other stakeholders)

Thank you

Sunita.Satyapal@ee.doe.gov

www.hydrogenandfuelcells.energy.gov

Additional Information

State: Pennsylvania
Project Name: Wegmans Distribution Center – H_2
SEP ARRA Cost: $1,009,176:
Total Project Cost: $4,078,510
Project Description: The Wegmans Distribution Center located in Pottsville, PA utilized a $1M SEP ARRA grant to purchase a hydrogen fueling system for all their forklifts and pallet jacks. The fueling system consists of external hydrogen storage tanks and four interior fueling stations. Wegmans used their own funds to convert the forklifts and pallet jacks from battery to hydrogen power. Currently, Wegmans is purchasing the hydrogen from a supplier but the second phase of this system is being planned that would utilize solar power to produce hydrogen onsite. At the time of the monitoring visit in September, 2011, the system was complete and fully operational.

State: Connecticut
SEP ARRA Obligation: $8,000,000
Project Description: Thus far, Connecticut has outlaid $2,000,000 and completed a 1.4MW fuel cell system.

EECBG Funded Fuel Cell Projects

City of Los Angeles, California's "Port Technology Advancement Program" Activity – $1,482,000

- This activity is aimed at identifying, evaluating, and demonstrating new and emerging emissions reduction and electrification technologies applicable to the port industry
- The grantee will purchase a Hydrogen fuel cell powered, zero emission Class 8 electric truck (the cost of which will not exceed $280,000) with mileage enhancement to be used by the Harbor Department to move the Department's TransPorter Exhibit
- Approximately $722,000 will be used for Harbor Department tenants to procure Hydrogen fuel cell powered, zero emission Class 8 electric trucks to be used for drayage, with the grant funding paying the cost between traditional diesel trucks and fuel cell trucks

City of Milford, Connecticut's "Fuel Cell at 2 Wastewater Treatment Plants" Activity - $110,000

- Technical Assistance and Engineering plan to test viability of installing a 300kWh Fuel Cell at the Housatonic Wastewater Treatment Plant
- EECBG funds will be used for engineering, financial packaging, and potentially construction management (the total cost of the system is estimated at $2m)
- The Fuel Cell will be powered with methane gas recovered from the wastewater plant digester supplemented with natural gas
- The electricity generated will be used entirely by the Wastewater Plant for pumps, fans, motors and lighting
- At 300 kWh, the Fuel Cell will provide approximately 85% of the electricity needed with a net savings of about $155,000 annually

City of Lansing, Michigan's "Fuel Cell Powered UPS for Emergency Ops Center" Activity - $28,207

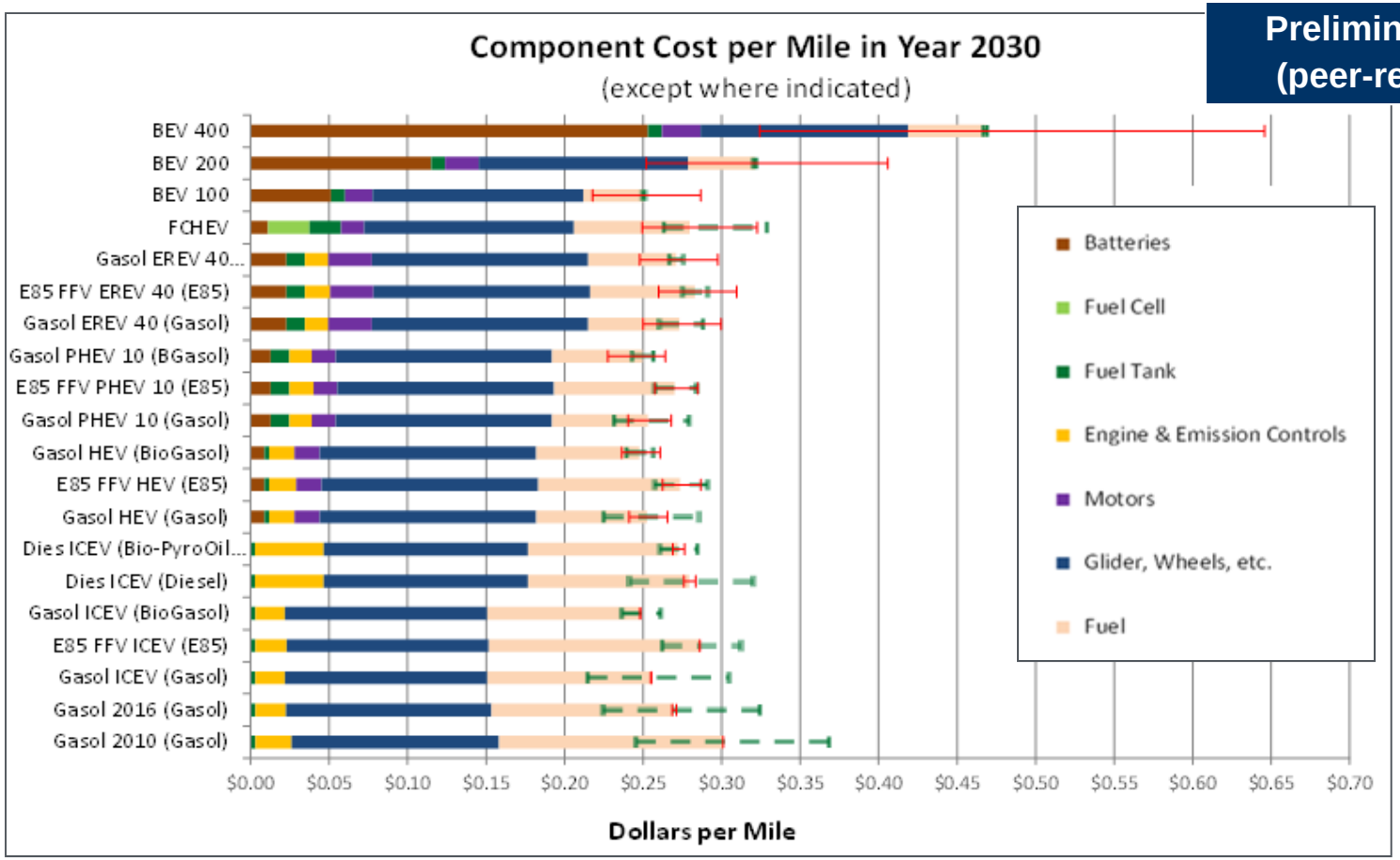
- Purchase and deployment of a fuel cell powered uninterrupted power supply (UPS) unit to replace the City's diesel powered back-up generators currently in place at the Emergency Operations Center (EOC)
- With the fuel cell powered UPS, the city will be able to power critical telecommunications services without producing emissions
- The city will also leverage funds from the City of Lansing Budget for Fiscal Year 2011 in order to purchase and install the fuel cell powered UPS

Vehicle Lifecycle Cost Analysis

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

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

Preliminary DOE analysis (peer-review in process)



RFI closes 3/1/2012

'Error bars' reflect range of assumptions:
Green: range of assumptions for fuel prices (EIA projections for fuels other than hydrogen; hydrogen range: $3.50 - $7.50 per kg)
Red: range of assumptions for technology success
See RFI, http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/costs_mile_rfi.pdf, for range of assumptions.

Key Assumptions

	Fuel Cell HEV	BEV100 100-mile BEV	BEV200 200-mile BEV	BEV400 400-mile BEV
Battery Cost, $/kWh	$600, $800, $1000		$125, $220, $300	
Fuel Cell Cost, $/kW	$25, $30, $40	--	--	--
Fuel Cost in $/gge (¢/kWh)	$3.50, $4.50, $7.50	$3.44 (10.3¢/kWh); $3.54 (10.6¢/kWh); $3.61 (10.8¢/kWh)		

SC-EERE-ARPA-E Collaborations

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

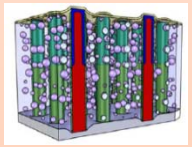
Examples of Cross-Office Collaborative Successes.
Need to continue to leverage activities across other Programs

Office of Science U.S. DEPARTMENT OF ENERGY

Advancing fundamental science knowledge base

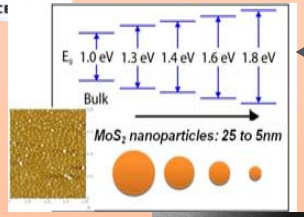
JCAP

Solar to Fuels Hub

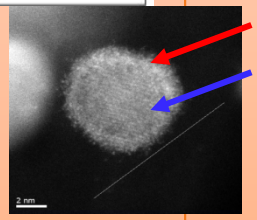


Nanowire based solar fuels generation (CalTech)

EFRC ENERGY FRONTIER RESEARCH CE



Bandgap tailoring (Stanford)



Mechanistic understanding of catalysts

Pt monolayer

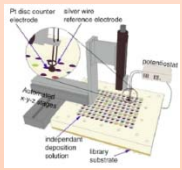
Pd core

Biological H_2 production
Materials-based H_2 storage

U.S. Department of Energy EERE

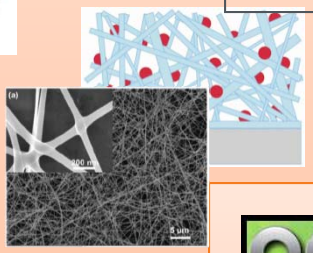
Applied RD&D of innovative technologies

High Throughput Processes (UCSB)



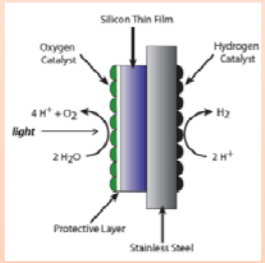
Working Groups PEC, Biological, High T Membranes, Storage Systems

Standard protocols and benchmarking



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

Sun Catalytix

Developing novel catalysts (high risk/high impact)

Alkaline Membranes

Key Challenges

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

The Program addresses the key challenges facing the widespread commercialization of fuel cells.

Technology Barriers

Fuel Cell Cost & Durability

Targets:

Stationary Systems: **$1,000 to $1,500 per kW, 60,000-80,000 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

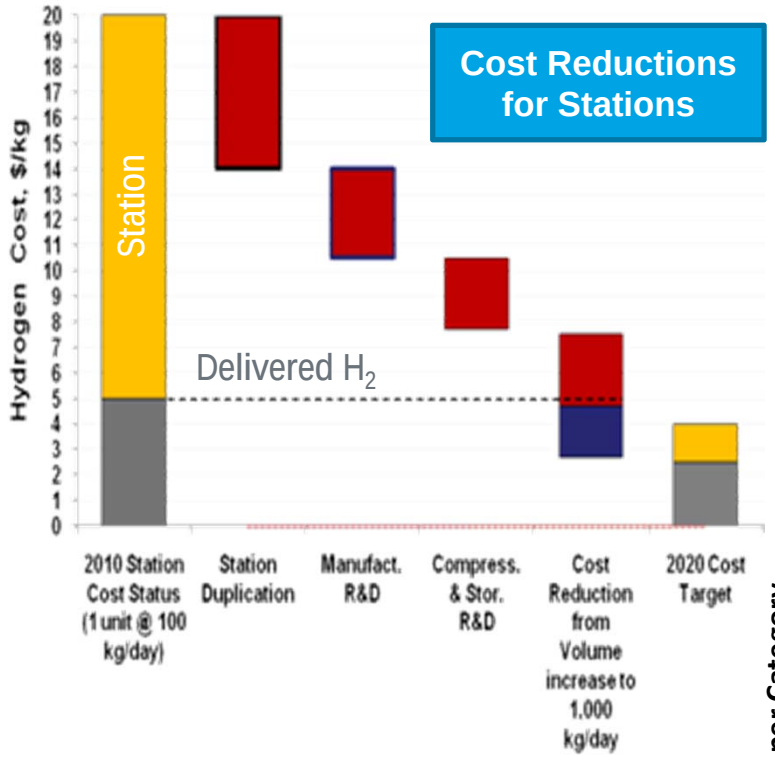
Public Awareness & Acceptance

Hydrogen Supply & Delivery Infrastructure

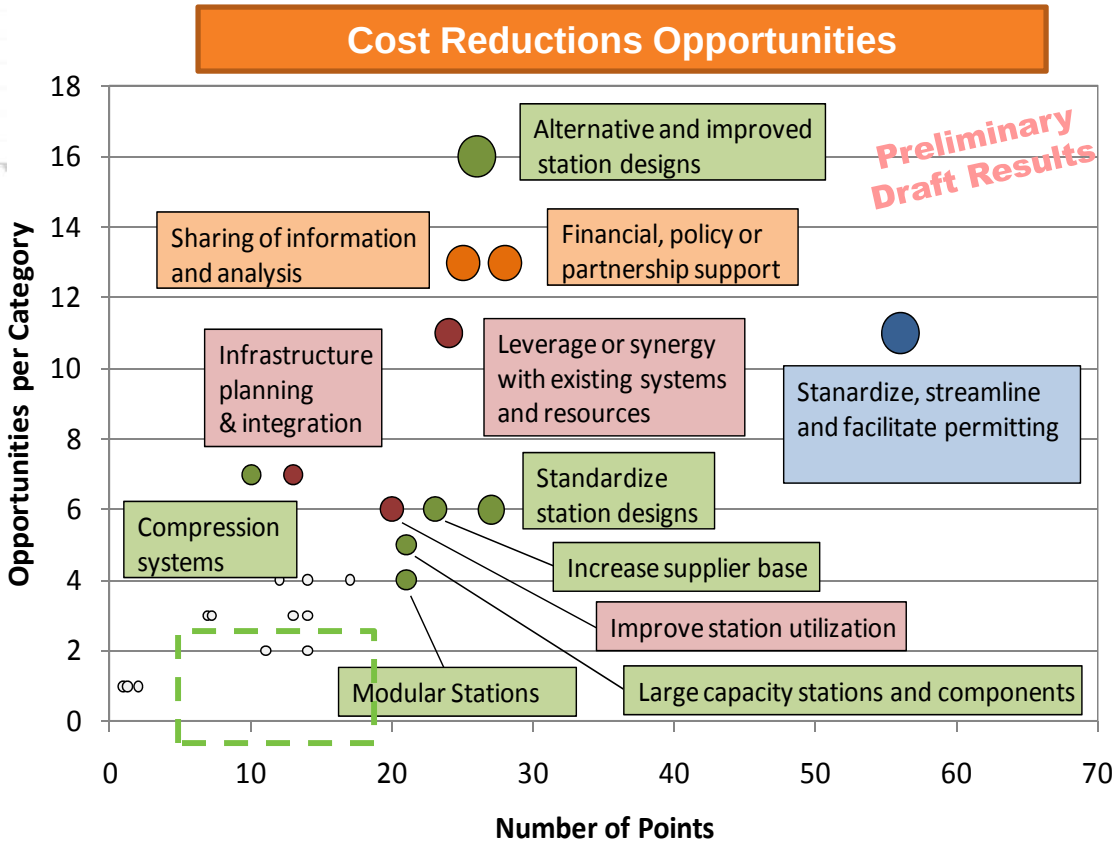
Market Transformation

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

Infrastructure Systems Analysis



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 Scenario 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.

Case Study: Verizon

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

High-reliability CHP system providing primary and back-up power, heating and cooling for a telephone and data service facility.

Location	Verizon Central Office Building Garden City, NY
Date Installed	2005
Equipment	• Seven UTC 200-kW natural gas fired fuel cells • Two absorption chillers, one unfired heat recovery steam generator, natural gas and diesel engines.
Facility	292,000 sq ft.
Energy Savings	$0.5 million for the first five years
Benefits	• 11.1 million pounds of CO_2 offset per year • NO_X emissions reduced by 19 tons per year • 5.5 million gallons of water saved per year
Performance*	• Availability: 88% • Efficiency: Approaching 90%

verizon

Contact: Jeremy Metz, 212-338-6405
Jeremy.metz@verizon.com

Case Study: Tulare Wastewater Treatment Plant

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

Turning Waste into Energy with Biogas-Fueled Molten Carbonate Fuel Cell Systems

Location	Tulare, California
Date Installed	September 2007
Equipment	Three 300 kW FuelCell Energy fuel cells fueled with digester biogas
Use	On-site electricity for wastewater treatment plant and heat for the anaerobic digestion process
Energy Savings	$2,500/day is saved in electricity costs
Benefits	• Estimated one-time cost of $600,000 avoided in Emission Reduction Credits (ERCs) that would have been required for combustion technologies. • Substantially reduced emissions • Reduced reliance on the grid
Performance	• ~69% overall efficiency • ~95% availability

Contact: Lew Nelson, (559) 684-4318
lnelson@ci.tulare.ca.us

Case Study: United States Postal Service

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

Stationary building base load with CHP for hot water

UNITED STATES POSTAL SERVICE

Location	24 hour mail processing facility San Francisco, CA
Date Installed	2005
Equipment	• 250 kW fuel cell • 2 GM HydroGen 3 minivans (2004-2007) • 1 GM Equinox vehicle deployed in 2008
Energy Savings	Approx $100,000 over one year
Benefits	Emissions reductions from decommissioning of one gas-fired boiler.
Performance	Efficiency: 65-70%

Contact: Ray Levinson, 415-405-4886
ray.a.levinson@usps.gov

Case Study: Sierra Nevada

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

Affordable and reliable power for a brewery

Location	State-of-the-art brewing facility Chico, CA
Date Installed	May 2005
Equipment	• Four 250 kW FuelCell Energy fuel cell power plants fueled with digester gas from the brewing process and natural gas
Use	• Provides nearly all of the brewery's power • Waste heat is used for brewing and other heating needs
Benefits	• 20% savings in energy costs • Doubled energy efficiency • Carbon savings equivalent to removing ~500 cars per year from the road • Excess electricity is sold back to the grid

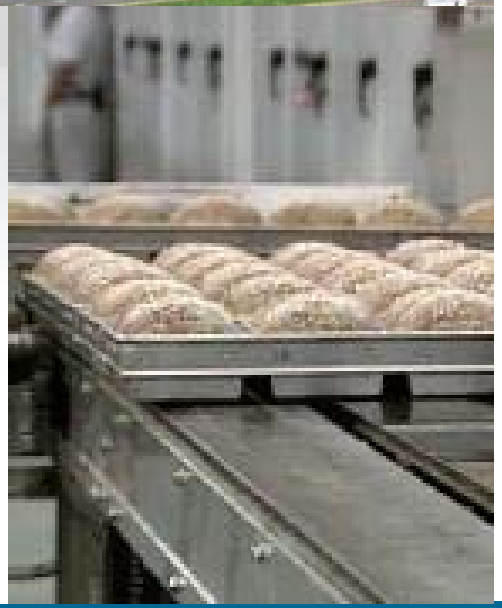
Contact: Frank Wolak.
fwolak@fce.com

Source: FuelCell Energy

Case Study: Pepperidge Farm

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

24/7 electricity and heat for bakery processes



Location	Bakery facility Bloomfield, CT
Dates Installed	2006, 2008
Equipment	• 1.2 MW FuelCell Energy fuel cell power plant (installed 2008) • 250 kW FuelCell Energy fuel cell (installed 2006)
Facility	260,000 sq. ft
Energy Savings	Projected $1 million / year*
Benefits	• Improved reliability • Reduced fuel needs for plant boilers • Reduced CO_2 emissions

Contact: Frank Wolak. *fwolak@fce.com*

*Source: WSFB, Hartford, CN http://www.wfsb.com/news/14053262/detail.html

Case Study: Whole Foods

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

Electricity, back-up power and hot water for a grocery store

Location	Whole Foods Market Glastonbury, CT
Dates Installed	March 2008
Equipment	One 200 kW UTC Power fuel cell
Use	Provides 50% of electricity, nearly 100% of hot water, climate control, refrigeration and emergency back-up power.
Facility	46,000 sq. ft store
Benefits	• Carbon emissions reduced by 90 metric tons/year • NO_X emissions reduced by 2 metric tons/year • Over 4 million gallons of water saved
Performance	• Availability: 95% • Efficiency: up to 90%

WHOLE FOODS MARKET

Contact: Bob Byron, 860-727-2745
Robert.Byron@UTCPower.com

*Source: UTC Power

California – Setting the Standard

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

California's Advanced Clean Cars Program is a "package" of regulations developed to address both air quality needs and climate change, helping California meet aggressive environmental goals.

Zero Emission Mandate

The Zero Emission mandate requires automotive manufacturers to produce a certain number of zero emission vehicles helping to commercialize advanced vehicle technologies.

Key changes to this mandate in 2012 include:

- Compliance flexibility for OEMs until 2017 to prepare for stricter requirements starting in 2018.
- Credit adjustments for FCEVs to appropriately incentivize this longer term technology.

Clean Fuels Outlet

Clean Fuels Outlet regulation requires a certain number of gasoline stations to be equipped to dispense clean alternative fuels.

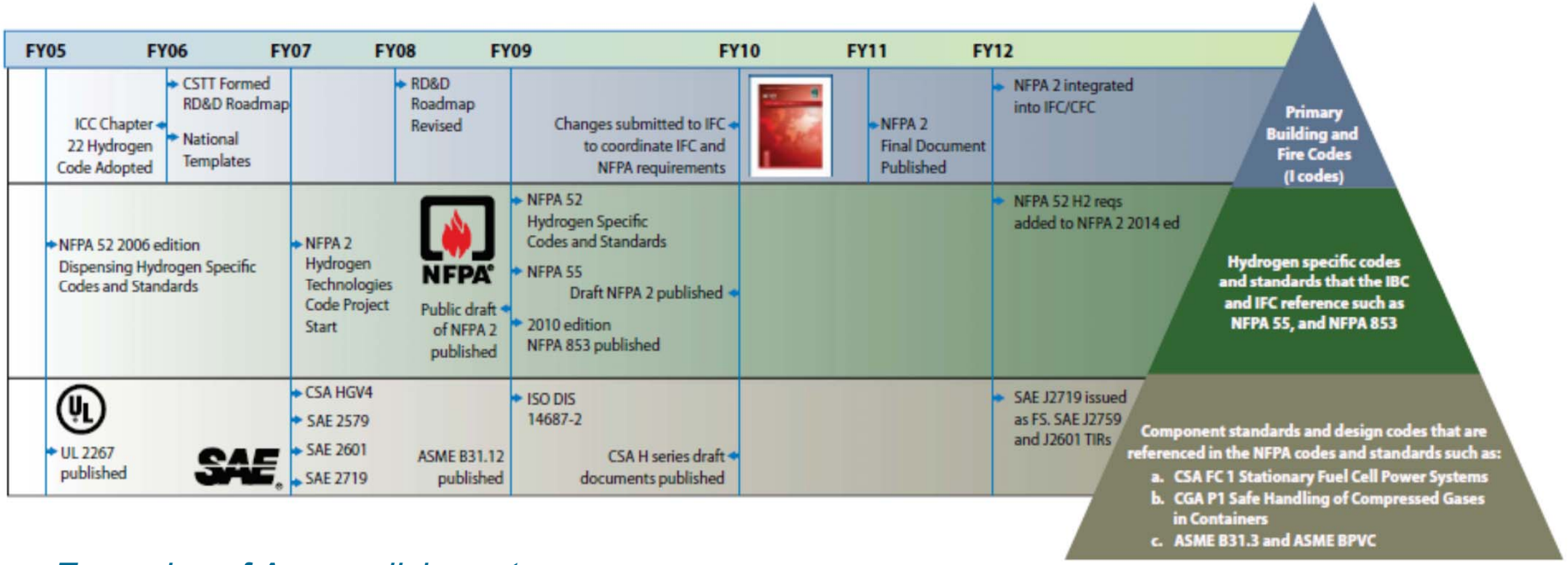
Key changes proposed for this regulation include:

- Defining the party responsible for equipping stations as major refiners/importers of gasoline.
- Adding a lower vehicles trigger of 10,000 vehicles within a region (statewide trigger is 20,000).
- Requirements distribution determined on a market share basis instead of a minimum ownership level.

CA Stations to be Installed by the end of 2012

Station planned throughout CA, with an emphasis in Southern California.

Timeline of Hydrogen Codes and Standards



Examples of Accomplishments:

- Demonstrated cycle-life of >50,000 refuelings of metals tanks for forklift applications
- Provided technical data and incorporated a risk-informed approach that enabled NFPA2 to update bulk gas storage separation distances
- Launched international round robin testing of Type IV tanks
- Implemented a science-based approach to develop an ISO standard for hydrogen fuel quality (standard approved).
- Completed R&D to enable Test Method for Evaluating Materials Compatibility standard.

Developed training material for first responders, code officials.
> 23,000 to-date (online & in-person)

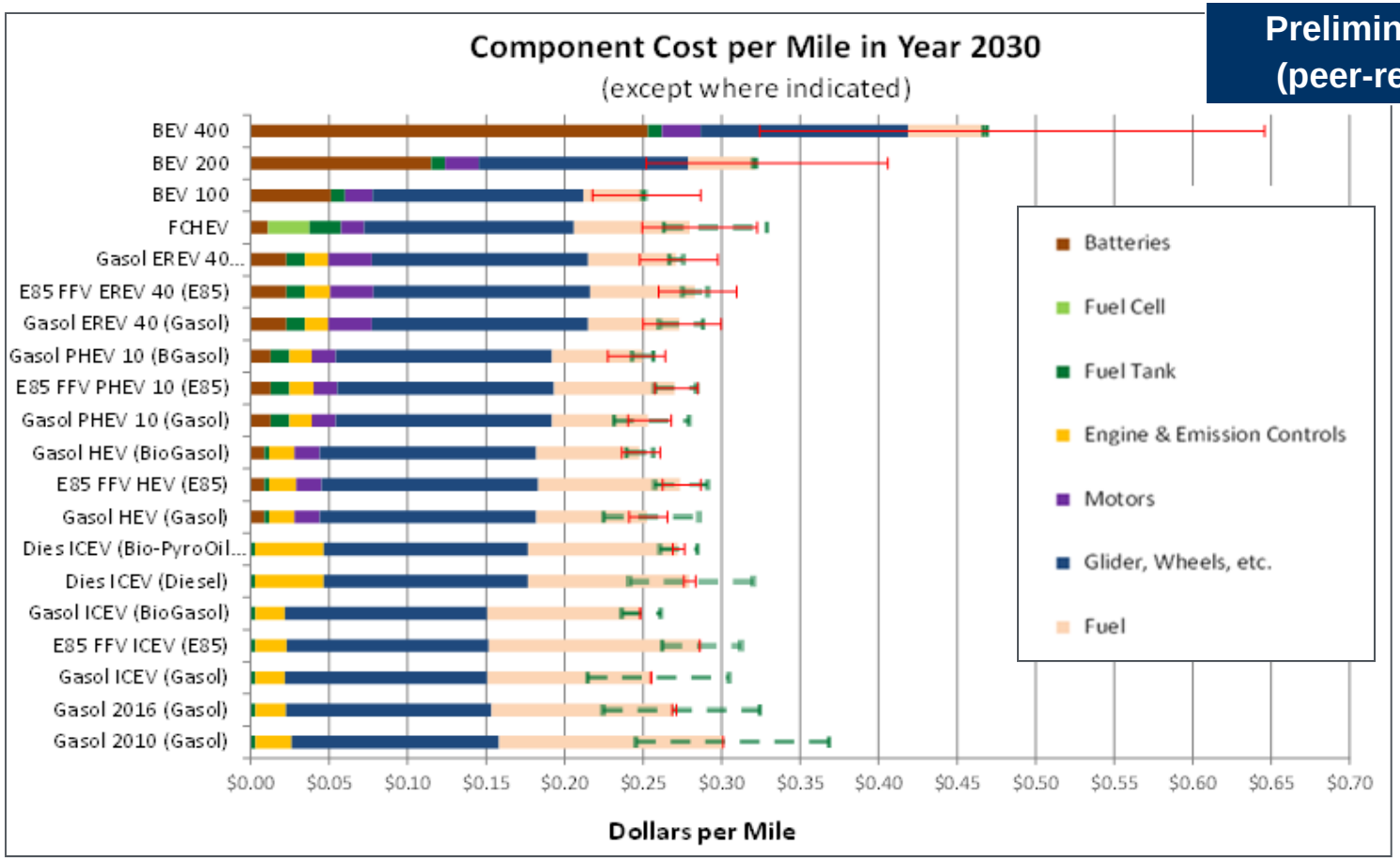
The United States will use the GTR as the technical underpinning for the development of the U.S. Federal Motor Vehicle Safety Standard (FMVSS). Submitted to the U.N. ECE WP29 Dec. 2011, Target Acceptance Dec. 2012

Vehicle Lifecycle Cost Analysis

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

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

Preliminary DOE analysis (peer-review in process)



RFI closes 3/1/2012

'Error bars' reflect range of assumptions:
Green: range of assumptions for fuel prices (EIA projections for fuels other than hydrogen; hydrogen range: $3.50 - $7.50 per kg)
Red: range of assumptions for technology success
See RFI, http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/costs_mile_rfi.pdf, for range of assumptions.

Key Assumptions

	Fuel Cell HEV	BEV100 100-mile BEV	BEV200 200-mile BEV	BEV400 400-mile BEV
Battery Cost, $/kWh	$600, $800, $1000		$125, $220, $300	
Fuel Cell Cost, $/kW	$25, $30, $40	--	--	--
Fuel Cost in $/gge (¢/kWh)	$3.50, $4.50, $7.50	$3.44 (10.3¢/kWh); $3.54 (10.6¢/kWh); $3.61 (10.8¢/kWh)		

Natural Gas and Hydrogen Infrastructure Opportunities

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

Workshop convened industry (including vehicle OEMs) and stakeholders with expertise in natural gas and hydrogen technologies, CHP, policy, and regulations. The focus of the workshop was to facilitate the growth of natural gas and hydrogen use in the U.S. for transportation and other applications.

Workshop Activities Included:

- Discussion led by plenary speakers and expert panels
- Break-out sessions to identify key questions and resolutions on:
  - R&D Needs
  - Regulatory / Environmental Barriers
  - Innovative Approaches

U.S. DEPARTMENT OF ENERGY

Argonne NATIONAL LABORATORY

Outcomes:

- Summarized the status of natural gas and hydrogen infrastructure
- Identified opportunities and barriers for expanding the infrastructure
- Identified synergies between natural gas and H_2 use
- Identified and prioritize specific actions to address barriers
- Identified the roles of government and industry in promoting growth of natural gas and H_2 infrastructure

Organized by the Argonne National Laboratory for the U.S. Department of Energy
see: http://www1.eere.energy.gov/hydrogenandfuelcells/wkshp_proceedings.html

Hawaii's Hydrogen Initiative (H_2I)

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

A public/ private effort that seeks to be a major component of the solution to Hawaii's energy challenges

- **Letter of Understanding signed on Dec 8, 2010 by DOE and DOD, among others**
  - State of Hawaii, the Hawaii Gas Company, University of Hawaii, General Motors, Fuel Cell Energy, and others
- **Mission is to fill a strategic role that supports Hawaii's transformation to a clean energy economy**
- **Part of a portfolio approach of technologies and fuels for reducing emissions and petroleum use**
  - Supports the deployment of fuel cell vehicles to Hawaii as a means of reducing petroleum consumption as well as green house gas emissions
  - Takes advantage of the existing gas pipelines to deliver hydrogen for dispensing hydrogen to fuel cell vehicles

HAWAIIGAS

FuelCell Energy
Ultra-Clean, Efficient, Reliable Power

NREL

DOE - DOD Collaborations

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

Extensive coordination and collaboration have allowed the Program to successfully deploy fuel cells at 30 DOD sites. Efforts continue in promising new areas. Key focus will be to increase Federal deployments.

Coordination

- Interagency Task Force
- Interagency Action Plan
- Interagency Working Group
- Workshops
  - Aviation APUs
  - Waste-to-Energy
  - Shipboard APUs
- Hawaii Hydrogen Initiative (H2I)

Army CERL - Backup power deployments

- U.S Army Aberdeen Proving Ground, MD
- Fort Bragg, NC
- Fort Hood, TX
- National Guard, OH
- Picatinny Arsenal, NJ
- Ames Research Ctr, CA
- USMC AGGC 29 Palms, CA
- U.S. Military Academy West Point, NY
- U.S. Air Force Cheyenne Mountain Air Station

- Defense Logistics Agency
  - Nearly 100 FC lift trucks deployed
- Office of Naval Research
  - Utility scale renewable hydrogen generation and grid management for transportation fuel
- Army/Marine Corps
  - Soldier power: battery rechargers for forward operation bases
- Navy, Army, Air Force
  - Deploy fuel cell vehicles and infrastructure at bases in Hawaii.
- Army/AF (Joint Base Lewis McCord)
  - Biogas reforming and material handling equipment.

World Class Researchers - Examples

Radoslav Adzic honored as Brookhaven National Lab **Inventor of the Year** for his work on fuel cell catalysis

The International Energy Agency Hydrogen Implementing Agreement :

•**Jim Ohi - (retired NREL),** honored for R&D, technical excellence and advancing international cooperation that contributes to the understanding and advancement of hydrogen science.

3 Presidential Awardees:

• **Professor Susan Kauzlarich** – UC Davis, a 2009 recipient of the ***Presidential Award for Excellence in Science, Mathematics and Engineering Mentoring***—and a partner of the Chemical Hydrogen Storage Center of Excellence

• **Dr. Jason Graetz** – Brookhaven National Laboratory, a 2009 recipient of the ***Presidential Early Career Award for Scientists and Engineers***—and a partner of the Metal Hydride Center of Excellence

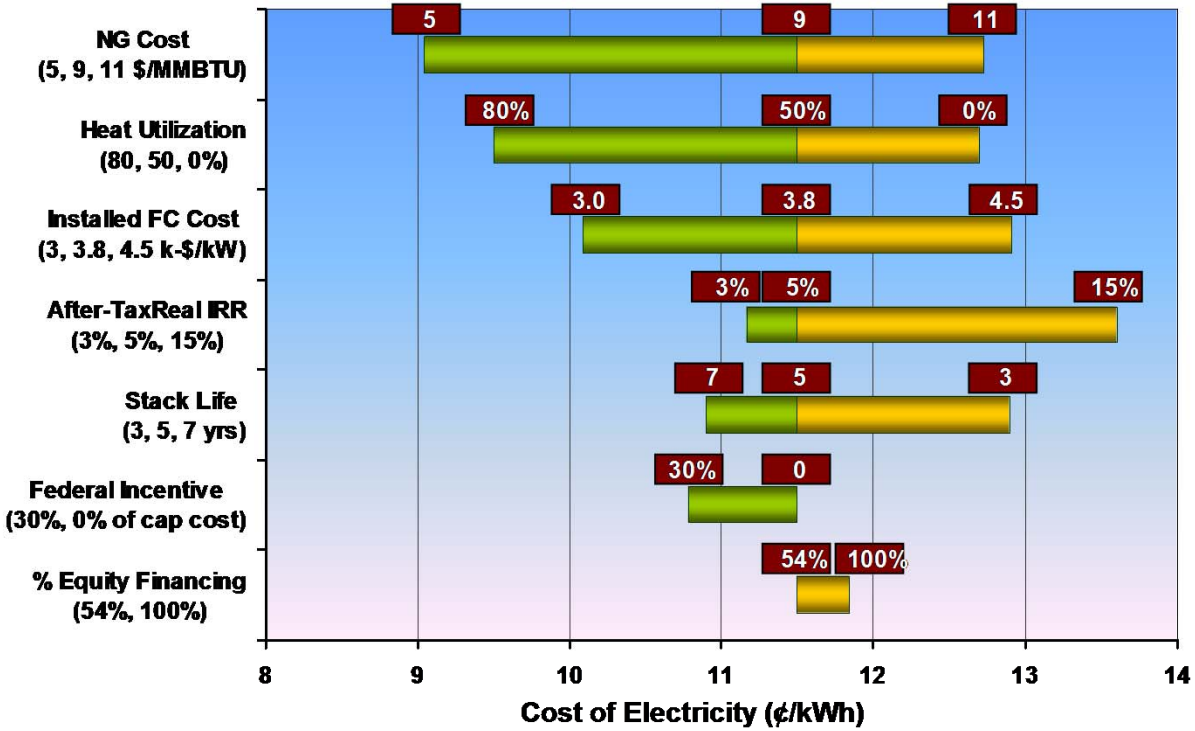
• **Dr. Craig Brown** – NIST, a 2009 recipient of the ***Presidential Early Career Award for Scientists and Engineers***—and a Partner of the Hydrogen Sorption Center of Excellence

Stationary Fuel Cells – Cost analysis

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

Analysis efforts are underway, to provide information on potential costs and benefits of a variety of stationary fuel cell applications.

Example: Cost of Electricity from Commercial-Scale Stationary Fuel Cell



Performance Parameters

System Electric Efficiency	= 45% (LHV Basis)
System Total Efficiency	= 77% (LHV Basis)
System Size	= 1,400 kW
System Life	= 20 years
Capital cost	= $3.5 million
Installed cost	= $5.3 million

Financial Assumptions

Startup year	= 2010
Financing	= 54% equity
Interest rate	= 7%
Financing period	= 20 years
After-tax Real IRR	= 5%
Inflation rate	= 1.9%
Total tax rates	= 38.9%
Depreciation schedule	= 7 years (MACRS)
Payback period	= 11 years

Stack replacement cost distributed annually

Operation Assumptions

System utilization factor	= 95%
Restacking cost	= 30% of installed cap. cost
Heat value	= cost of displaced natural gas from 80% efficient device

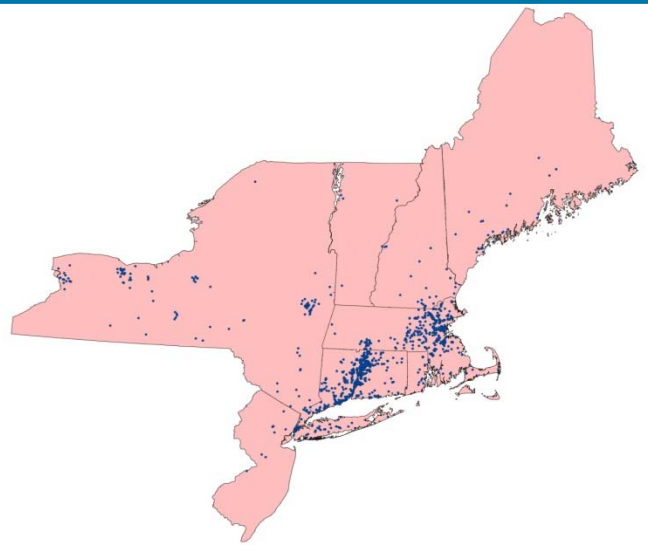
Source: NREL Fuel Cell Power Model

Example for MCFC 1.4 MW

Northeast Hydrogen Fuel Cell Cluster

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

Hydrogen and Fuel Cell Supply Chain



Economic Impact Summary

	CT	NY	MA	ME	NH	RI	VT	NJ	Regional
Total Employment	2,529	1,728	964	18	45	32	16	111	**5,443**
Total Revenue / Investment in 2010 ($ million)	$496	$292	$171	$2.9	$8.7	$6.9	$3.3	$26.5	**$1,009**
Total Supply Chain Companies	599	183	322	28	25	19	5	8	**1189**

Targets: Criteria for Selection

Primary Criteria

- High electric and thermal demand
- Fuel availability
- Energy reliability

Secondary Criteria

- Economic development
- Transportation Opportunities
- Environmental enhancement
- Educational value
- Military applications
- Community support

The Connecticut Center for Advance Technology, Inc.

Targets: Assessment Summary

Stationary Sites

Description	#
Education	2,190
Food Sales	1,201
Food Services	387
Inpatient Healthcare	422
Lodging	884
Public Order and Safety	313
Energy Intensive Industries	429
Government Operated Buildings	90
Telecommunication Towers	397
Wastewater Treatment Plants	16
Landfills	14
Airports (w/"Joint-Use")	50 (20)
Military	19
Total	**6,426**

Transportation Sites

Description	#
Current Gasoline Stations	15,701
Alternative Fueling Stations	400
DOT Owned Sites	391
Distribution Center/ Warehouses	225
Ports	128
Total	16,845

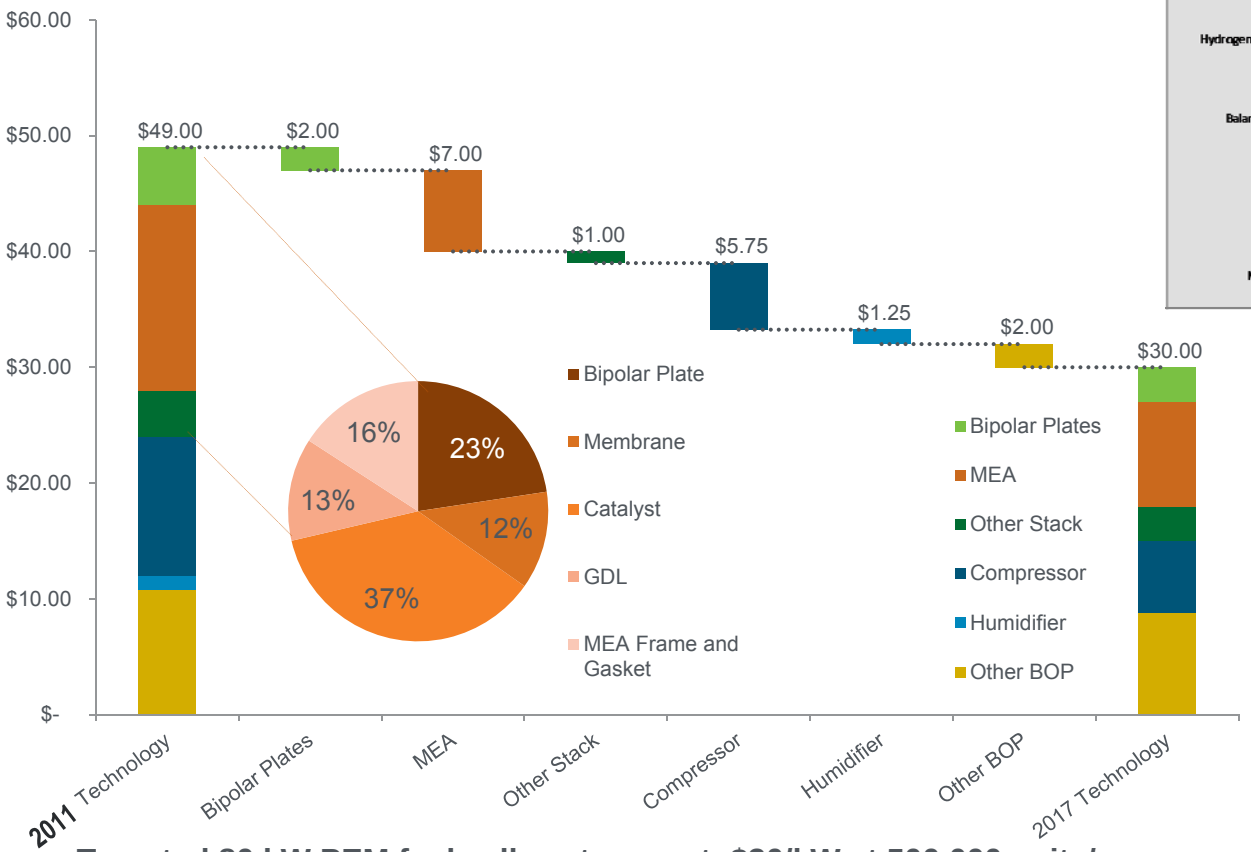
Transportation Vehicles

Description	#
State Registered Fleet Vehicles	58,319
Federally Owned Passenger Cars	22,258
Federally Owned Trucks/Vans	27,529
Transit Buses	14,721
Total	122,827

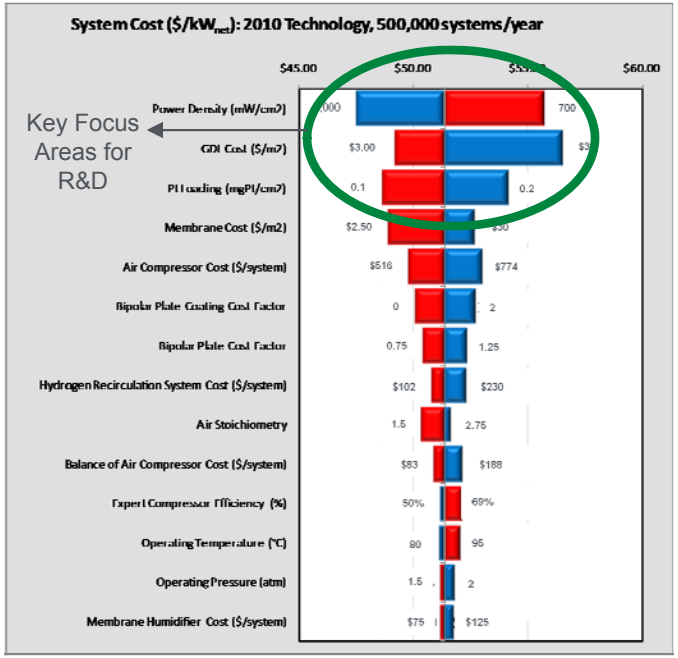
Current Portfolio Addresses High-Impact Areas

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

Strategic technical analysis guides focus areas and priorities for budget.
Need to reduce cost from $49/kW to $30/kW and increase durability from 2,500-hr to 5,000-hr.



Targeted 80 kW PEM fuel cell system cost: $30/kW at 500,000 units/yr



Sensitivity Analysis helps guide R&D

Strategies to Address Challenges – Catalyst Examples

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

H_2 Production & Delivery Cost Status

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

Significant progress has been made toward achieving hydrogen cost goals—*the cost at which hydrogen fuel cell electric vehicles are projected to become competitive on a cost-per-mile basis with competing vehicles (gasoline hybrid-electric vehicles) in 2020.*

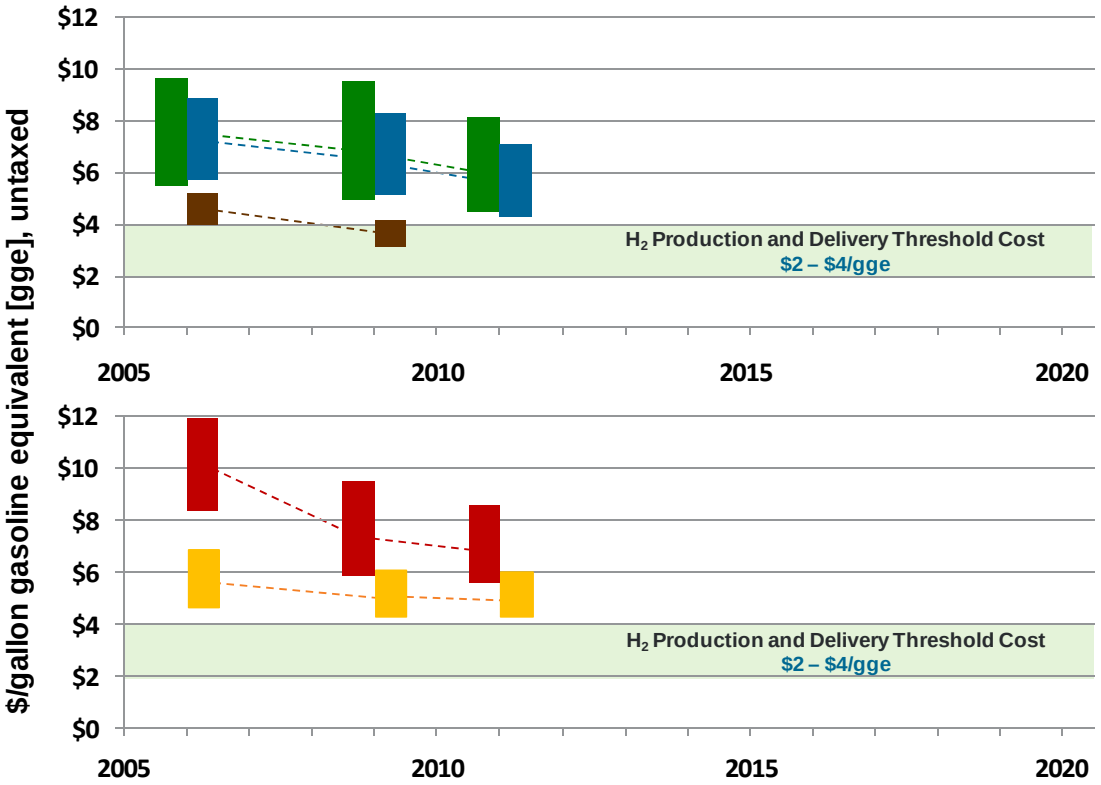
Projected High-Volume Cost of Hydrogen[i] —Status

Distributed Production (near-term)

- **Electrolysis**
  Feedstock variability: $0.03 – $0.08 per kWh
- **Bio-Derived Liquids**
  Feedstock variability: $1 – $3 per gallon ethanol
- **Natural Gas Reforming[ii]**
  Feedstock variability: $4 – $10 per MMBtu

Central Production (longer-term)

- **Electrolysis**
  Feedstock variability: $0.03 – $0.08 per kWh
- **Biomass Gasification**
  Feedstock variability: $40 – $120 per dry short ton

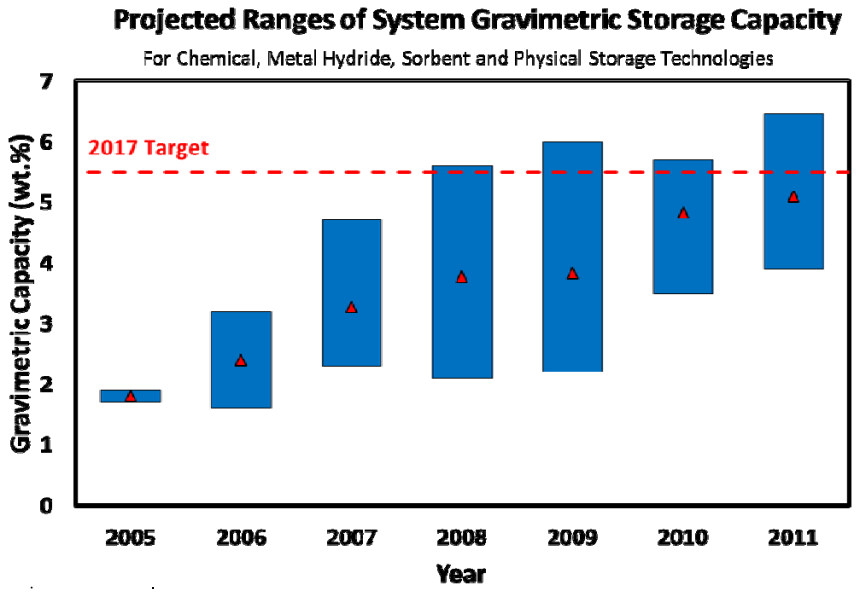


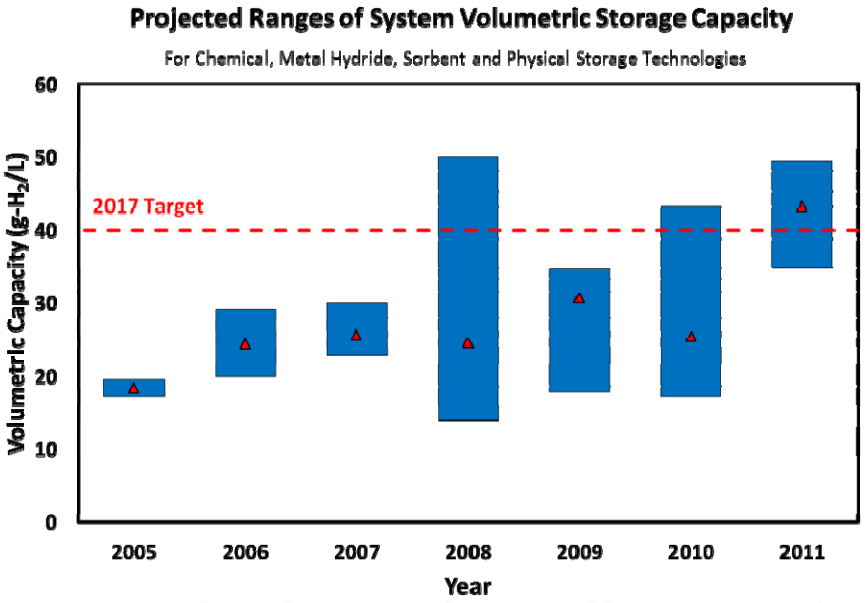
Notes:

(i) *Costs shown include all delivery and dispensing costs, but do not include taxes. A cost of $1.80 for forecourt compression, storage, and dispensing is included for distributed technologies, and $2.60 is included as the total cost of delivery (including transportation, compression, storage, and dispensing) for centralized technologies. All delivery costs are based on the Hydrogen Pathways Technical Report (NREL, 2009). Projections of distributed costs assume station capacities of 1,500 kg/day, with 500 stations built per year. Projections of centralized production costs assume capacities of ≥50,000 kg/day. Cost ranges for each pathway are shown in 2007 dollars, based on high-volume projections from H2A analyses, reflecting variability in major feedstock pricing and a bounded range for capital cost estimates.*

(ii) *DOE funding of natural gas reforming projects was completed in 2009 due to achievement of the threshold cost, based on projections to high-volume production. Incremental improvements will continue to be made by industry.*

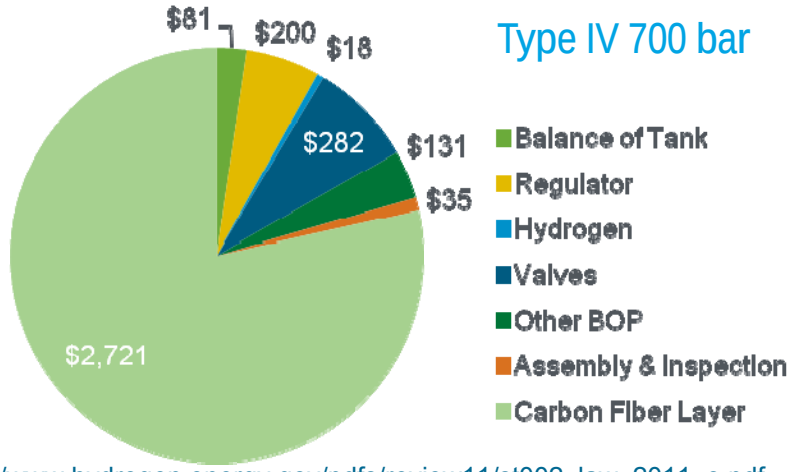
Projected Capacities for Complete 5.6-kg H_2 Storage Systems





- Compressed H_2 tanks can achieve >250 mile range
- Validated a vehicle that can achieve 430 mile range (with 700 bar Type IV tanks)
- Developed and evaluated more than 400 material approaches experimentally and millions computationally

Costs in the Carbon-Fiber Matrix



http://www.hydrogen.energy.gov/pdfs/review11/st002_law_2011_o.pdf

Fuel Cells Offer High Value Proposition to Food Industry

Fuel cells can provide energy for multiple uses in a grocery store including both power and thermal energy needs.

A 400-kW fuel cell (grey box) meets 85 percent of the energy needs of this Price Chopper supermarket in Albany, NY. The installation reduces the building's carbon footprint by 71 tons, provides energy security for perishable items, and saves more than 4 million gallons of water each year. *(Photo taken from the Executive Summary of the New York State Climate Action Plan Interim Report)*