Fuel Cell Technologies Overview

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

HTAC
Washington, DC
5/10/2012

Dr. Sunita Satyapal
U.S. Department of Energy
Fuel Cell Technologies Program
Program Manager

Agenda

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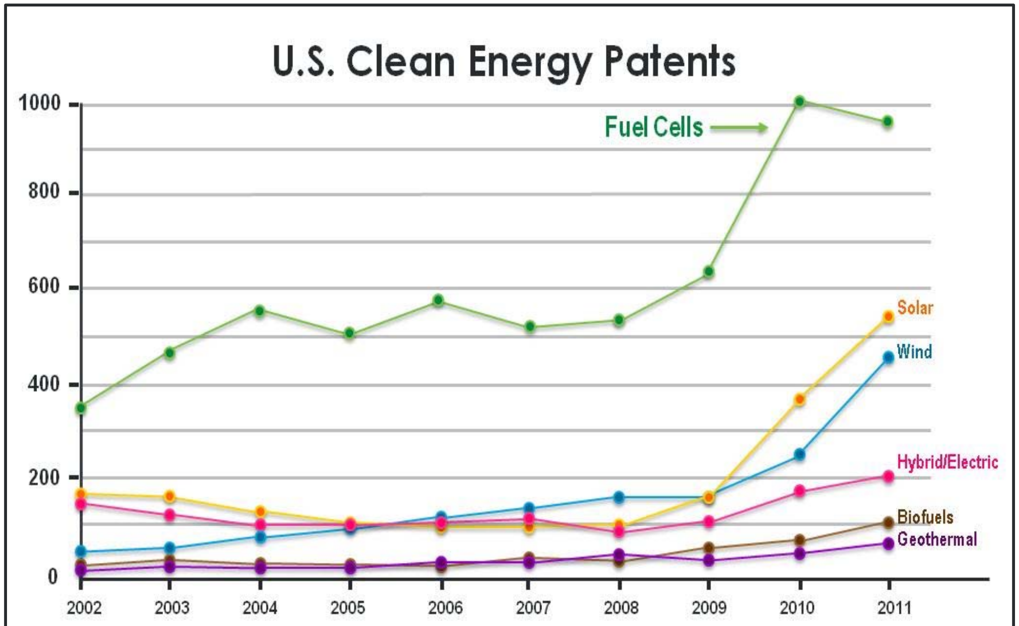
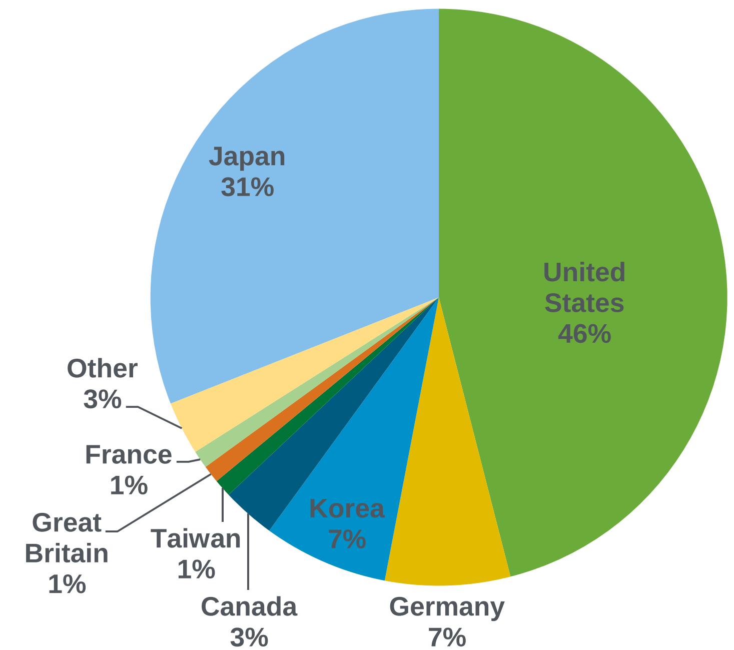
- Fuel Cell Industry Overview
  - Clean Energy Patents
  - Global OEM Update
- Update on Progress
  - RD&D
  - Recovery Act
- Budget Update
  - Funding Announcements
- Additional Information

Fuel Cells – An Emerging Industry



Clean Energy Patent Growth Index

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



Clean Energy Patent Growth Index[1] shows that fuel cell patents lead in the clean energy field with over 950 fuel cell patents issued in 2011.

- Nearly double the second place holder, solar, which has ~540 patents.

[1] http://cepgi.typepad.com/files/cepgi-4th-quarter-2011-1.pdf

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

Manufacturer	Activities and Plans
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.

DOE Program Structure

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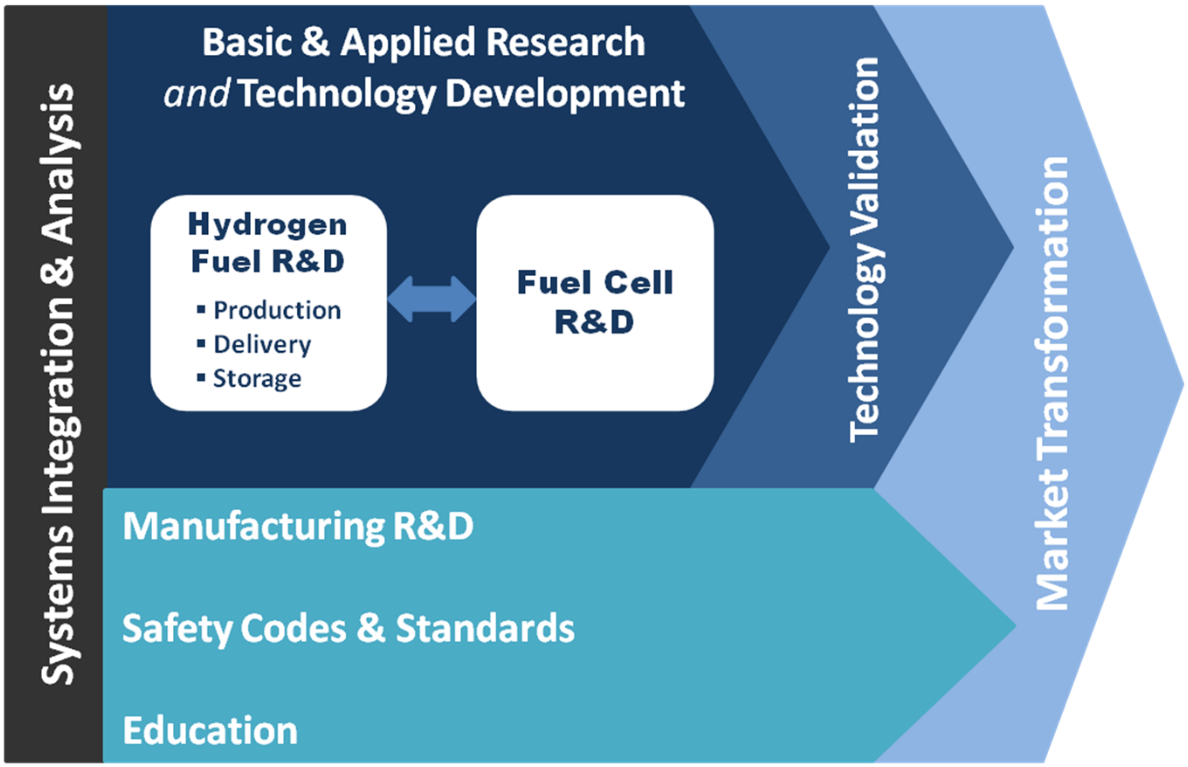
The Program is an integrated effort, structured to address all the key challenges and obstacles facing widespread commercialization.



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

More than $1B DOE funds spent from FY 2007 to FY 2011

Federal Role in Fuel Cells: RD&D to Deployments

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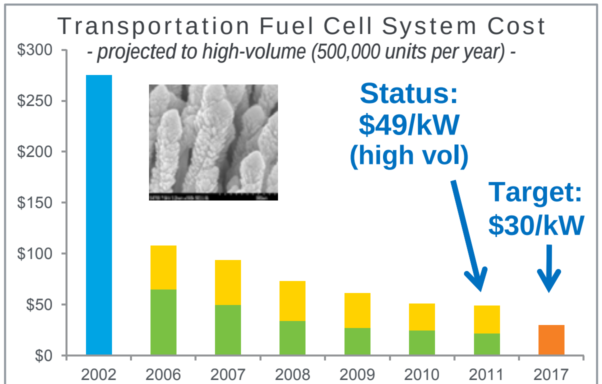
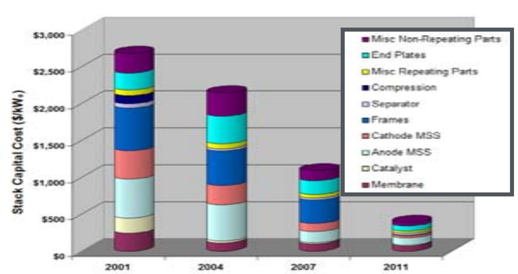
DOE R&D

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

Examples:



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



→ Reduced cost of electrolyzer stacks 60% since 2007

DOE Demonstrations & Technology Validation

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

Examples—validated:

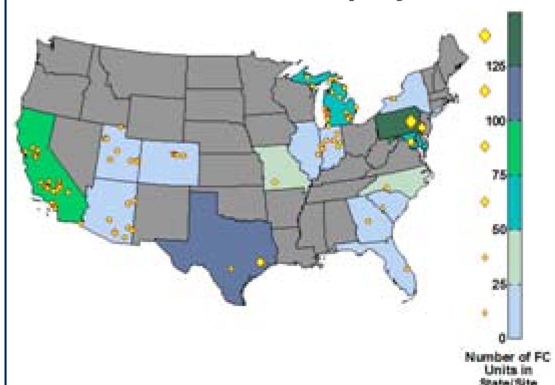
- ***59% efficiency***
- ***254 mile range (independently validated 430-mile range)***
- ***75,000-mi durability***

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

Deployments

- ***Market Transformation***
- ***DOE Recovery Act Projects***
- ***Government Early Adoption (DoD, FAA, California, etc.)***
  - ***IDIQ****
- ***Tax Credits: 1603, 48C***

Recovery Act & Market Transformation Deployments



➢ ***1,000 fuel cell deployments in ~ 2 years***

➢ ***1 million hours of operation***

*IDIQ = indefinite delivery/indefinite quality

Assessing the Impact of DOE Funding

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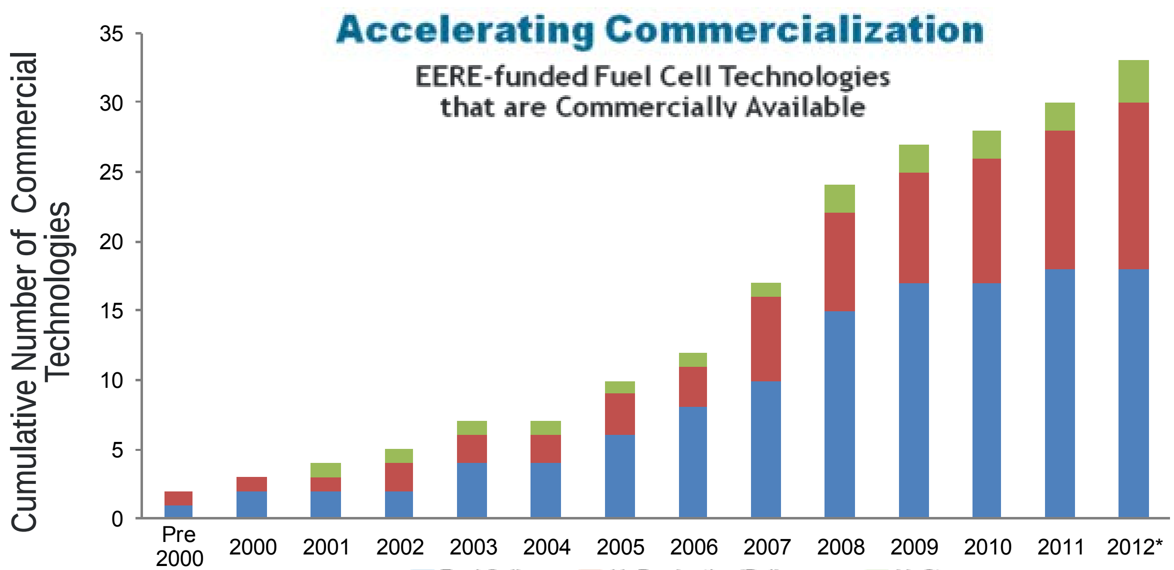
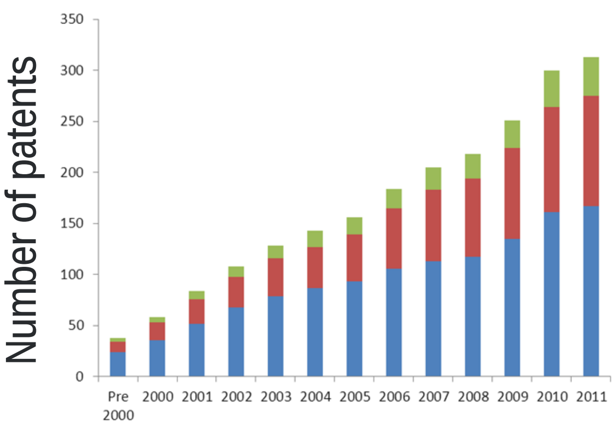
DOE funding has led led to 313 patents, ~33 commercial technologies and >60 emerging technologies.

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

*Partial data for 2012



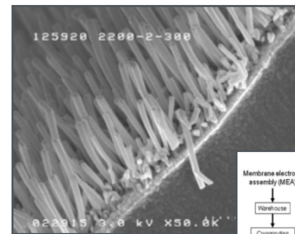
>310 PATENTS resulting from EERE-funded R&D:

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

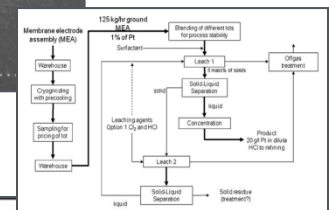
http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/pathways_2011.pdf

Examples

3M



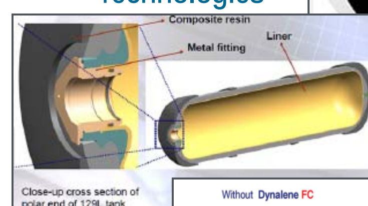
BASF Catalysts LLC



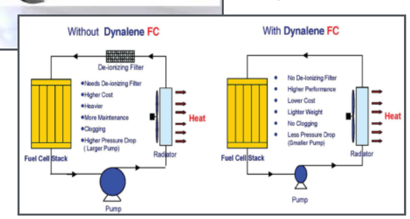
Proton Energy Systems

DuPont

Quantum Technologies



Dynalene, Inc.



Program Mission

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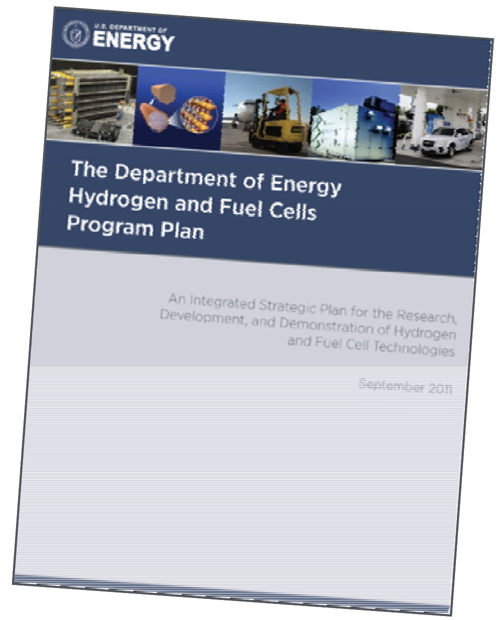
The mission **of the Hydrogen and Fuel Cells Program is to enable the widespread commercialization of hydrogen and fuel cell technologies through:**

- **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

Key Challenges

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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.

Key Analysis Guides R&D Area

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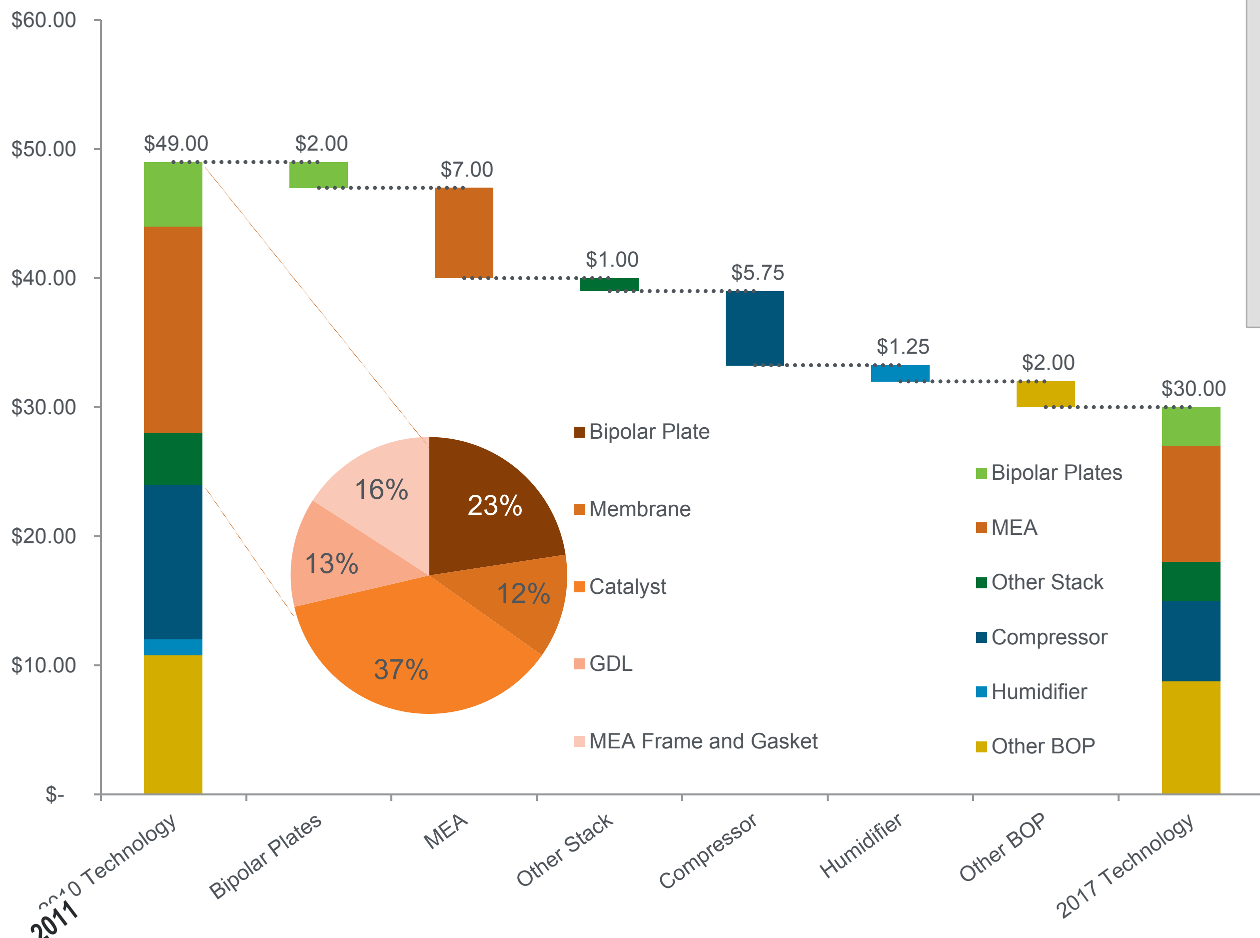
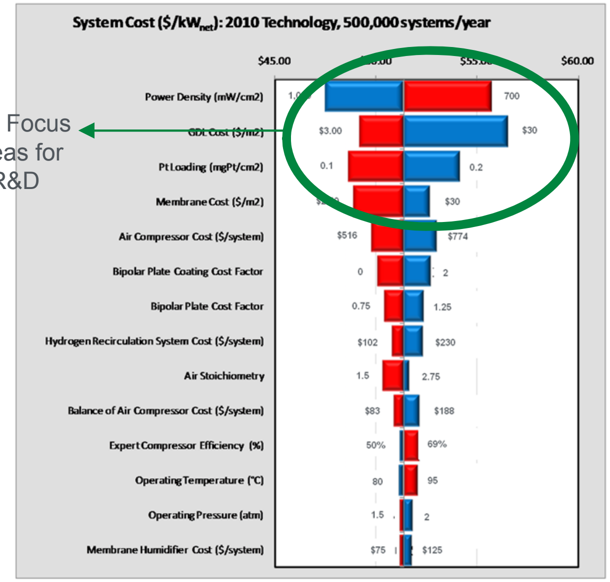
Strategic technical analysis guides focus areas and priorities for budget.
Need to reduce high volume cost from $49/kW to $30/kW and increase durability from 2,500-hr to 5,000-hr.



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



Key Focus Areas for R&D

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

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The revised hydrogen threshold cost is a key driver in the assessment of Hydrogen Production and Delivery R&D priorities

Projected High-Volume Cost of Hydrogen Production[1] (Delivered[2])—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

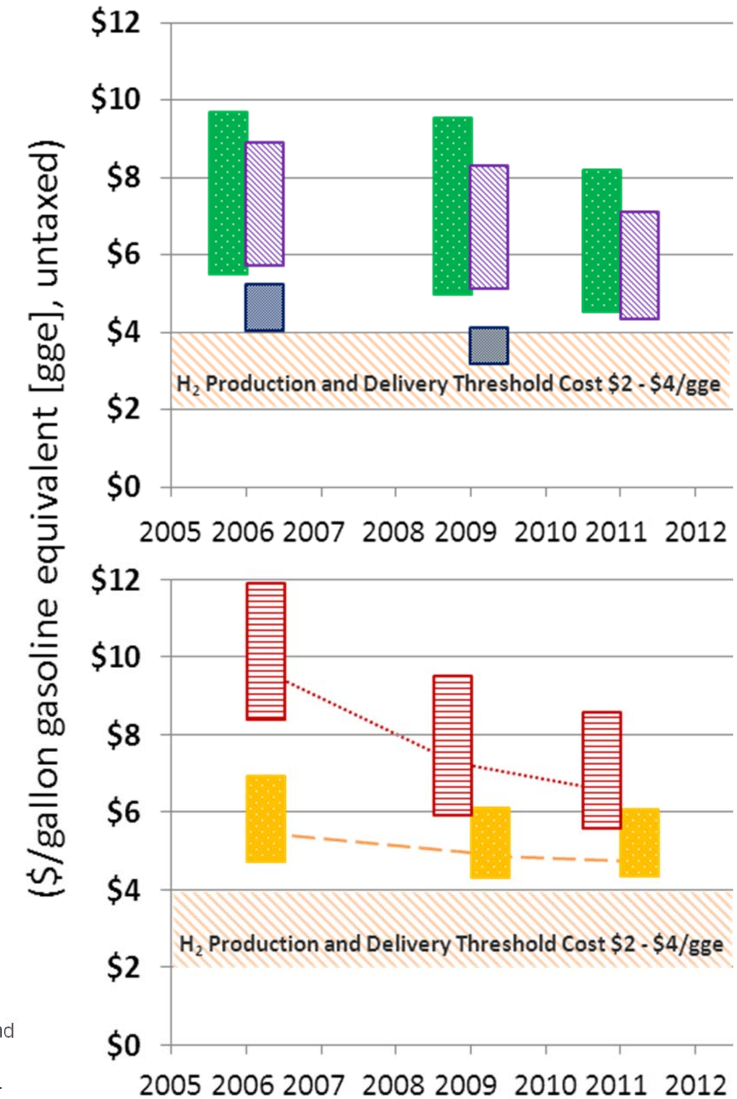
Central Production (longer term)

Electrolysis

Feedstock variability: $0.03 - $0.08 per kWh

Biomass Gasification

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



Notes:
[1] Cost ranges for each pathway are shown in 2007$ based on high-volume projections from H2A analyses, reflecting variability in major feedstock pricing and a bounded range for capital cost estimates.
[2] Costs include total cost of production and delivery (dispensed, untaxed). Forecourt compression, storage and dispensing added an additional $1.82 for distributed technologies, $2.61 was added as the price of delivery to central technologies. All delivery costs were based on the Hydrogen Pathways Technical Report (NREL, 2009).

Hydrogen Production - Strategies

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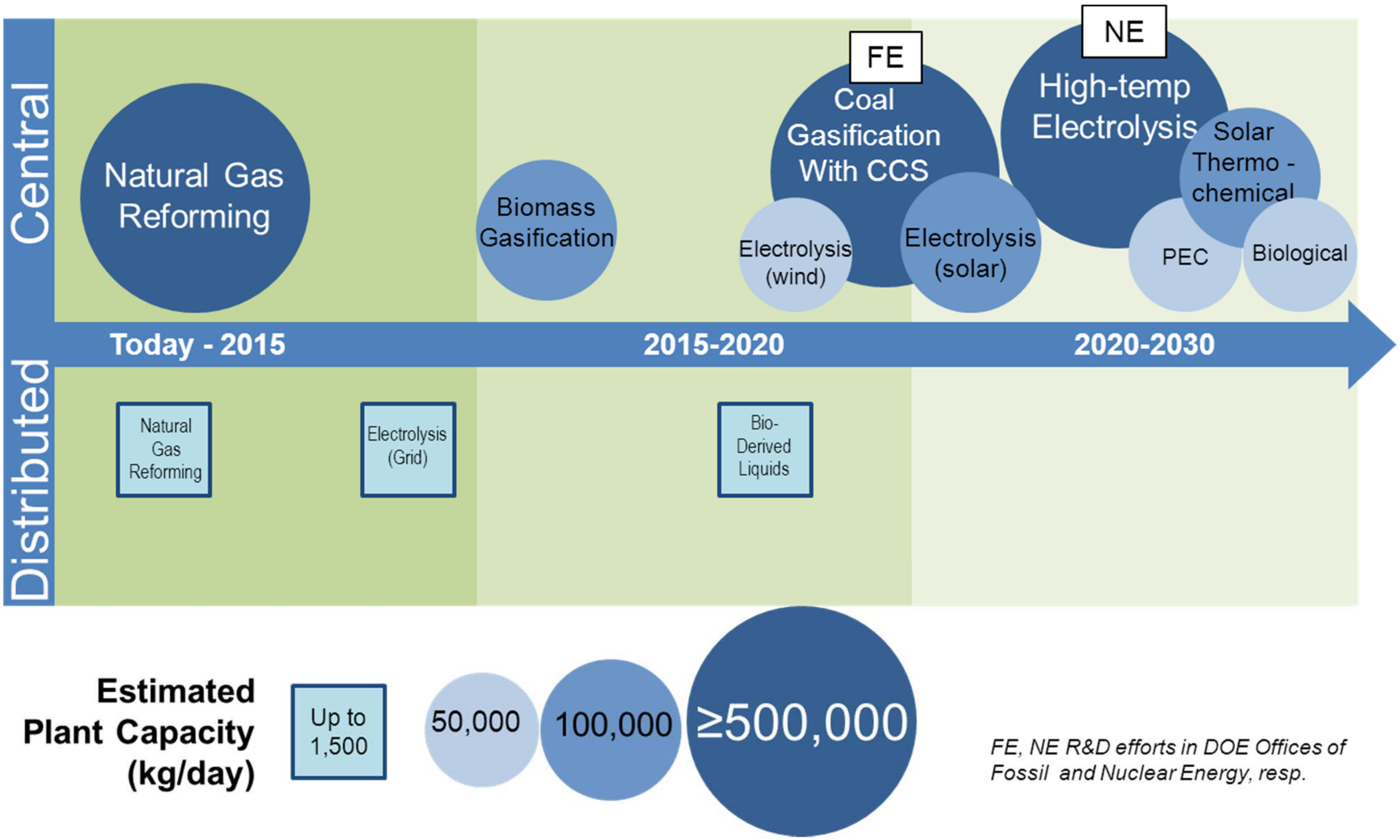
Develop technologies to produce hydrogen from clean, domestic resources at a delivered and dispensed cost of \$2-\$4/gge H_2 by 2020



FE, NE R&D efforts in DOE Offices of Fossil and Nuclear Energy, resp.

Renewable Integration: Production from Wind

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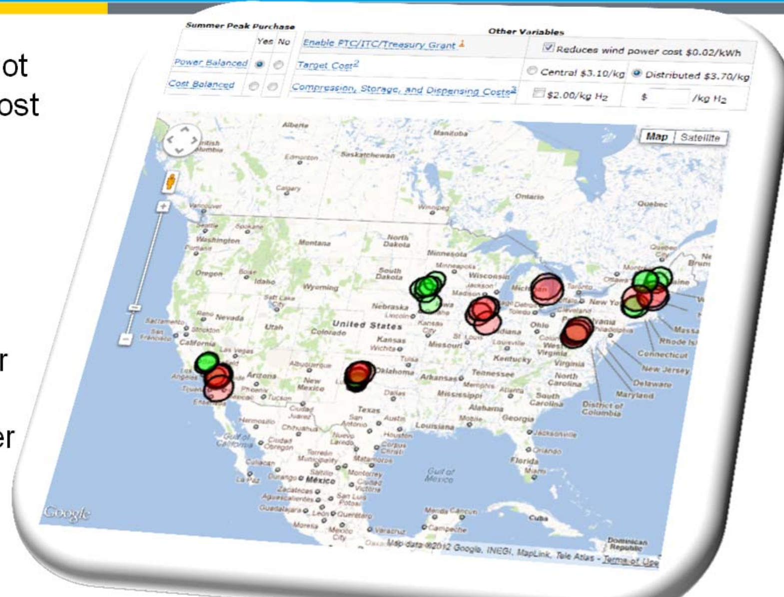
Current DOE threshold costs can be met in some locations using electrolysis to produce hydrogen from wind

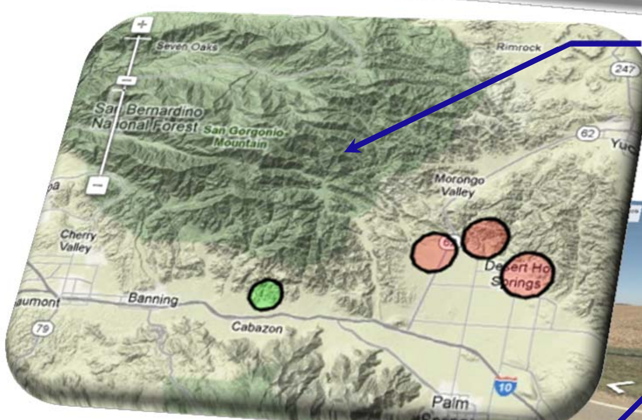
Significance of Results

- Wind incentives amounting to \$0.02/kWh result in a \$~1/kg H_2 cost reduction.
- These incentives allow some sites to meet DOE targets.
- Interactive tool allows users to provide input to the analysis and see updated results immediately.

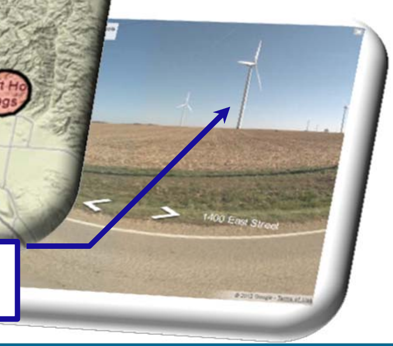
Does not meet cost target

Meets cost target; Smaller is cheaper





Mountains degrade the wind resource increasing H_2 costs by \$1.5/kg.



Street view showing wind turbines at a site.

Users can:

- Explore the effects of the four different balance scenarios; cost or power with & without the purchase of peak summer electricity.
- Compare H_2 costs with DOE targets.
- See the effects of wind power incentives on H_2 costs.
- Add compression, storage, and dispensing costs.
- See the effects of local topography.
- See what's at the site with Google Street View ™.

http://www.nrel.gov/hydrogen/production_cost_analysis.html

International Collaboration: Resource Analysis

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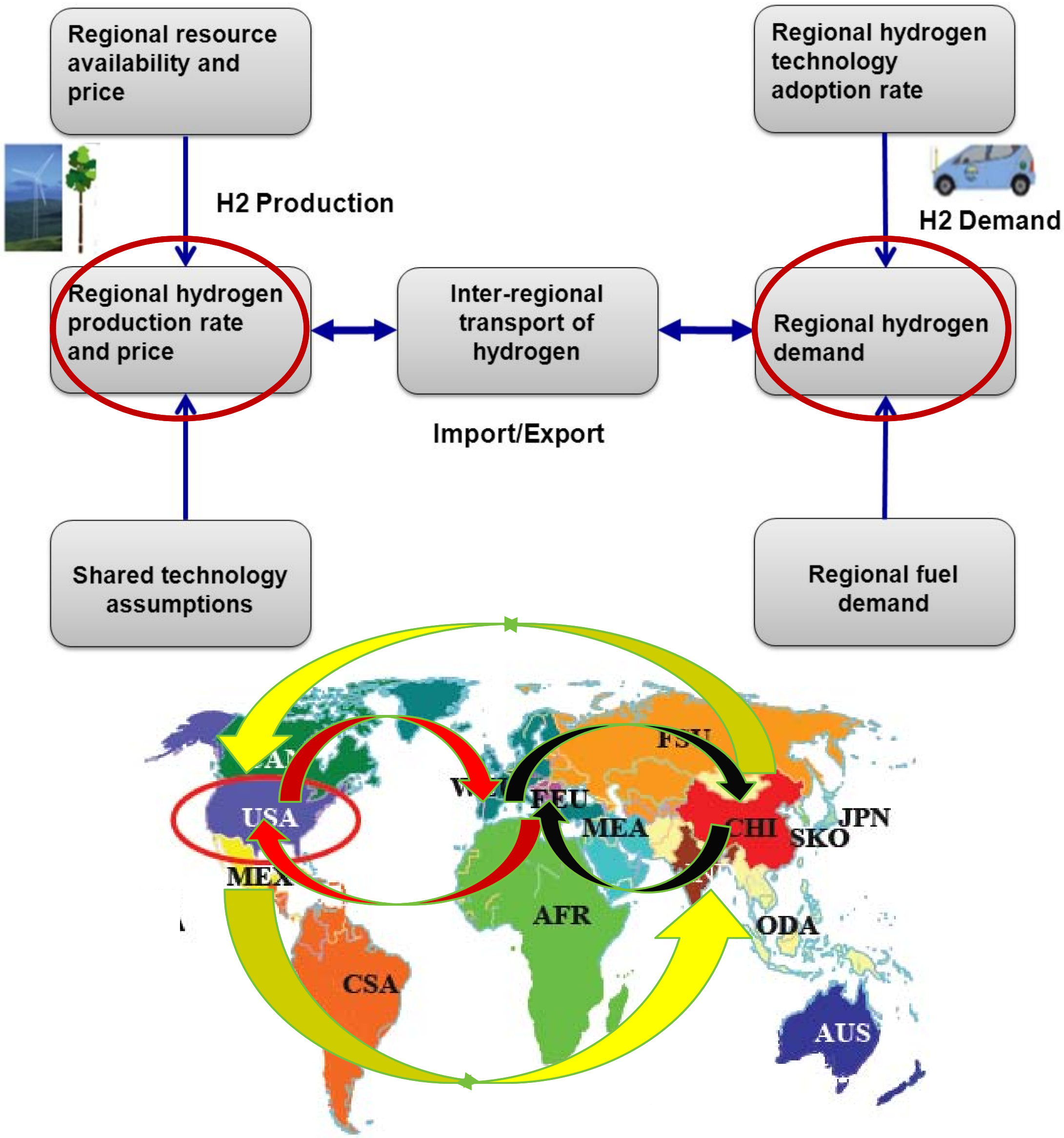


International Resource Flow

Objectives*:

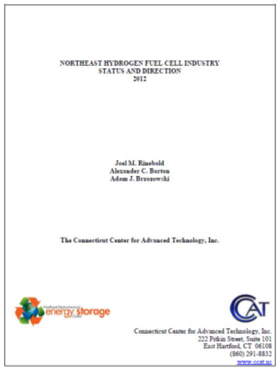
- Through collaboration with IEA analysts and IPHE, perform comprehensive technical and market analysis of
  - Hydrogen technologies and resources
  - Resource supply and demand related to projected hydrogen use
  - Global hydrogen infrastructure
  - GHG emissions and petroleum reduction
- Identify international flows of:
  - Energy
  - Hydrogen
  - Natural gas, LNG, coal
  - Platinum and other materials

*Objectives for IEA Hydrogen Implementing Agreement Task 30

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.

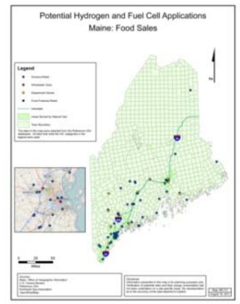
1.85 GW opportunity identified.

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)

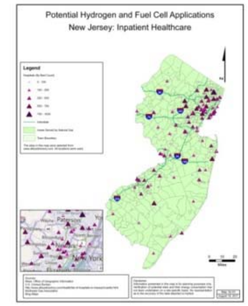
Targets: Geographic Information System (GIS) Mapping

Food Sales

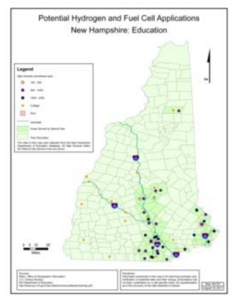


Food Services

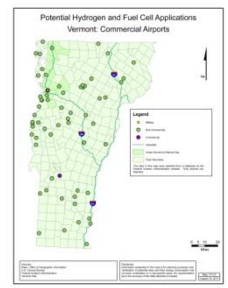
Inpatient Healthcare



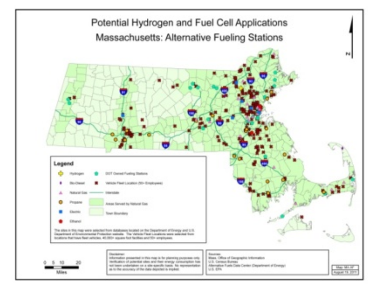
Education



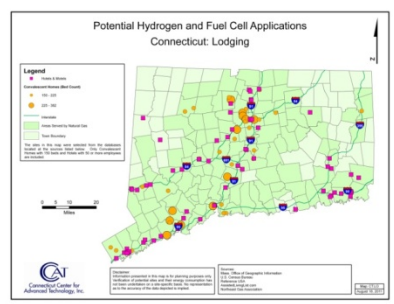
Airports (Military)



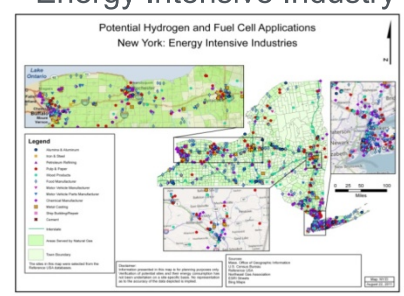
Alternative Fueling Stations



Lodging



Energy Intensive Industry



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

Spark-Spread Determines Regional Opportunities for DG from Natural Gas

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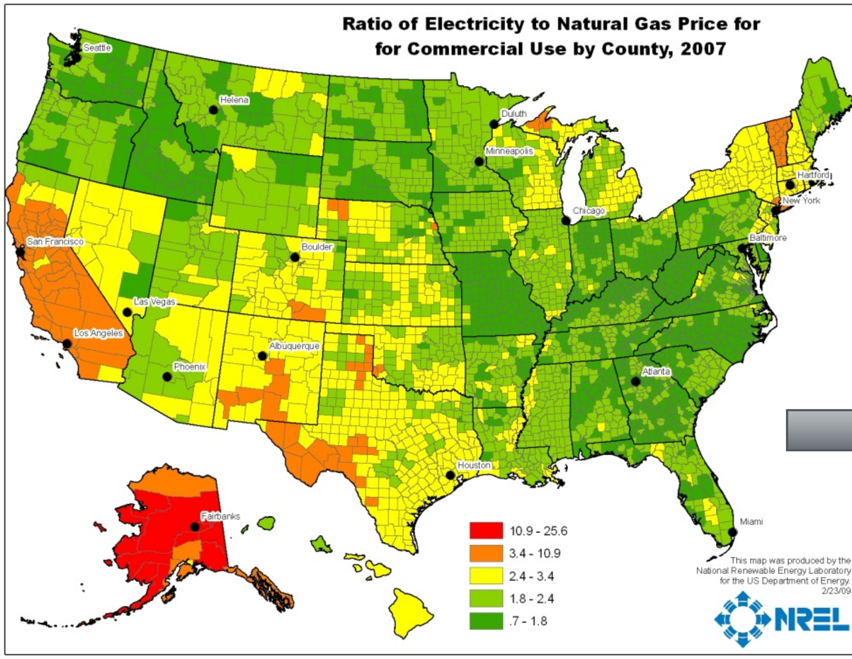
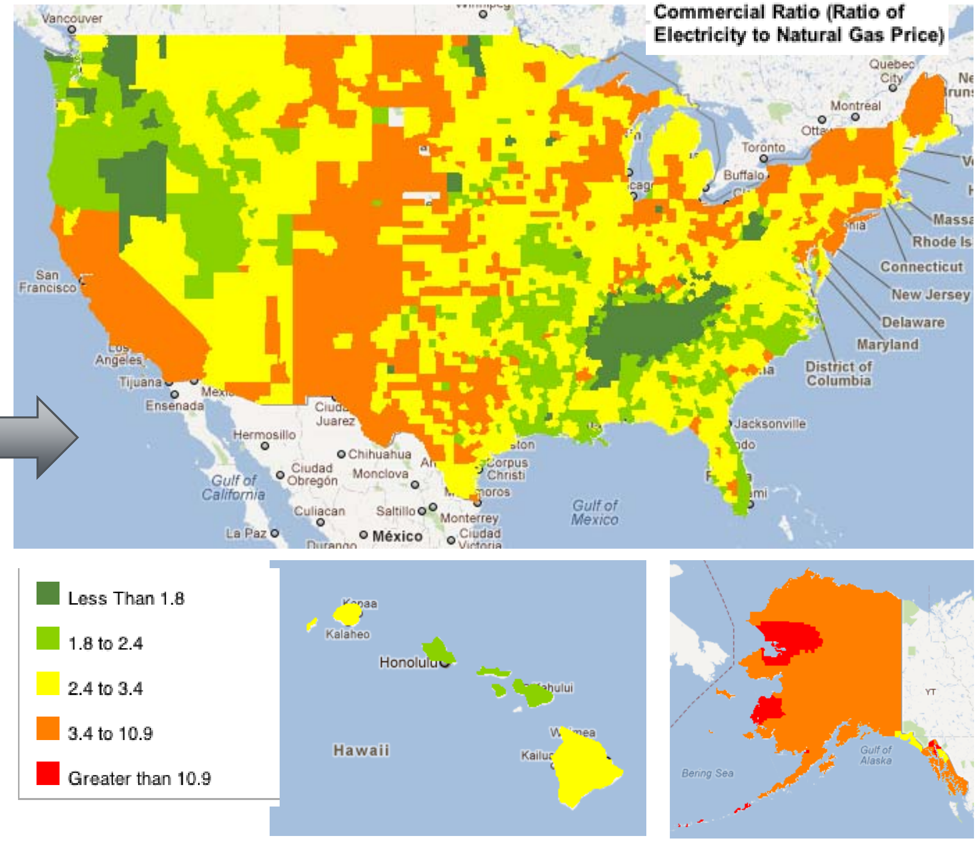
2007



2010



Spark spread determines regions for favorable use of natural gas

Red/orange regions: High electricity cost, low natural gas cost- favorable for DG

Lower natural gas prices offer increased opportunities for CHP and distributed generation- current vs. 2007

Source: NREL

Progress – Durability Assessment

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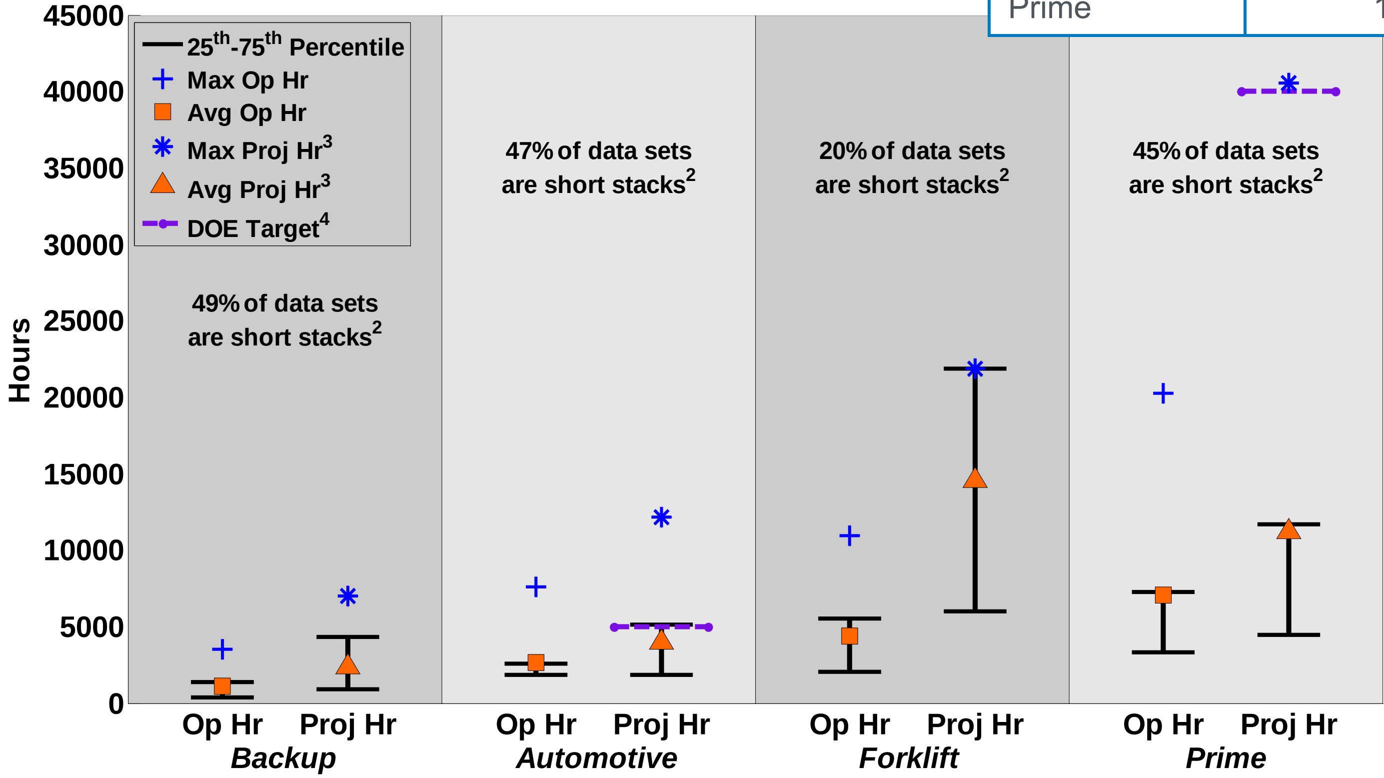
Aggregated results provide a benchmark in time of state-of-the-art fuel cell durability

NREL is aggregating and analyzing durability results by application that protect proprietary data, providing a benchmark in time of state-of-the-art fuel cell durability. Results include 82 data sets from 10 fuel cell developers.

Application	Avg Projected Time to 10% Voltage Drop	Avg Operation Hours
Backup power	2,400	1,100
Automotive	4,000	2,700
Forklift	14,600	4,400
Prime	11,200	7,000



PEM & SOFC data from lab tested, full active area short stacks and systems with full stacks. Data generated from constant load, transient load, and accelerated testing.

Please send inquires to Fuelcelldatacenter@ee.doe.gov

J. Kurtz, et al., NREL

FY 2012 Senate Mark Language and Impact

DOE FCT Program adjusted FY 2012 budget based on Senate Mark language.

Excerpts from Senate Mark Language in the FY 2012 Appropriation

" The **Committee recognizes the progress and achievements** of the Fuel Cell Technologies program. The **program has met or exceeded all benchmarks, and has made significant progress** in decreasing costs and increasing efficiency and durability of fuel cell and hydrogen energy systems."

" Within the available funds, the **Committee recommends funding is provided for Technology Validation focused on passenger vehicle and hydrogen infrastructure applications, hydrogen fuels R&D, and for Market Transformation in early markets**."

IMPACT

FY 2012 Request: $100.5 M

FY 2012 Appropriation: $104 M

Following guidance from the Senate mark language:

- $1 M was added to the original request for Technology Validation (total $9M)
- $3 M was added for Market Transformation (total $3M)

($33.8 M already planned for Hydrogen Fuels R&D)

EERE H_2 & Fuel Cells Budgets

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Appropriations (FY 10 – FY 12) and Budget Request (FY 13)
Hydrogen and Fuel Cell Technologies

Funding *($ in thousands)*				
Key Activity	**FY 2010 Appropriation**	**FY 2011 Allocation**	**FY 2012 Appropriation**	**FY 2013 Request**
Fuel Cell Systems R&D	75,609	41,916	44,812	38,000
Hydrogen Fuel R&D	45,750	32,122	34,812	27,000
Technology Validation	13,005	8,988	9,000	5,000
Market Transformation	15,005	0	3,000	0
Safety, Codes & Standards	8,653	6,901	7,000	5,000
Education	2,000	0	0	0
Systems Analysis	5,408	3,000	3,000	3,000
Manufacturing R&D	4,867	2,920	2,000	2,000
Total	$170,297	$95,847	$103,624	$80,000

FY 13 House Mark $82 M

FY 13 Senate Mark $104 M

Notes: Hydrogen Fuel R&D includes Hydrogen Production & Delivery R&D and Hydrogen Storage R&D. FY11, FY12 include SBIR/STTR funds to be transferred to the Science Appropriation; prior years exclude this funding

FY 2010 to FY 2013 Request and Appropriation

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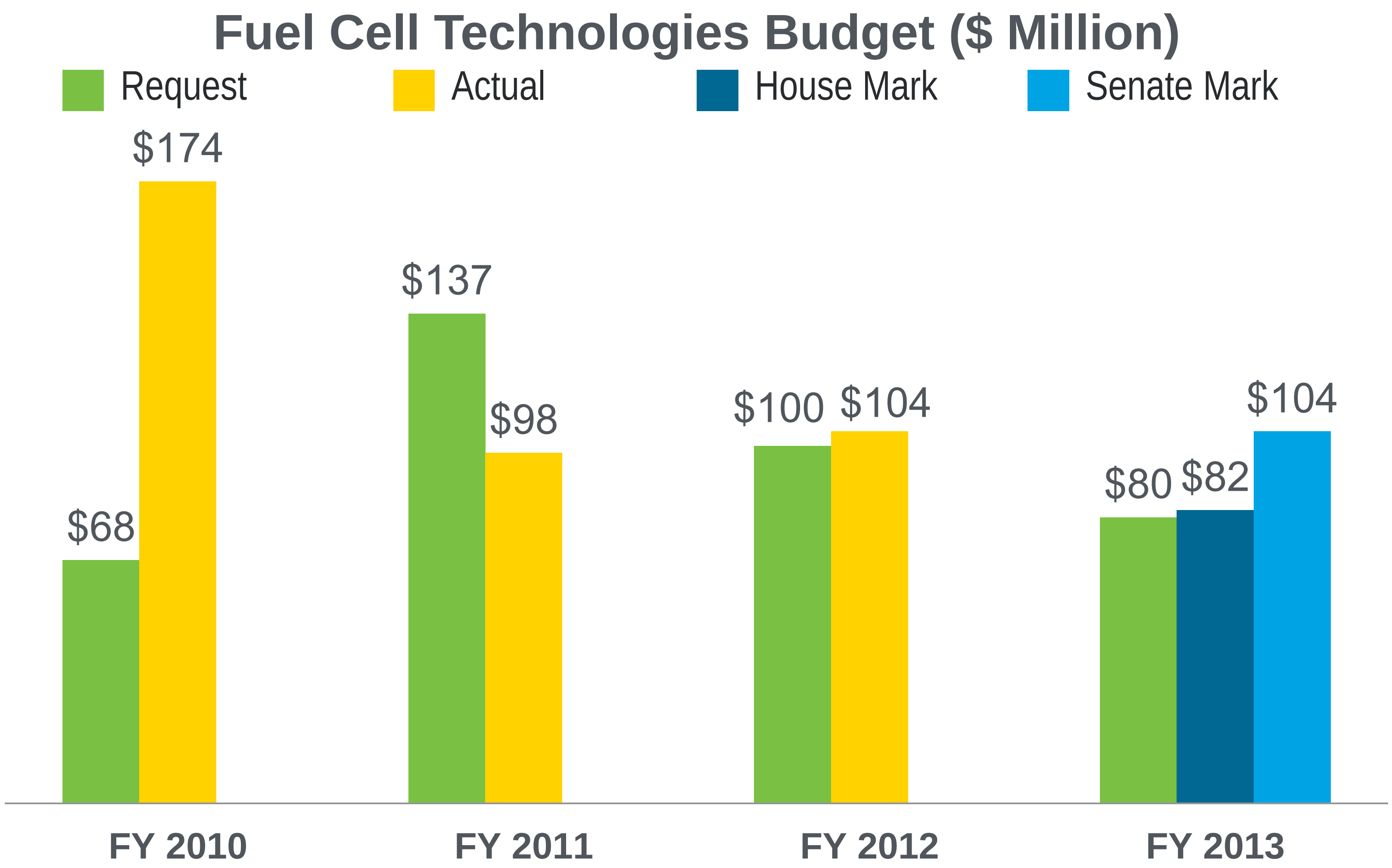
The Fuel Cell Technologies budget requests and appropriations summary



Funding Changes for New Awards

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The conference committee appropriation language changes how new R&D awards could be funded.

Excerpts from Language

"The conferees are concerned the Department is over-committing future budgets by announcing multi-year awards subject to future appropriations for a substantial portion of activities within Energy Programs."

"The Department is directed to transition to a model in which it fully funds multi-year awards with appropriated funds, except in the cases of major capital projects, management and operating contracts, and large research centers which require multi-year awards subject to appropriations."

POTENTIAL FUNDING CHANGES	
CURRENT SYSTEM	PROPOSED SYSTEM
Fund projects on a fiscal year basis	Fully fund all projects up front
Number of awards based on projected spending pattern	Fewer awards made since all funds must be available in current year
Quantitative Go/No Go milestones	Quantitative Go/No Go milestones

Methodology – Includes competitive review processes, peer reviews & risk analyses

Topic Selection

- **Stakeholders**
  - e.g.: RFIs, industry, etc.
- **U.S. DRIVE**
- **Peer Reviews**
  - NAS
  - GAO
  - Others

→

- **Targets**
- **"Critical Path" needs**
- **Technology Gaps**

→

RD&D Plan and Solicitation Topics

- **Risk Analysis**
- **Technology Reviews**

↓ **RD&D Plan and Solicitation Topics**

Example Fuel Cell Membrane Targets

Characteristic	Units	2011 status	2017 target	Nafion® NRE211
Maximum oxygen crossover	mA/cm²	<1	2	2.7
Maximum hydrogen crossover	mA/cm²	<1.8	2	2.2
Area specific resistance at:				
Max operating temp and 40 – 80 kPa water partial pressure	ohm cm²	0.023 (40 kPa) 0.012 (80 kPa)	0.02	0.186
80°C and water partial pressures from 25 - 45 kPa	ohm cm²	0.017 (25 kPa) 0.006 (44 kPa)	0.02	0.03-0.12
30°C and water partial pressures up to 4 kPa	ohm cm²	0.02 (3.8 kPa)	0.03	0.049
-20°C	ohm cm²	0.1	0.2	0.179
Operating temperature	°C	<120	≤120	120
Minimum electrical resistance	ohm cm²		1000	
Cost	$/m²		20	
Durability				
Mechanical	Cycles w/<10 sccm crossover	>20,000	20,000	5,000
Chemical	hours	>2,000	500	

Technical targets help guide go/no-go decisions.

Project & Program Review Processes

- Annual Merit Review & Peer Evaluation meetings (EE, NE, FE, SC)
- FreedomCAR & Fuel Partnership Tech Team reviews (monthly)
- Other peer reviews- National Academies, GAO, etc.
- DOE quarterly reviews and progress reports

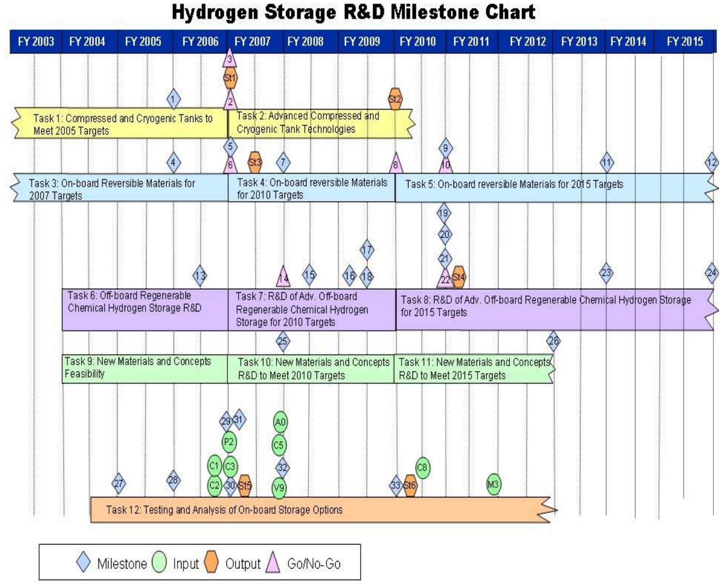
Project Number	Project Title *PI Name & Organization*	Final Score	Continue	Discontinue	Other	Summary Comment
123	Fluoroalkyl-Phosphonic-Acid-Based Proton Conductors *Xxx University*	2.7		X		Progress was made in molecular dynamics modeling of model compounds, but the membranes synthesized failed in testing and did not meet the conductivity targets. The project will not be continued.

Over $19M saved in the last 3 years through go/no-go decisions

Reviewer comments for projects posted online annually. Projects discontinued/ work scope altered based on performance & likelihood of meeting goals.

Subprogram Milestones and Targets - Examples

Each subprogram has detailed milestones, inputs, outputs, go-no go decision points and technical targets



Update of Multiyear RD&D Plan in process

Example- Target Table for Electrocatalysts

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

[a] single cell status – will require scale-up
[b] preliminary targets – approval pending
[c] after 30,000 cycles from 0.6 – 1.0 V; after 400 hours at 1.2 V
[d] after 400 hours at 1.2 V
[e] baseline @ 900mV$_{IR\text{-}free}$
[f] baseline @ 800mV$_{IR\text{-}free}$

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

Go / No-go Decisions & Independent Assessments

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

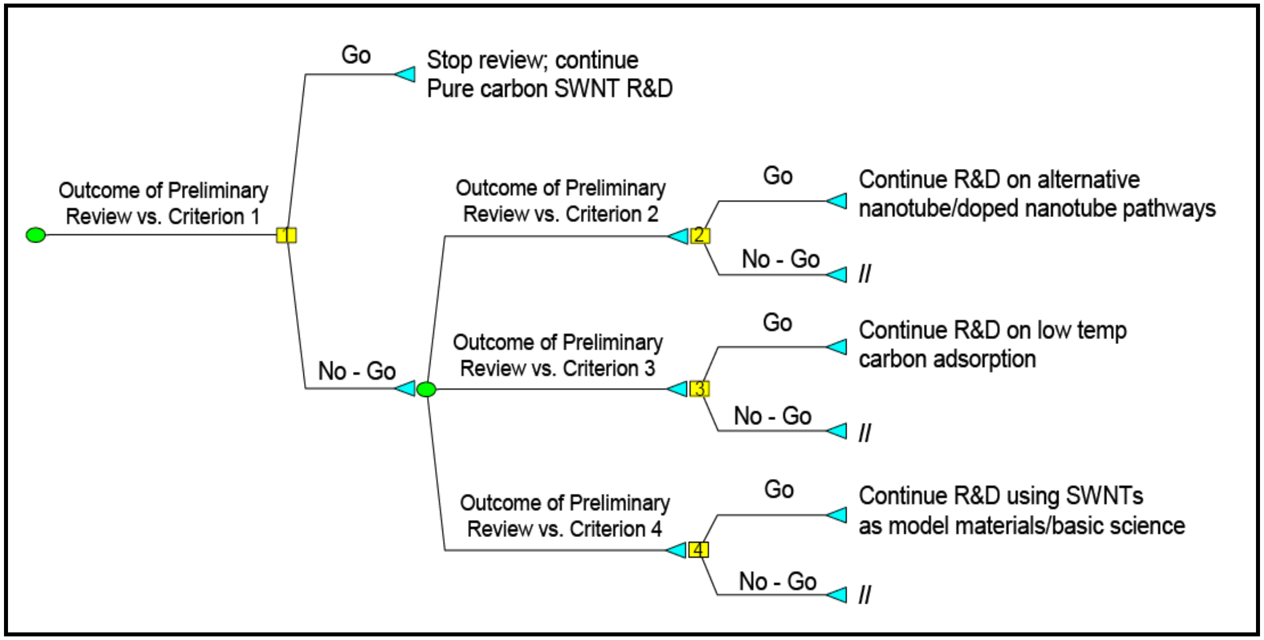
"Go / No-go" decisions are used in downselecting certain research pathways to focus on the most promising areas. They are defined by performance-based technical milestones and quantitative metrics. Expert Panels are convened for independent assessments.

A "no-go" decision

- May indicate that further advances in basic science are needed
- May eliminate an entire technology pathway

Key examples

- Single-walled Carbon Nanotubes — "no-go"
- Thermochemical Hydrogen Production — three cycles selected out of 350
- Sodium Borohydride for On-Board Vehicular Hydrogen Storage — "no-go"
- On-board Fuel Processing — "no-go"



The decision tree used by the Program in the process of down-selecting pure carbon single-walled nanotubes (SWNTs) for hydrogen storage.

As a result of the first no-go decision shown on the left side of the figure, funding was redirected to the areas shown on the right side of the figure.

"Go/No-Go Decision: Pure, Undoped Single-Walled Carbon Nanotubes for Vehicular Hydrogen Storage," U.S. Department of Energy, October 2006, www.hydrogen.energy.gov/pdfs/go_no_go_nanotubes.pdf.

Funding Opportunity Announcements & Request for Information

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

FY 2012 FOAs	$M
Collect Performance Data on Fuel Cell Electric Vehicles	$6.0
Hydrogen Fueling Stations and Innovations in Hydrogen Infrastructure Technologies	$2.0
Fuel Cell Powered Baggage Vehicles at Commercial Airports	$2.5
Zero-Emission Cargo Transport Vehicles (VTP)	$10.0

Request for Information

- Fuel Cell RFI on Preliminary Cost, Performance, and Durability Targets for Class I, II, and III Lift Trucks.
- Storage RFI on Early Market Targets
- Hydrogen Production RFI on Potential Topics for H-Prize

Examples of Key Activities: HTAC and Program Impact

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

- Annual Report
- Input on Program Requests
  - Feedback on H_2 Threshold Cost
  - H_2 Enabling Renewables Working Group (subcommittee)
  - H_2 Production Expert Panel
    - Comprised of experts from industry, academia and the national labs
    - Goals:
      - Evaluate current status of hydrogen production technologies
      - Identify remaining challenges
      - Prioritize R&D needs
      - Strategize how to best leverage R&D among DOE Offices and with other agencies

Tasked with establishing paths forward for the widespread production of affordable renewable hydrogen for current markets and future energy scenarios

Communication & Outreach

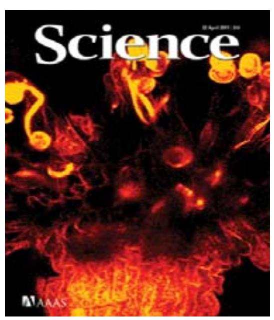
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

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
  - 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
- Monthly Newsletter
- Blogs

"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

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

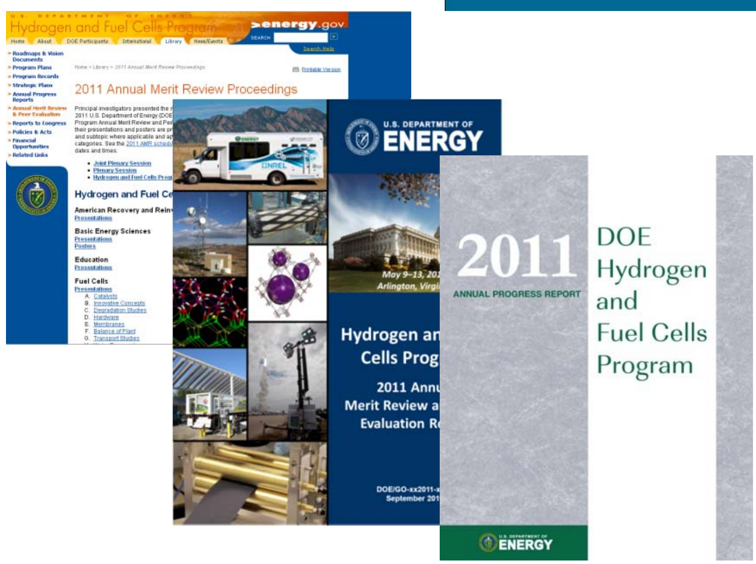
See report: ttp://www.fuelcells.org/StateoftheStates2011.pdf

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/

Partnerships & Collaboration

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.*

Universities

~ 50 projects with 40 universities

International

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

External Input

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

DOE Hydrogen & Fuel Cells Program

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

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

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

World Class Researchers - Examples

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

Adam Weber (LBNL) honored as Energy Technology Division Supramaniam Srinivasan Young Investigator Award from The Electrochemical Society in Seattle.

Scott Samuelsen (UC Irvine) named a White House Champion of Change for his work as Director of the Advanced Power and Energy Program and the National Fuel Cell Research Center.

Dr. Fernando Garzon (LANL) was elected President of the National Electrochemical Society (ECS).

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

Additional Information

Progress – Fuel Cells

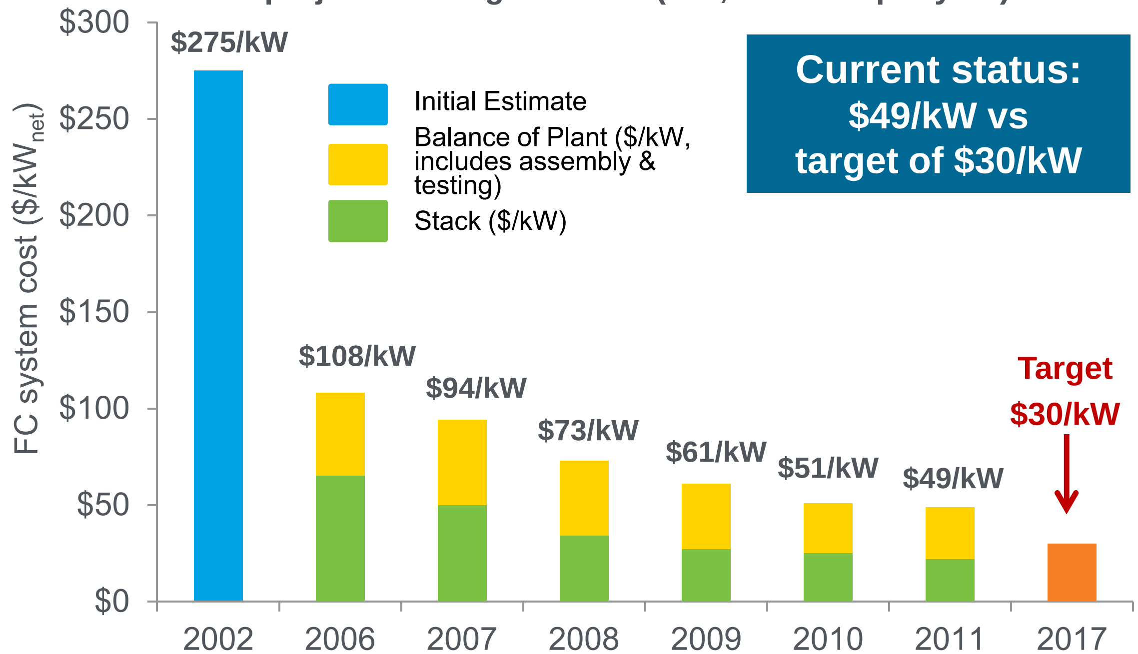
Projected high-volume cost of fuel cells has been reduced to $49/kW (2011)*

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

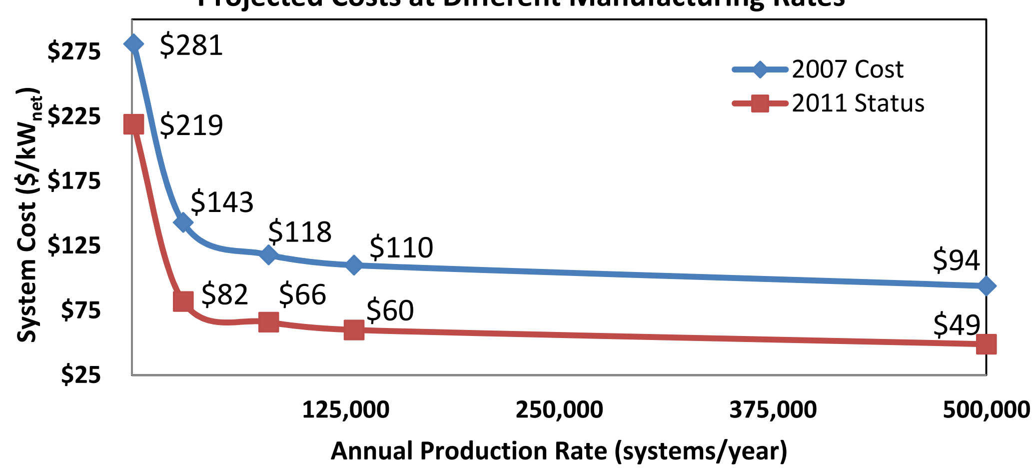
- ***More than 80% reduction since 2002***

Projected Transportation Fuel Cell System Cost

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



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.

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
- 3.6 million miles traveled
- 152,000 kg of hydrogen produced or dispensed
- 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 150,000 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)

State of the States

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

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.

Fuel Cells at the Olympics

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

UK H_2 Mobility plans fuel cell taxis at the 2012 London Olympics as a part of their greater goal to ensure the UK is positioned for the commercial roll-out of FCEVs

London landscape - largest urban zone in the EU with 23.8 million transport trips per average London day

- Clean Air Zone already implemented; clean-up of London buses (particulate filters, new hybrids); age limit to taxis; focus on ultra low emission vehicles (free access to congestion charge zones)
- Mayor Boris Johnson proponent – quoted in Leading to a Greener London: *"London has an unrivalled opportunity to benefit from an emphatic shift to a low carbon economy. The time for trials and experiments is over. We are putting in place large scale programmes that can deliver significant CO2 reductions and billions of pounds in energy savings"*
- The Greater London Authority has set aims and objectives to promote clean transportation via adoption of the London Hydrogen Action Plan :
  - Creating conditions for the deployment of hydrogen refuelling infrastructures
  - Considering all aspects of hydrogen supply and storage to ensure a future proof solution
  - Vehicle fleets (buses) being implemented in service

Intelligent Energy and HyTEC consortium is bringing the first zero emission taxi fleet to the streets of London for launch in time for the Olympics

5 taxis planned for use throughout Olympics

Portable Power Targets

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

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

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

APU Targets

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

Revised FCT fuel cell APU targets published in 2010

Characteristic	2011 Status	2013 Targets	2015 Targets	2020 Targets
Electrical efficiency at rated power[a]	25%	30%	35%	40%
Power density	17 W/L	30 W/L	35 W/L	40 W/L
Specific power	20 W/kg	35 W/kg	40 W/kg	45 W/kg
Factory cost, stack plus required BOP[b]	$750/kW[c]	$700/kW	$600/kW	$500/kW
Factory cost, system[d]	$2,000/kW	$1,400/kW	$1,200/kW	$1,000/kW
Transient response (10 to 90% rated power)	5 min	4 min	3 min	2 min
Start-up time from: 20 °C Standby conditions[e]	50 min 50 min	45 min 20 min	45 min 10 min	30 min 5 min
Degradation with cycling[f]	2.6%/1,000 h	2%/1,000 h	1.3%/1,000 h	1%/1,000 h
Operating lifetime[f, g]	3,000 h	10,000 h	15,000 h	20,000 h
System availability[h]	97%	97.5%	98%	99%

Assumptions and supporting information can be found here:
http://hydrogen.energy.gov/pdfs/11001_apu_targets.pdf

APU targets were developed using:
- **Comparison with incumbent technology (diesel ICE APUs)**
- **An RFI process to obtain input from stakeholders**
- **Direct discussion with developers**

Example: 2020 power density target

Stakeholder recommendations: 20 – 55 W/L

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

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

Micro-CHP Targets

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

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

Characteristic	2011 Status	2015 Targets	2020 Targets
Electrical efficiency at rated power[b]	34-40%	42.5%	>45% [c]
CHP energy efficiency[d]	80-90%	87.5%	90%
Equipment cost[e], 2-kW $_{avg}$[f] system	NA	$\$1,200/kW_{avg}$	$\$1,000/kW_{avg}$
Equipment cost[e], 5-kW $_{avg}$ system	\$2,300 - \$4,000/kW[g]	$\$1,700/kW_{avg}$	$\$1,500/kW_{avg}$
Equipment cost[e], 10-kW$_{avg}$ system	NA	$\$1,900/kW_{avg}$	$\$1,700/kW_{avg}$
Transient response (10 90% rated power)	5 min	3 min	2 min
Start-up time from 20°C ambient temperature	<30 min	30 min	20 min
Degradation with cycling[h]	<2%/1,000 h	0.5%/1,000 h	0.3%/1,000 h
Operating lifetime[i]	12,000 h	40,000 h	60,000 h
System availability[j]	97%	98%	99%

Assumptions and supporting information can be found here:
http://hydrogen.energy.gov/pdfs/11016_micro_chp_target.pdf

2010 Independent Assessment of CHP Fuel Cell Status & Targets

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

EERE Budget Appropriations and Request

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

Funding ($ in thousands)				
EERE Program	**FY 2010 Appropriation**	**FY 2011 Allocation**	**FY 2012 Appropriation**	**FY 2013 Request**
Hydrogen & Fuel Cell Technologies	170,297	95,847	103,624	80,000
Biomass & Biorefinery Systems R&D	216,225	179,979	199,276	270,000
Solar Energy	243,396	259,556	288951	310,000
Wind Energy	79,011	78,834	93,254	95,000
Geothermal Technologies	43,120	36,992	37,862	65,000
Water Power	48,669	29,201	58,787	20,000
Vehicle Technologies	304,223	293,151	328,807	420,000
Building Technologies	219,046	207,310	219,204	310,000
Advanced Manufacturing	94,270	105,899	115,580	290,000
Federal Energy Management Program	32,000	30,402	29,891	32,000
Facilities & Infrastructure	19,000	51,000	26,311	26,400
Weatherization and Intergovernmental	270,000	231,300	128,000	195,000
Program Direction	140,000	170,000	165,000	164,700
Strategic Programs	45,000	32,000	25,000	58,900
Adjustments	292,135	(29,750)	(9,909)	(69,667)
Total	**$2,216,392**	**$1,771,721**	**$1,809,638**	**$2,267,333**

FY 13 House Mark (HFCT) $82M

FY 13 Senate Mark (HFCT) $104 M

DOE Hydrogen Budget

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

	Funding *($ in thousands)*						
	FY 2007 Approp.	FY 2008 Approp.	FY 2009 Approp.	FY 2010 Approp.	FY 2011 Allocation	FY 2012 Approp.	FY 2013 Request
EERE Hydrogen & Fuel Cells	189,511	206,241	195,865	170,297	95,847	101,087	77,850
Fossil Energy (FE)	21,513	14,891	20,151	13,970	11,394	0	0
Nuclear Energy (NE)	18,855	9,668	7,340	5,000	2,800	0	0
Science (SC)	36,388	36,483	38,284	38,053	34,611	~34,611	TBD
DOE TOTAL	**266,267**	**267,283**	**261,640**	**227,320**	**144,652**	**~135,698**	**TBD**

EERE FY 13 House Mark: $82 M

EERE FY 13 Senate Mark: $104 M

SECA House & Senate Mark: $25 M

Notes
Nuclear Energy: In 2010 and 2011, development of HTSE at the Idaho National Laboratory (INL) continued with funding from the NGNP project. Several industry partners now have stack technologies for high temperature steam electrolysis in development. After demonstration of pressurized HTSE stack operation in FY 2012 by INL, the technology readiness is expected to be sufficiently advanced (TRL5) to allow for further development by industry.
EERE: FY 2012 appropriation and FY 2013 request exclude the estimated SBIR/STTR funding.