Fuel Cell Technologies Program Overview

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

US DOE CSD Workshop

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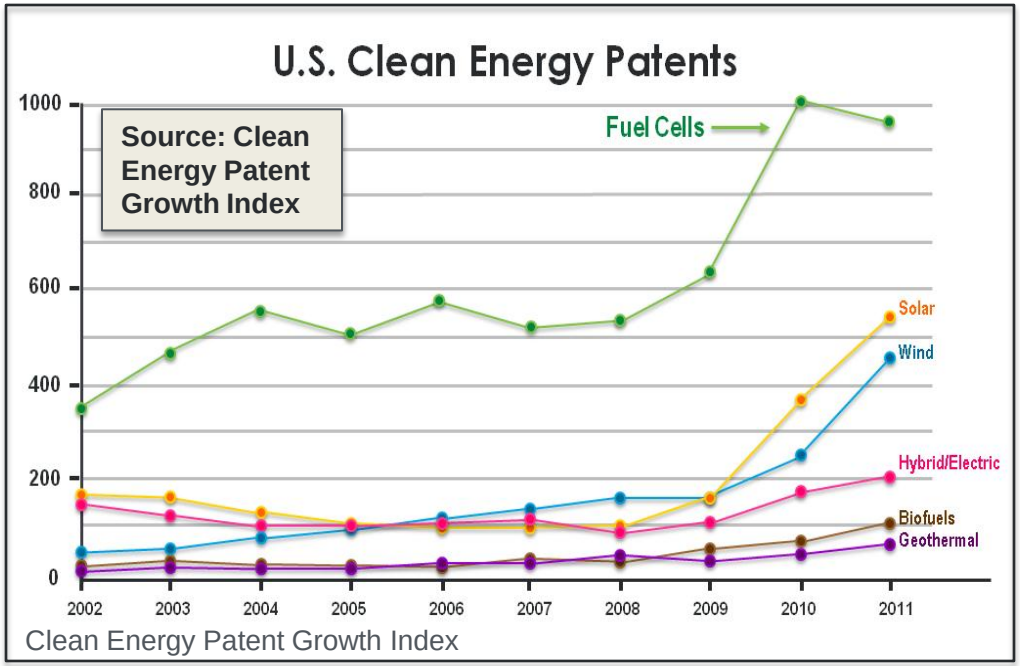
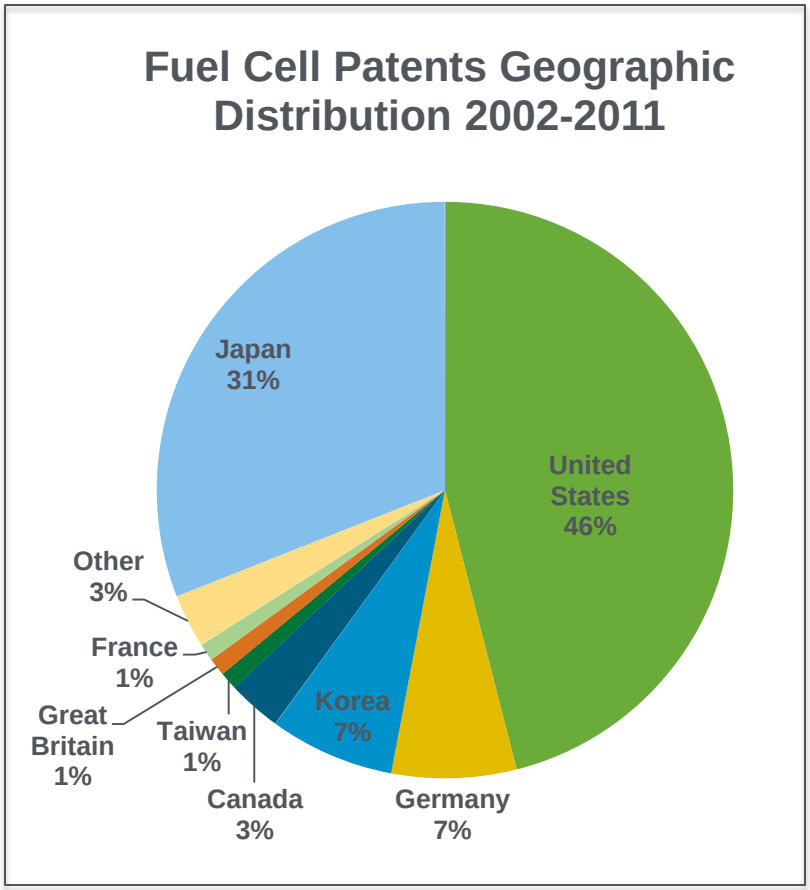
Fuel Cells – An Emerging Global Industry





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 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 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); projected demand for 1,000 hydrogen stations; >22,000 small fuel cells shipped.

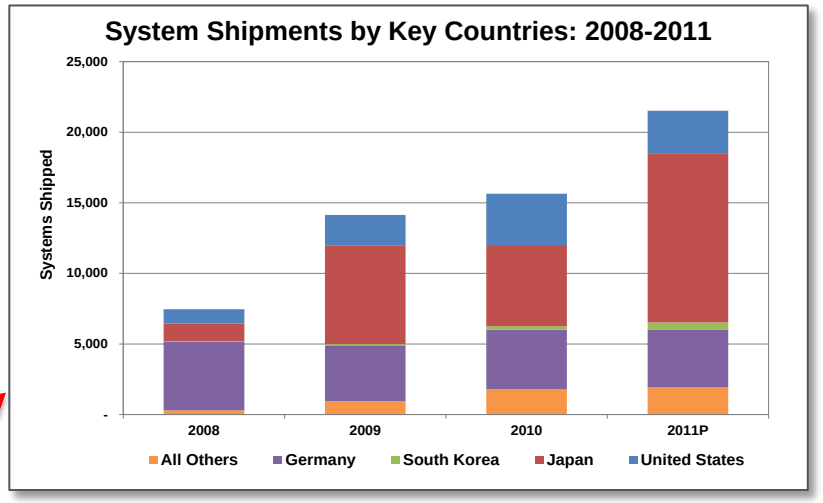
Japan: ~$1.0 Billion in funding ('08 – '12); plans for 2 million FCEVs and 1000 H_2 stations by 2025; 100 stations by 2015; 15,000 residential fuel cells deployed

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

Many of the world's major automakers are planning commercialization of FCEVs in the 2012 – 2015 timeframe, including Toyota, Honda, GM, Daimler, Hyundai-Kia.



Fuel cell and hydrogen markets continue to grow

- **>20,000 systems shipped in 2011 (>35% increase from 2010)**
- **>55 Mtons produced in 2011 and >70Mtons projected for 2016**

Widespread market penetration could create:

- **180,000 new jobs in the US by 2020**
- **675,000 jobs by 2035**

Projected Global Market Revenues over the next 10-20 Years		
Stationary Power	Portable Power	Transportation
$14-$31B/yr	$11B/yr	$18-$97B/yr

Completed world's largest single FCEV & H_2 Demonstration to date (50-50 DOE-Industry cost share)

- >180 fuel cell vehicles and 25 hydrogen stations
- 3.6 million miles traveled; 500,000 trips
  - ~152,000 kg of hydrogen produced or dispensed; >33,000 refuelings

	Status	Project Target
Durability	~2,500	2,000
Range	196 – 254*	250*
Efficiency	53 – 59%	60%
Refueling Rate	0.77 kg/min	1 kg/min

	Status (NG Reforming)	Status (Electroylsis)	Ultimate Target
H_2 Cost at Station	$7.70 - $10.30/kg	$10.00 - $12.90/kg	$2.00 - $4.00/kg

Demonstrated world's first Tri-generation station

Anaerobic digestion of municipal wastewater (Orange County Sanitation District)

- Produces 100 kg/day H_2; generates ~ 250 kW; 54% efficiency co-producing H_2 and electricity
- Nearly 1 million kWh of operation
- >4,000 kg H_2 produced

(Air Products, FuelCell Energy)

Demonstrated H_2 for Energy Storage (NREL)

- Showed PEM and alkaline electrolyzers provide grid frequency regulation, 4X faster than 'control' with no electrolyzers
- Achieved >9,000 hrs of variable electrolyzer stack operation to determine effects of wind AC power on stack degradation

* Independently targeted vehicle that can achieve a 430 mile range.

Options for Early Hydrogen Infrastructure

Current Status

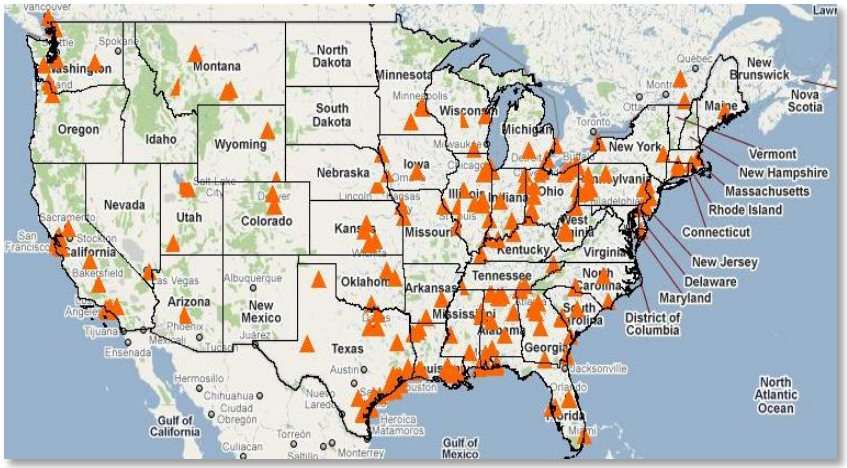
- Over **9MMT** of H_2 produced per year
- Over **1,200 miles** of H_2 pipelines in use (CA, TX, LA, IL, and IN)
- Over **50 fueling stations** in the U.S.

Two Main Options for Low-cost Early Infrastructure

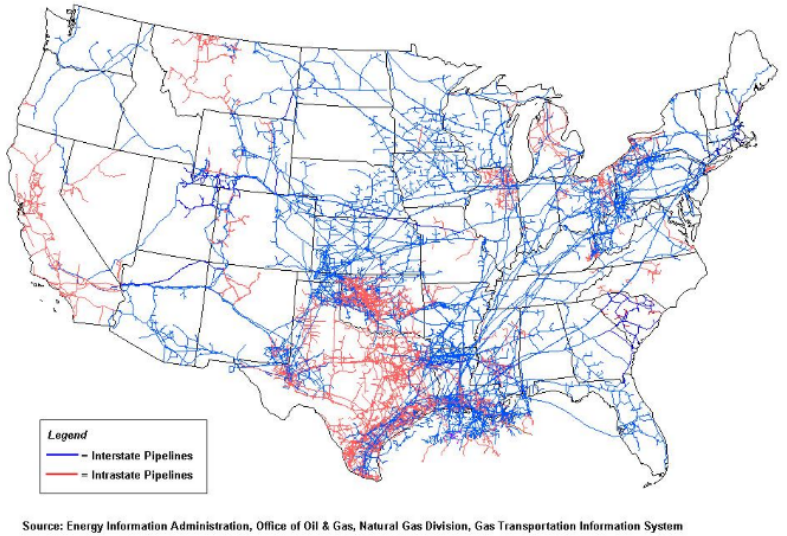
- **H_2 delivered from central site**
  - Low-volume stations (~200-300 kg/day) would cost <$1M and provide hydrogen for $7/gge *(e.g., high-pressure tube trailers, with pathway to $5/gge at 400–500 kg/day)*
- **Distributed production (e.g. natural gas, electrolysis)**

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



Natural Gas Pipeline Network, 2009

Summary: Program Impact

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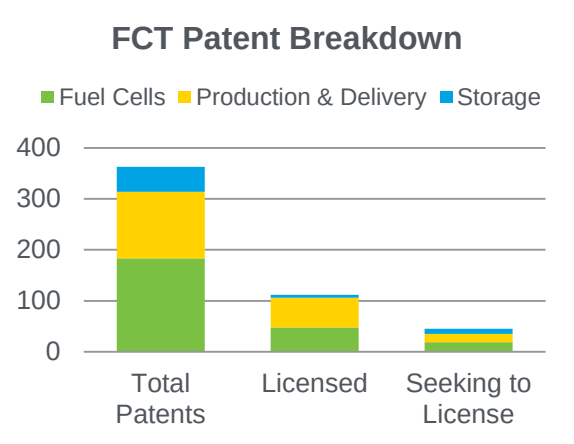
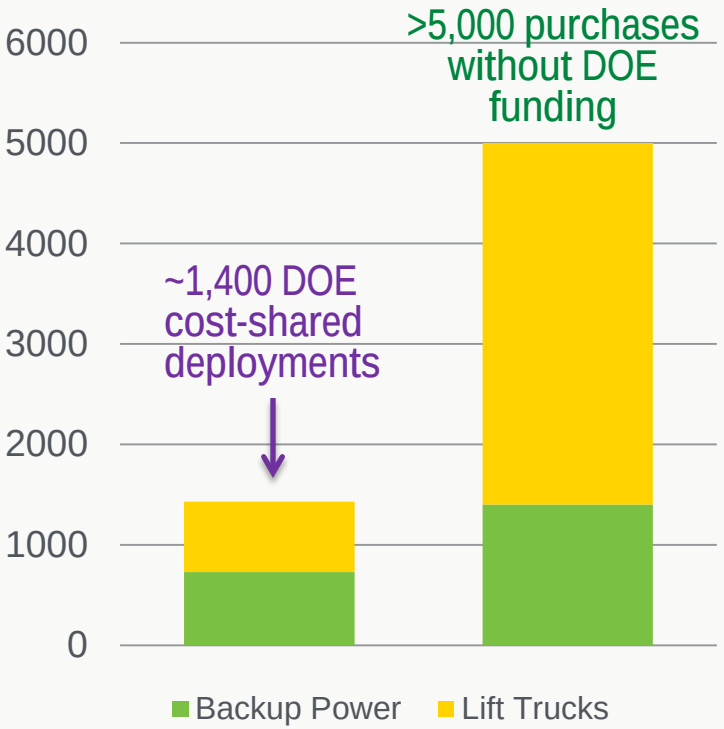
DOE FCT funding has led to 363 patents, 35 commercial technologies and 65 emerging technologies. Example of Impact: ~$70M in funding for specific projects was tracked – and found to have led to nearly $200M in industry investment and revenues.

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.

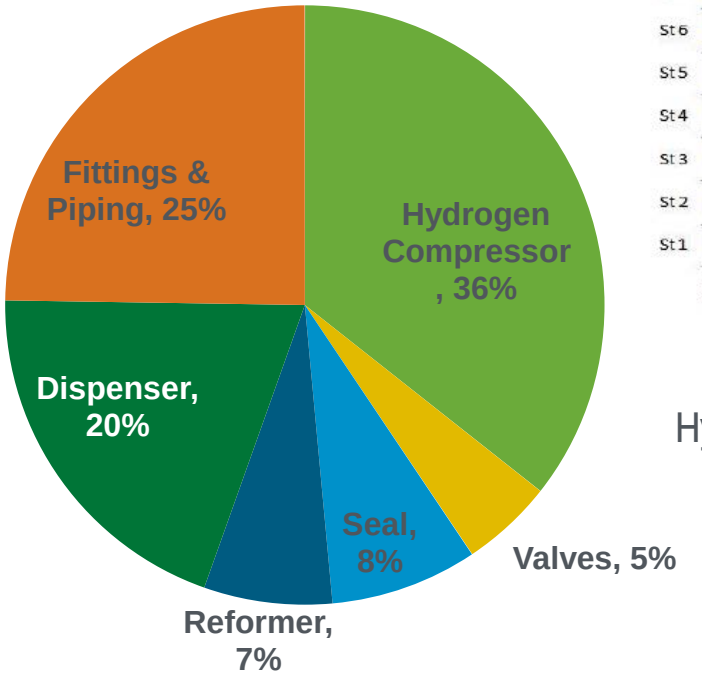


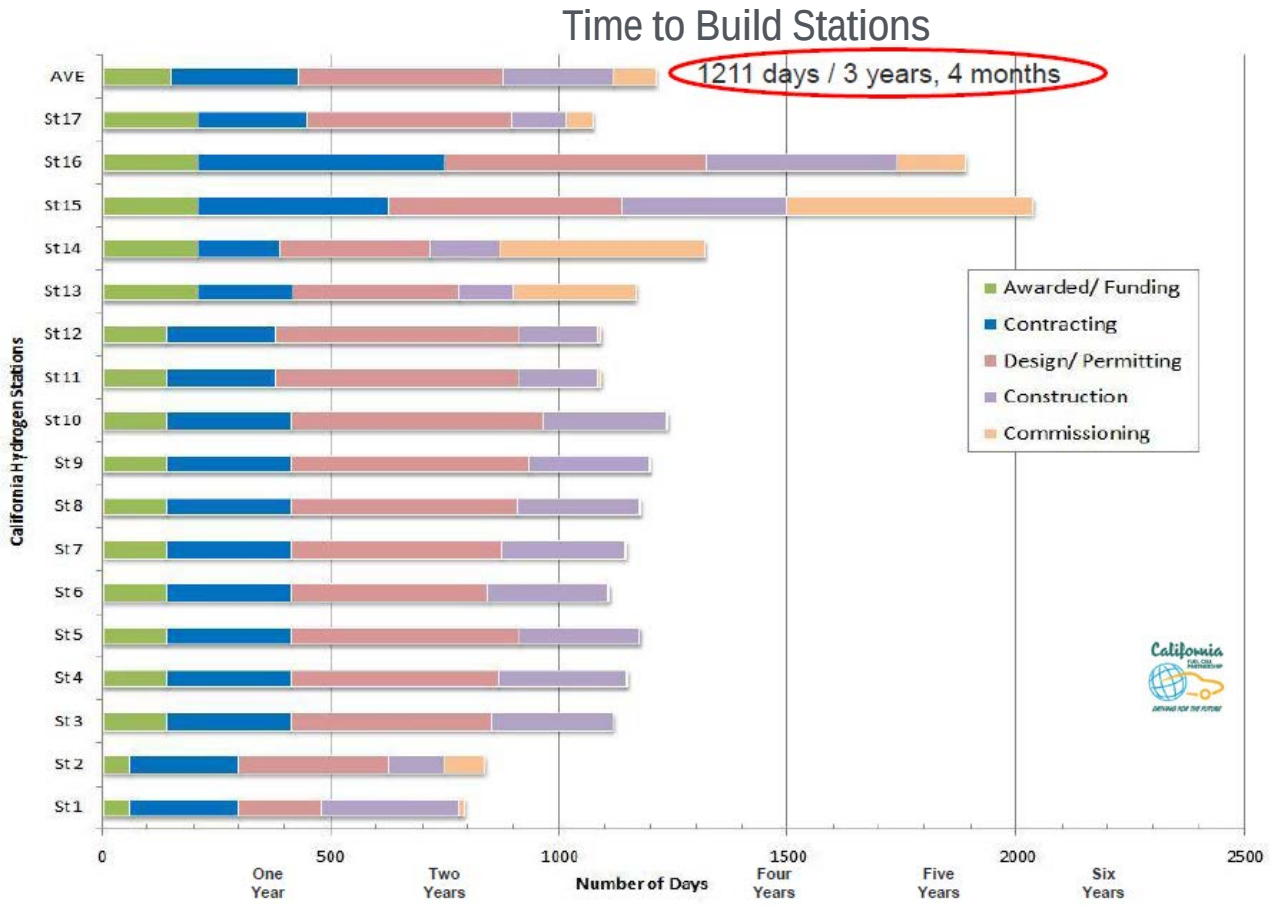
*DOE cost-shared deployments led to **>3X** additional purchases.*

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

Infrastructure: Current Barriers

Despite progress in infrastructure development, more work is needed to address permitting times, contract issues, and equipment reliability.





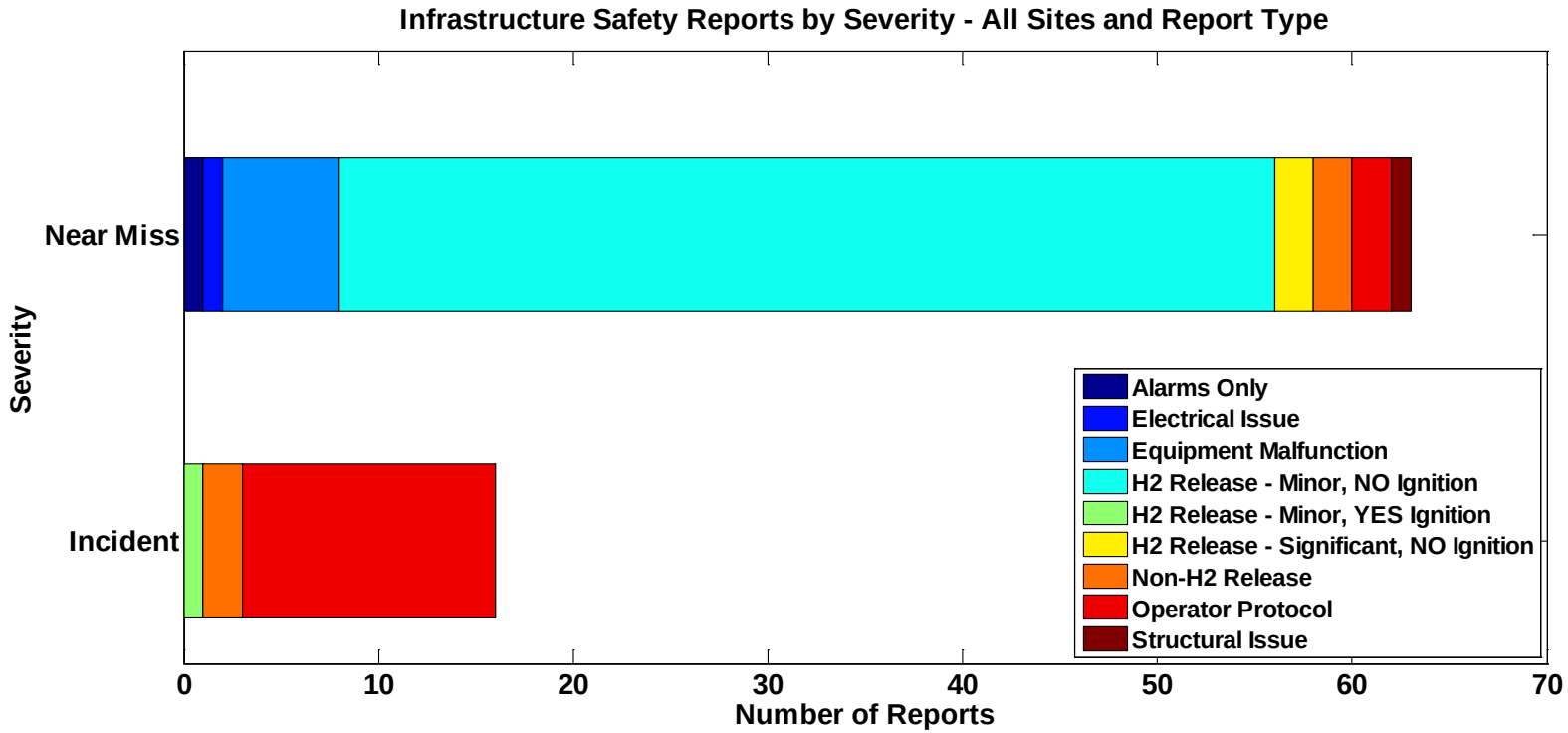
Hydrogen Leaks by Equipment Category: Infrastructure

36% of hours lost due to hydrogen leaks come from hydrogen compressors with another 25% from fittings and piping.

Source: NREL http://www.nrel.gov/hydrogen/cfm/images/cdp_mhe_51_infhydrogenleaksbyequipmenttype.jpg

Infrastructure Safety Categories

A large portion of the incidents can be contributed to drive-aways



An INCIDENT is an event that results in:
- a lost time accident and/or injury to personnel
- damage/unplanned downtime for project equipment, facilities or property
- impact to the public or environment
- any hydrogen release that unintentionally ignites or is sufficient to sustain a flame if ignited
- release of any volatile, hydrogen containing compound (other than the hydrocarbons used as common fuels)

A NEAR-MISS is:
- an event that under slightly different circumstances could have become an incident
- unplanned H2 release insufficient to sustain a flame

NREL cdp_mhe_41

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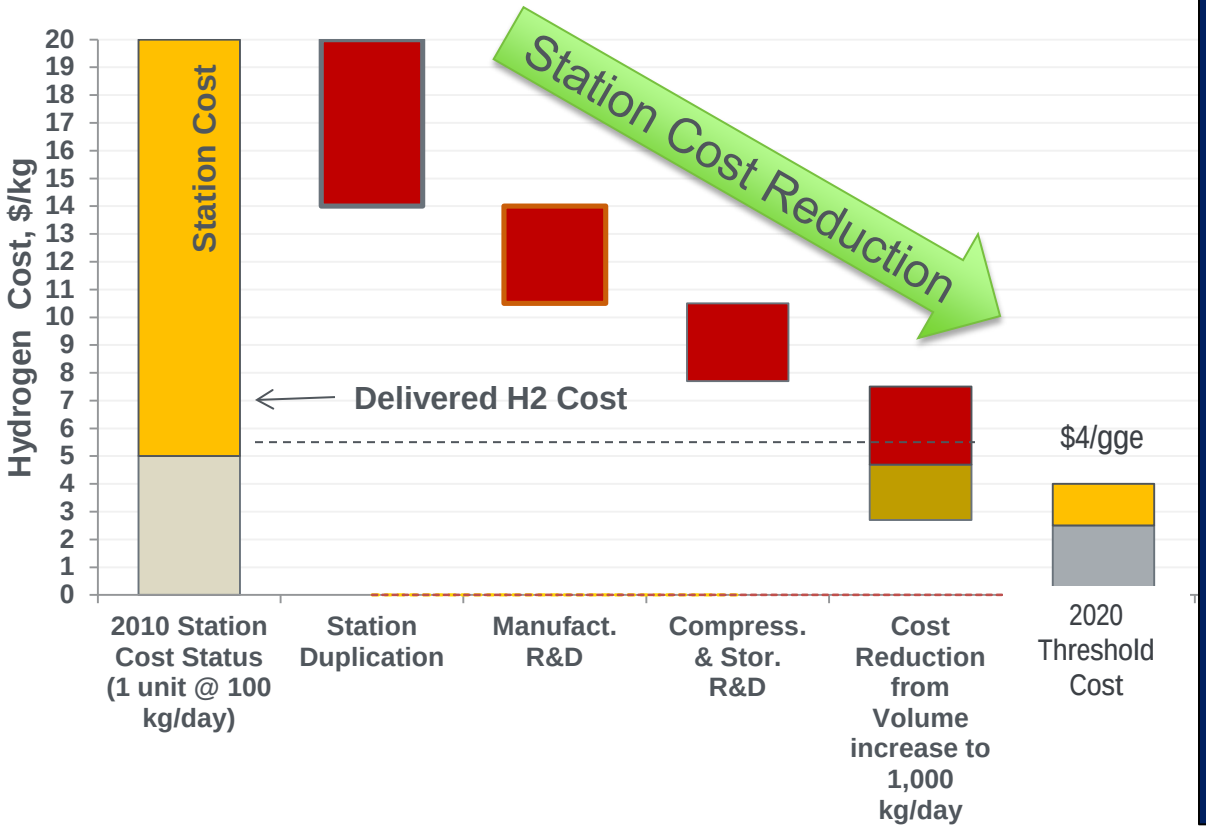
Early Market Analysis: Station Cost Reduction

Developed cost reduction opportunity assessment

Preliminary Analysis: Cost Reductions for Stations



Preliminary results of Infrastructure Workshop highlighted current station costs can be reduced through

- Economies of scale
- Standardized station design
- Multiple station installations
- Continued R&D of manufacturing station components, compressors and hydrogen storage
- Increase the number of station installers and component suppliers

1. Cost reduction from station duplication will required ~120 stations and was based on 3% reduction for a doubling of capacity. Reference: "A portfolio of power-trains for Europe: a fact-based analysis" by McKinsey & Co.
2. Cost of hydrogen delivered to station is ~$5/kg based on TTC Hydrogen Market Study 2009.
3. Station cost reductions based on ANL Hydrogen Delivery Systems Analysis Model (HDSAM).
4. The current station cost is based on costs from the current California state funded stations. The capital cost for the station was assumed to be $2.5 million.
5. The starting station capacity is 100 kg/day.

Hydrogen Delivery

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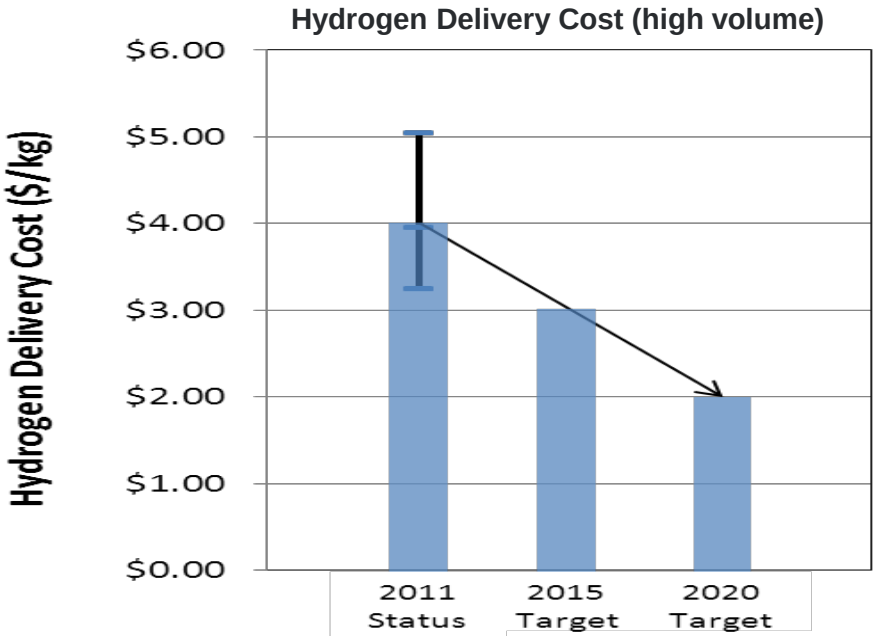
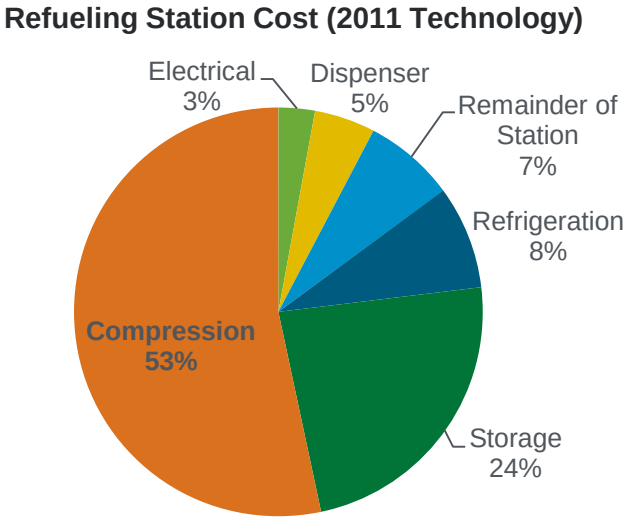
Station costs dominate delivery costs—key focus area.





*Based on preliminary HDSAM (v2.3) analysis assuming 10% market penetration in a city with a population of 1.5M

Fueling Station (CSD) Projections (high volume)

	2011 Projected Cost*	2020 Projected Cost*
Centralized Production	$1.70-$2.20/kg	<$0.70/kg
Distributed Production	$2.50/kg	<$1.70/kg

Delivery 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

Meeting Objective and Outcome

Objective:

To identify research, development, and demonstration (RD&D) needs in the areas of compression, storage, and dispensing to enable cost reduction of hydrogen fuel.

Outcome:

- Summary of key forecourt cost drivers and existing initiatives
- Summary of key R&D topics with potential for cost reduction at the forecourt
- Provide the resulting workshop report for public dissemination

Thank You

For questions please contact:

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hydrogenandfuelcells.energy.gov

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_2Mobility. 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)

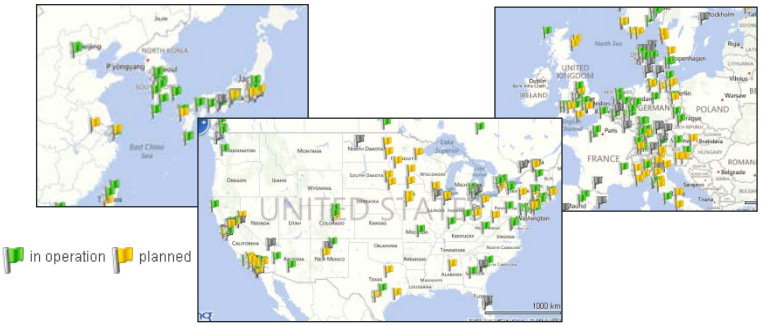
Scandinavian H_2 Highway Partnership (SHHP)

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***

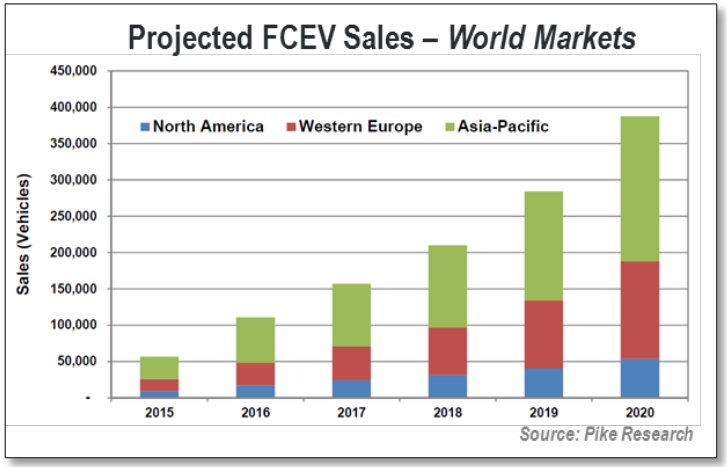
MOU signed October 2012: 4 auto companies *(Toyota, Nissan, Honda, Hyundai)*, 3 H_2 infrastructure companies (*HyOP AS*, *H2 Logic A/S*, *Copenhagen H_2 Network A/S*), and 5 NGOs agreed to introduce FCEVs and H_2 infrastructure by 2014 – 2017 timeframe.

Current Status:

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



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



Safety, Codes & Standards Overview

Goals: Support the widespread commercialization of hydrogen and fuel cells by facilitating development of regulations, codes, and standards (C&S), and by developing and implementing practices to ensure the safe use of hydrogen and fuel cell technologies

Approach

Identify R&D needs

- Lead stakeholder workshops, develop R&D roadmaps
- Analyze existing codes and standards, safety knowledge
- Participate in technical working groups

Perform High-Priority R&D

- Understand foundational hydrogen behavior
- Quantitative Risk Assessments
- **Compatible materials and components**
- Develop and harmonize test protocols

Impact Codes and Standards

- Participate in and lead technical committees to develop requirements
- Publish R&D results
- Disseminate critical data and safety information

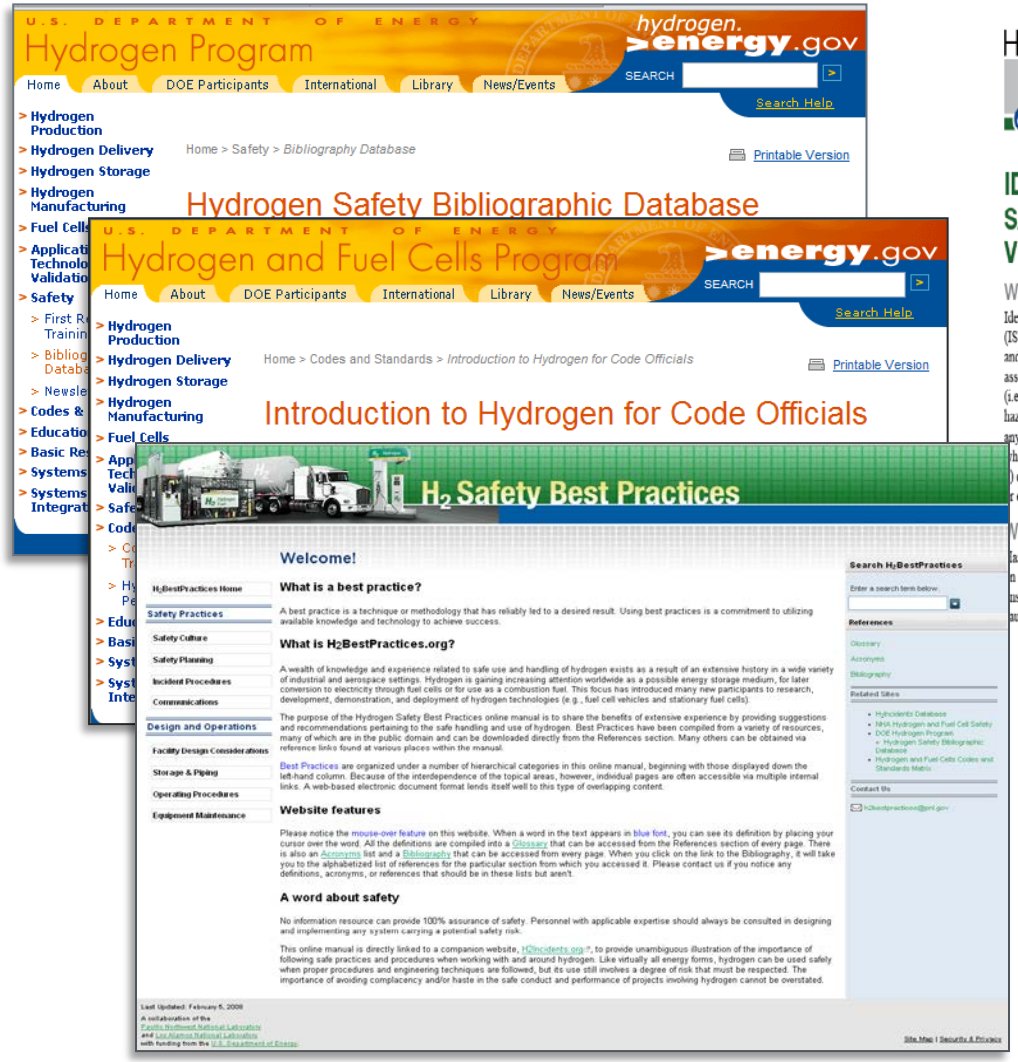
Harmonize Internationally

Global Technical Regulations (GTR Phase 1-SAE J2578, SAE J2579)
International Standards Development Organizations(e.g., ISO, IEC)
International Partnerships and Agreements (IPHE, IEA)

Key challenges include:

- Lack of sufficient hydrogen safety information (including materials compatibility in a hydrogen environment)
- Need to synchronize codes and standards development with technology deployment needs
- Lack of coordination of R&D with codes and standards development cycle and revision schedule
- Need to harmonize C&S domestically and internationally
- Need to standardize the permitting process for H_2 infrastructure

Progress: Safety Knowledge Tools



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

- 206 Lessons Learned events in "H2Incidents.org"
- Approximately 750 entries in the Hydrogen Safety Bibliographic Database

Developed training material for first responders, code officials.

Educated > 23,000 to-date (online & in-person)

Analytics – "H_2incidents.org"

Year	Total Visitors	Max Visitors in 1 Month
2006	3,357	751
2007	15,797	1,928
2008	25,539	4,568
2009	17,081	2,084
2010	17,502	1,954
2011	20,936	2,339
2012	28,684	3,315

Visitors = unique visits as tracked by PNNL on a monthly basis. Regardless of how many times a particular individual may access a website during a particular month, they are counted as one unique visitor.

Total Incidents: 207

http://h2incidents.org/

Lessons Learned Corner *Archives*

Most popular LLCs

- Burst disk failures
- Battery charging facility ventilation
- The importance of purging