Fuel Cell Technologies

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

Overview

April 2, 2013

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U.S. Department of Energy
Fuel Cell Technologies Office
Market Transformation

Benefits: Well-to-Wheels CO_2 Analysis

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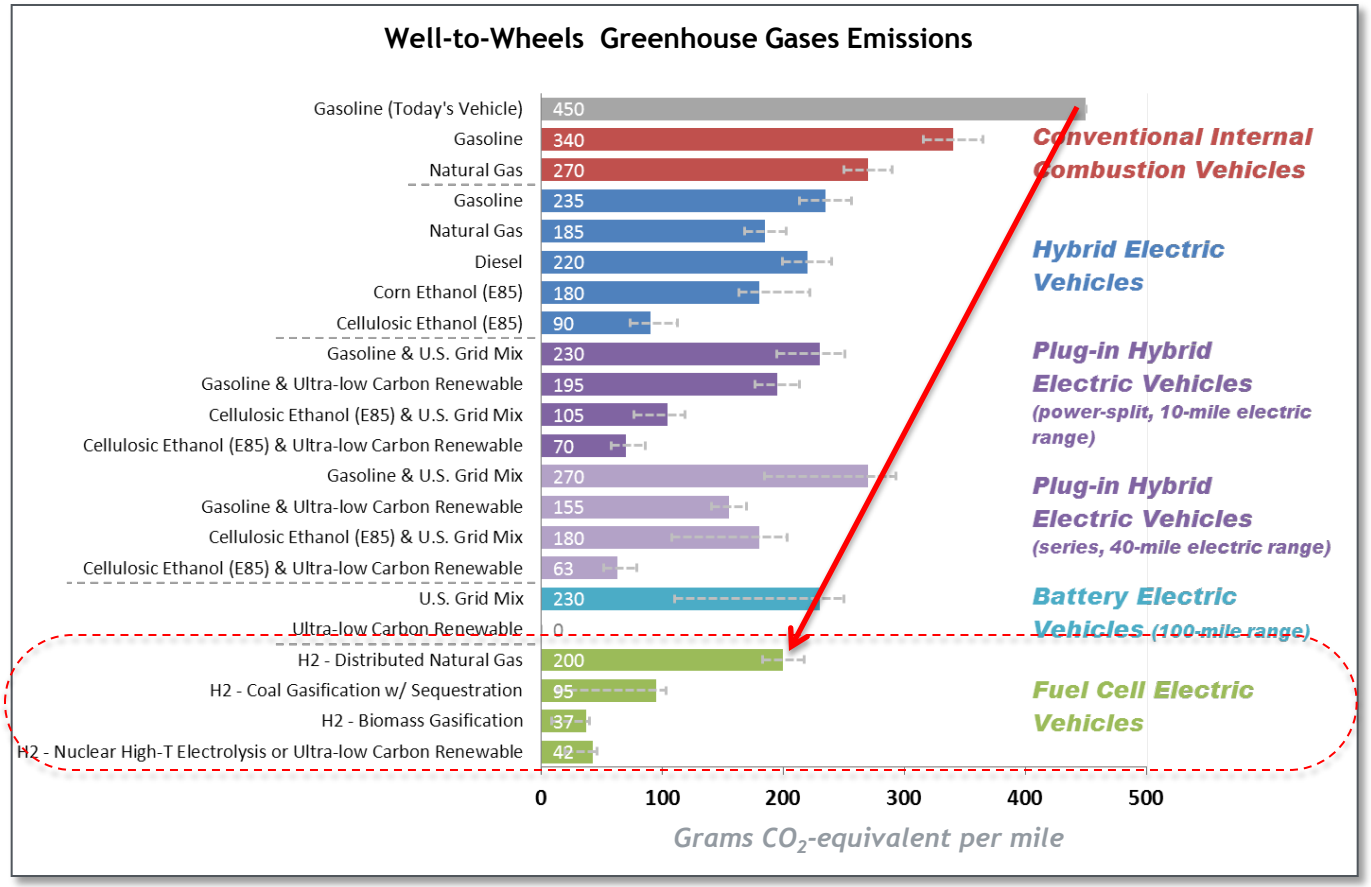
Analysis by Argonne National Lab, DOE Vehicle Technologies Office, and DOE Fuel Cell Technologies Office shows benefits from a portfolio of options



H_2 from Natural Gas

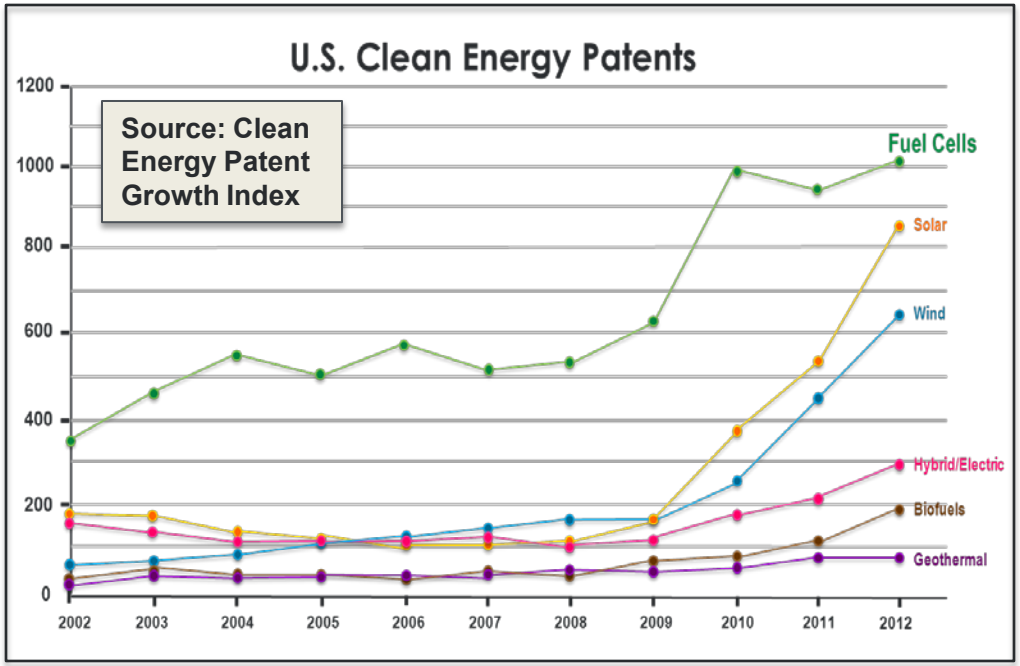
Even FCEVs fueled by H_2 from distributed NG can result in a >50% reduction in GHG emissions from today's vehicles.

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.

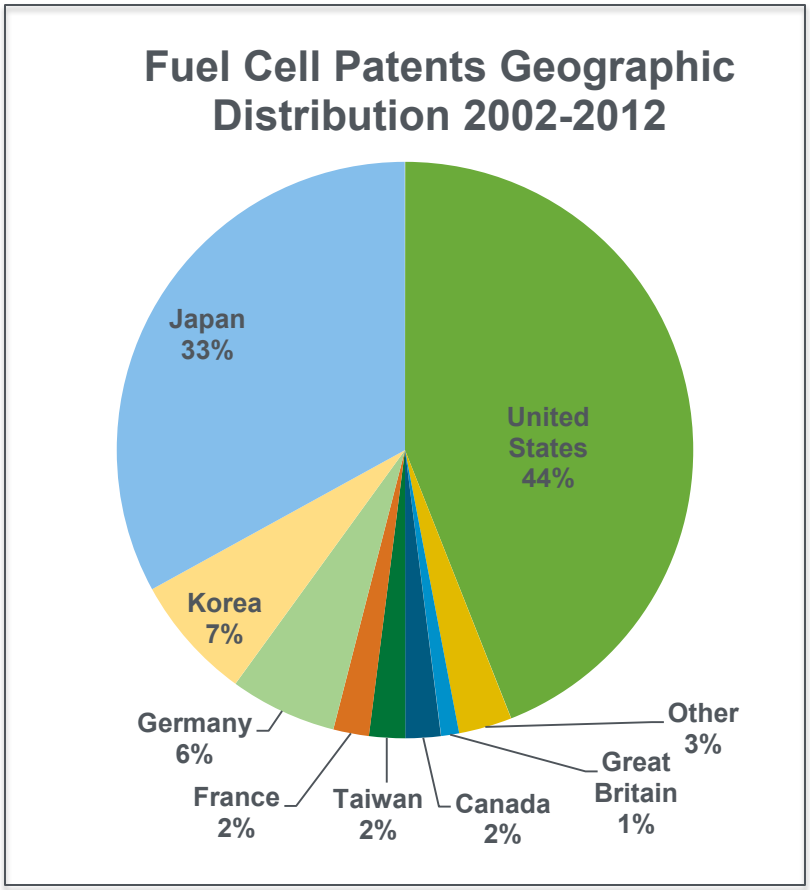
Even greater emissions reductions are possible as hydrogen from renewables enter the market.

Projected technologies analysis & assumptions at: http://hydrogen.energy.gov/pdfs/10001_well_to_wheels_gge_petroleum_use.pdf
Assumptions on efficiency, fuel economy, etc. updated as R&D progresses. Next update in 2013.

Fuel Cells – An Emerging Global Industry



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 1,000 fuel cell patents issued in 2012.

[1] http://cepgi.typepad.com/heslin_rothenberg_farley_/2013/03/clean-energy-patent-growth-index-2011-year-in-review.html

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.

Examples of Global Players in addition to the U.S.

Japan: $242 million in FY12, (~$1.0 Billion in funding for FY08–FY12);

- Nearly 30,000 residential fuel cells deployed (40,000 by April 2013)
- Plans for 2 million FCEVs and 1000 H_2 stations by 2025 (100 stations by 2015)

Germany: >$1.2 Billion in funding ('07 – '16)

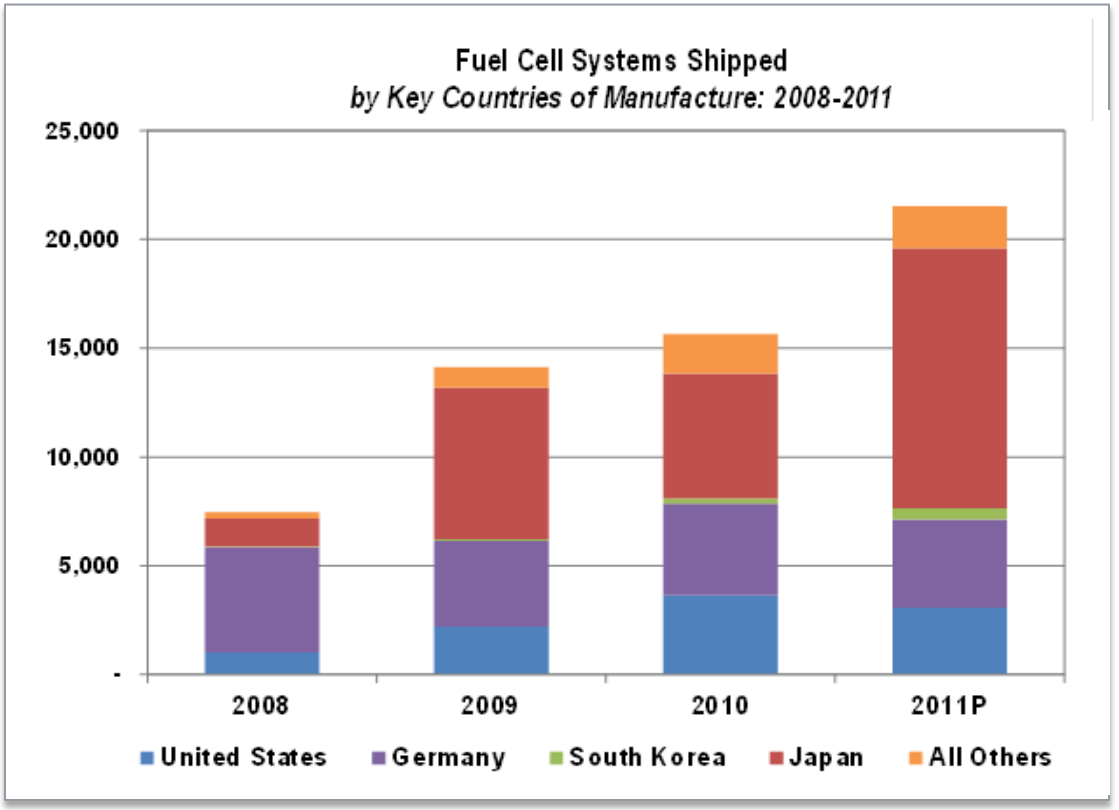
- plans for hydrogen stations
- >22,000 small fuel cells shipped.

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

Worldwide fuel cell markets continue to grow (>20,000 units shipped in 2011; >35% increase over 2010),



Sources: Pike Research, BTI, DOE Fuel Cells Market Report

Plans for FCEVs and H_2 Infrastructure

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Major public-private partnerships have been formed, and plans have been developed for the rollout of FCEVs and hydrogen infrastructure by 2015.

Hydrogen Supply/Utilization Technology (HySUT). 18 companies, including 3 auto companies, have announced plans to commercialize FCEVs and provide infrastructure by 2015.

By 2015: ***100 H_2 stations*** and ***FCEVs launched in 4 urban areas***

Toyota, Nissan, Honda, JX Nippon Oil, Idemitsu Kosan, Iwatani, Osaka Gas, Cosmo Oil, Saibu Gas, Showa Shell Sekiyu K.K., Taiyo Nippon Sanso, Tokyo Gas, Toho Gas, Japan Petroleum Energy Center, Engineering Advancement Assn. of Japan, Kawasaki Heavy Industries, Air Liquide Japan, and Mitsubishi Kakoki Kaisha, Ltd.

H_2Mobility. Public-private initiative for nationwide H_2 infrastructure—will develop into joint venture to install stations.

By 2015: ***50 H_2 stations*** (public-private funds committed); and ***5,000 FCEVs expected on the road***

National Organization of Hydrogen and Fuel Cell Technology (NOW Gmbh), Daimler, GM, Toyota, Nissan, Hyundai-Kia, Volkswagen, BMW, Siemens, EnBW, Linde, OMV, Shell, Total, Vattenfall, EnBW, Air Liquide, Air Products

UKH$_2$Mobility. Evaluating anticipated FCEV rollout in 2014-2015

- **Will develop action plan to make UK a leading market for FCEVs**

Air Liquide, Air Products, Daimler, Hyundai, ITM Power , Johnson Matthew, Nissan, Scottish & Southern Energy, Tata Motors, The BOC Group, Toyota, Vauxhall Motors, and 3 gov't departments (Business, Innovation & Skills; Energy; and Transport)

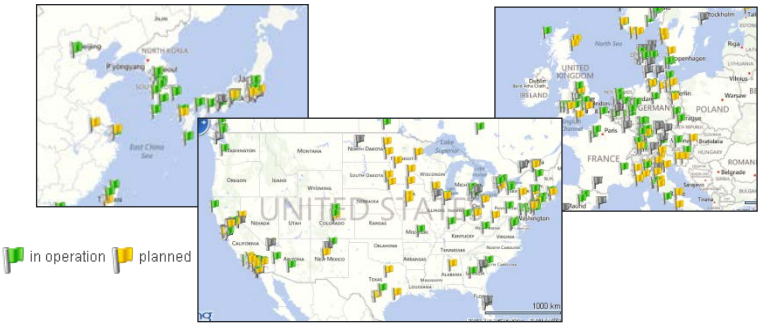
Scandinavian H_2 Highway Partnership (SHHP)

Partnership of ***Hydrogen Link*** (Denmark), ***HyNor*** (Norway) and ***Hydrogen Sweden.*** Goals is to establish a network of 45 H_2 stations (15 main stations, 30 satellite stations) and a large fleet of vehicles (500 cars, 100 buses, 500 specialty vehicles). Projects include ***H2Moves Scandinavia*** and ***Next Move***

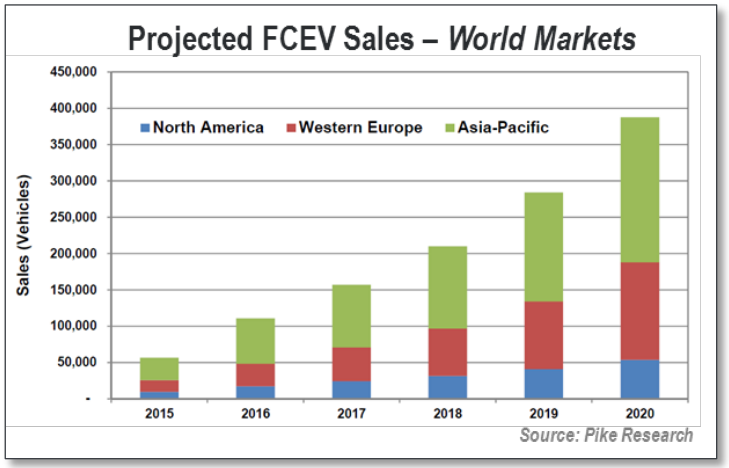
MOU signed October 2012: 4 auto companies *(Toyota, Nissan, Honda, Hyundai)*, 3 H_2 infrastructure companies (*HyOP AS*, *H2 Logic A/S*, *Copenhagen H_2 Network A/S*), and 5 NGOs agreed to introduce FCEVs and H_2 infrastructure by 2014 – 2017 timeframe.

Current Status:

- **>220 hydrogen stations in operation worldwide (with >100 in planning stages)**



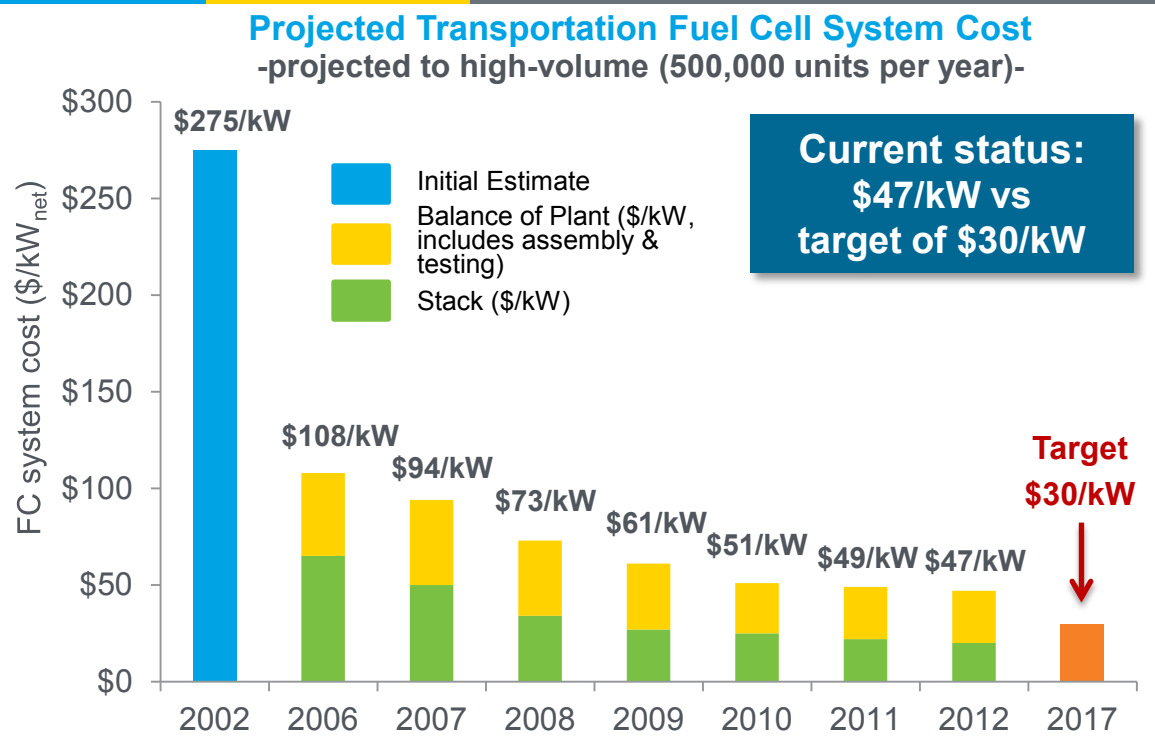
- **>500 FCEVs demonstrated worldwide**
- **>100 fuel cell buses estimated worldwide**

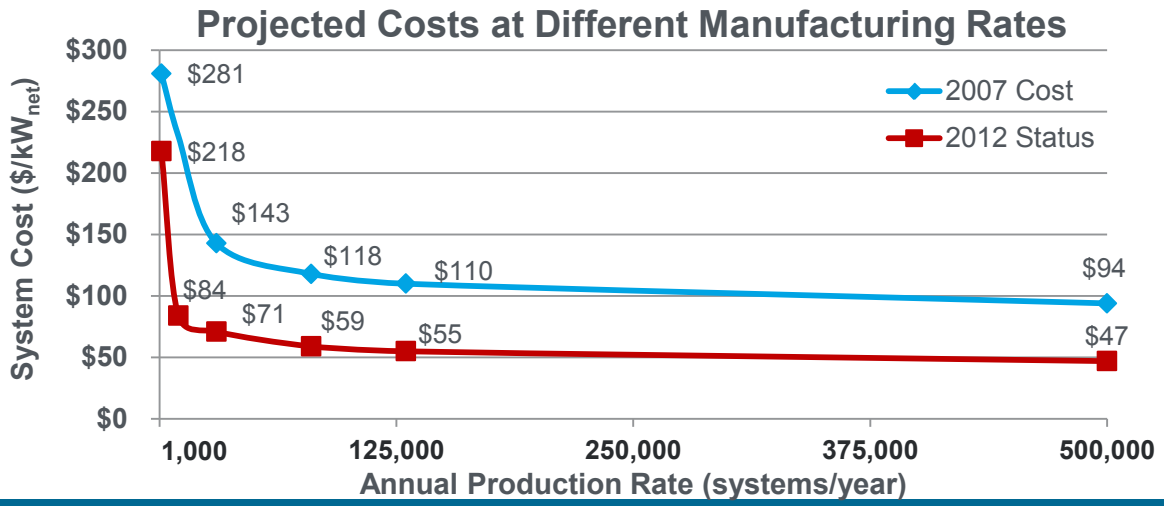


Progress Example– Fuel Cells

Projected high-volume cost of fuel cells has been reduced to $47/kW (2012)*

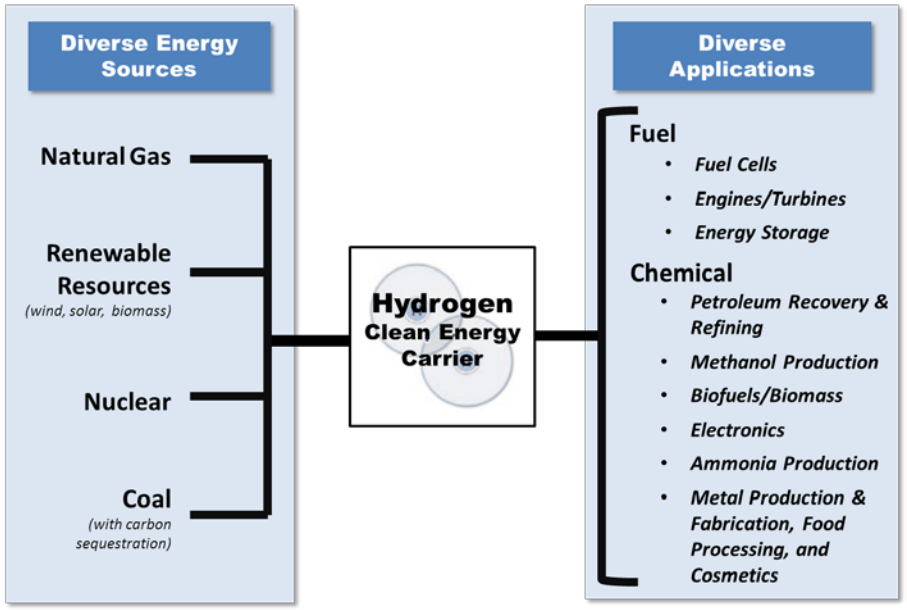
- ***More than 35% reduction since 2008***
- ***More than 80% reduction since 2002***

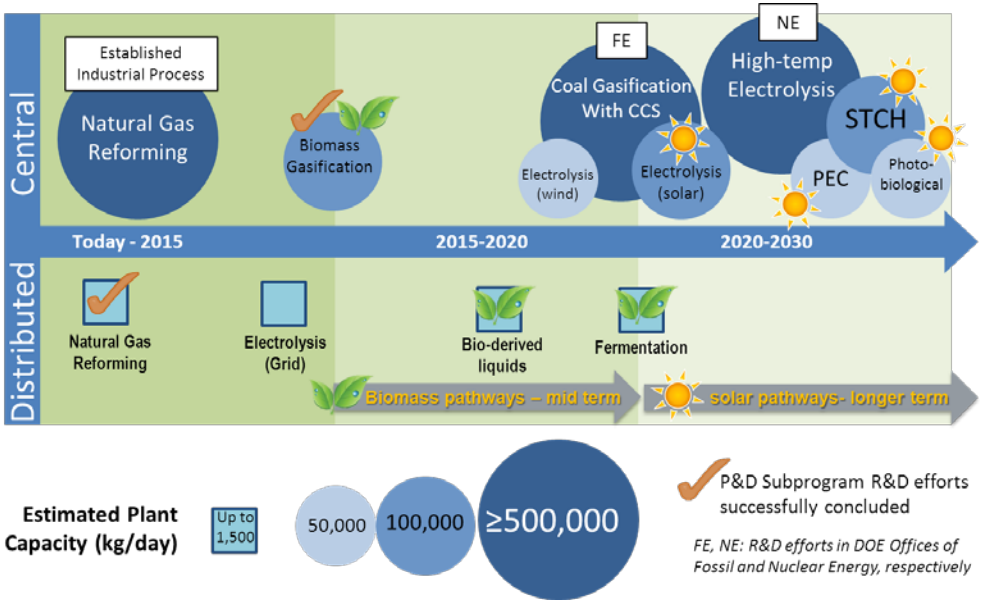




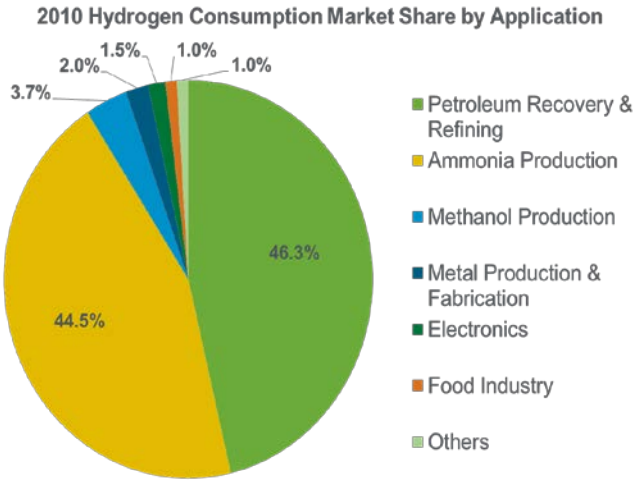
Based on projection to high-volume manufacturing (500,000 units/year). *The projected cost status is based on an analysis of state-of-the-art components that have been developed and demonstrated through the DOE Program at the laboratory scale. Additional efforts would be needed for integration of components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

Hydrogen: Sources & Applications





Hydrogen from renewables and low carbon sources is key for a number of applications



Options for Early Hydrogen Infrastructure

Current Status

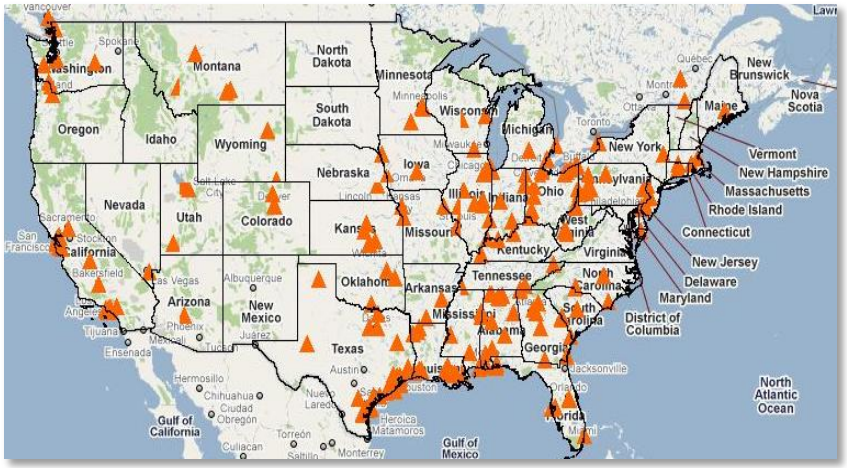
- Over **9MMT** of H_2 produced per year
- Over **1,200 miles** of H_2 pipelines in use (CA, TX, LA, IL, and IN)
- Over **50 fueling stations** in the U.S.

Two Main Options for Low-cost Early Infrastructure

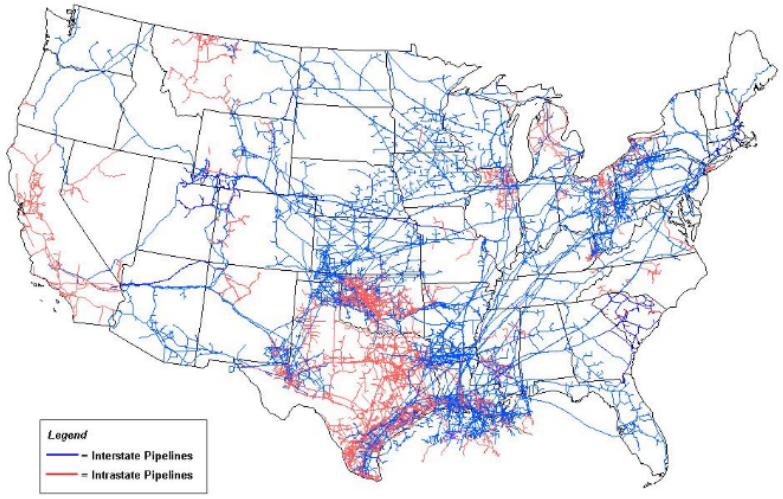
- **H_2 delivered from central site**
  - Low-volume stations (~200-300 kg/day) would cost <$1M and provide hydrogen for $7/gge *(e.g., high-pressure tube trailers, with pathway to $5/gge at 400–500 kg/day)*
- **Distributed production (e.g. natural gas, electrolysis)**

Other options

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



Existing Hydrogen Production Facilities



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

Natural Gas Pipeline Network, 2009

Tri-Generation

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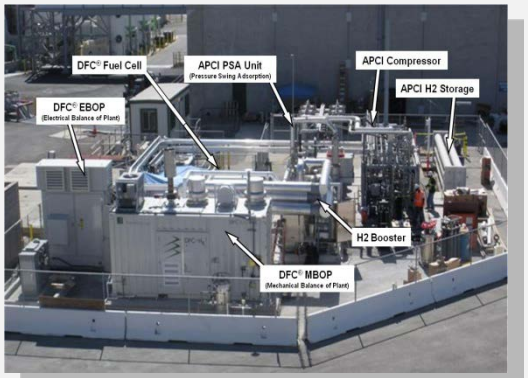
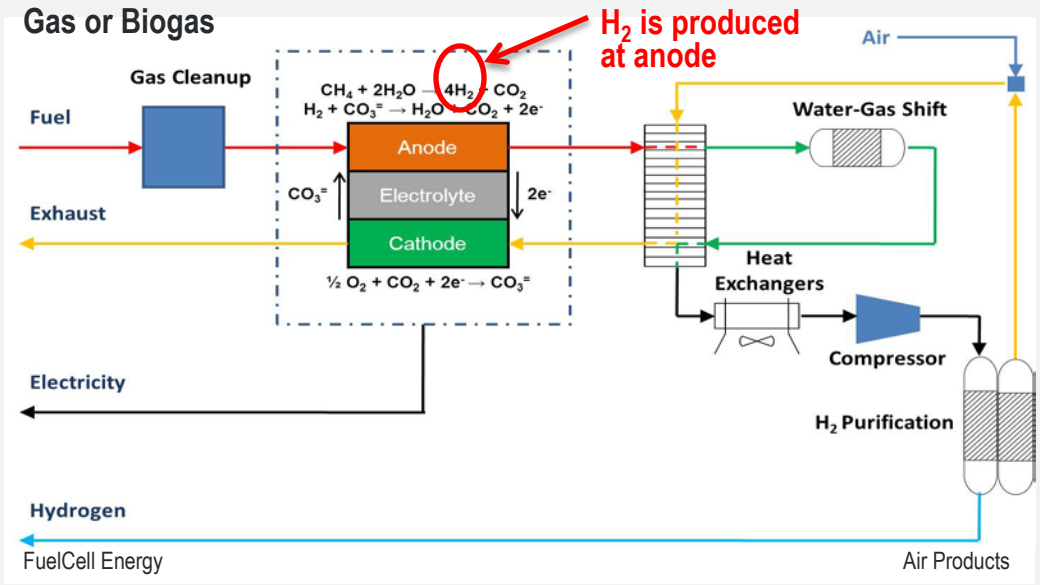
Tri-Generation co-produces power, heat and hydrogen. World's First Fuel Cell and Hydrogen Energy Station demonstrated in Orange County (DOE/FCT project)

Demonstrated world's first Tri-generation station

- Demonstrated co-production of electricity and hydrogen with 54% efficiency
- Uses biogas from wastewater treatment plant



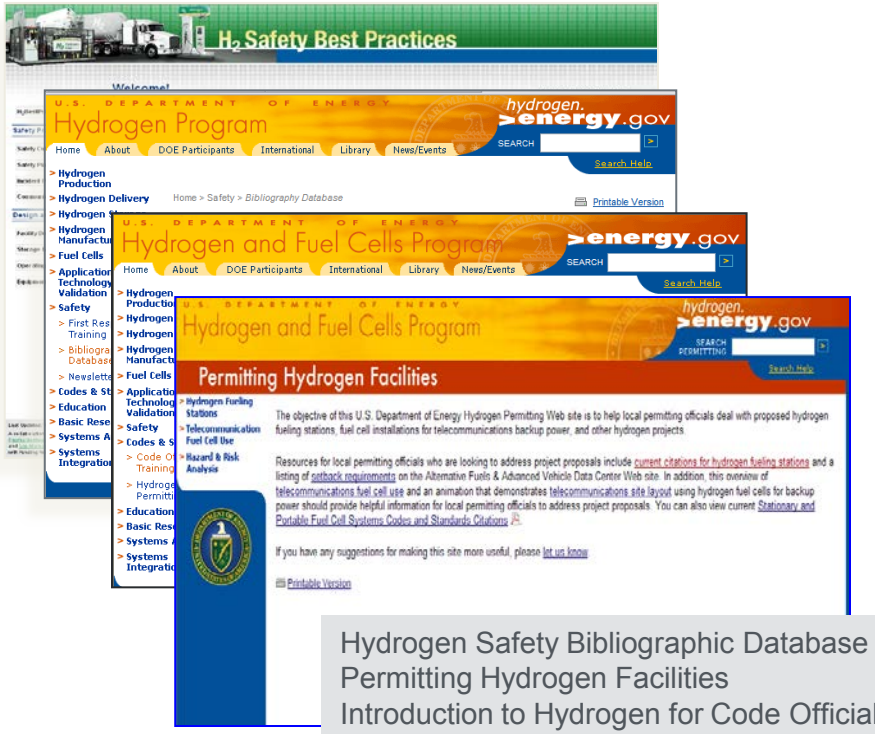


Co-funded by DOE/FCT and multiple partners

Fountain Valley demonstration

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

Safety, Codes and Standards



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/

Summary: Program Impact

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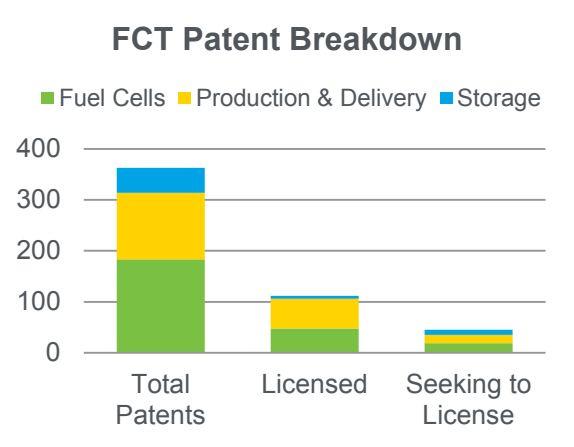
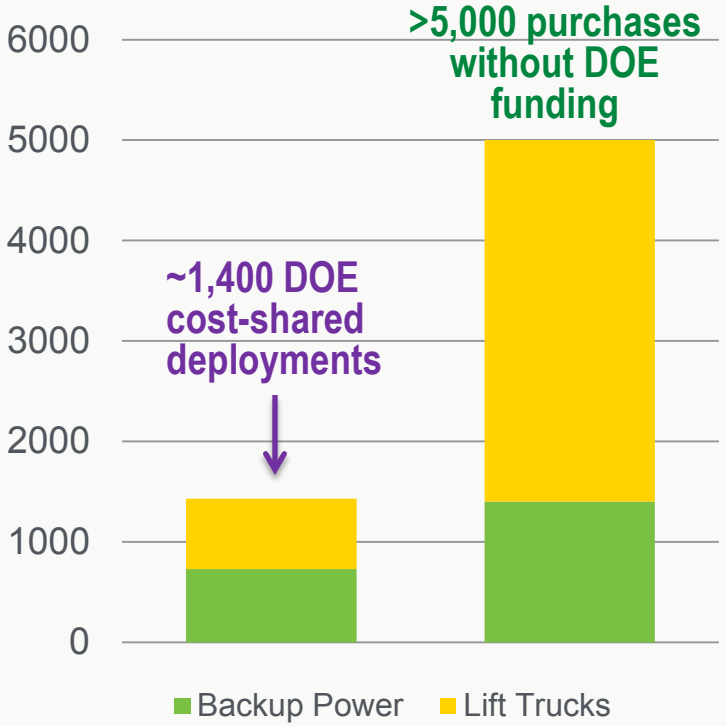
DOE FCT funding has led to 363 patents, 35 commercial technologies and 65 emerging technologies. Example of Impact: ~$70M in funding for specific projects was tracked – and found to have led to nearly $200M in industry investment and revenues.

DOE FCT funding has enabled:

- > 80% cost reduction in PEM fuel cells since 2002, > 35% since 2008
- Reduction in Pt by a factor of 5 since 2005
- > Double the durability since 2006
- > 80% cost reduction in electrolyzer stacks in the last decade



Leveraging DOE funds: Early market deployments of ~1,400 have led to >5,000 additional purchases by industry with *no* DOE funding.



*DOE cost-shared deployments led to **>3X** additional purchases.*

Recovery Act and Market Transformation – Government as "catalyst" for market success of emerging technologies.

Program R&D - Portfolio

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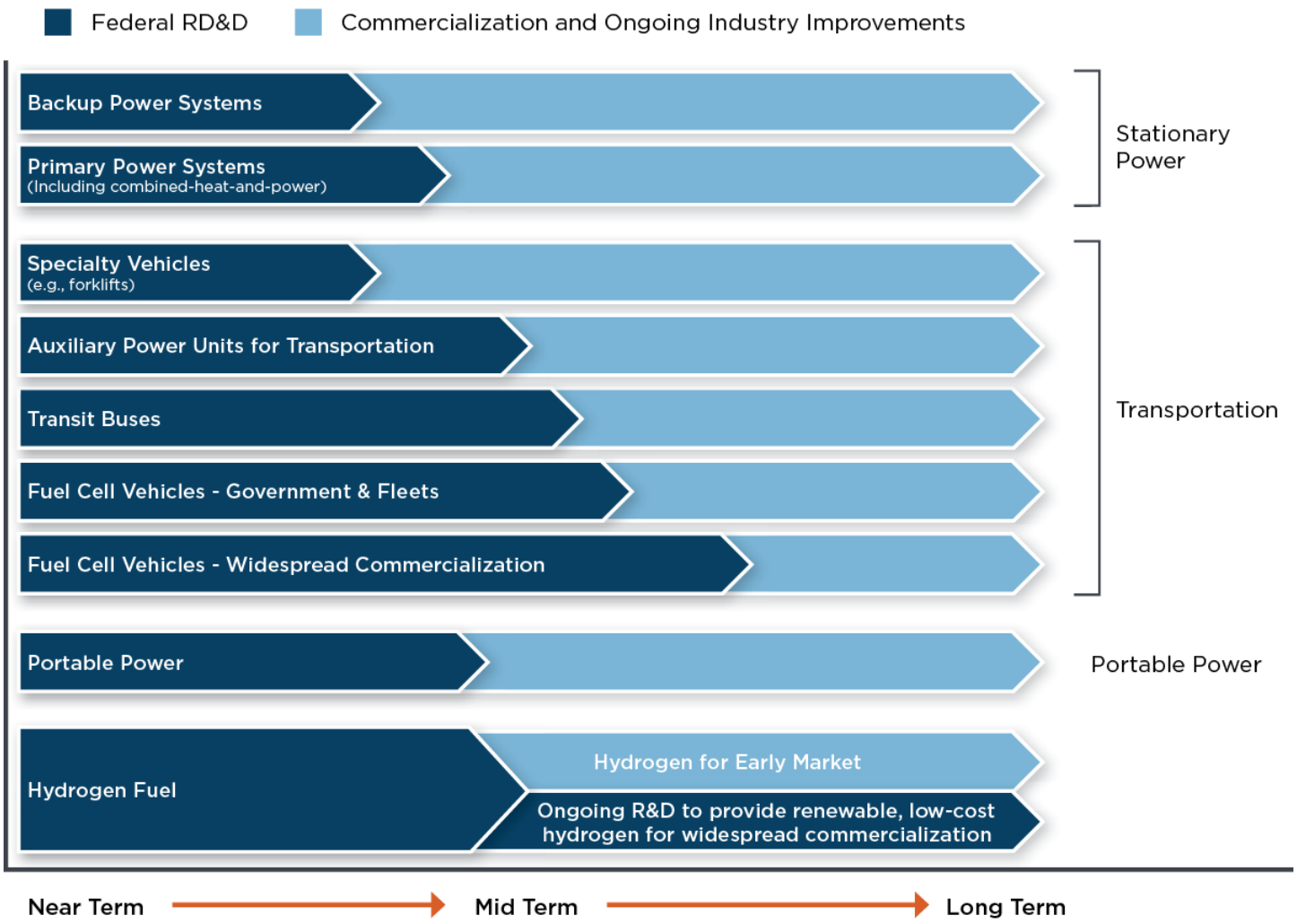
Program efforts are planned to transition to industry as technologies reach commercial-readiness

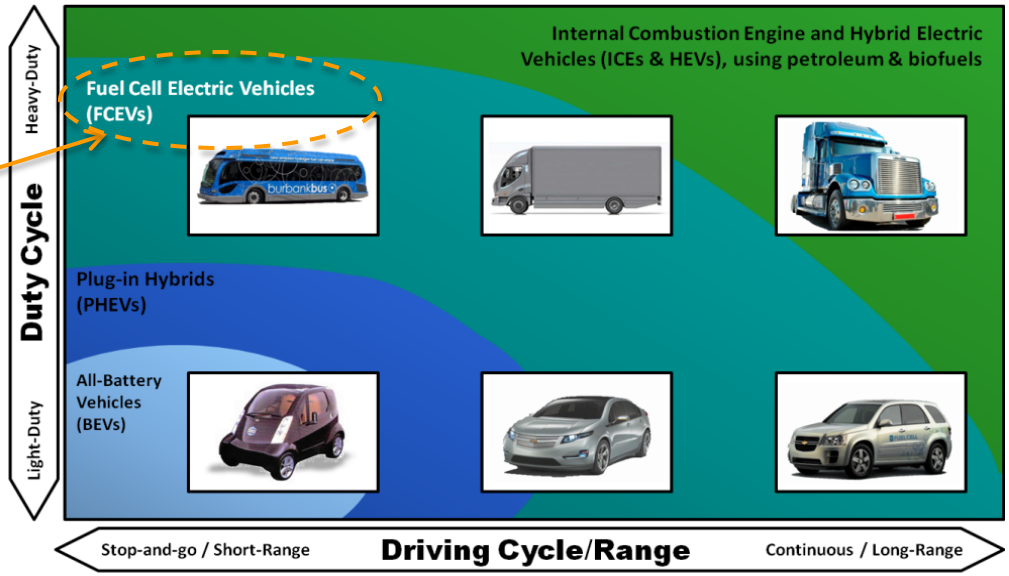


Portfolio Examples

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

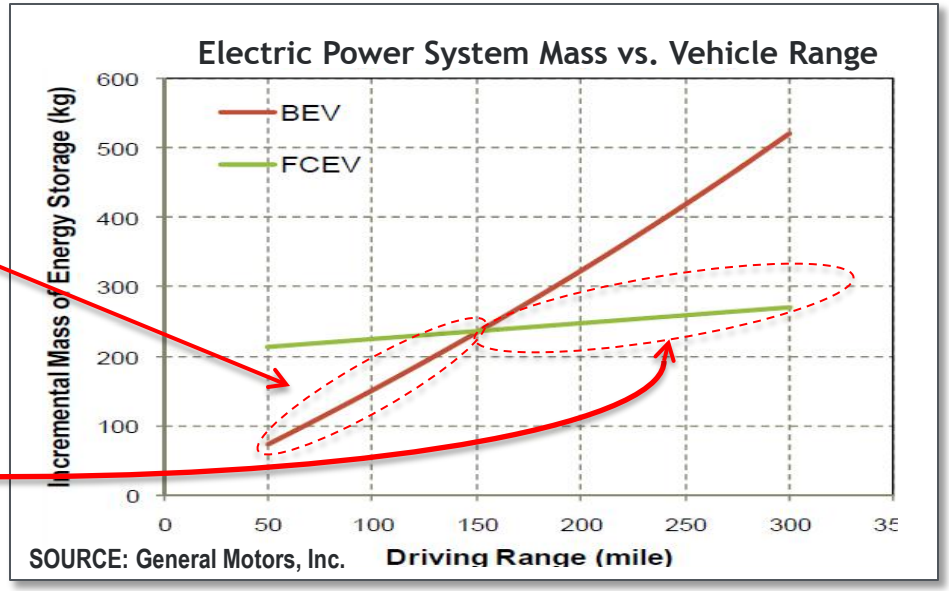
H_2 and fuel cells can play a key role

— 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**)*



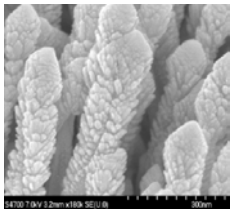
Advantages of Batteries and Fuel Cells:

- 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***



DOE – DOT Collaborations

DOE and DOT support the development and deployment of fuel cell technology



Developed low Pt approach
Reduced cost by >30% since 2008, 80% since 2002

DOE RD&D

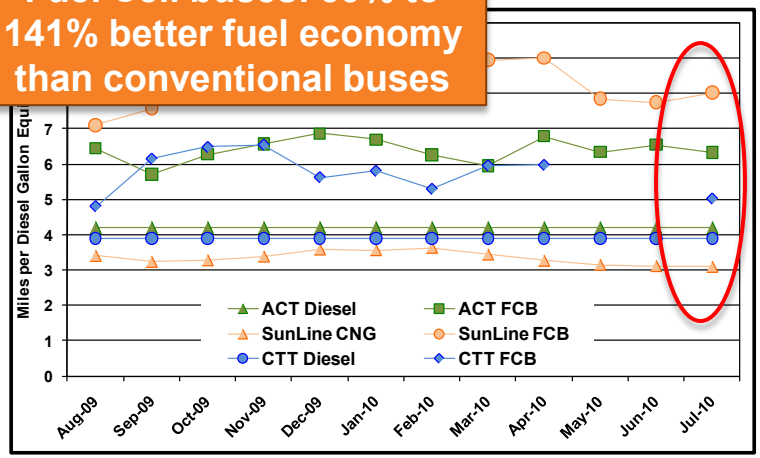
Data Collection & Validation

NREL HSDC
NREL's Hydrogen Secure Data Center

National Bus Program
($49 million for 4 years)

DOT Deployment

Fuel Cell buses: 39% to 141% better fuel economy than conventional buses



Accomplishments

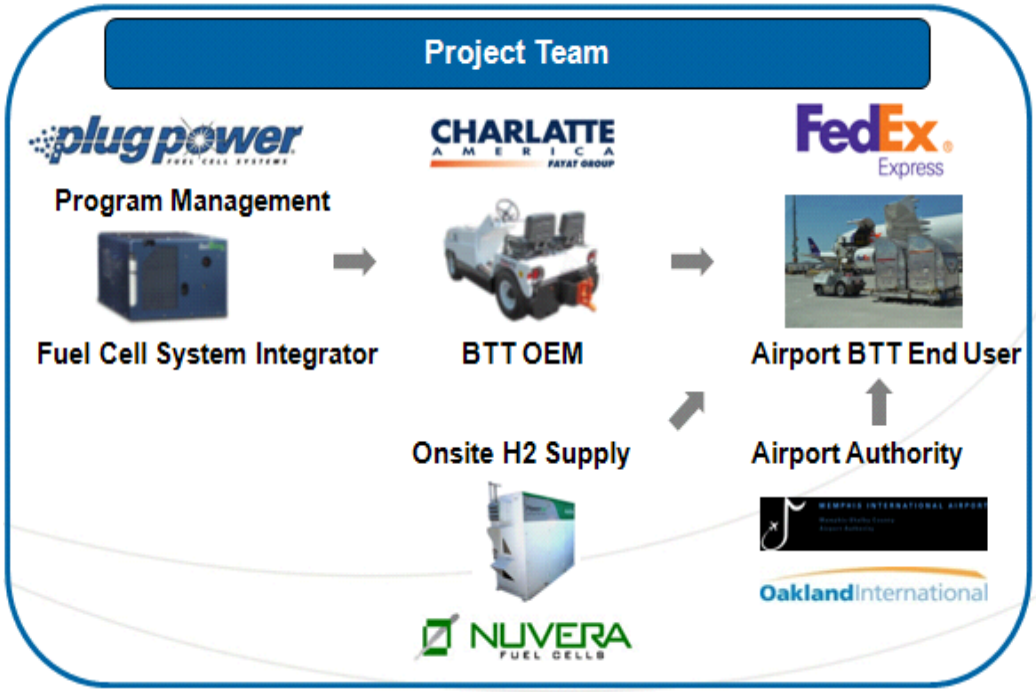
Demonstrated:

- Doubled fuel economies (8 mpg, >2X compared to diesel buses)
- 41% increase in average miles between roadcall with new fuel cell system (~8,500 MBRC)
- Demonstrated more than 7,000 hr fuel cell durability

Fuel Cell Airport GSE Demonstrations

Background/Status:

- Awarded January 31, 2013
- Fuel Cell Powered Airport Ground Support Equipment (GSE) Deployment
- 3 years, $2.5M DOE share, 50% cost share, two phases:
  - Product development and testing
  - Demonstrations under "rear world" operating environments
- Partners: Plug Power, Charlatte, Federal Express, Nuvera, Ballard
- 15 Baggage Tow Tractors (BTTs) with ~20kW fuel cell systems
- 10 units at FedEx in Memphis, TN
- 5 units at FedEx in Oakland, CA
- H2 to be provided by 20kg/day Nuvera PowerTap systems



Air Canada with retrofit fuel cell baggage tug

Charlatte CTGE Cargo Tractor

Nuvera PowerTap SMR

Ports: Opportunities for Air Quality Improvements/Oil Reduction Projects

Ports are some of America's most polluted areas with significant impacts on the **environment** and **public health**. Nationally, each year, ports:

- Emit over 3.8M tons of CO_2 eq.
- Emit 47K tons of criteria pollutants
- Consume 1.8B gallons of petroleum

A coordinated deployment integrating advanced technologies (fuel cells, EVs, wind or solar) can help address this problem!

Clean Energy Technology for Ports

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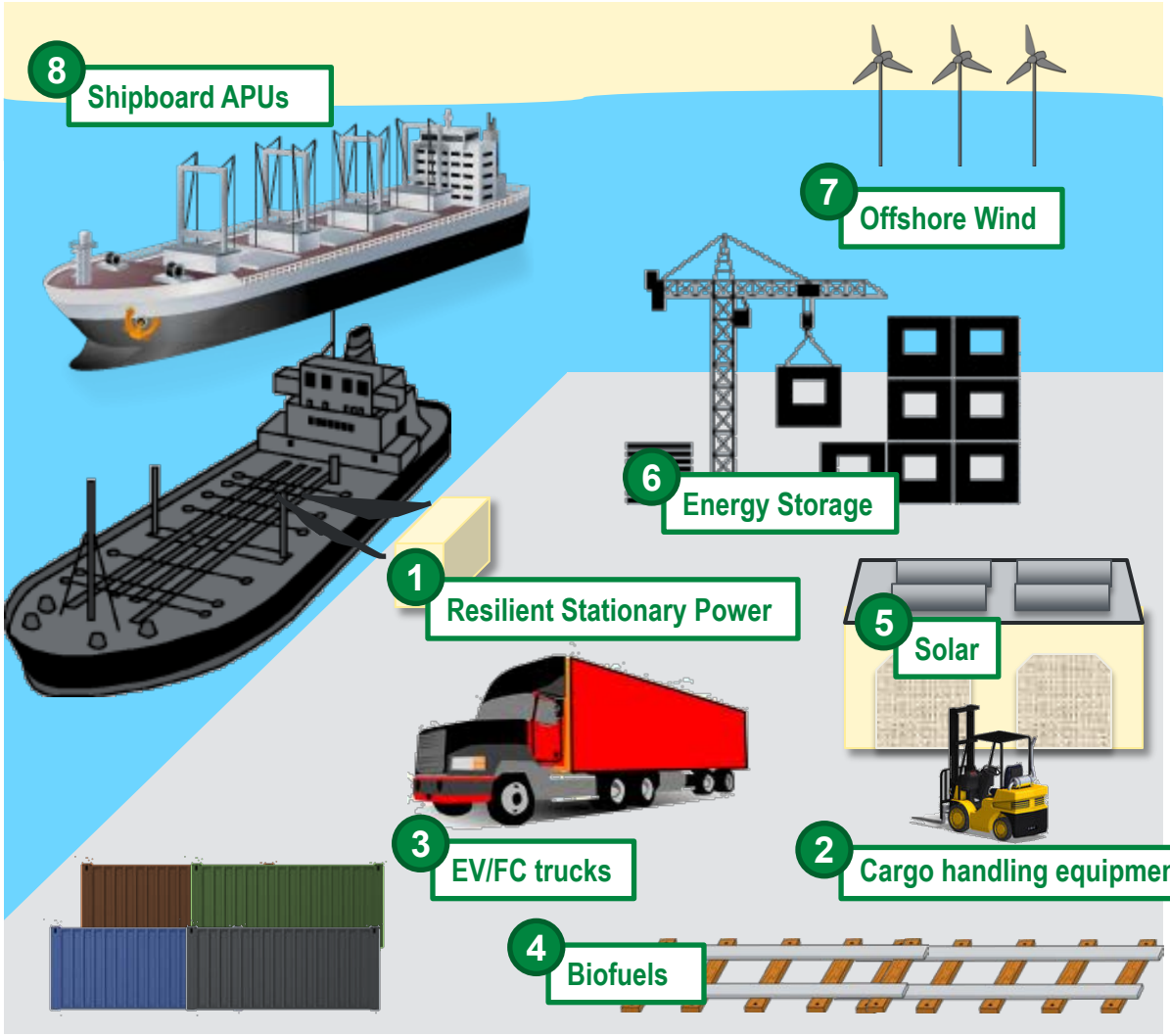
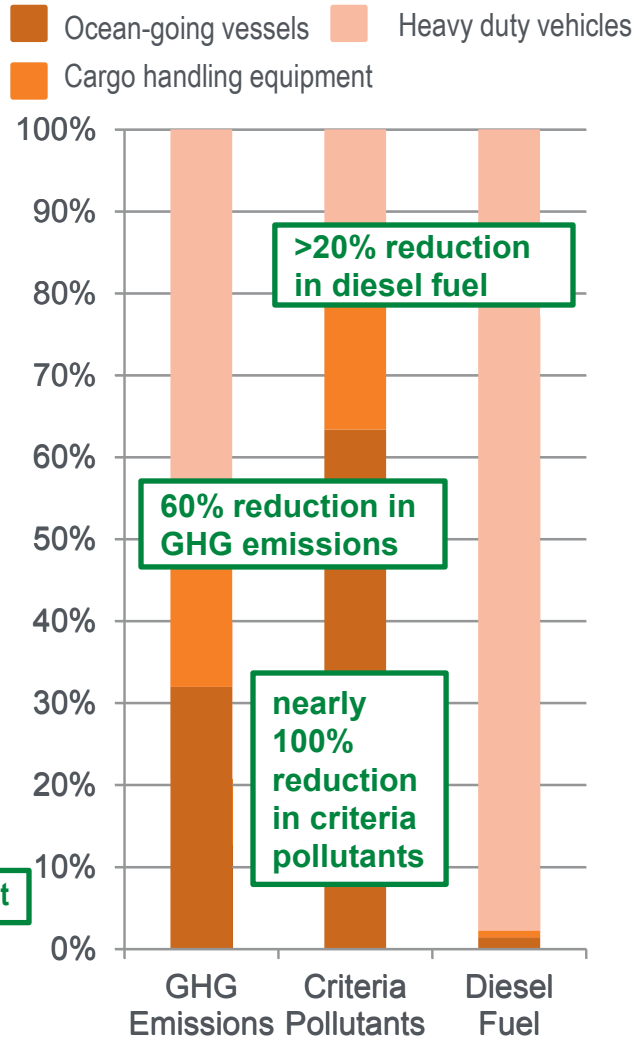
Using an array of clean energy technologies in a major U.S. seaport could result in a reduction of 725K tons of CO_2 emissions, ~80M gallons of petroleum, and 9,000 tons of criteria pollutants.





HD and MD eTruck Demonstrations

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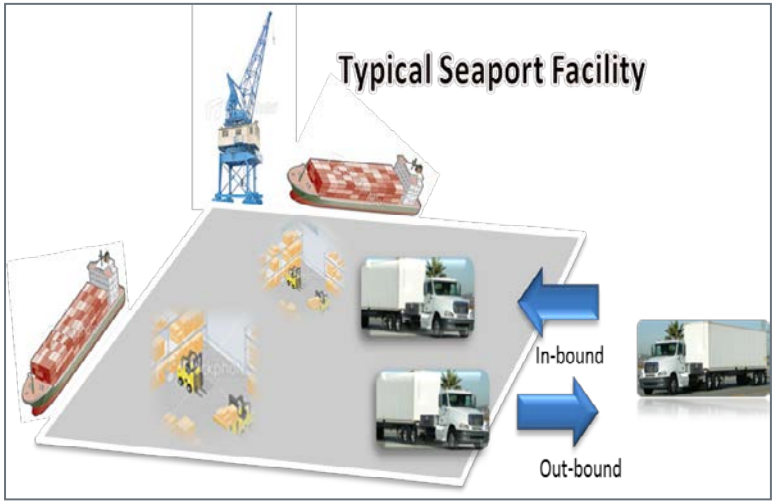
Electric Transportation Technologies (ETT) FOA Issued March 5, 2012 - Closed May 4th, Three Awards Made on August 8, 2012

Vehicle Technologies Program FY2012 Appropriations:

Zero emission cargo transport in areas of severe nonattainment and severe traffic congestion.

- **SCAQMD (CA) $4.12 M and Houston Area Council (TX) $3.4 M (Kick Off November 20, 2012)**
  - **on-board fuel cell rechargers for ~23 C8 drayage trucks**
- **Houston Area Council (TX) $2.4 M**
  - **30 all battery C6 delivery trucks**
- **50/50 cost share**
- **Kick Off Mid-April 2013**



C6 Delivery Truck

C8 Drayage Truck

OEM FCEV Announcements

Hyundai Motor America

- First ix35 Fuel Cell vehicle rolled off the assembly line at the Hyundai's Plant No. 5 in Ulsan, South Korea on February 26, 2103

Toyota Motor Corporation

- 2015 global FCV introduction planned
- Proposed NEC Market Regions: New York, Boston Providence, Hartford
- 100 demonstration vehicles on the road- used by academia, government, & fueling developers

Honda Motor Company

- Working on cluster concept of communities and refueling stations in California
- First Fuel Cell Vehicle Dealership Network (Honda FCX Clarity)
- Three Official Clarity/FCX dealerships: Santa Monica, Torrance, and Costa Mesa
- Leasing in Southern California – current infra (Torrance, Irvine and Santa Monica)

OEM FCEV Collaborations

BMW- Toyota

"It's game-on for a jointly developed fuel-cell system from BMW and Toyota."
(January 24, 2013)

Ford, Nissan, Daimler

"Daimler the third-biggest maker of luxury vehicles, and Ford Motor added Nissan Motor Co. as a partner in developing fuel cells for electric cars, which the manufacturers plan to start selling in 2017."
(January 28, 2013)

VW- Ballard

"Ballard Signed Long-Term Engineering Services Contract To Advance Volkswagen Fuel Cell Research"
(March 7, 2013)

Hydrogen and Fuel Cell Initiatives at the State Level

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Several states have major hydrogen and fuel cell programs underway.

California

FCEVs and Fuel Cell Buses

- **> 560 vehicles** in operation since 1999 — ~230 currently operating
- **~ 5 million miles** driven
- **> 1 million passengers** on fuel cell buses

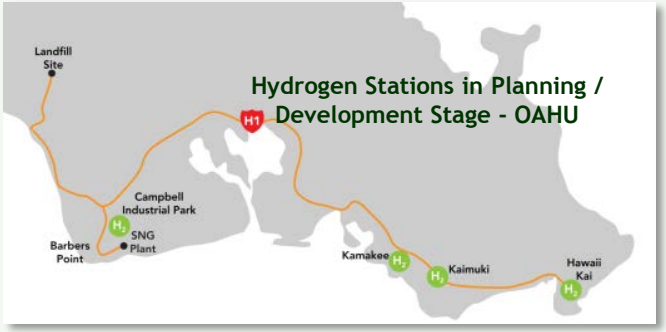
H_2 Station Investment

- **20 stations** — including planned/funded
- **~$34M invested** *(CARB and CEC)*
- **$5.5M invested** by SCAQMD
- **~$29M available (**CEC solicitation currently closed**)**
- **$20M proposed for 2013/14** (CEC)

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 a nascent refueling infrastructure on Oahu by 2015 to support initial deployments of government and industry FCEV fleets



H2 Infrastructure Roadmapping: CA

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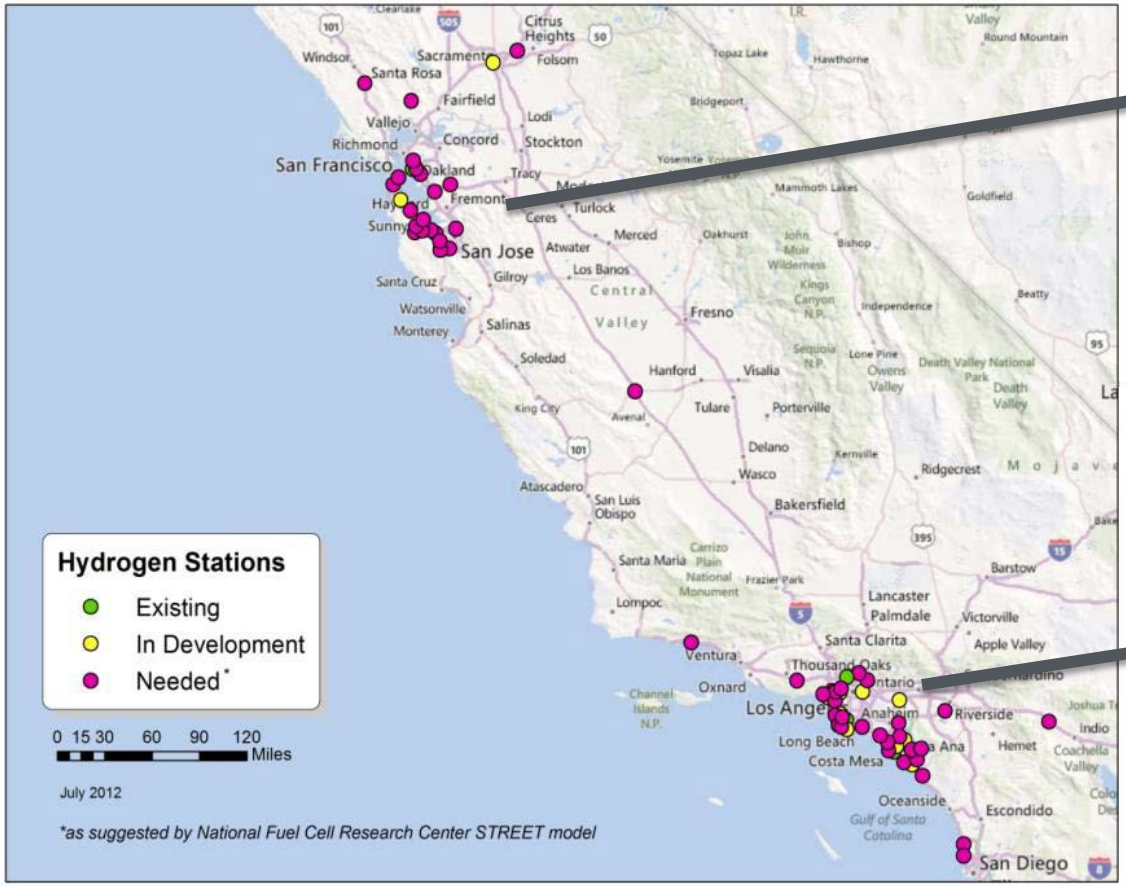

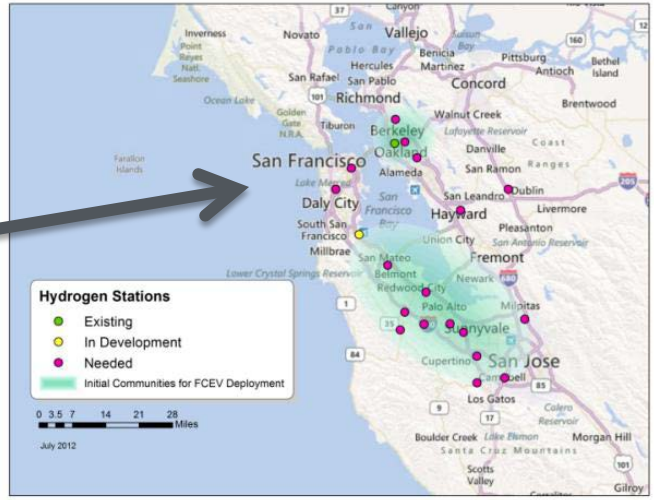

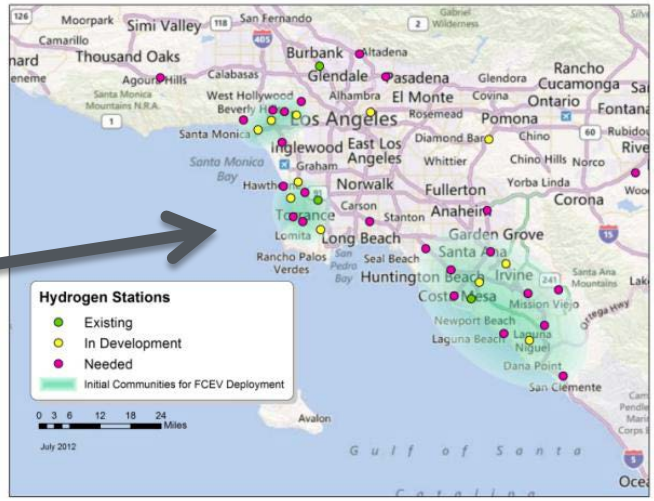

H2 Infrastructure Roadmapping: CA

Hyundai Motor America

- Preliminary Fleet Program running for 2013 to end of 2014 (FC Tucson)
- Working with California to establish more fueling stations

Honda Motor Company

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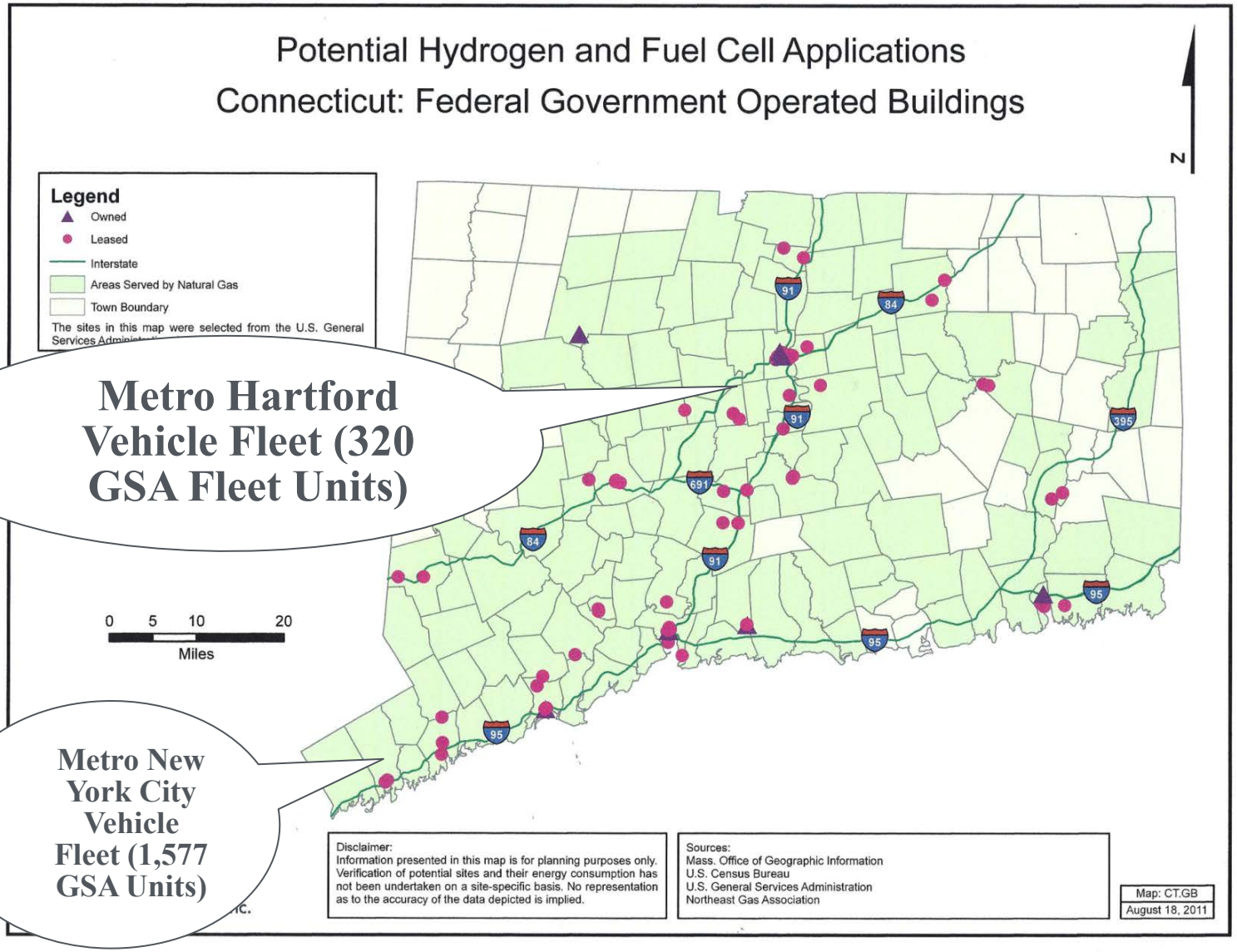
- First Fuel Cell Vehicle Dealership Network (Honda FCX Clarity)
- Three Official Clarity/FCX dealerships: Santa Monica, Torrance, and Costa Mesa
- Leasing in Southern California – current infra (Torrance, Irvine and Santa Monica)

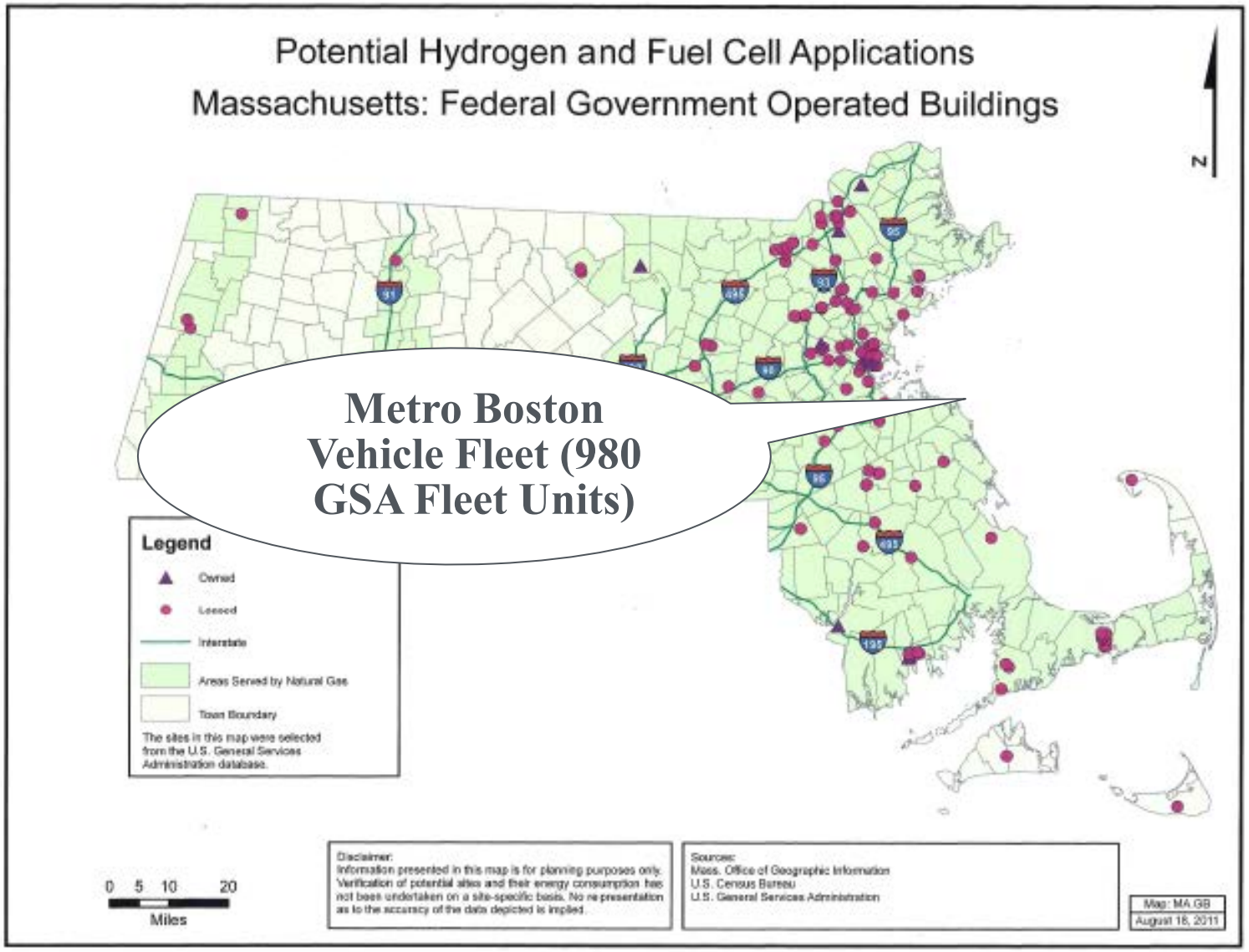
GSA Light Duty Fleet City Breakdown of California

Berkley	150
City of LA	1368
Fremont	17
Long Beach	215
Oakland	197
Orange County	967
Riverside	39
Sacramento	875
San Bernardino	36
San Francisco	677
San Jose	98
Ventura	33
Total	**4672**

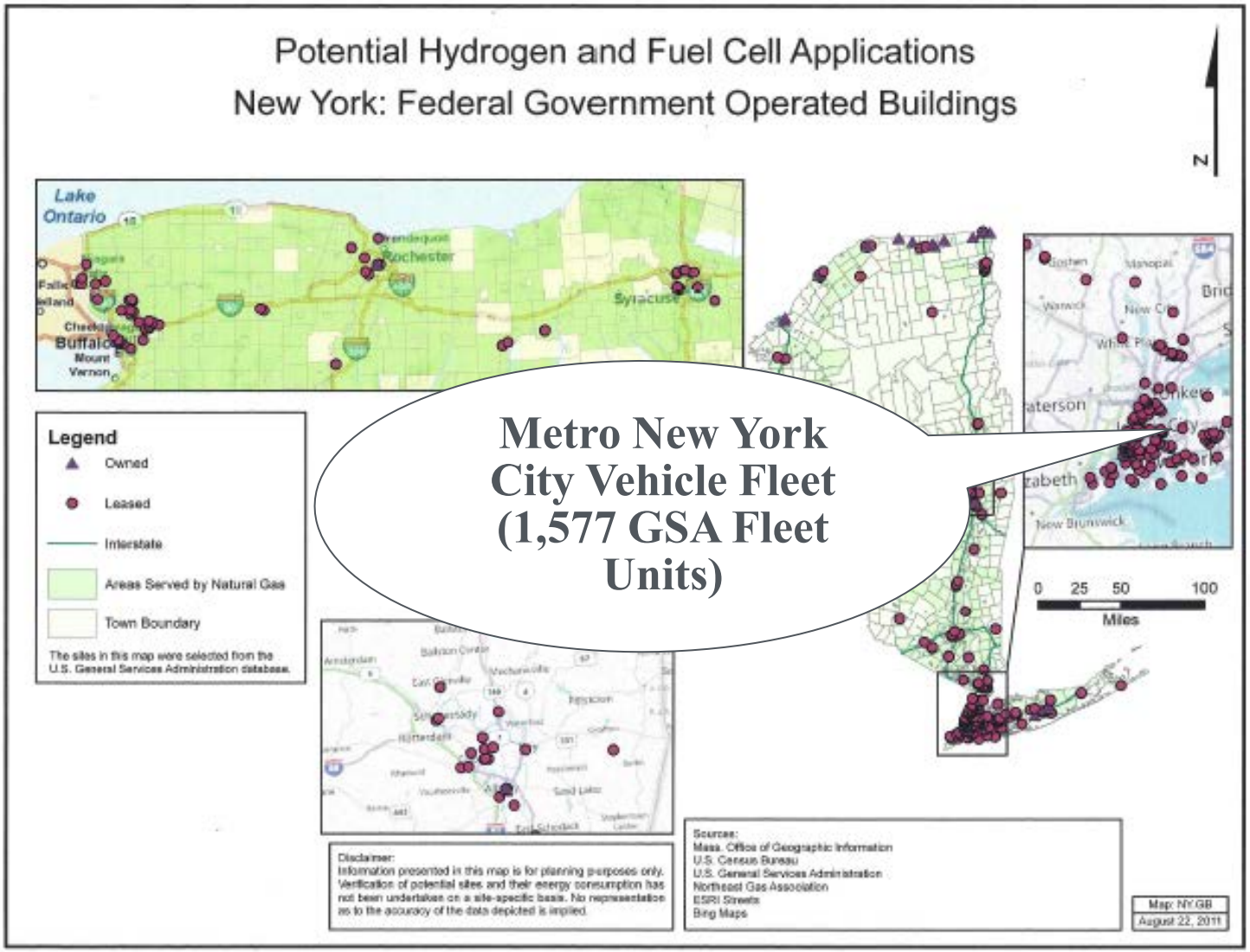
Northeast Roadmapping: CT



Northeast Roadmapping: MA



Northeast Roadmapping: NY



Future Plans

Work With Clean Cities to:

- Inform stakeholders and general public about fuel cell vehicle progress and events
  - Distribute fact sheets, coordinate events and expo displays;
- Develop and distribute lessons learned case studies on fuel station permitting, codes and standards applications, and public acceptance pamphlets;
- Plan and execute outreach activities such as information webinars, public acceptance actions (e.g. questionnaires, data collections, et. al.);
- Support fuel cell vehicle fleet deployments by:
  - Coordinating planning meetings with stakeholders, assisting in safety training and awareness, etc.

Thank You

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