National Fuel Cell and Hydrogen Energy Overview

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

Total Energy USA
Houston, Texas
11/27/2012

Dr. Sunita Satyapal

Director, Office of Fuel Cell Technologies
Energy Efficiency and Renewable Energy
U.S. Department of Energy

National Support for Clean Energy

"We've got to invest in a serious, sustained, all-of-the-above energy strategy that develops every resource available for the 21st century."

– President Barack Obama

"Advancing hydrogen and fuel cell technology is an important part of the Energy Department's efforts to support the President's all-of-the-above energy strategy, helping to diversify America's energy sector and reduce our dependence on foreign oil."

- Energy Secretary Steven Chu

"Fuel cells are an important part of our energy portfolio…deployments in early markets are helping to drive innovations in fuel cell technologies across multiple applications."

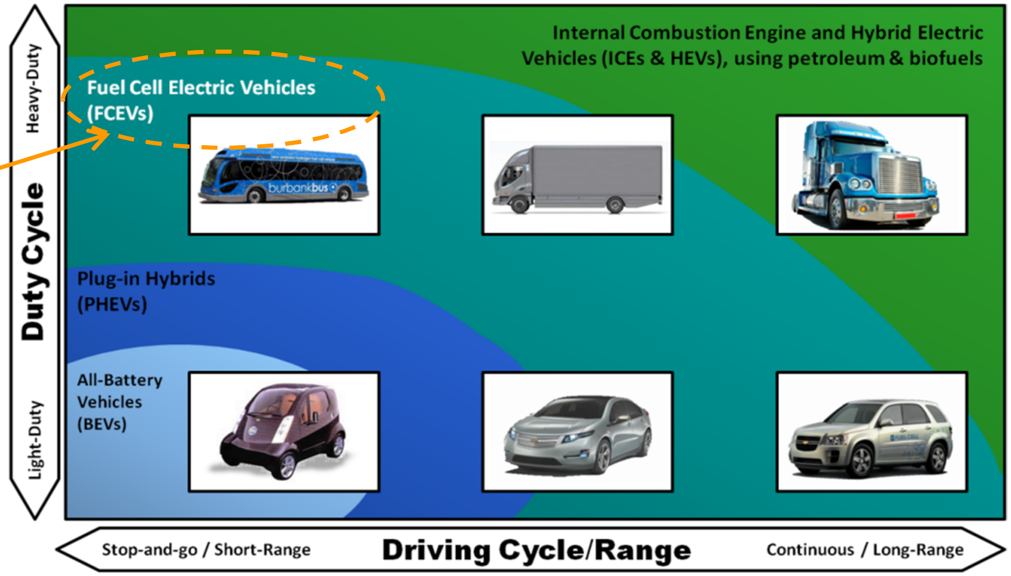
- Dr. David Danielson
Assistant Secretary for Energy Efficiency and Renewable Energy

Portfolio Examples

Transportation: A diverse portfolio to meet the full range of driving cycles and duty cycles in the nation's vehicle fleet.

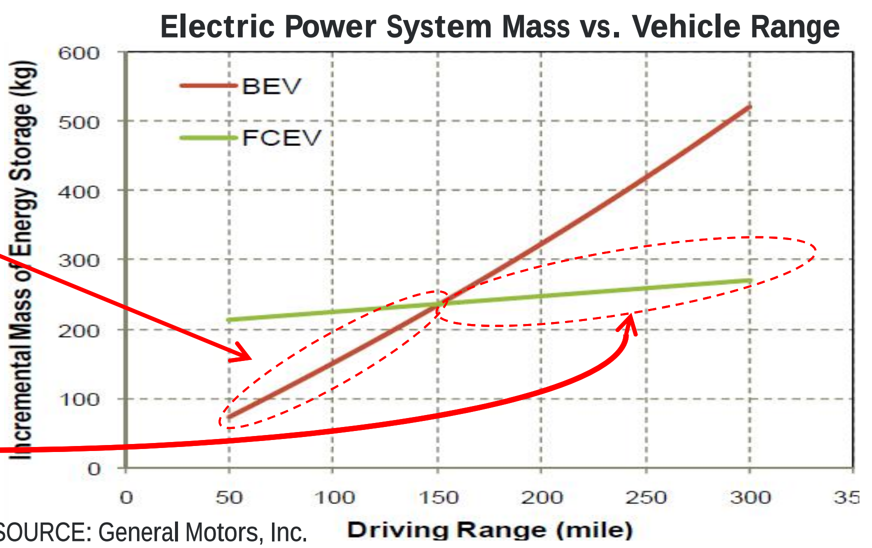
H_2 and fuel cells can play a key role

— by enabling longer driving ranges and heavier duty cycles for certain vehicle types *(including **buses**, **light-duty cars & trucks**, **delivery vans**, and **short-haul trucks**)*



Advantages of Batteries and Fuel Cells:

- For shorter distances, batteries are more effective in terms of system mass
- ***Fuel cells can provide the driving ranges of today's vehicles without the weight penalty***
- ***But there are challenges: H_2 production, infrastructure, fuel cell cost & durability***



SOURCE: General Motors, Inc.

Hydrogen: A Diverse Energy Carrier

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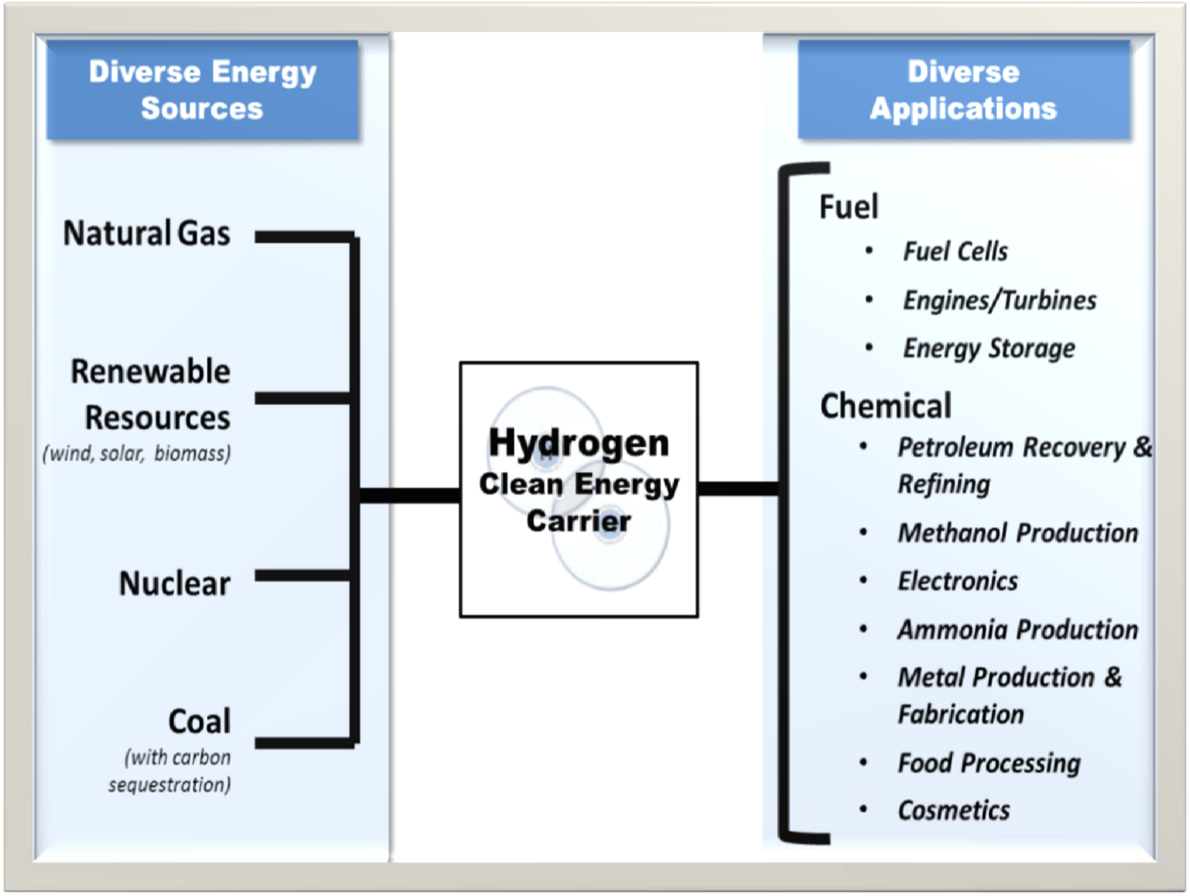

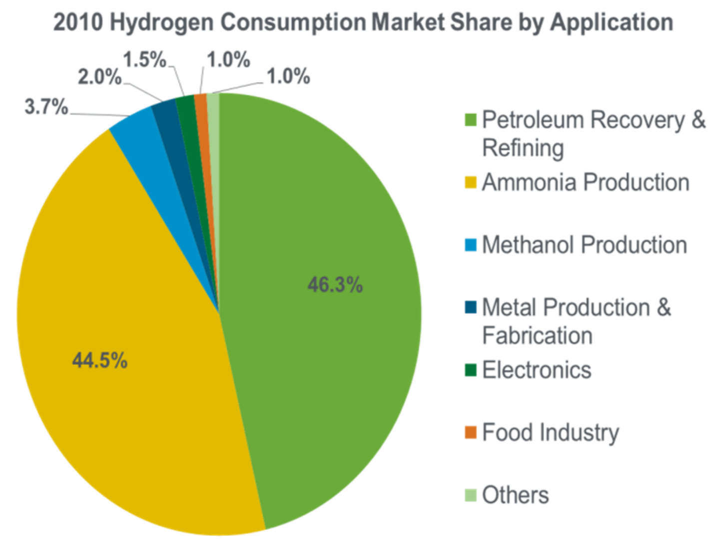

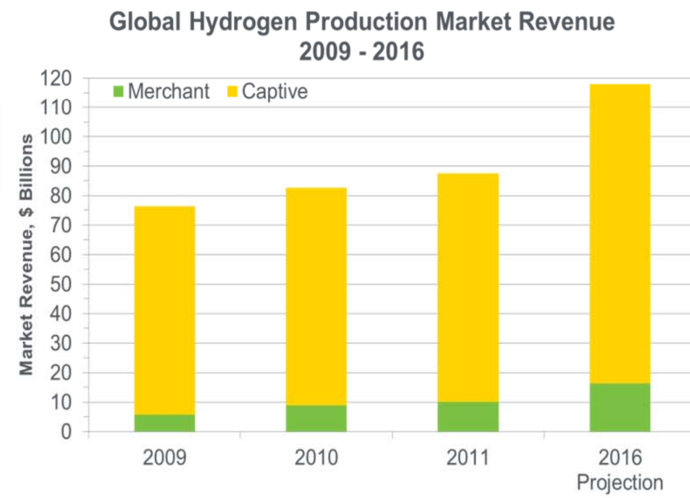

- H_2 can be produced from diverse domestic resources
- ~95% of U.S. H_2 comes from natural gas reforming
- ~30% growth estimated for global production by 2016 $118 billion in market revenues projected

Fuel Cells Overview and Benefits

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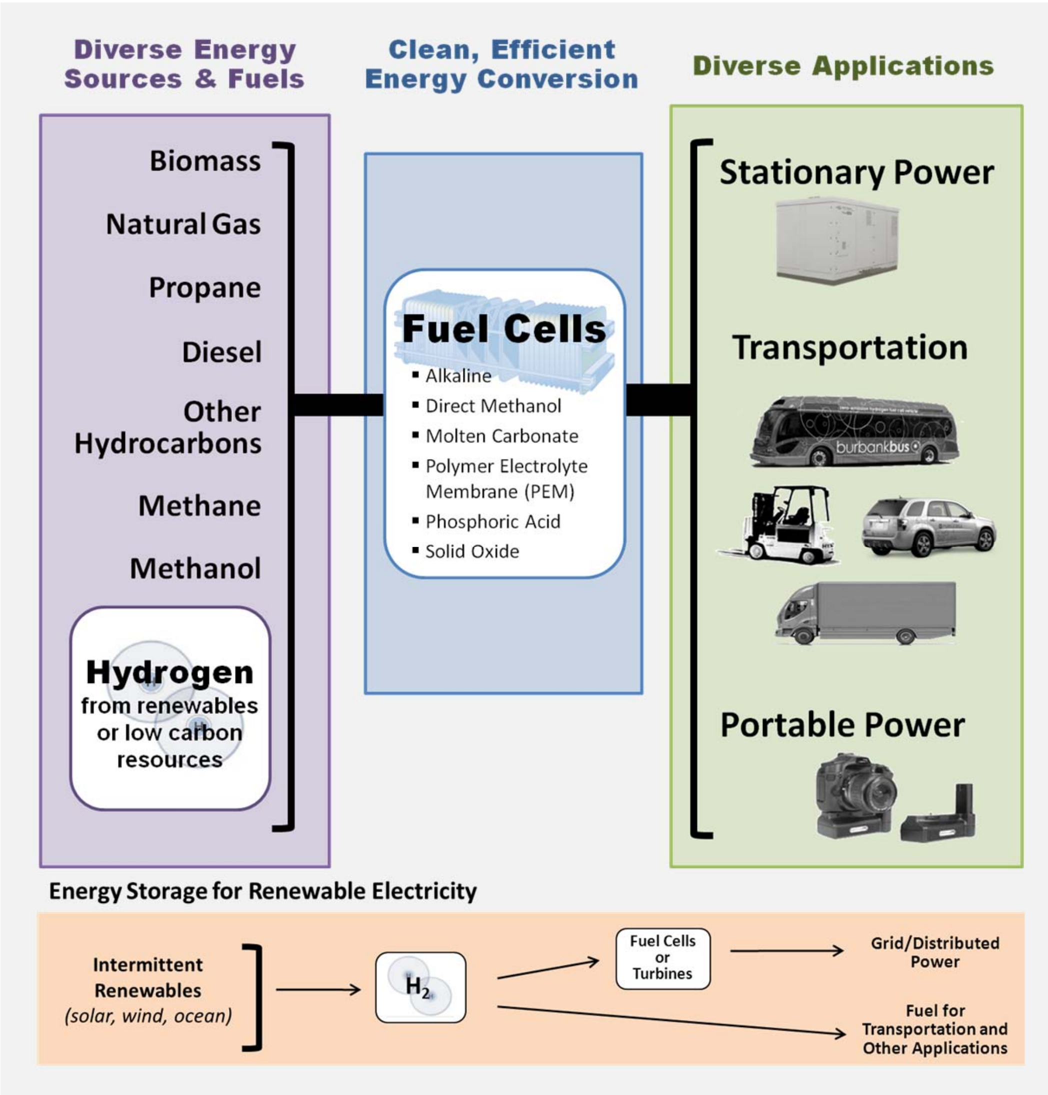
The Role of Fuel Cells



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)*

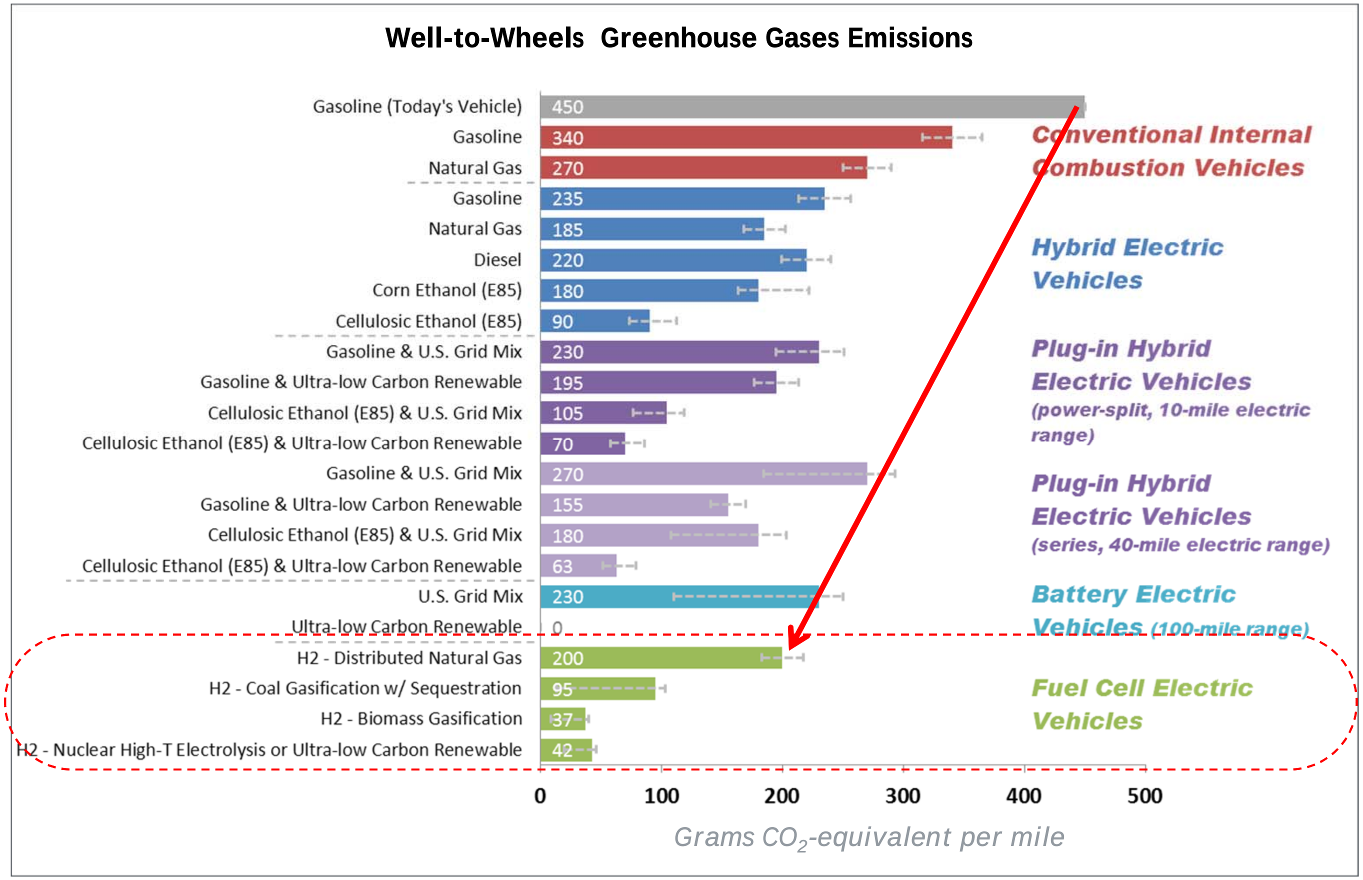
Reduced Air Pollution

- **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*

Analysis by DOE -Argonne National Lab, DOE Vehicle Technologies Program, and Fuel Cell Technologies 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*

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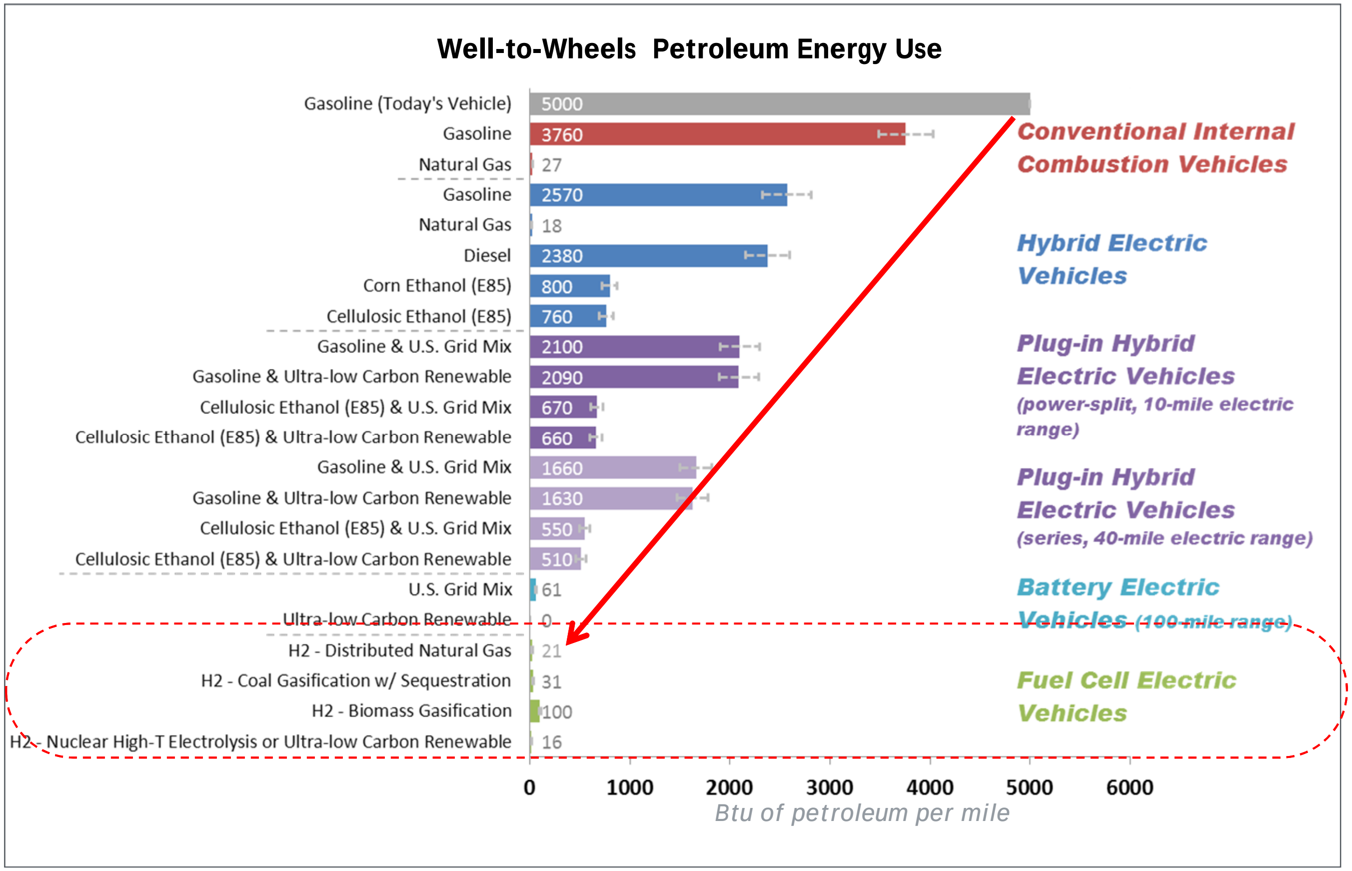

H_2 from Natural Gas

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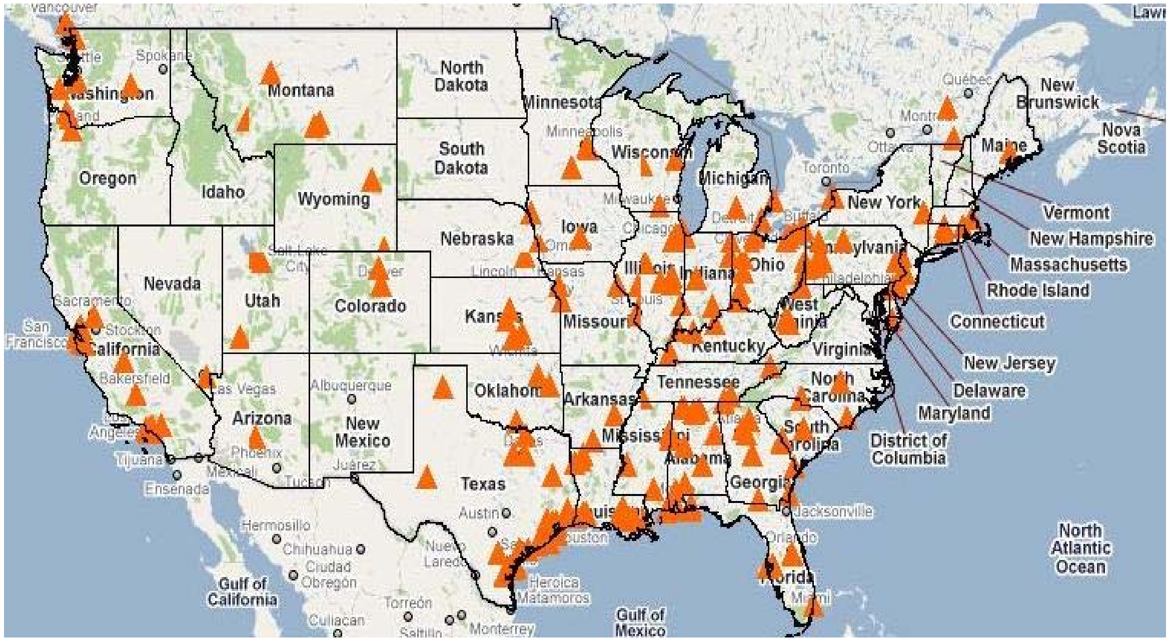
** 1 million FCEVs would require ~1 billion cubic meters/year of NG; current NG consumption is about 600 billion cubic meters/yr*

Current Hydrogen Infrastructure

Current Status

- Over **9 million metrics tons** of hydrogen produced per year
- Over **1,200 miles** of hydrogen pipelines in use (CA, TX, LA, IL, and IN)
- Hydrogen is delivered via liquid tank truck and gas tube trailer.
- There are more than **50 fueling stations** in the U.S.

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 (Air Products).**

Hydrogen Production Strategies

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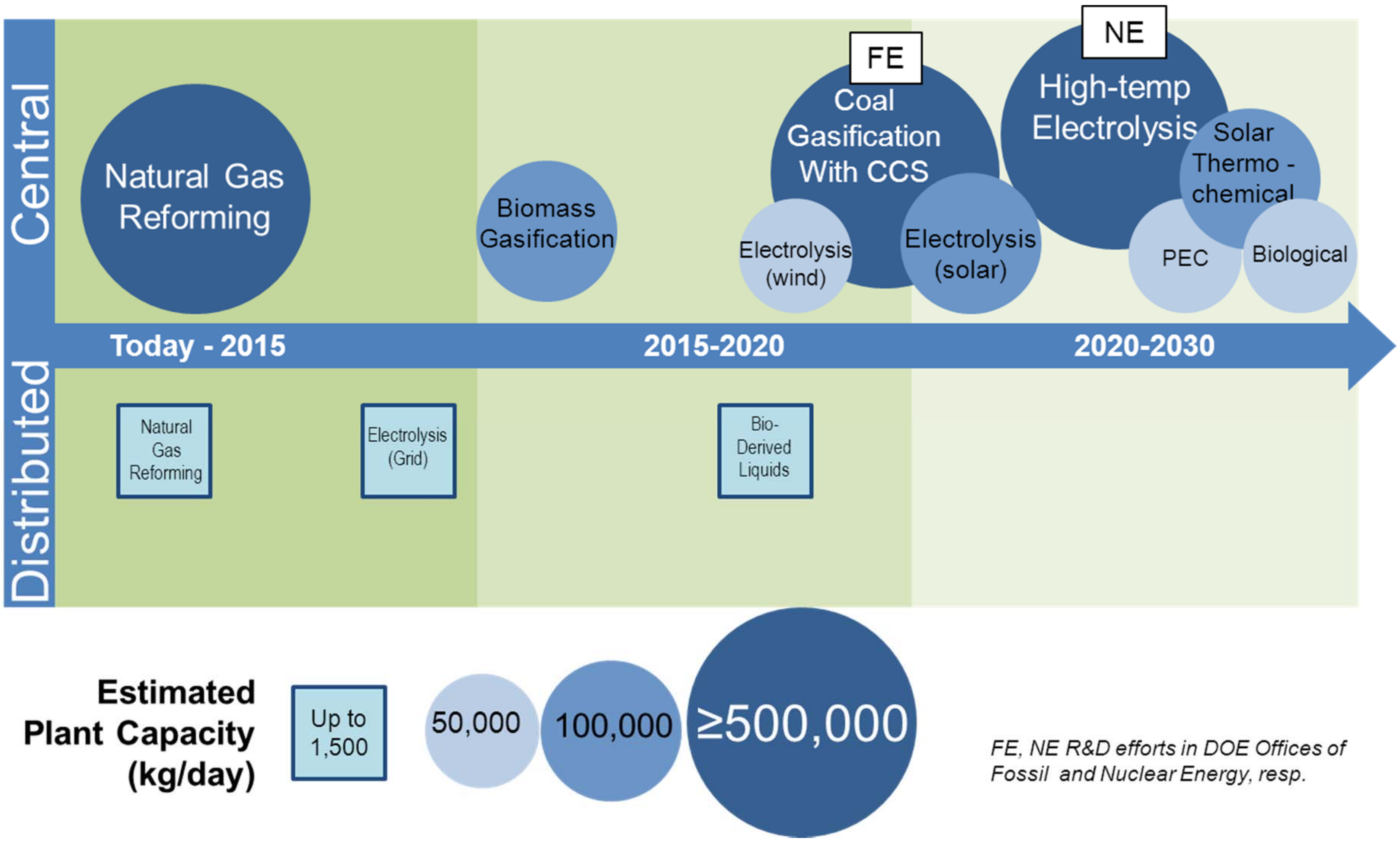
Goal: Develop technologies to produce hydrogen from clean, domestic resources at a delivered and dispensed cost of $2-$4/gge H_2 by 2020



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

Techno-economic Pathway Analysis

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The 2012 “new & improved” H2A Model v3 with unified cost assumptions

General Features

User Input
- Process modeling
- Vendor quotes
- Literature sources

H2A Values
- AEO fuel prices
- Fuel properties
- GREET emissions factors
- Industry cost indexes

H2A Calculations
- Cost escalation
- Plant Scaling
- Financial Calculations
- Cash flow calculations and leveled cost of hydrogen

Improvements

- **Streamlined and clarified user input**
- **Updated H2A “Built-In” database**
- **New plant scaling and CSD calculations**
- **Allows for across-the-board assessment of status and targets for production pathways**

Updated Production Targets*

		2010 Status	2015 Target	2020 Target	Ultimate Production Target
Distributed	Electrolysis from grid electricity	$4.10	$3.90	$2.30	$1-$2
Distributed	Bio-derived Liquids (based on ethanol reforming case)	$6.65	$5.10	$2.25	
Central	Electrolysis From renewable electricity	$4.10	$3.00	$2.00	
Central	Biomass Gasification	$2.20	$2.10	$2.00	
Central	Solar Thermochemical	NA	$8.00	$3.00	
Central	Photoelectrochemical	NA	$26.00	$4.00	
Central	Biological	NA	NA	$10.00	

**Production only. Preliminary numbers. All units are per gge*

Apportionment of Threshold Cost: $1-$2/gge for production, $1-$2/gge for delivery.

H_2 Production Cost Challenge

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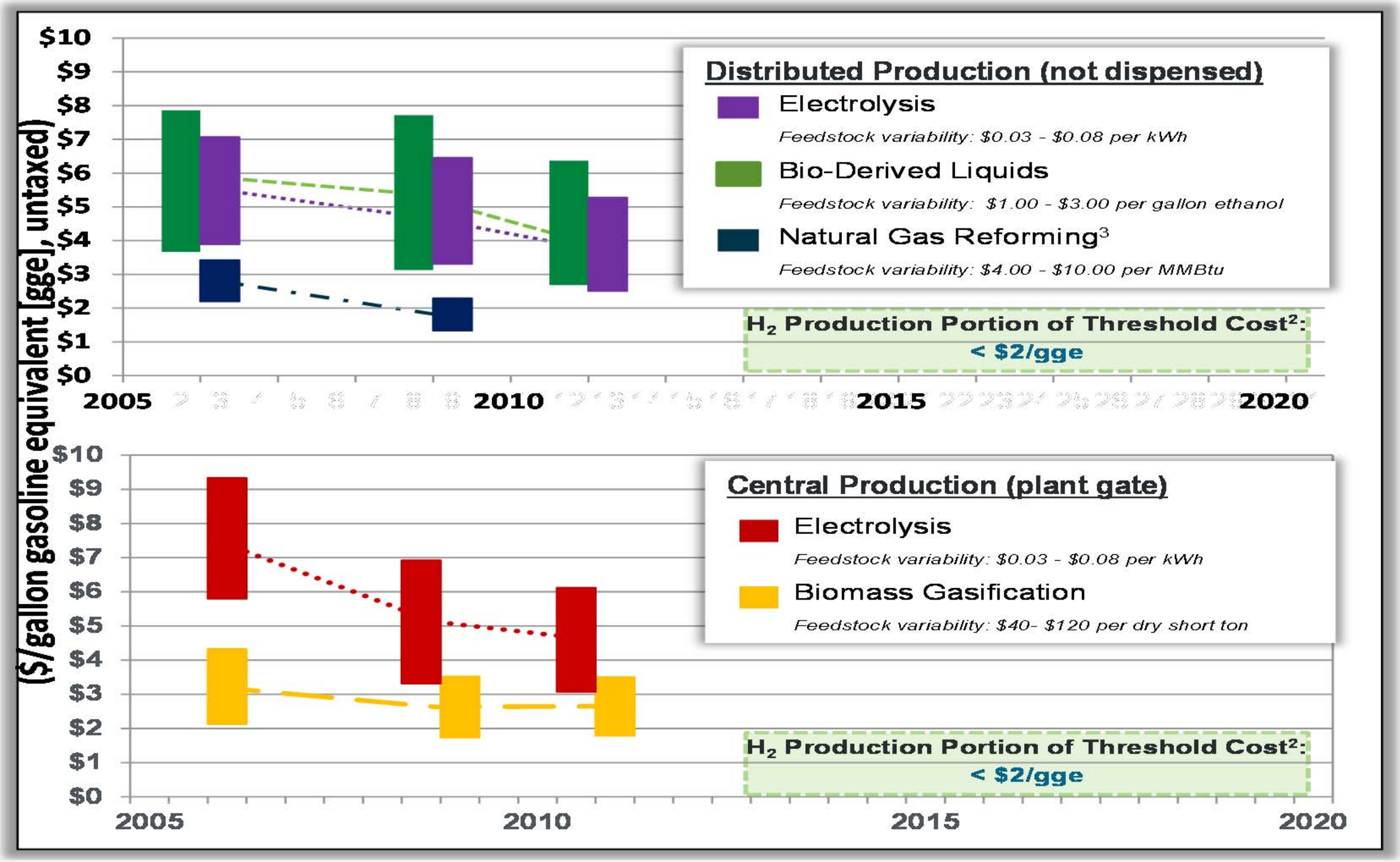
Natural gas reforming can provide H_2 production for expanding near-term fuel cell applications and serve as a bridge to longer-term low-carbon alternative pathways.

Projected High-Volume Cost of Hydrogen Production with Feedstock Sensitivities[1]



Notes:[1] ***Based on projections from H2A analyses, excludes delivery and dispensing costs. Projections of costs assume N^{th}-plant construction, distributed station capacities of 1,500 kg/day, and centralized station capacities of ≥50,000 kg/day. [2] The H2 Production Threshold Cost of <$2/gge reflects the Production apportionment***

Technology Validation—Tri-Generation

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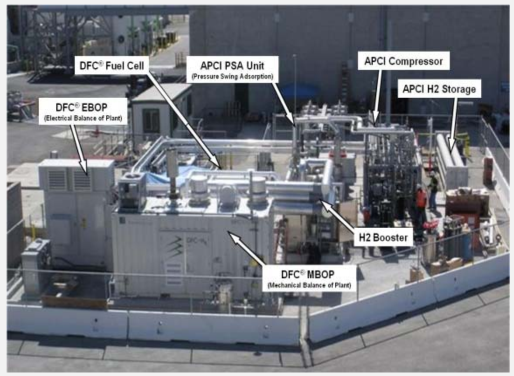
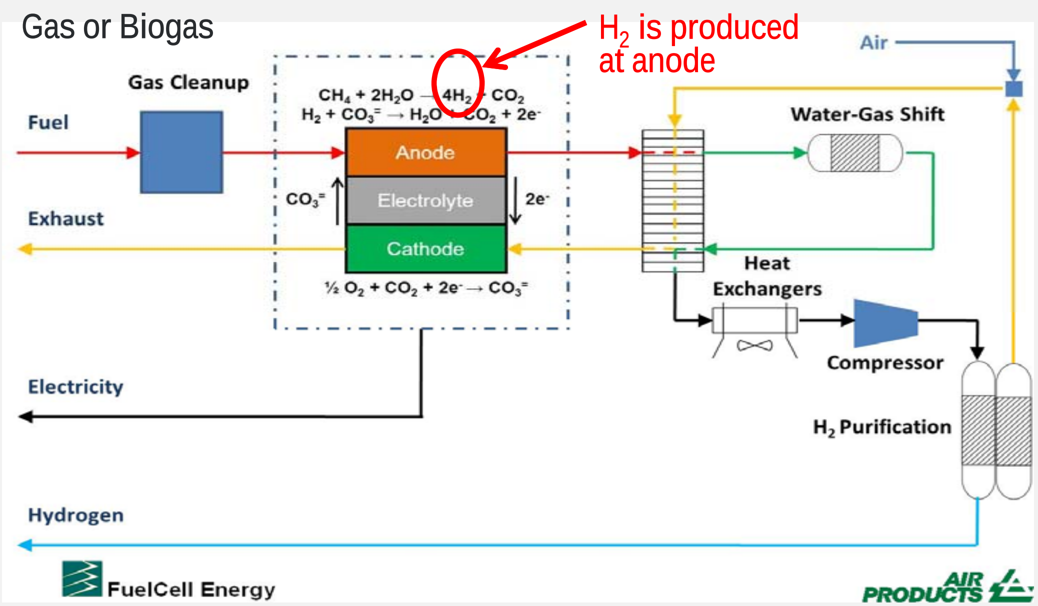
"Energy Department Applauds World's First Fuel Cell and Hydrogen Energy Station in Orange County"

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.

Options for Early Hydrogen Infrastructure

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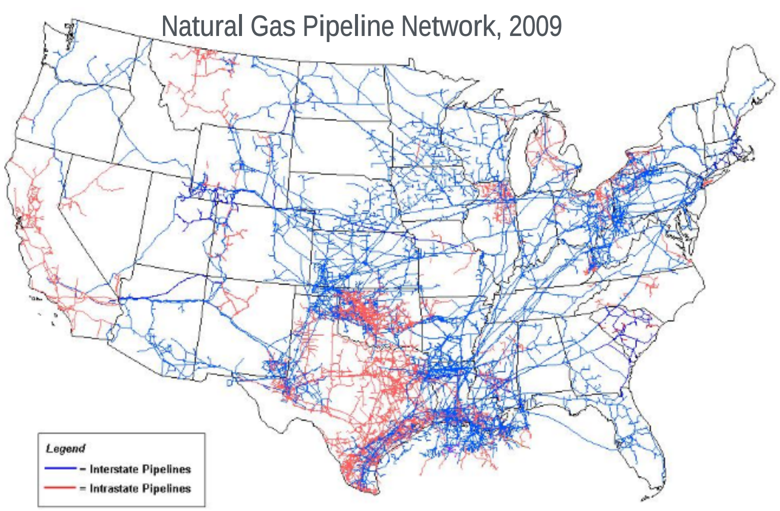
Two Main Options for Low-cost Early Infrastructure

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

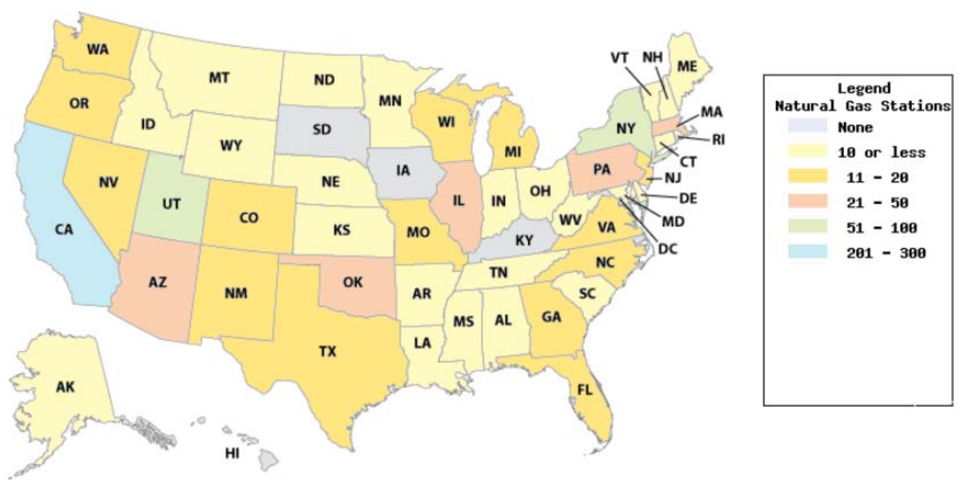
Other options

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

Natural Gas Pipeline Network, 2009



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



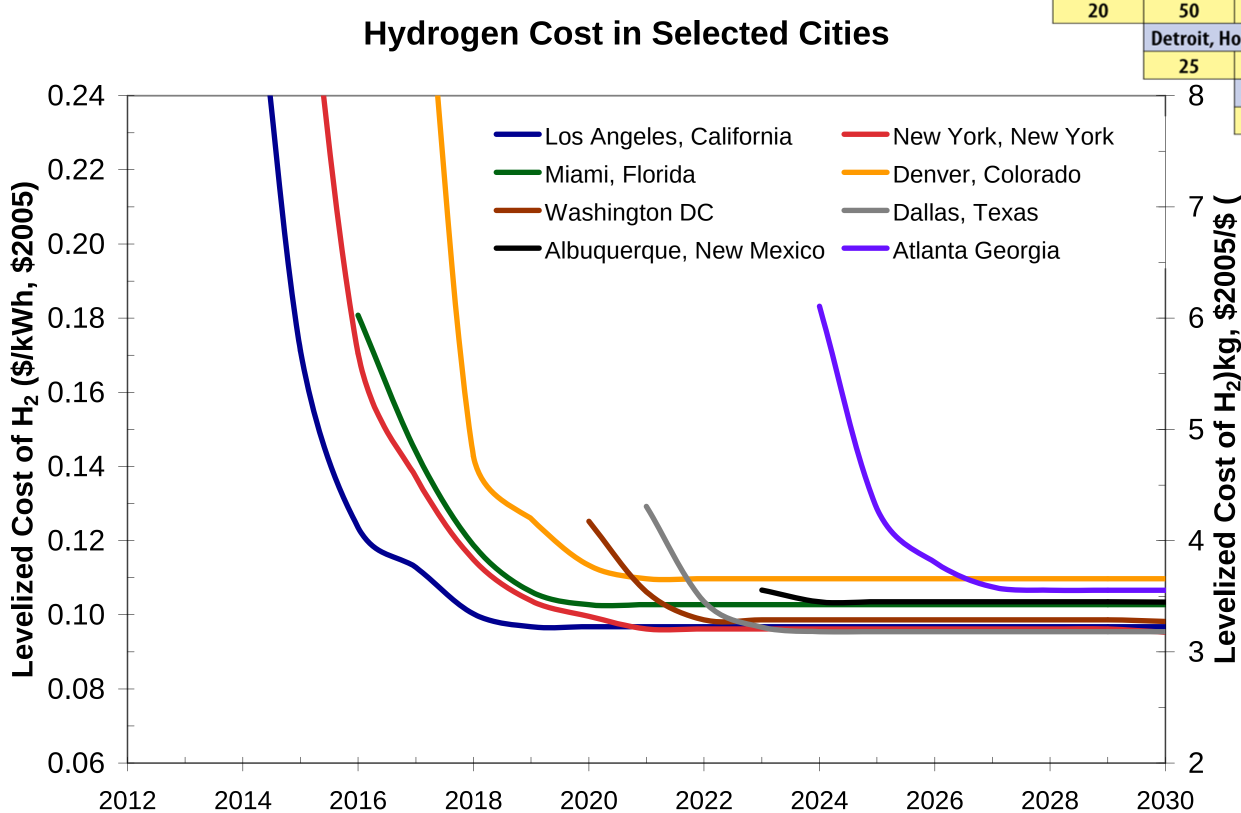
Natural gas fueling stations

Hydrogen Cost – Infrastructure Analysis

Early hydrogen cost is high, but falls with increasing scale to $3-4/gge.

Analysis is underway to determine cost reduction scenarios

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Los Angeles	1	2	2	25	40	50	85	120	160	190	210	250	270	300
New York, Chicago				25	40	50	85	120	150	175	185	225	240	270
San Francisco, Washington/Baltimore					20	30	55	85	120	140	160	190	210	230
Boston, Philadelphia, Dallas						20	50	85	120	145	165	195	210	220
Detroit, Houston							25	50	80	120	140	160	190	210
Atlanta, Minneapolis, Miami								40	75	100	115	130	160	180
Cleveland, Phoenix, Seattle									45	70	90	120	150	170
Denver, Pittsburgh, Portland, St. Louis, Cincinnati, Indianapolis, Kansas City										60	80	110	130	150
Milwaukee, Charlotte, Orlando, Columbus, Salt Lake City											55	80	110	130
Nashville, Buffalo, Raleigh												40	70	90
Nationwide													260	540



Source: J. Ogden and C. Yang, "Build-up of a hydrogen infrastructure in the US," Chapter 15, in The Hydrogen Economy: Opportunities and Challenges, edited by Dr Michael Ball and Dr Martin Wietschel, Cambridge University Press, 2009, pp.454-482.

Challenges & Barriers

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Distributed Production

Bioderived Liquid Reforming
- Capital costs
- Operation and Maintenance costs
- Design for manufacturing
- Feedstock quantity and quality

Electrolysis
- System efficiency and capital costs
- Integration with renewable energy sources
- Design for manufacturing

Central Production

Solar Thermochemical
- Cost-effective reactor
- Effective and durable construction materials

Photoelectrochemical
- Effective photocatalyst material

Biological
- Sustainable H_2 production from microorganisms
- Optimal microorganism functionality
- Cost effective reactor materials

Biomass Gasification
- Capital costs
- Feedstock costs & purity
- System efficiency

Delivery

Forecourt
- Compressor reliability
- Station infrastructure (compression, storage, and dispensing) costs

Tube Trailer Delivery
- Vessel capacity

Liquid Delivery
- Liquefaction efficiency & associated GHG emissions

Pipelines
- Embrittlement/cyclic fatigue effects on pipeline steel
- Infrastructure installation and lifetime costs

Analysis & Standards
- Impact of code requirements
- Trade study: production pressure vs. station compression.

Materials durability, efficiency improvements, and capital cost reductions are key challenges for all pathways

Challenges: Delivery

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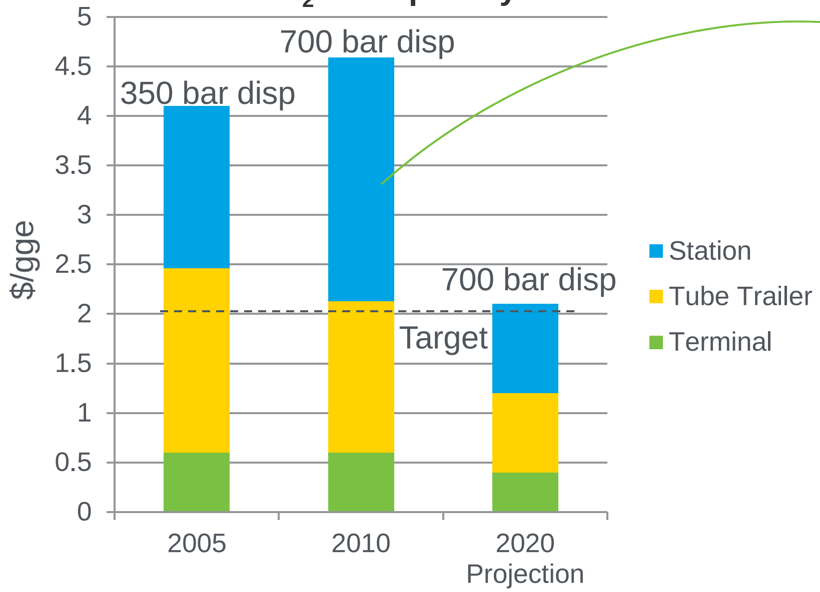
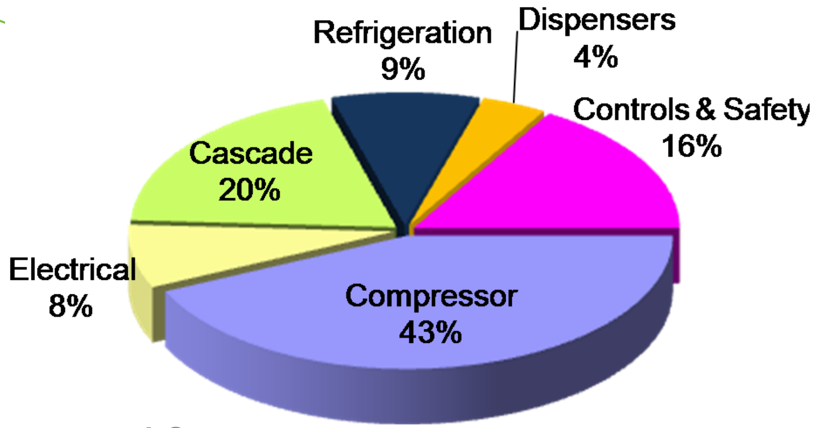
Station costs dominate delivery costs—key focus area.

Pathway Cost

Ex: CGH_2 Transport by Tube Trailer



Refueling Station (2011 Technology)



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*Based on preliminary HDSAM (v2.3) analysis assuming 15% market penetration in a city with a population of 1.2M

Fueling Station (CSD) Costs

	2011 Projected Cost*	2020 Projected Cost*
Centralized Production	$1.90/kg	$1.30/kg
Distributed Production	$2.50/kg	$1.70/kg

FY2012 Analysis Focus

- ✓ Identify cost drivers for H_2 delivery in early market applications
- ✓ Evaluate options to improve station compressor reliability
- ✓ Investigate the role of high-pressure tube trailers in reducing station costs

Safety, Codes and Standards

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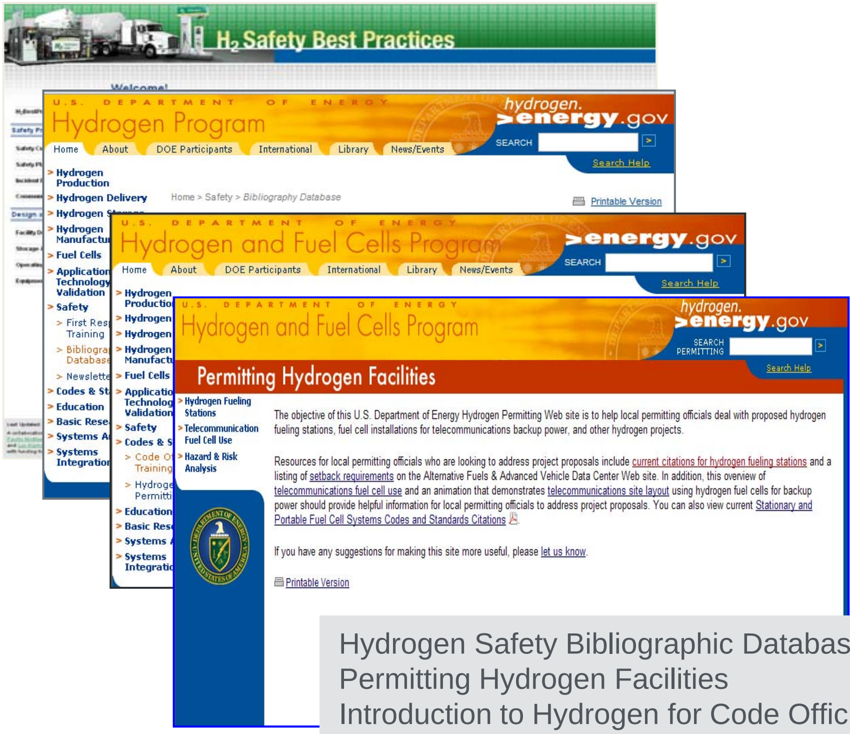

Hydrogen Safety Bibliographic Database
Permitting Hydrogen Facilities
Introduction to Hydrogen for Code Officials
Hydrogen Safety Best Practices Manual

H_2 Safety Snapshot bulletin
Introduction to Hydrogen Safety for First Responders
Hydrogen Incident Reporting Database

- Trained > 23,000 first-responders and code officials on hydrogen safety and permitting through on-line and in-classroom courses
- 206 Lessons Learned Events in "H2Incidents.org"
- Approximately 750 entries in the Hydrogen Safety Bibliographic Database

www.eere.energy.gov/hydrogenandfuelcells/codes/

Funding Opportunity Announcements (FOAs)- Examples

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Recent Relevant FOAs	$M Planned
Collect Performance Data on Fuel Cell Electric Vehicles	$6.0
Hydrogen Fueling Stations and Innovations in Hydrogen Infrastructure Technologies	$2.4
Fuel Cell Powered Baggage Vehicles at Commercial Airports	$2.5
Fuel Cell Hybrid for Refrigerated Truck Delivery (PNNL)	$0.65
Zero-Emission Cargo Transport Vehicles (VTP)	$10.0
Hydrogen Production Cost Analysis	Up to $1.0
SBIR: Dispenser Hose Assemblies (active)	Phase 1 $0.15 Phase 2 $1.0
Total	**$23.7M**

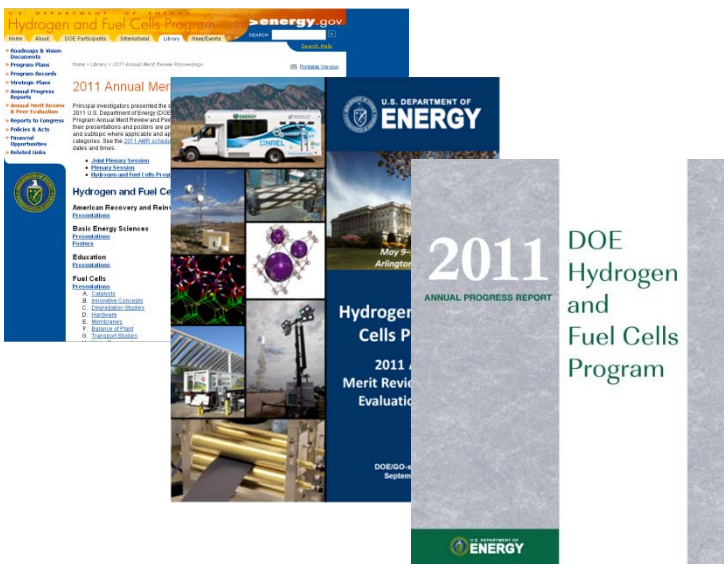
Key Reports

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

Pathways to Commercial Success: Technologies and Products Supported by the Fuel Cell Technologies Program
By PNNL, http://www.pnl.gov/
See report: http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/pathways_2011.pdf

The Business Case for Fuel Cells 2011: Energizing America's Top Companies
By FuelCells2000, http://www.fuelcells.org
See report:
http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/business_case_fuel_cells_2011.pdf

State of the States 2011: Fuel Cells in America
By FuelCells2000, http://www.fuelcells.org
See report:
http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/stateofthestates2011.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 13– 17, 2013 Arlington, VA
http://annualmeritreview.energy.gov/

Acknowledgements- World Class Researchers

Professor Thomas Jaramillo (Stanford) received a 2012 Presidential Early Career Award for Scientists & Engineers (PECASE). PECASE is the highest honor bestowed by the U.S. government on outstanding scientists and engineers who are early in their independent research careers. Jaramillo is the first ever EERE awardee.

Dr. Adam Weber (LBNL) and Professor Vijay Ramani (IIT) honored as Energy Technology Division Supramaniam Srinivasan Young Investigator Award from The Electrochemical Society in Seattle.

Professor 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).

Dr. Radoslav Adzic (BNL) honored as 2012 Inventor of the Year by the NY Intellectual Property Law Association.

Other 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

Thank You

Sunita.Satyapal@ee.doe.gov

New energy data initiative to share the latest energy information and data. Please visit:

http://en.openei.org/wiki/Gateway:Hydrogen

hydrogenandfuelcells.energy.gov