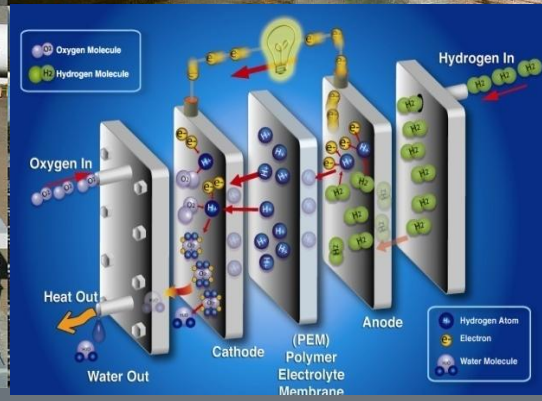
# Fuel Cell Technologies Overview

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

# Background:
## Potential of Fuel Cell Technology

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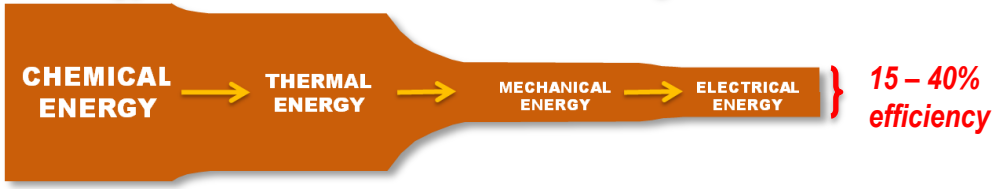
***Fuel cells convert chemical energy directly to electrical energy — with very high efficiency — and without criteria pollutant emissions.***

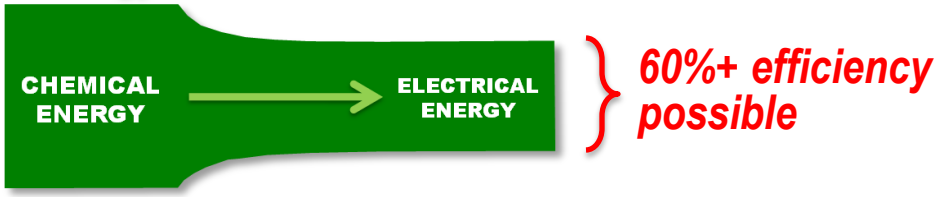
**Combustion Engines** — convert chemical energy into thermal energy and mechanical energy, and then into electrical energy.

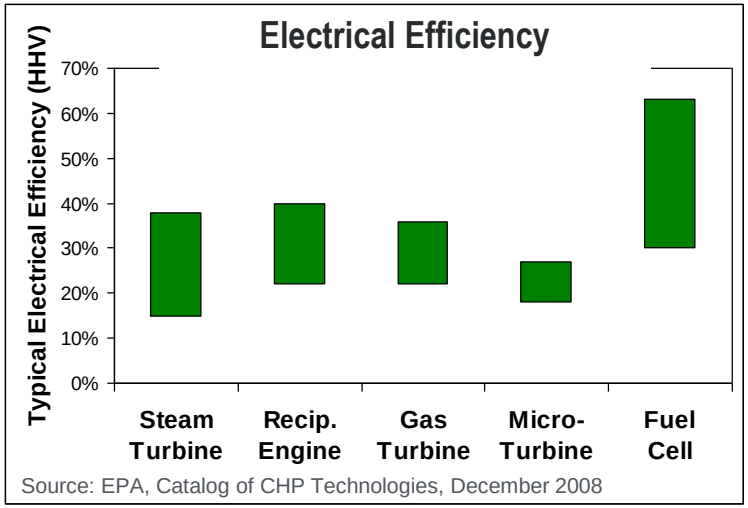
**Fuel cells —** convert chemical energy directly into electrical energy, bypassing inefficiencies associated with thermal energy conversion. Available energy is equal to the Gibbs free energy.

*Energy Conversion in Combustion Engines*

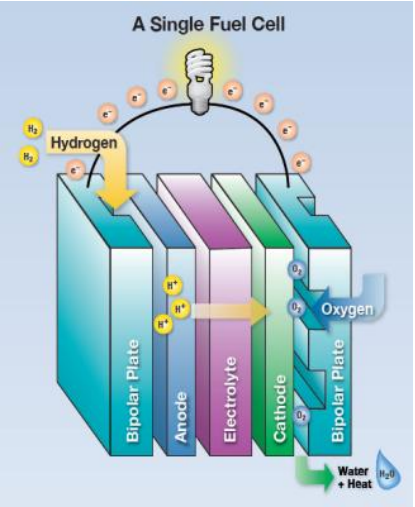



*Energy Conversion Fuel Cells*

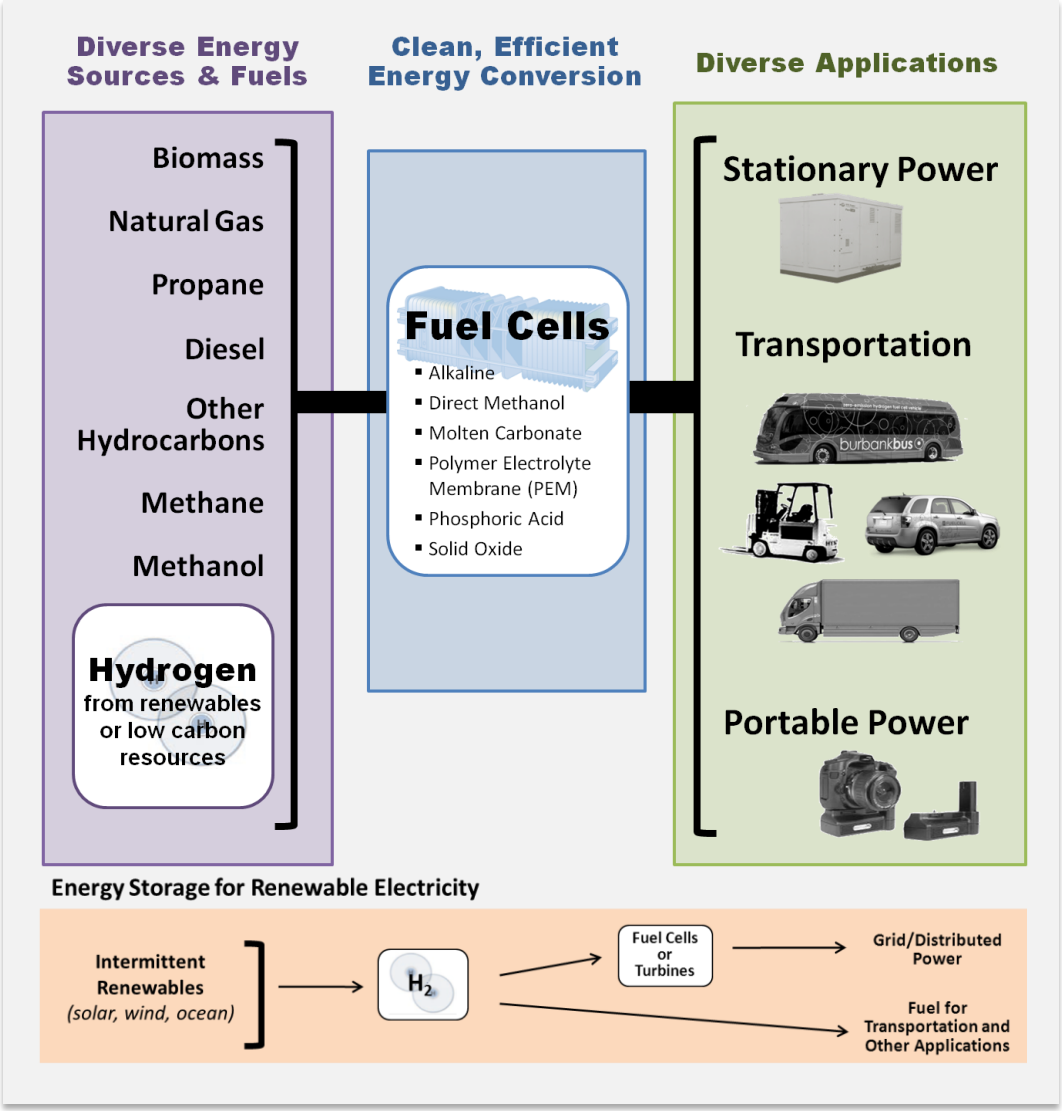



Fuel cells convert chemical energy directly into electrical energy, bypassing inefficiencies associated with thermal energy conversion



## The Role of Fuel Cells




## Key Benefits

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

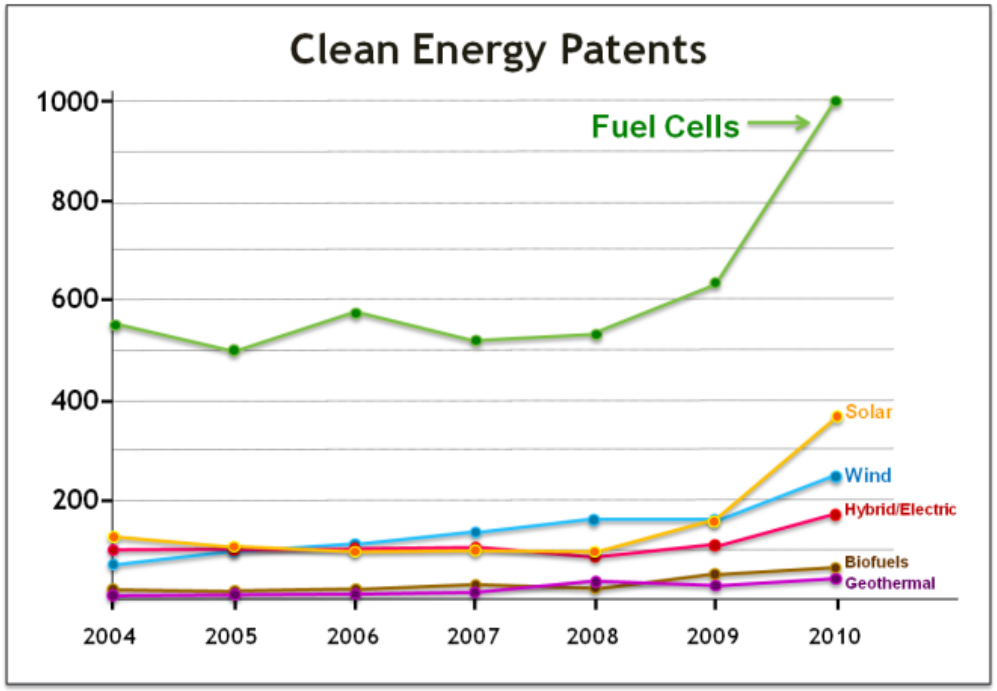
**Reduced $CO_2$ Emissions**
- **35–50%+ reductions** *for CHP systems (>80% with biogas)*
- **55–90% reductions** *for light-duty vehicles*

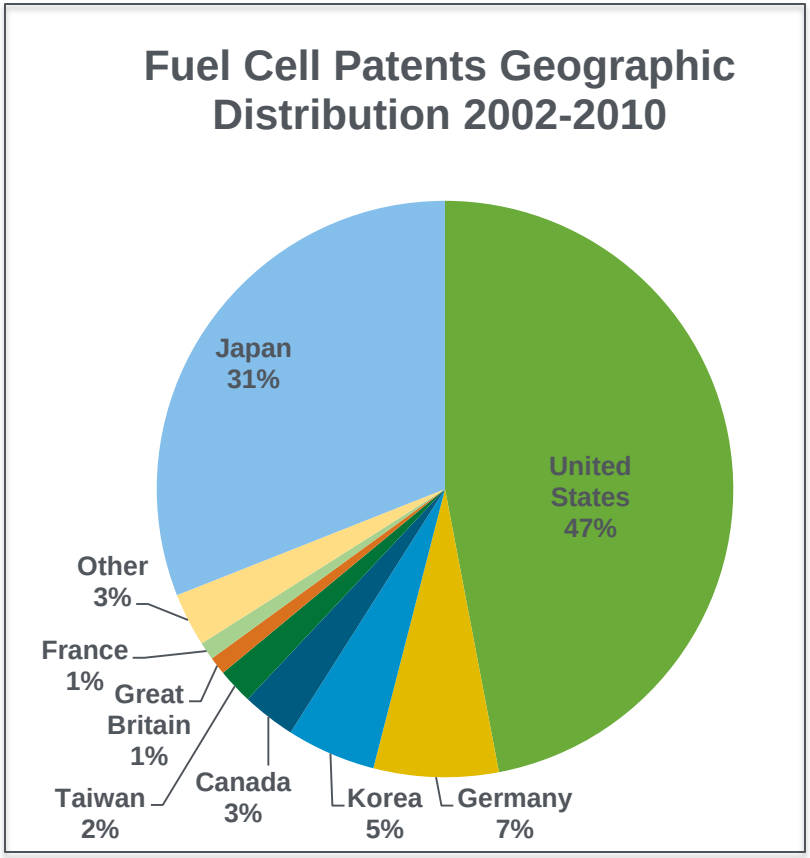
**Reduced Oil Use**
- **>95% reduction** *for FCEVs (vs. today's gasoline ICEVs)*
- **>80% reduction** *for FCEVs (vs. advanced PHEVs)*

**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*

# Overview
# 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*

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***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

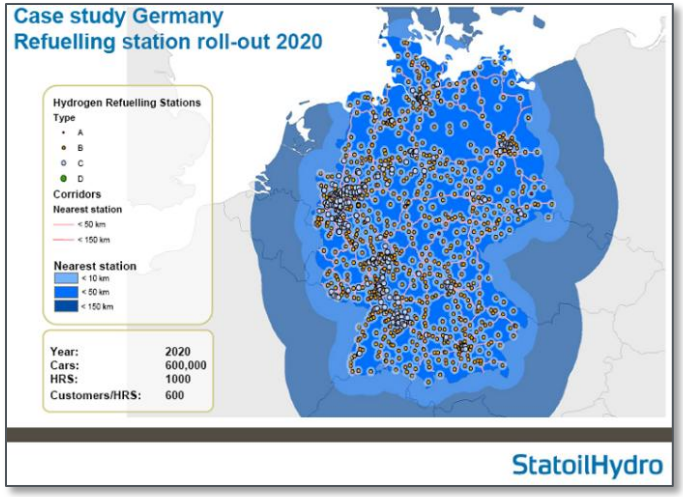
**European Union:** >$1.2 Billion in funding ('08–'13)

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

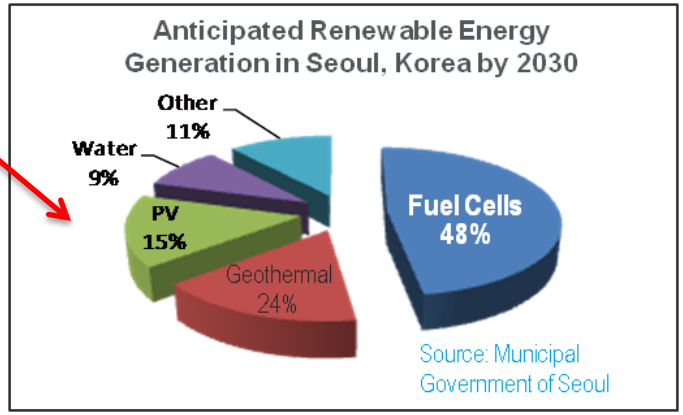
**China:** Thousands of small units deployed; 70 FCEVs, buses, 100 FC shuttles at World Expo and Olympics

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

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***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

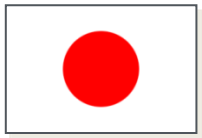
**Ford**
- Alan Mulally, CEO, sees 2015 as the date that fuel cell cars will go on sale.

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

Based on publicly available information during 2011

**$H_2$Mobility - 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.

**UK$H_2$Mobility 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

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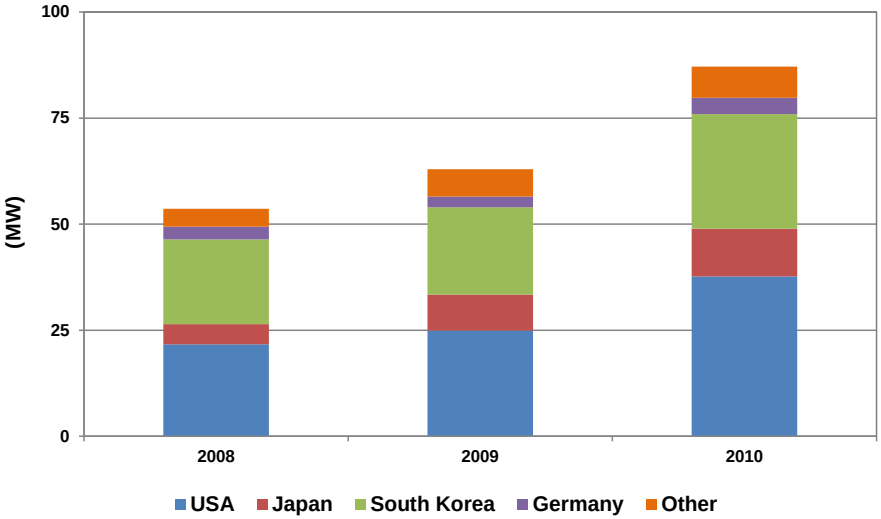
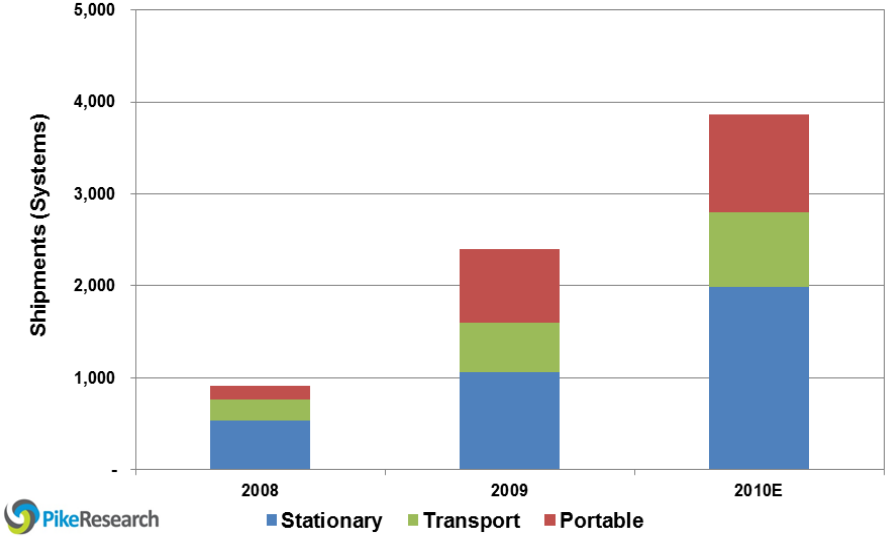
## Megawatts Shipped, Key Countries: 2008-2010




## North American Shipments by Application




PikeResearch

**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

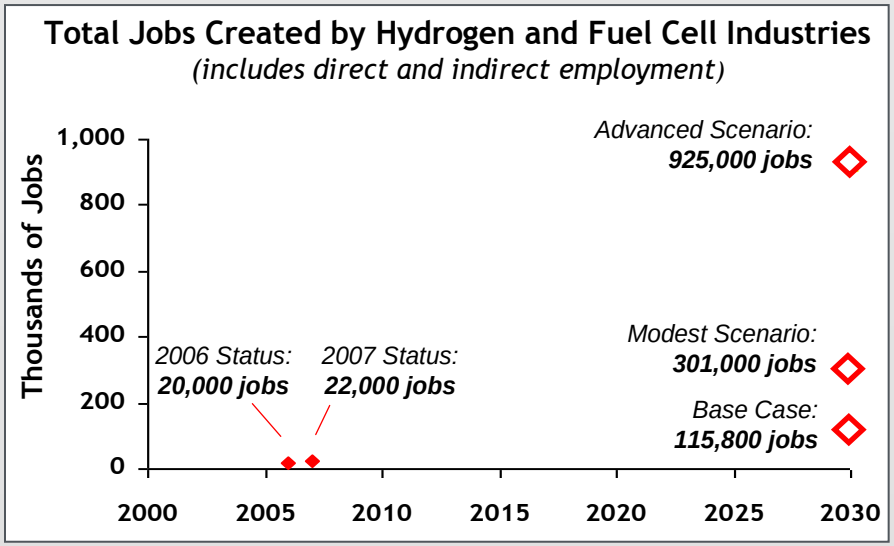
# Fuel Cells - *The Economic Potential*

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*

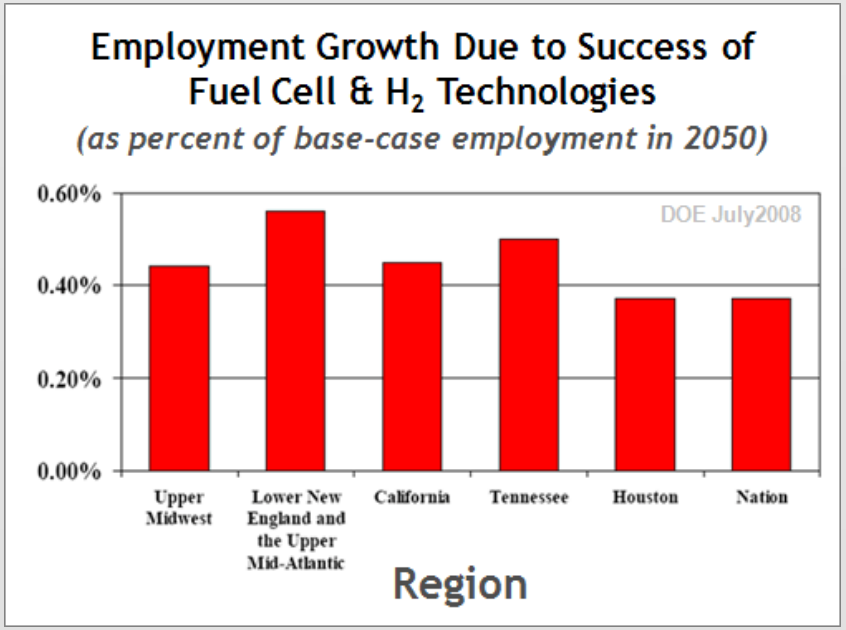
- **Fuel cells are the third-fastest growing renewable energy industry** (after biomass & solar).
- Potential U.S. employment from fuel cell and hydrogen industries of **up to 925,000 jobs** (by 2030).
- Potential gross revenues up to **$81 Billion/year** (by 2030).




*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

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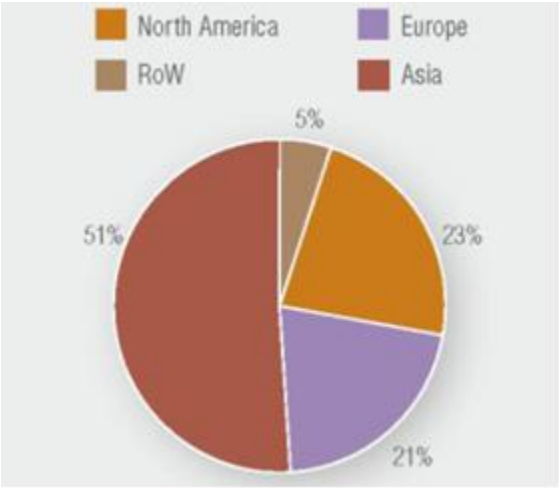
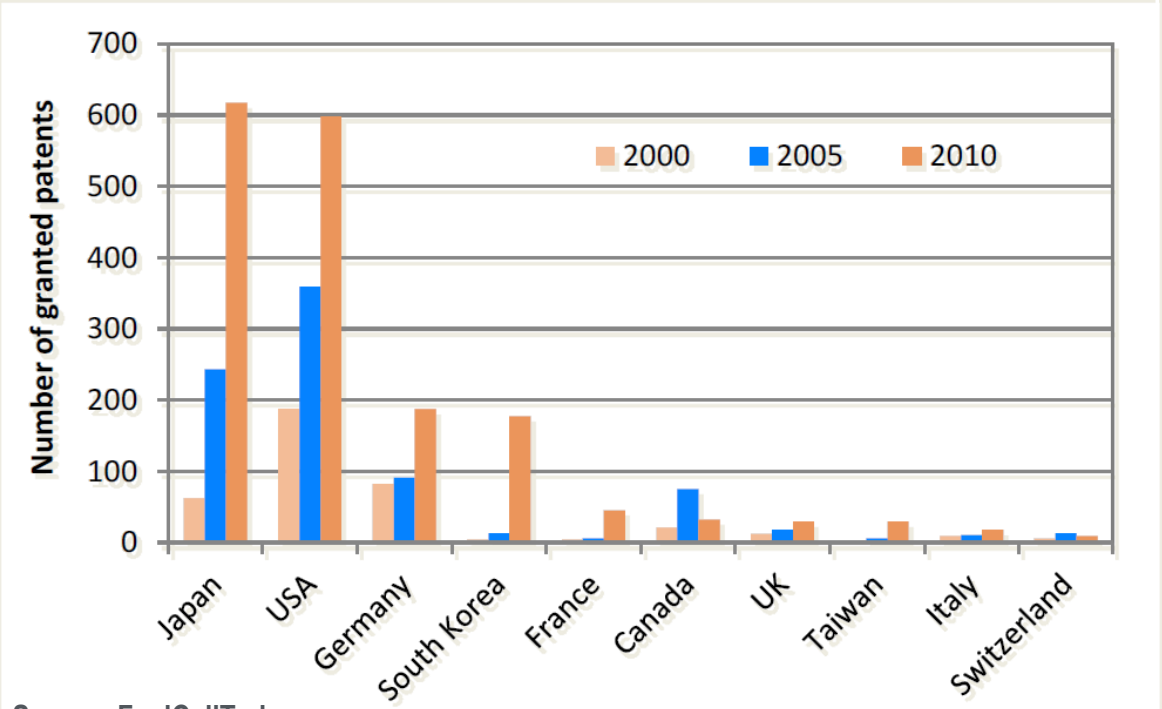
**Significant growth in number of patents filed by Japan, Korea, Germany, U.S.**
**Job creation projections show significant growth in Asia and Europe.**

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

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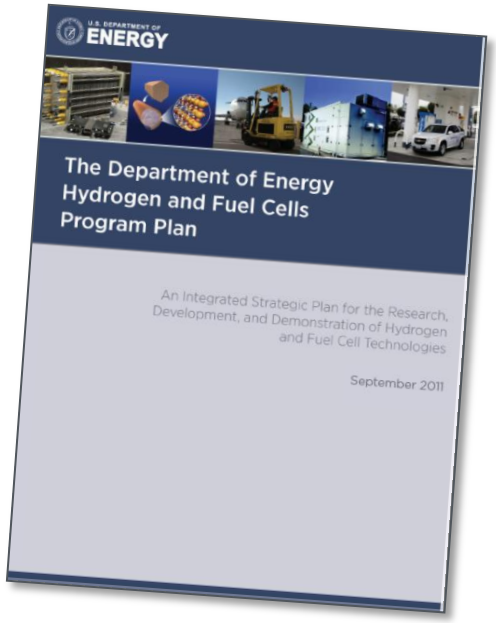
**The mission of the Hydrogen and Fuel Cells Program is to enable the widespread commercialization of hydrogen and fuel cell technologies through:**

- **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)*



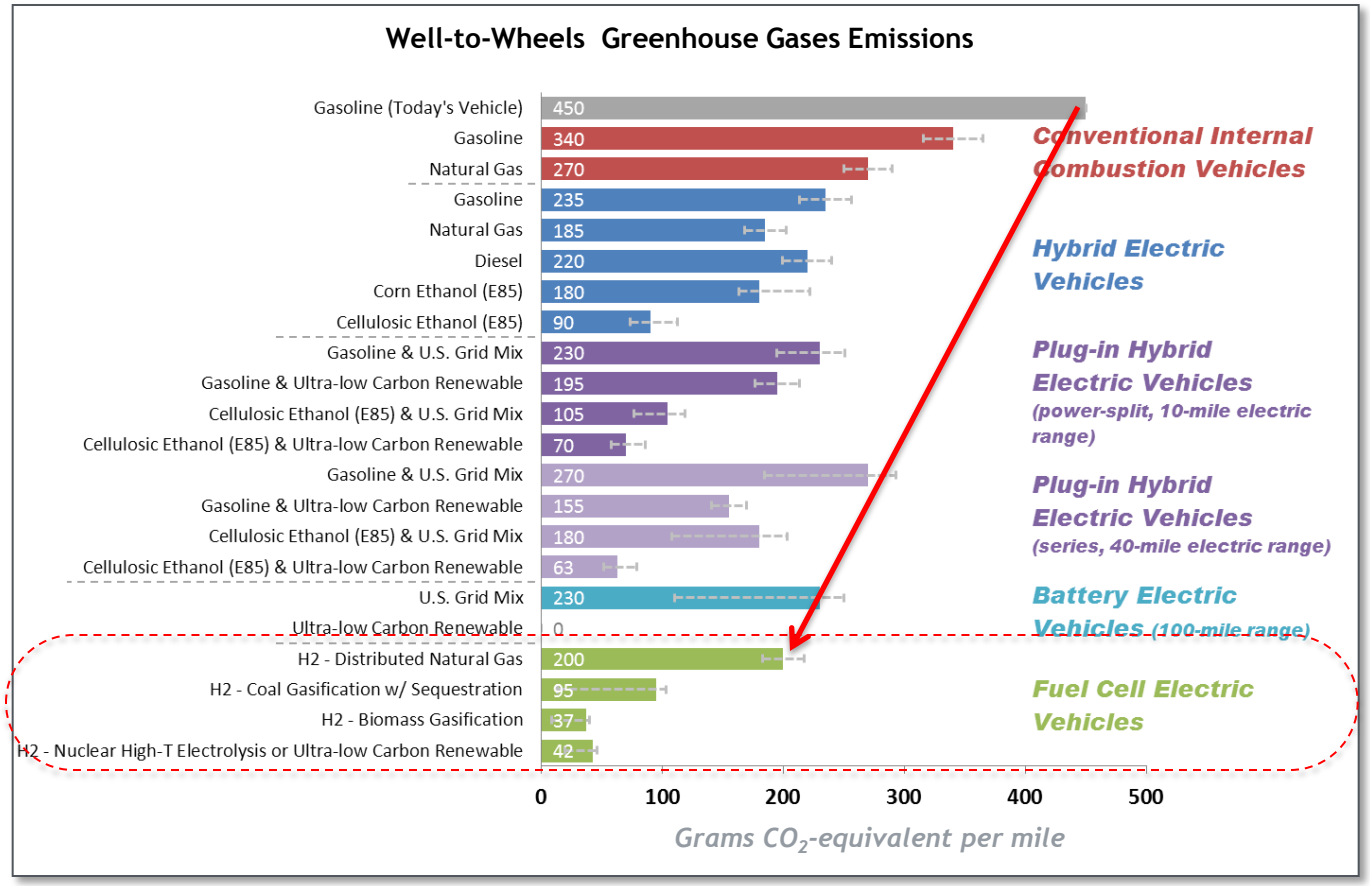

***An integrated strategic plan for the research, development, and demonstration activities of DOE's Hydrogen and Fuel Cells Program***

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.**

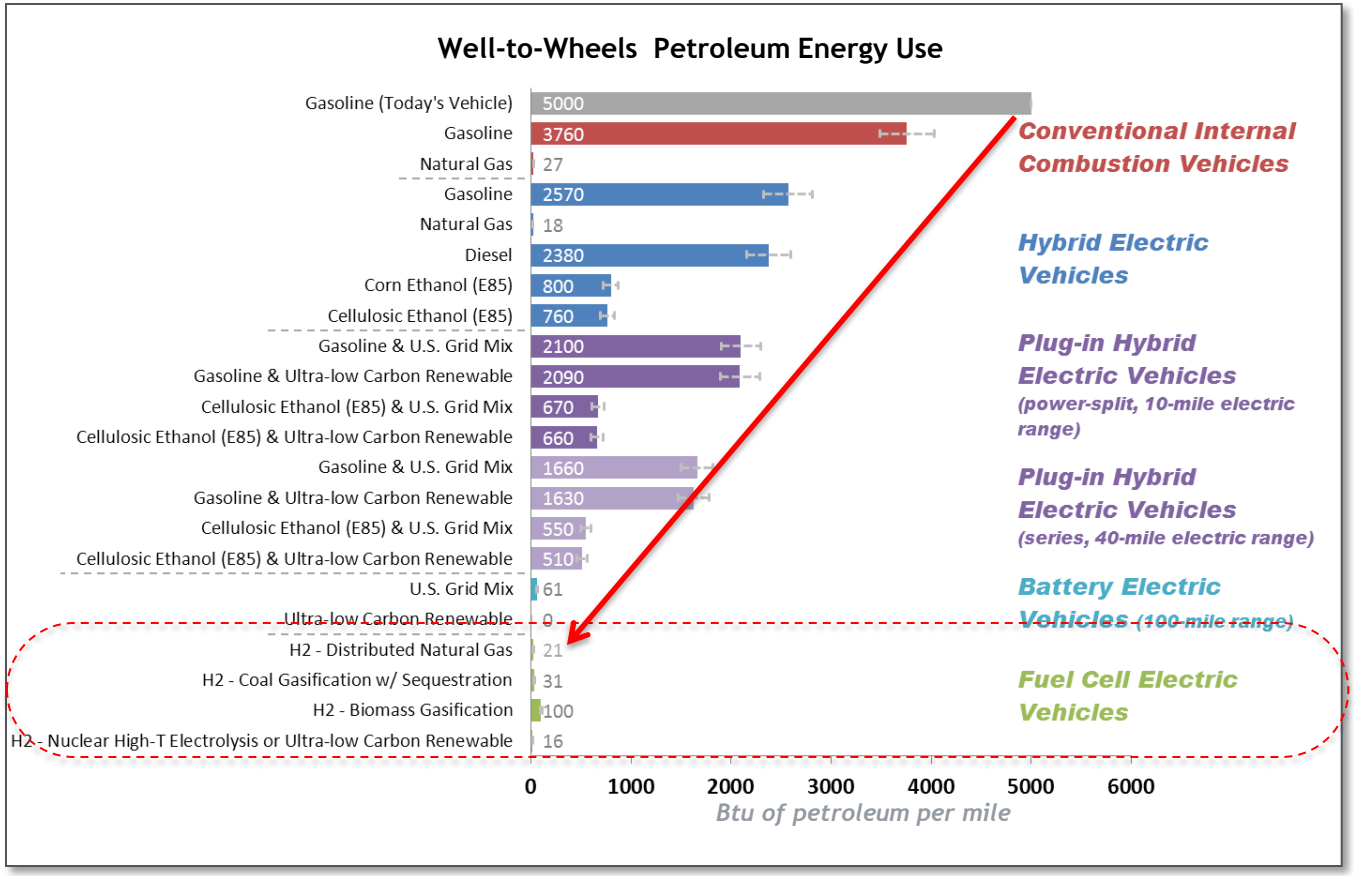
***Even greater emissions reductions are possible as hydrogen from renewables enter the market.***

**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.*

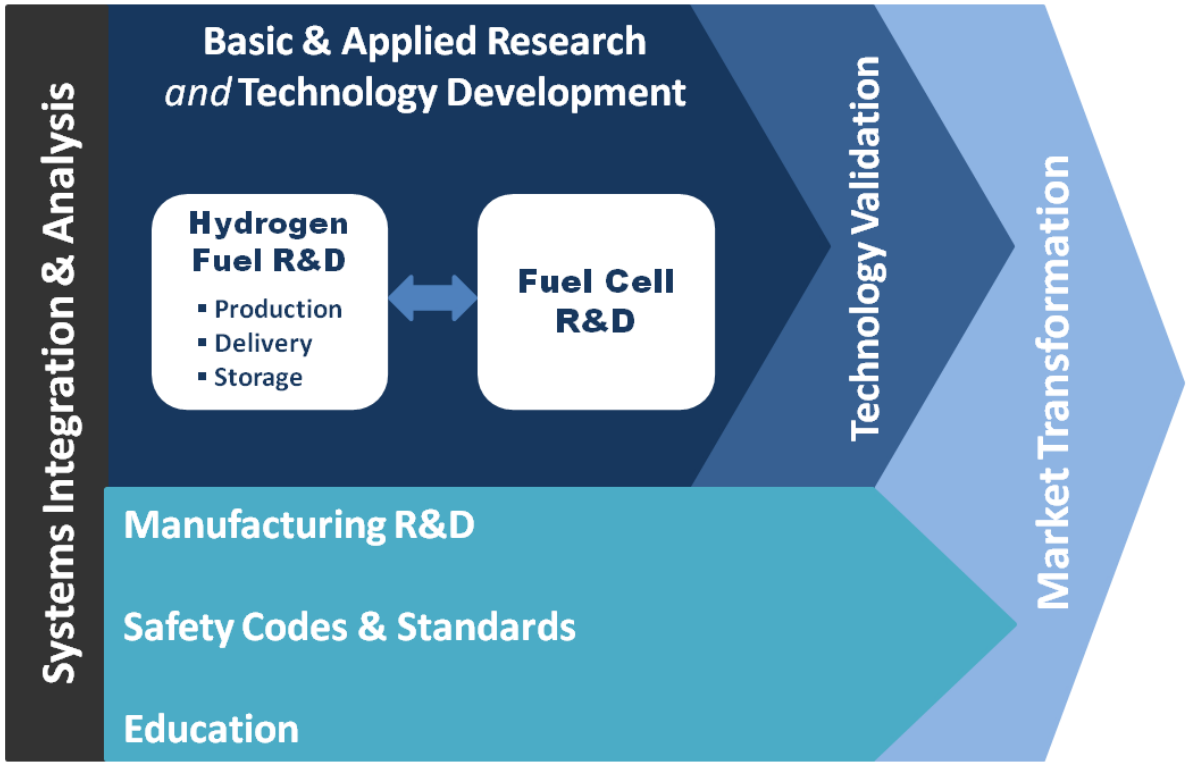



### $H_2$ from Natural Gas

***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




**WIDESPREAD COMMERCIALIZATION ACROSS ALL SECTORS**

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

***Nearly 300 projects currently funded at companies, national labs, and universities/institutes***

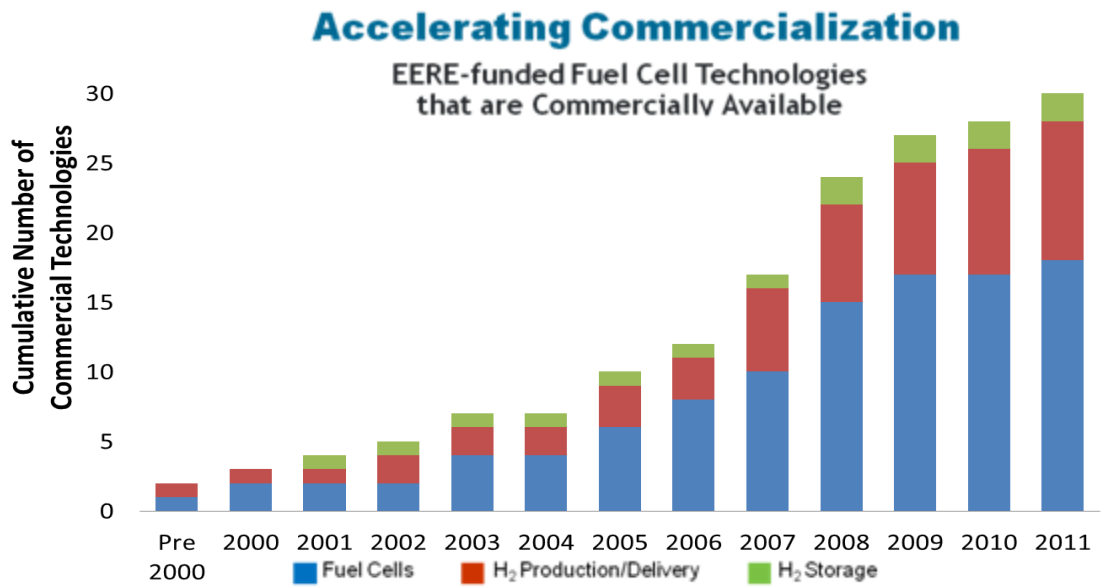
***FY12 EERE $H_2$ and Fuel Cells Budget: $104M***

# Assessing the Impact of DOE Funding

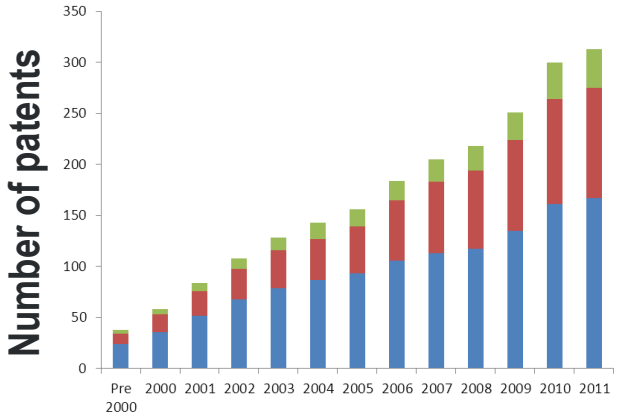
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

***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*



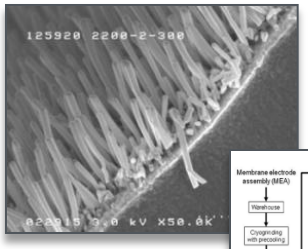

**>310 PATENTS resulting from EERE-funded R&D:**

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

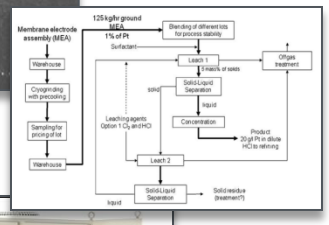
http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/pathways_2011.pdf

**Examples**

3M



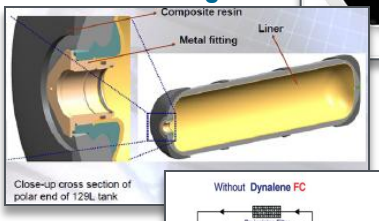
BASF Catalysts LLC



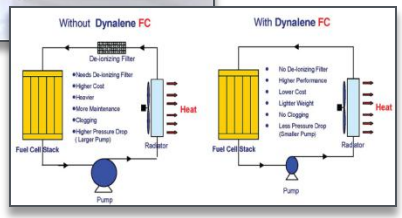
Proton Energy Systems

DuPont

Quantum Technologies




Dynalene, Inc.



# Progress – Fuel Cells

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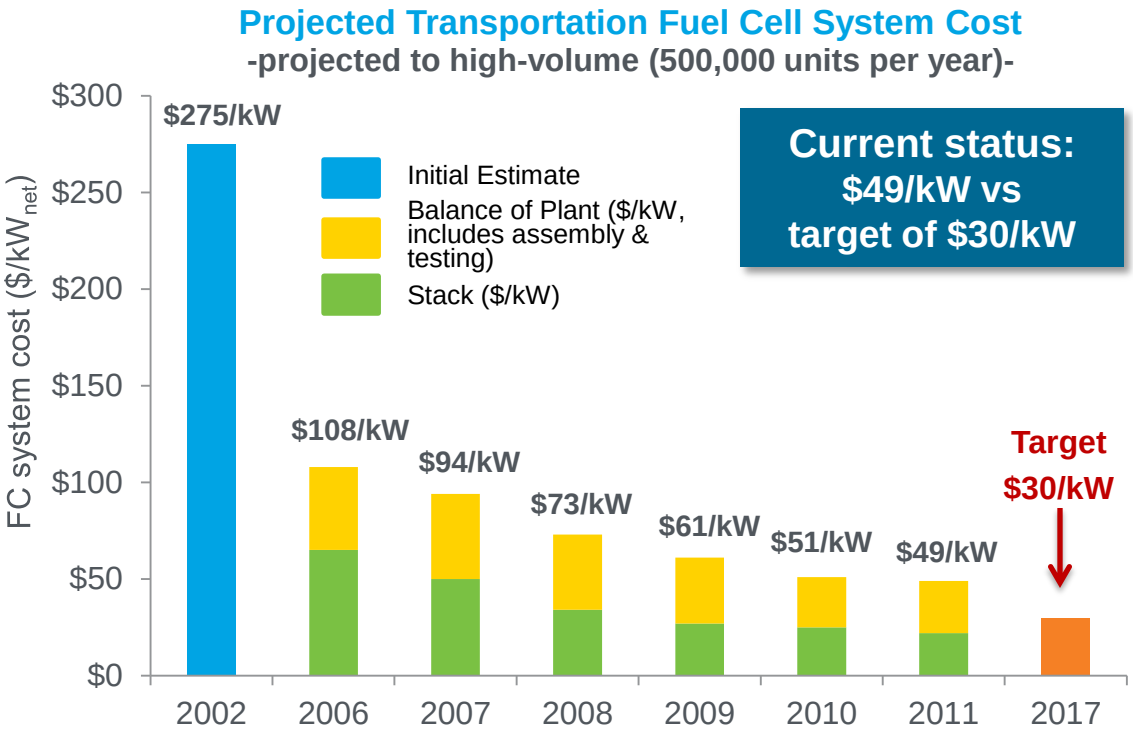
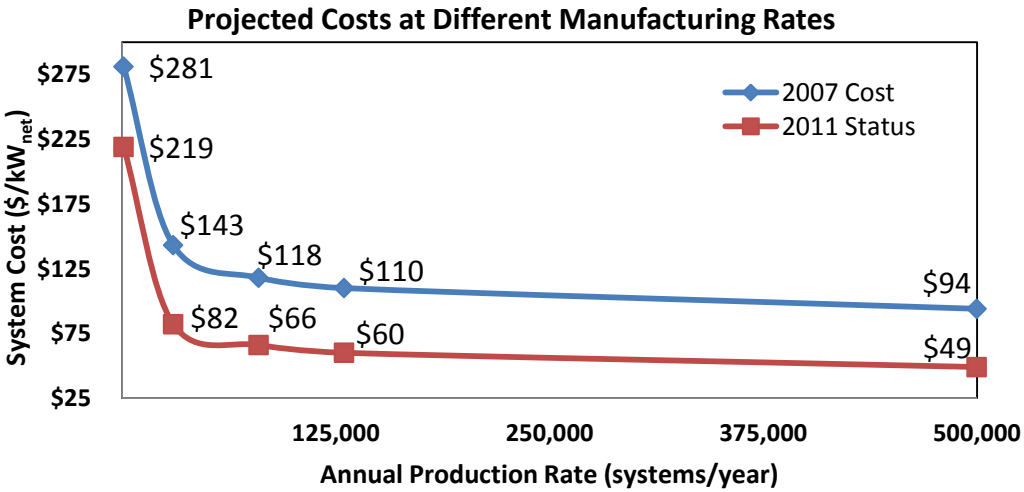
## Projected high-volume cost of fuel cells has been reduced to $49/kW (2011)*

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




***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

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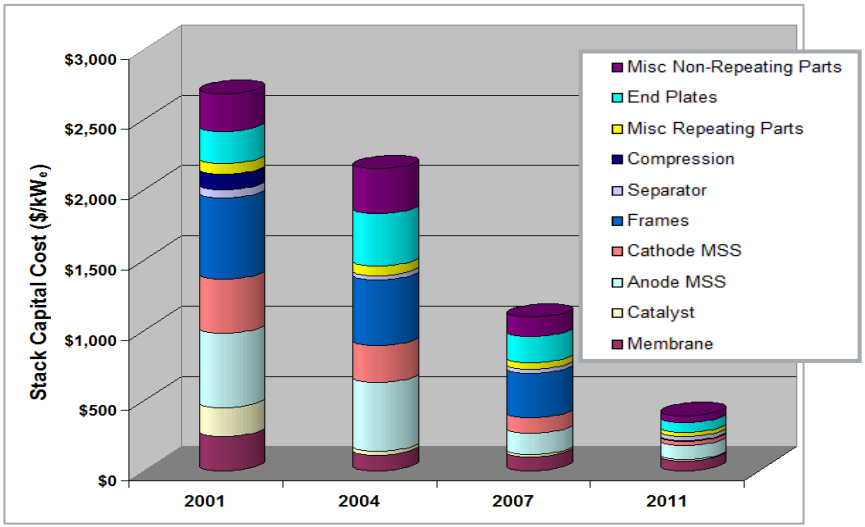
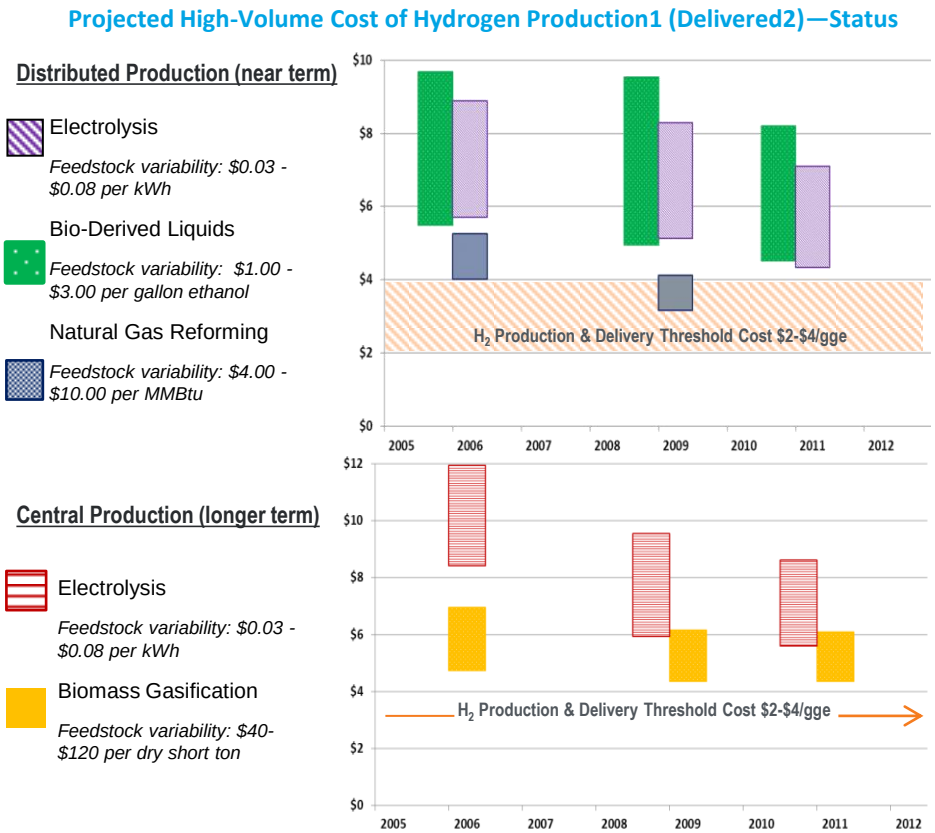
## Reduced cost of $H_2$ production (multiple pathways)

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




- **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

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

***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)

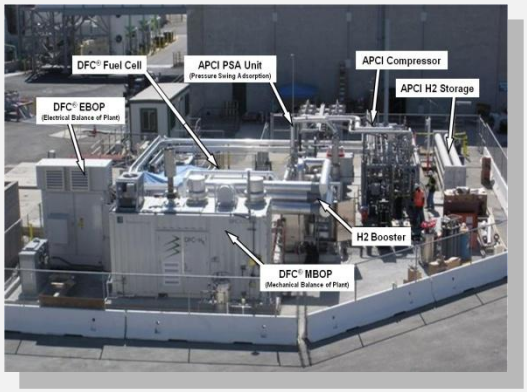
# Technology Validation—Tri-Generation

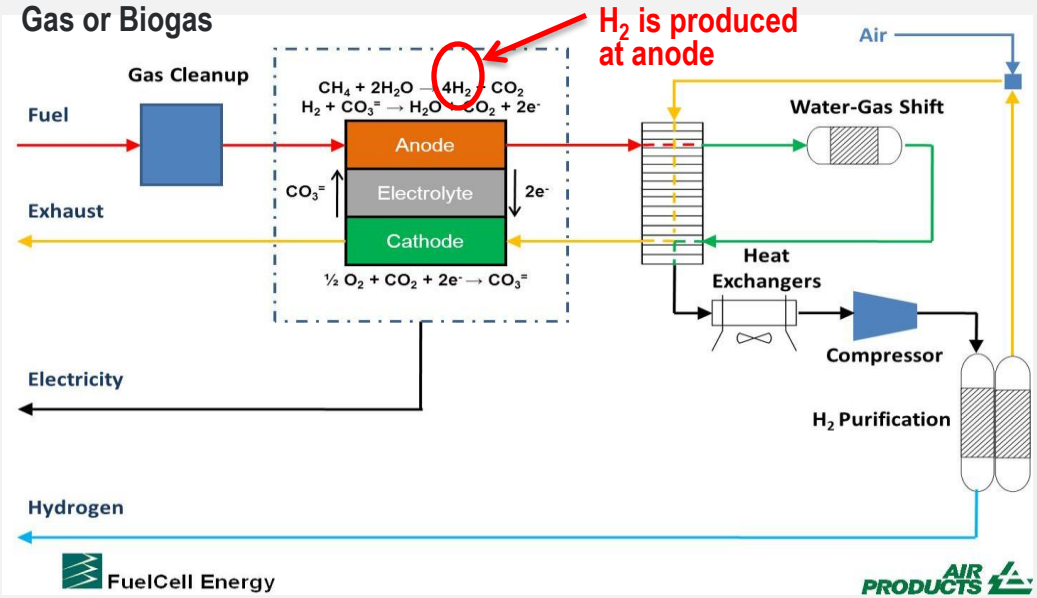
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

***"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

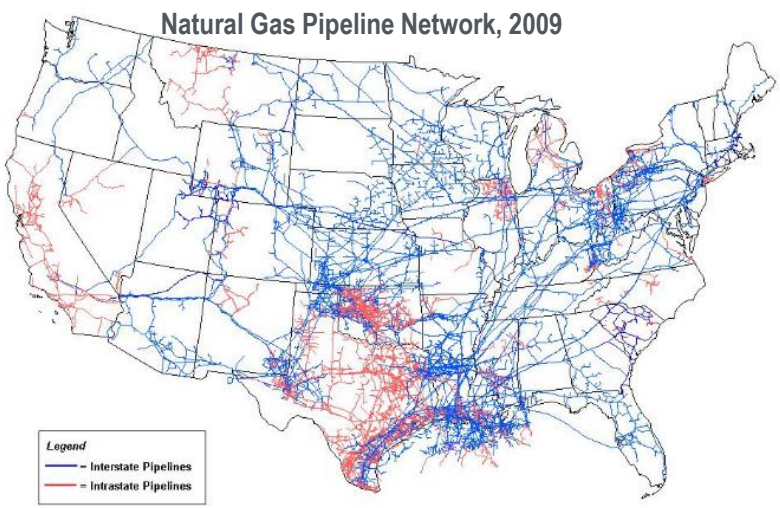
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

## Two Main Options for Low-cost Early Infrastructure

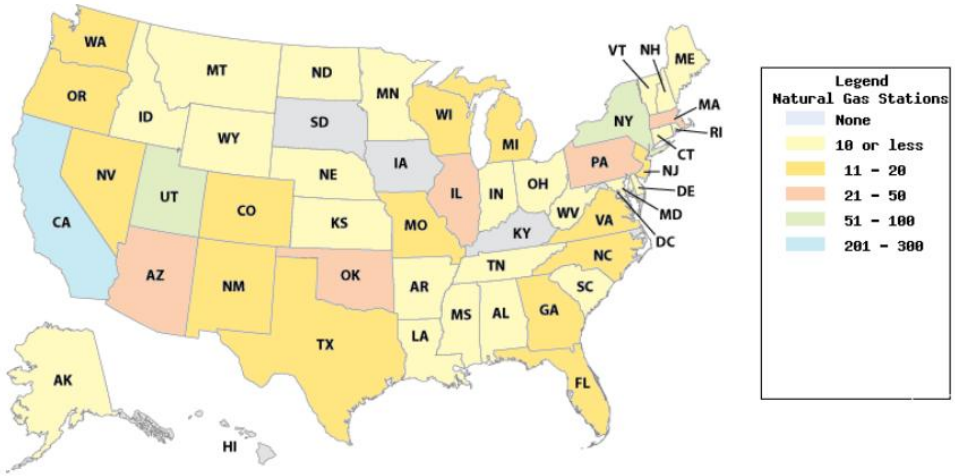
1. **Hydrogen delivered from central site**
   - Low-volume stations (~200-300 kg/day) would cost <$1M and provide hydrogen for $7/gge *(e.g., high-pressure tube trailers, with pathway to $5/gge at 400–500 kg/day- comparable to ~$2.10/gallon gasoline untaxed)*
2. **Distributed production (e.g. natural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




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




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

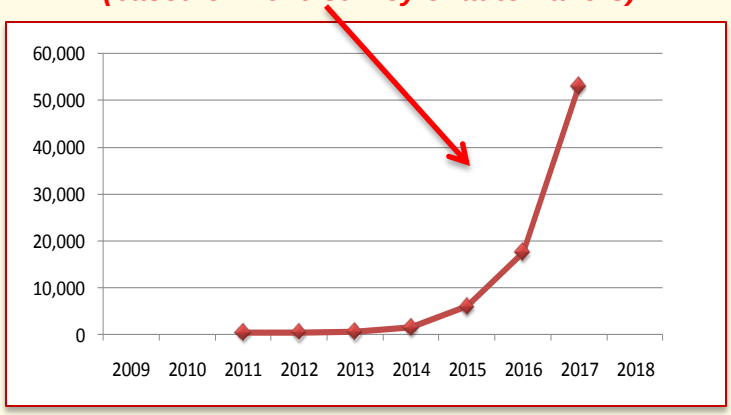
- **> 400 vehicles** in operation since 1999 — >160 currently operating
- **~3.9 million miles** driven
- **> 1 million passengers** on fuel cell buses

### 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

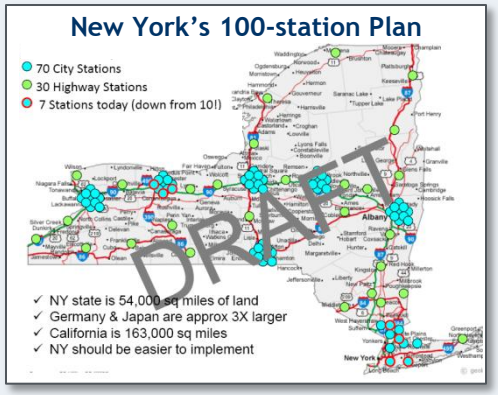
*(based on 2010 survey of automakers)*




## 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

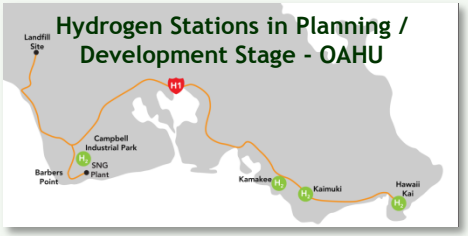



## Hawaii

***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**

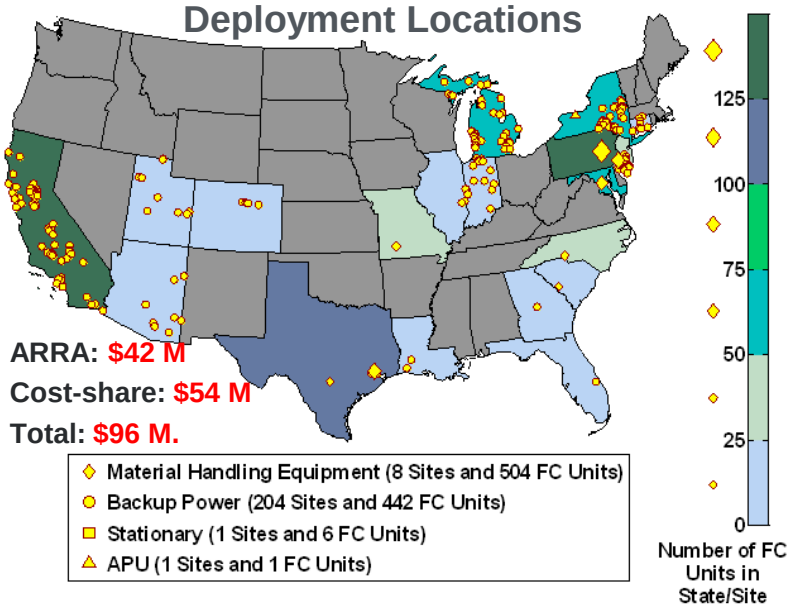
Plans include leveraging state activities (e.g. CA state funding for fueling stations)
FCT will not be funding infrastructure but can fund technology innovation that could be applicable to/enable infrastructure (e.g. innovative refueling/compression technologies)

# Recovery Act and Market Transformation Spur Deployments

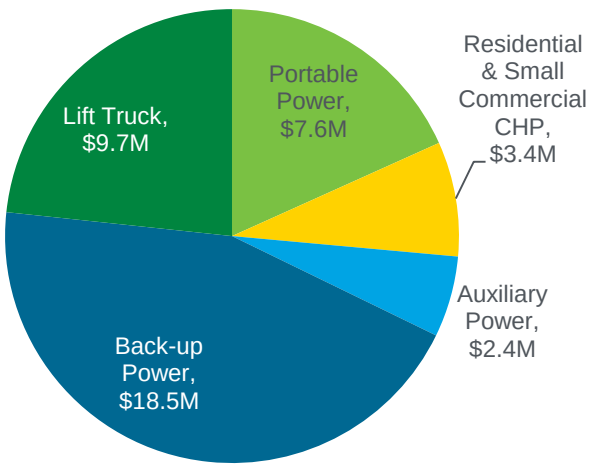
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

***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 |

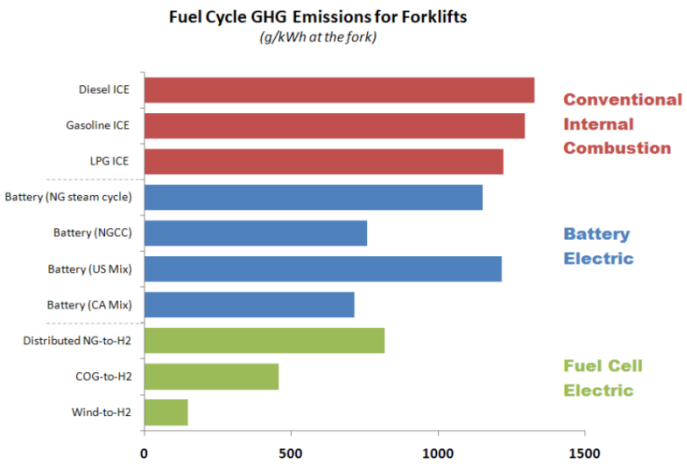
# ARRA as Catalyst for Deployments

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

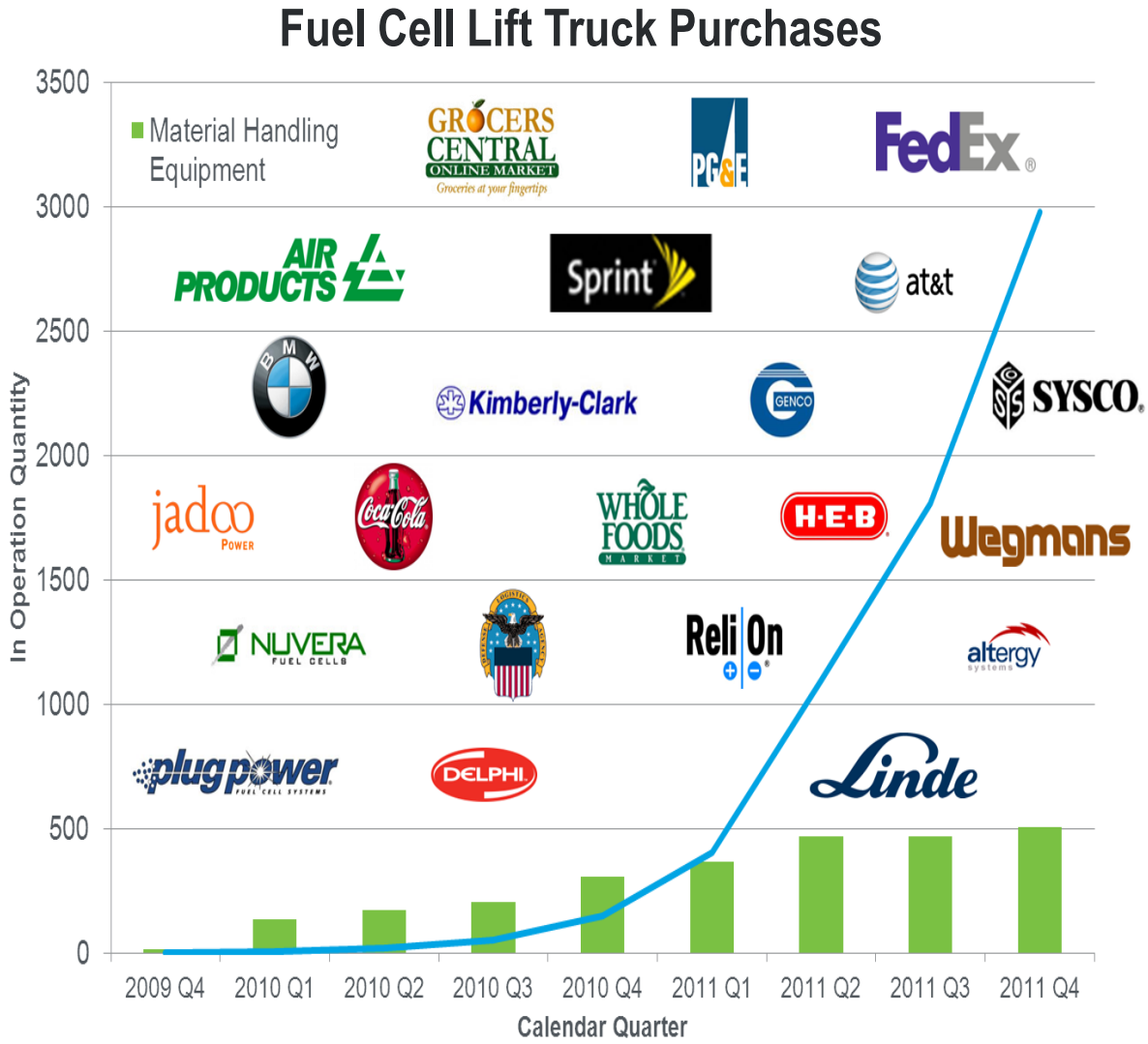
***ARRA deployments of fuel cells for lift trucks (~400) led to industry purchases* of an estimated 3,000 additional fuel cell lift trucks with NO DOE funding***

**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*



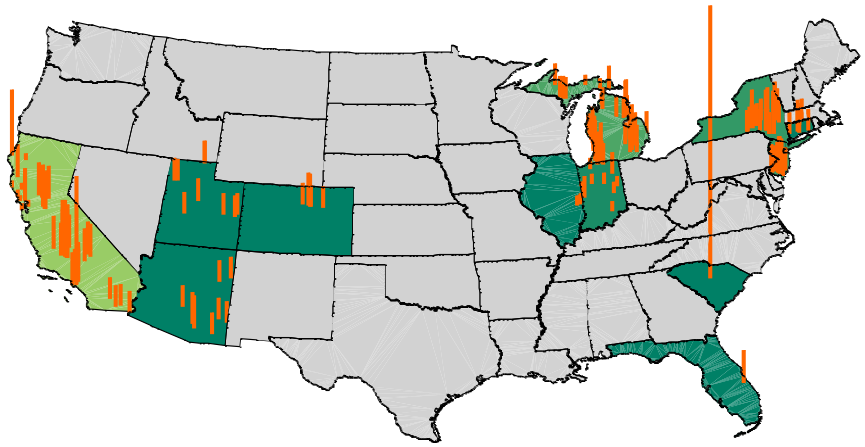

* Including deployed and on order

# 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** |



>100
91-100
81-90
71-80
61-70
51-60
41-50
31-40
21-30
11-20
1-10

Number of Sites in State

| Totals | 890 | 199 |
|---|---|---|

Site Capacity (line height proporational to installed site kW capacity)

NREL cdp_bu_03
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**Tracked by NREL**

## Next Steps

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

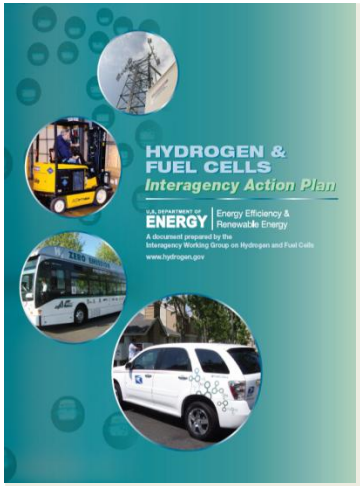
**Includes ARRA and DOE Interagency Agreement (IAA) Deployments**

# 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**

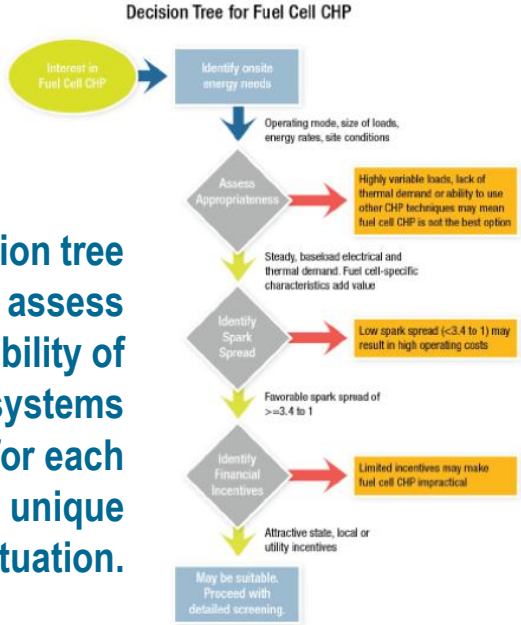
1. Strengthen and Accelerate Research and Development
2. Accelerate Development & Adoption of Codes, Standards & Safe Practices
3. Work with Industry to Validate Technologies under Real-World Conditions
4. Adopt Technologies in U.S. Government Operations
5. Track and Communicate Results

**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

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

## 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%<br>• 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.

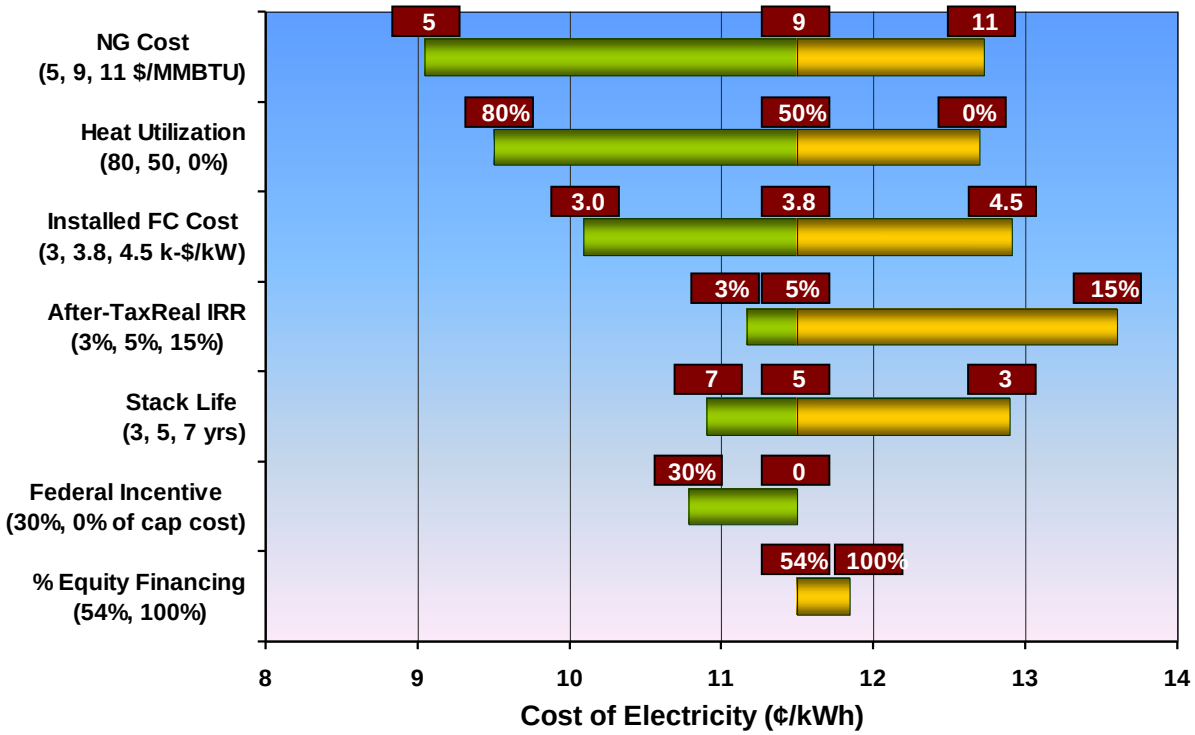
**Contact: Dennis Hughes, 402-633-3926**
**dhughes@fnni.com**

# 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**

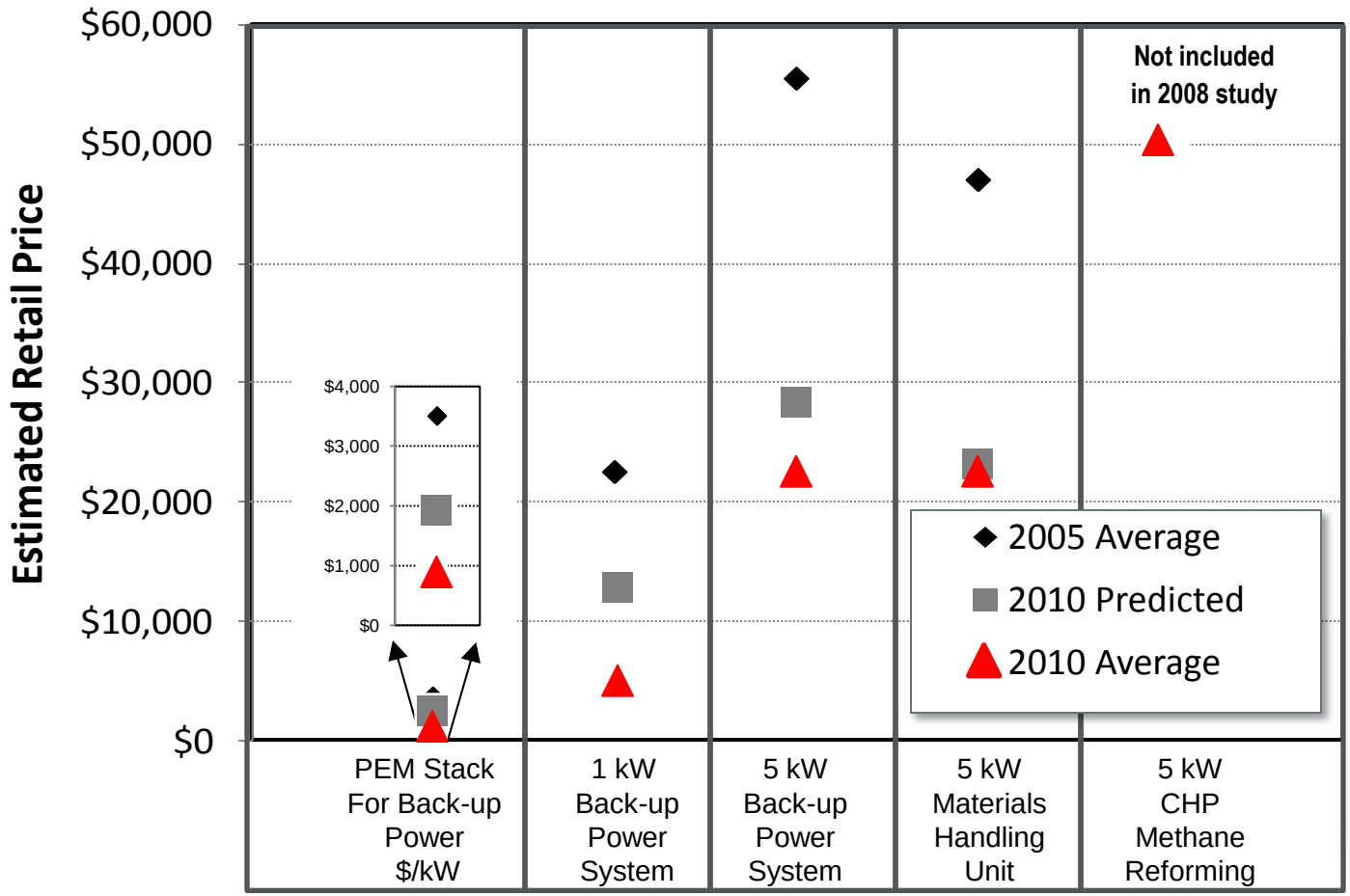
Example for MCFC 1.4 MW


U.S. Department of

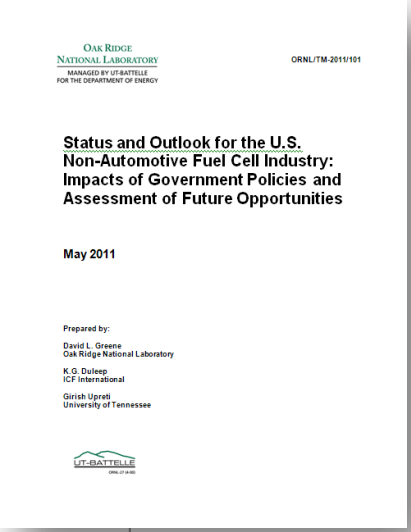
# Early Market Cost Reduction Analysis

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

## Cost Analysis, Modeling, and Validation (ORNL)




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



OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

ORNL/TM-2011/101

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

May 2011

Prepared by:

David L. Greene
Oak Ridge National Laboratory

K.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 |

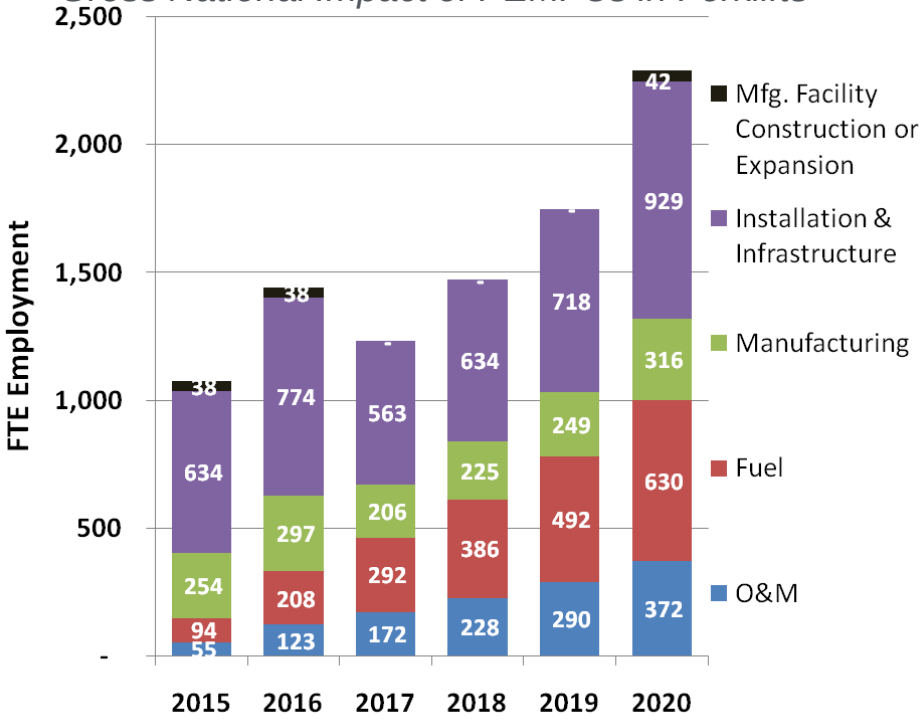
| OPTIONAL USER INPUT FIELDS | |
|---|---|
| Existing Fuel Cell Production Capacity (kW/year) | 0 |
| Additional Manufacturing Capacity to be Constructed (kW/year) | 10,000 |
| Sales Price ($/kW) | *$2,000* |
| Production Cost ($/kW, initial) | $1,301 |
| Progress Ratio | 0.97 |
| Production Volume for Initial C | 10,000 |
| Scale Elasticity | -0.2 |
| Full S | 25,000 |
| Annu | 2% |
| Averag Frame ($/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.

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.

Connecticut Center for Advanced Technology, Inc.
222 Pitkin Street, Suite 101
East Hartford, CT 06108
(860) 291-8832
www.ccat.us

**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

## Preliminary Analysis- Economic Impact Summary

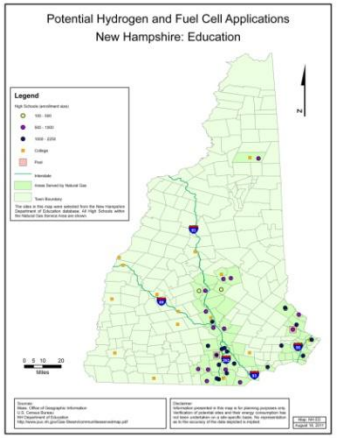
| | CT | NY | MA | ME | NH | RI | VT | NJ | Regional |
|---|---|---|---|---|---|---|---|---|---|
| **Total Employment** | 2,529 | 1,728 | 964 | 18 | 45 | 32 | 16 | 111 | **5,443** |
| **Total Revenue / Investment in 2010 ($ million)** | $496 | $292 | $171 | $2.9 | $8.7 | $6.9 | $3.3 | $26.5 | **$1,009**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

The Connecticut Center for Advance Technology, Inc.

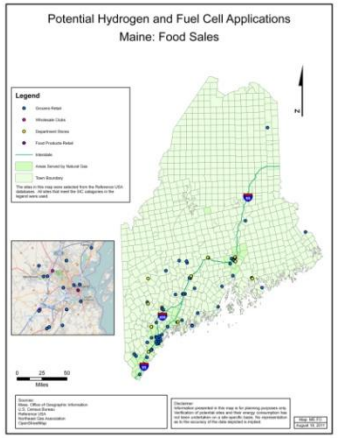
www.ccat.us

# Targets: Geographic Information System (GIS) Mapping

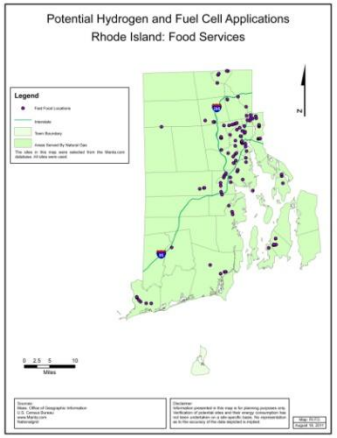
Education



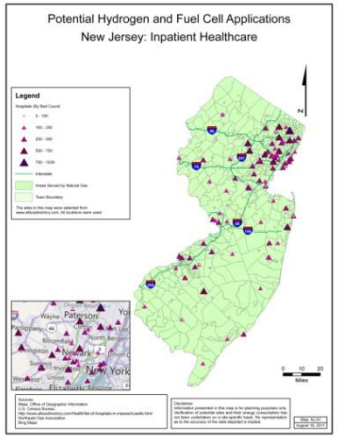

Food Sales



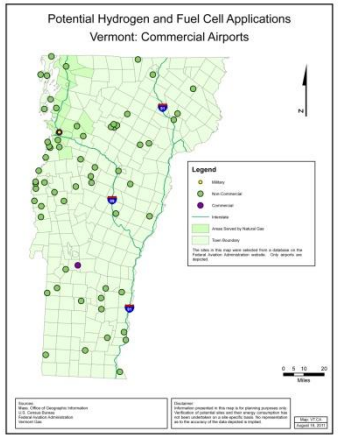

Food Services



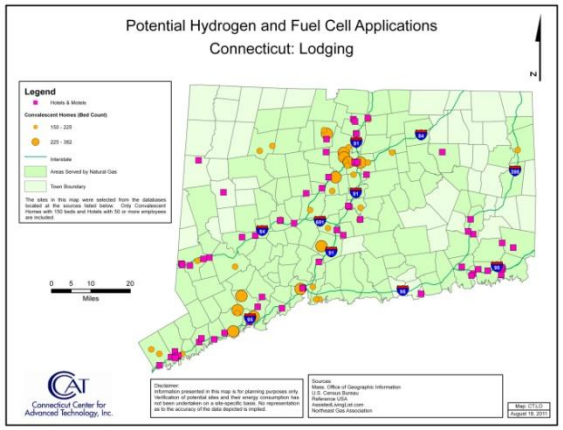

Inpatient Healthcare



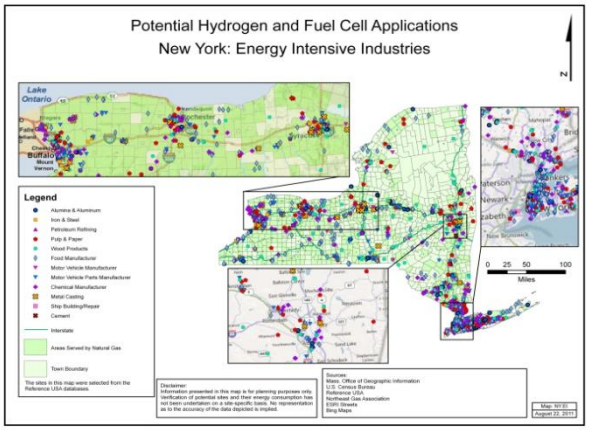

Airports (Military)



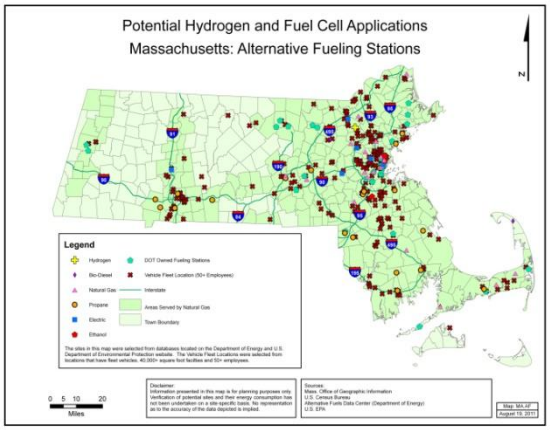

Lodging




Energy Intensive Industry




Alternative Fueling Stations



## 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

*** Fuel cells not specified, but distributed generation technologies eligible through Green Communities program

www.dsireusa.org

# 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

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

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

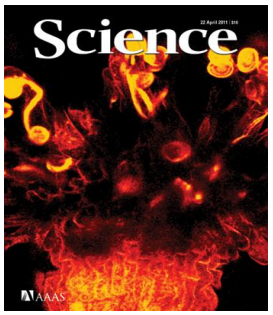
**Communication and Outreach Activities include:**

- 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

"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."

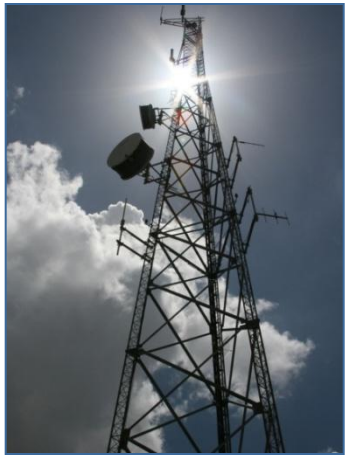
**Blogs Published to Energy.gov website include:**

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




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

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

**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**

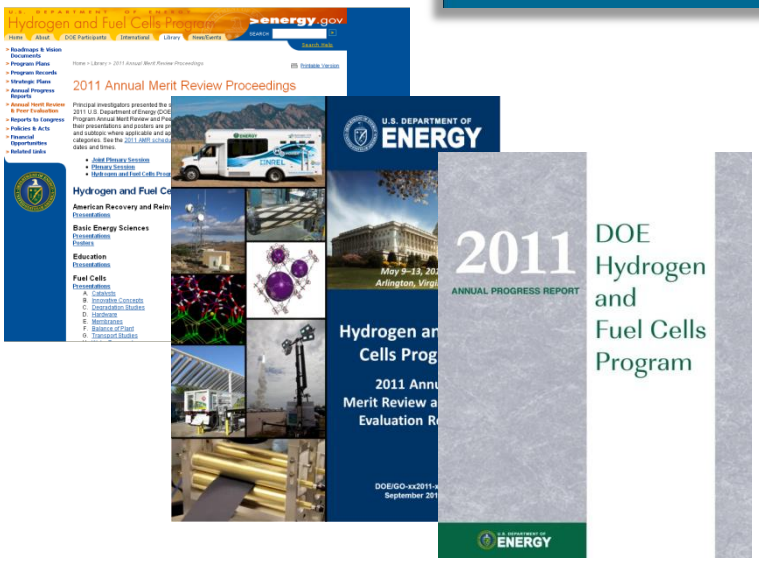
**See report: ttp://www.fuelcells.org/StateoftheStates2011.pdf**

### 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

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

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**