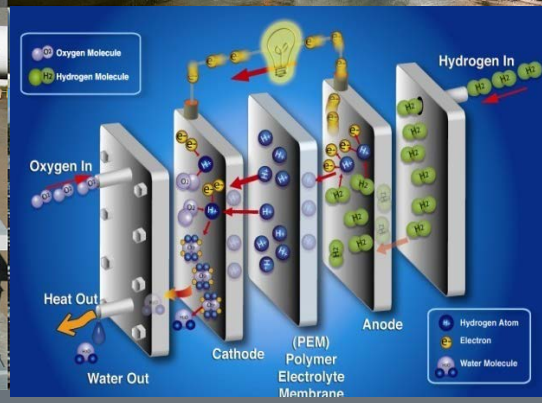
U.S. Department of Energy Fuel Cells Technology Office

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



Alt Wheels Fleet Day

Norwood, MA

October 7, 2015

Pete Devlin

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

Oil Dependency is Dominated by Vehicles

- Transportation is responsible for **66%** of U.S. petroleum usage
- **27%** of GHG emissions
- On-Road vehicles responsible for **85%** of transportation petroleum usage

- **16.0M** LDVs sold in 2014.
- **240 million** light-duty vehicles on the road in the U.S
- **10-15 years** for annual sales penetration
- **10-15 years** to turn over fleet

Poses significant economic, energy and environmental risks to U.S.

Photos courtesy of Spc. Jordan Huettl, U.S. Army; U.S. Environmental Protection Agency; and M. Studinger, NASA

It takes decades of sustained effort to turn over the fleet

2015: Landmark Year

Energy Policy Act of 2005 (Title VIII)

Program goals, include:

"To enable a commitment by automakers *no later than year 2015* to offer safe, affordable, and technically viable hydrogen fuel cell vehicles in the mass consumer market"

FCEVs are on U.S. Roads Now!

Recently Announced Publicly

Available for commercial sale in the US during late 2015

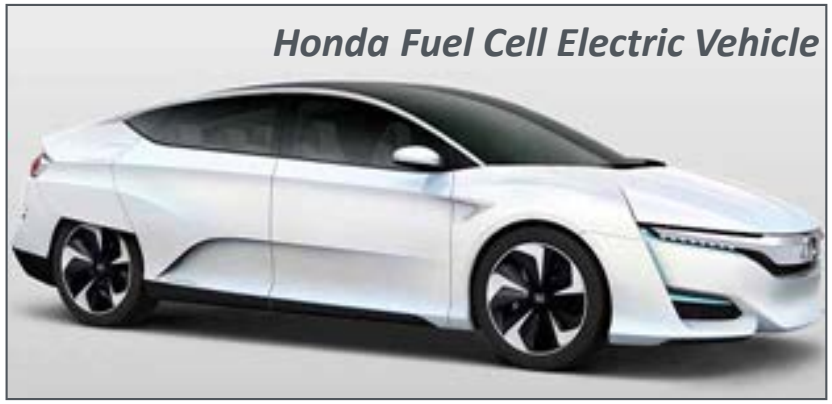
Toyota Mirai Fuel Cell Vehicle

~10 public retail H_2 stations
100 stations planned in CA
Plans underway in Northeast, Hawaii

Now Leasing…

Hyundai Tucson Fuel Cell SUV

In Auto Shows…



Honda Fuel Cell Electric Vehicle

OEMs bringing fuel cells vehicles to showrooms and driveways.

Toyota, Hyundai, Honda, GM, Daimler, Ford, Nissan, BMW, VW, and others!

Secretary Moniz Drive Fuel Cell Electric Vehicle

All-of-the-Above Energy Strategy

*"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

"As part of an all-of-the-above energy approach, fuel cell technologies are paving the way to competitiveness in the global clean energy market and to new jobs and business creation across the country."

- Secretary Moniz,
U.S. Department of Energy

Secretary Moniz at DC Auto Show

Sustainable Transportation Sector

Sustainable TRANSPORTATION

- Transportation Efficiency
- Diverse Fuel Sources
- Domestic & Renewable

Hydrogen and Fuel Cells

Vehicles

Bioenergy

National Energy Goals & Climate Action Plan

Net Oil Imports
↓ **50%** by 2020

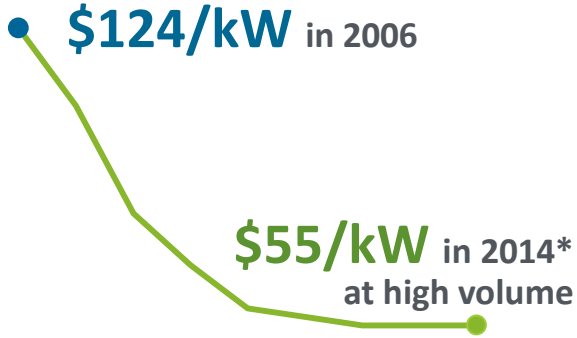
GHG Emissions
↓ **17%** by 2020
>80% by 2050

DOE Activities Span from R&D to Deployment

1. Research & Development

Cost Reductions

- 50% for fuel cell systems
- 5x less platinum
- > 2x increase in durability
- 80% for electrolyzers



*$280/kW low volume

2. Demonstration

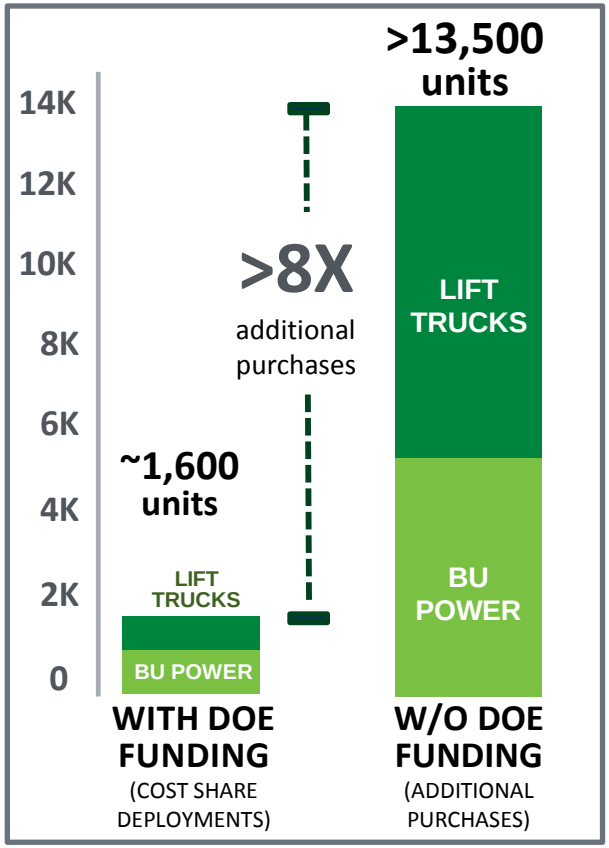
FCEV Demo

- >215 FCEVs, 30 stations, 5.7M miles traveled

World's first tri-gen station

Forklifts, back-up power, airport cargo tugs, marine APU, buses, mobile lighting

3. Deployment



Savings from Active Project Management

More than **$35M** last 5 yrs & More than **$3M** last year

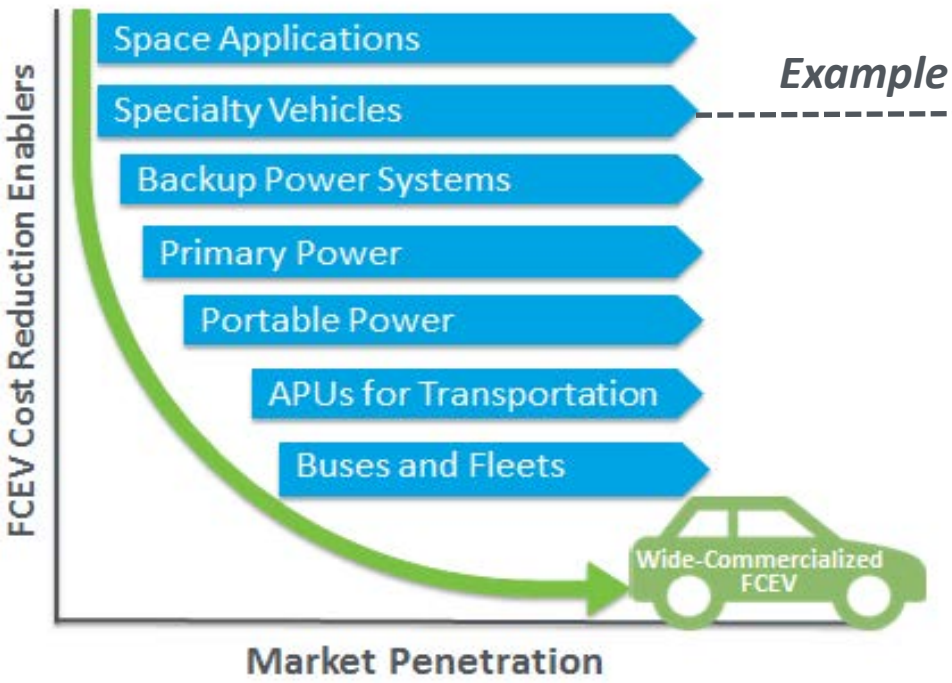
*Bar graphs not drawn to scale

Early Market Strategy

Early Markets enable:

- Fuel cell cost reduction
- Robust supply base
- Emerging Infrastructure
- Customer acceptance

Early Market Application Examples



Example

World's First Fuel Cell Cargo Trucks at Memphis International Airport

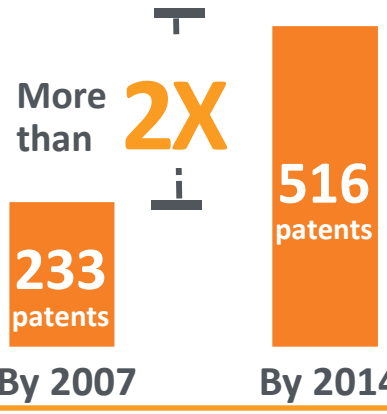
facebook Post Stats:

More than **180 shares** **240 likes** → **Over 45,000** people reached

Impact of Federal Investment in H_2 and Fuel Cells- DOE EERE

Innovation

Cumulative Number of Patents

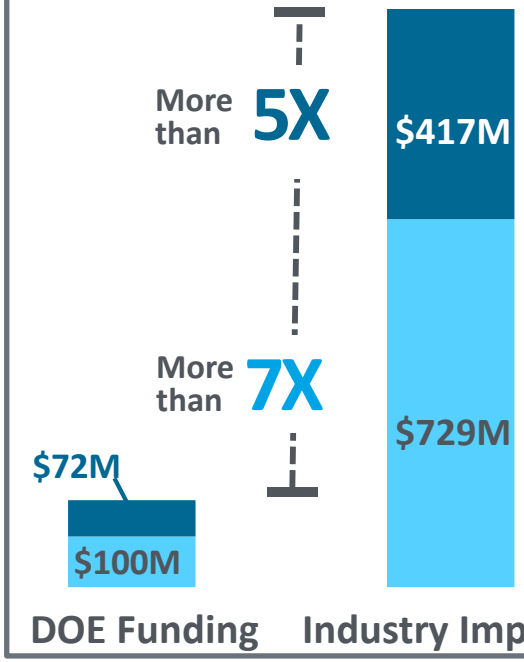


Commercialization

Commercial Products Entering the Market

Return on Investment

DOE impact on Private Investment and Industry Revenues



Jobs from commercial products and ARRA

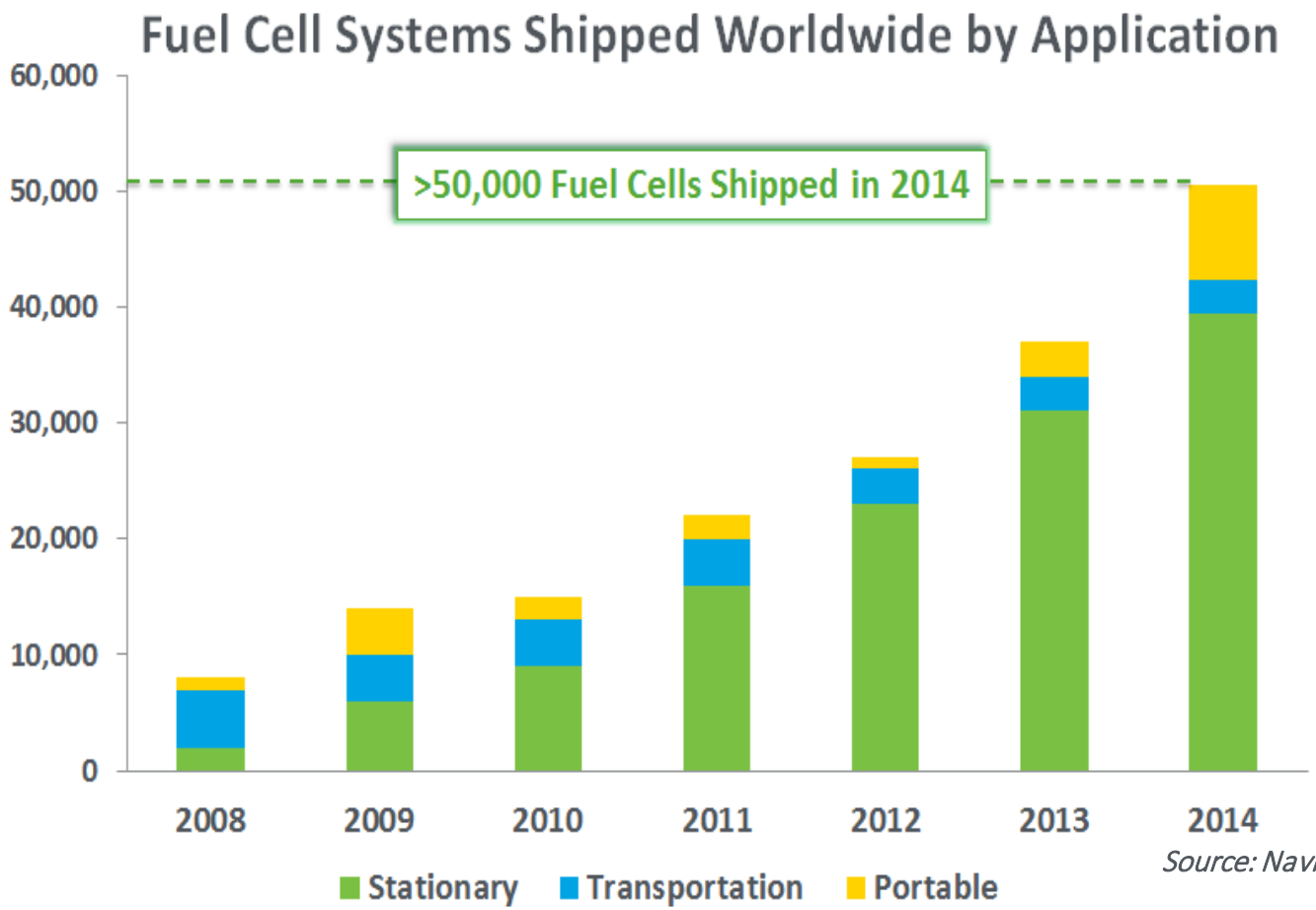
More than **450 jobs** tracked per year

1,400 jobs created or sustained

Commercial Products- Examples

- Catalysts
- Electrolyzers
- Tanks
- Fuel Cell System Components

Fuel Cells- Steady Market Growth



Source: Navigant & E4tech

Consistent 30% annual growth since 2010

Global market potential in 10–20 years: 14 – $31 billion/yr for stationary power
$11 billion/yr for portable power
$18 – $97 billion/yr for transportation

Commercial Products in Today's Market-Examples

Hydrogen Generation from Electrolysis

Proton's PEM Hogen S Series Electrolyzer System

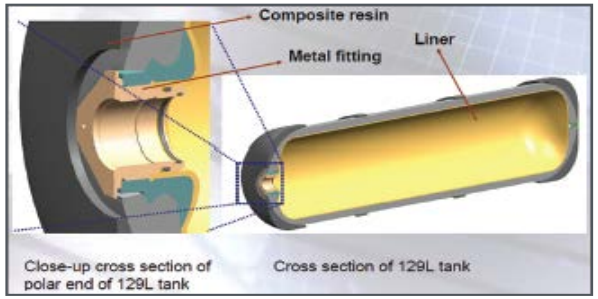
GenDrive™ Fuel Cell Power System

Class-1, -2, and -3 Forklifts Powered by Plug Power's GenDrive FCs

PEM Electrolyzer Incorporating a Low-Cost Membrane

Giner's PEM Electrolyzer System

Hydrogen Composite Tanks

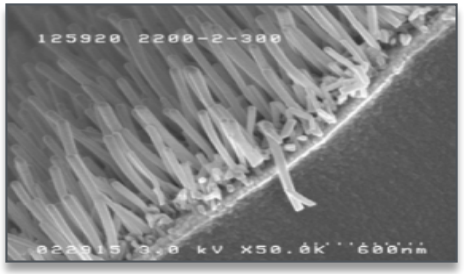


Quantum Technologies' Optimized 129L Tank

TITAN™: High-Pressure Hydrogen Storage Tank for Gaseous Truck Delivery

Hexagon Lincoln's 3,600 psi TITAN™ Tank and Frame System

3M Cathode Catalysts and Supports for PEM Fuel Cells

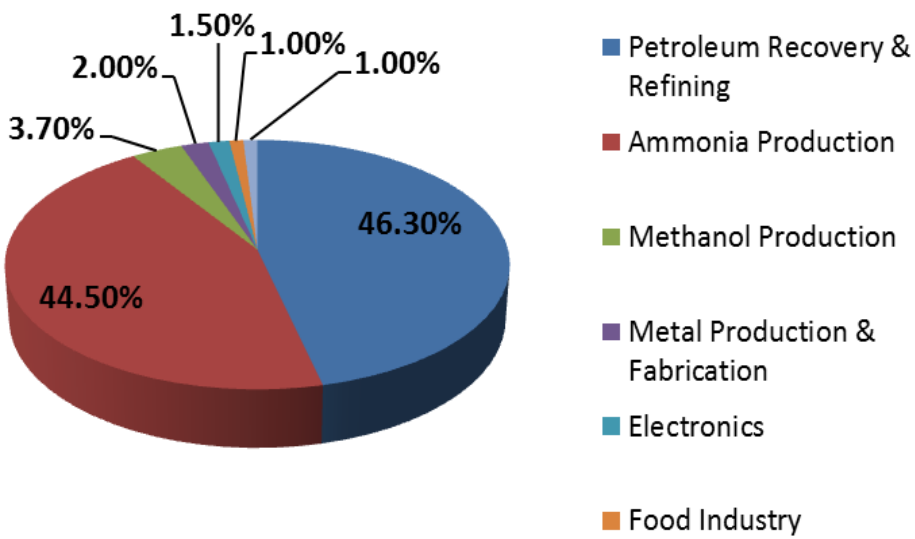


Scanning electron micrographs of 3M's nanostructured thin film

U.S. H_2 Production: Current Status

>9 million metric tons of H_2 mostly:

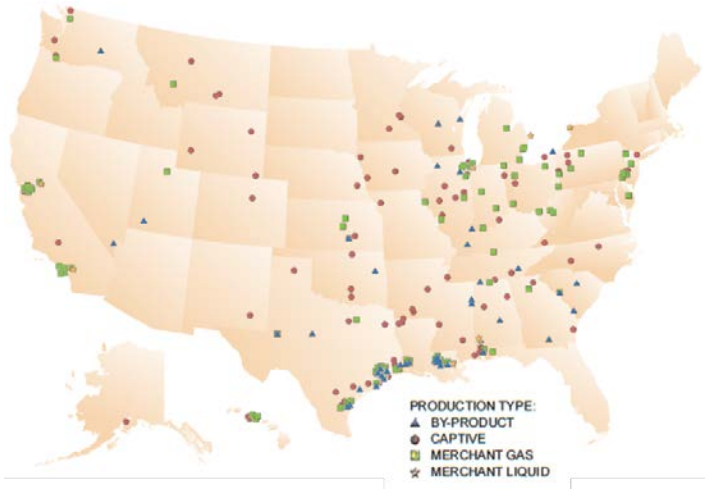
- From **steam methane reforming of natural gas (SMR)**
- For **petroleum refining**, ammonia production



H_2 consumption market share by application

Near-term strategy for cost-competitive hydrogen fuel

- **H_2 from Natural Gas** through SMR
- **At-scale** production
- **<$2/gge produced** ($4.50/gge delivered)



Centralized H_2 production facilities

Early adoption of H_2 and fuel cell technologies can leverage production and delivery infrastructure associated with low cost NG reforming

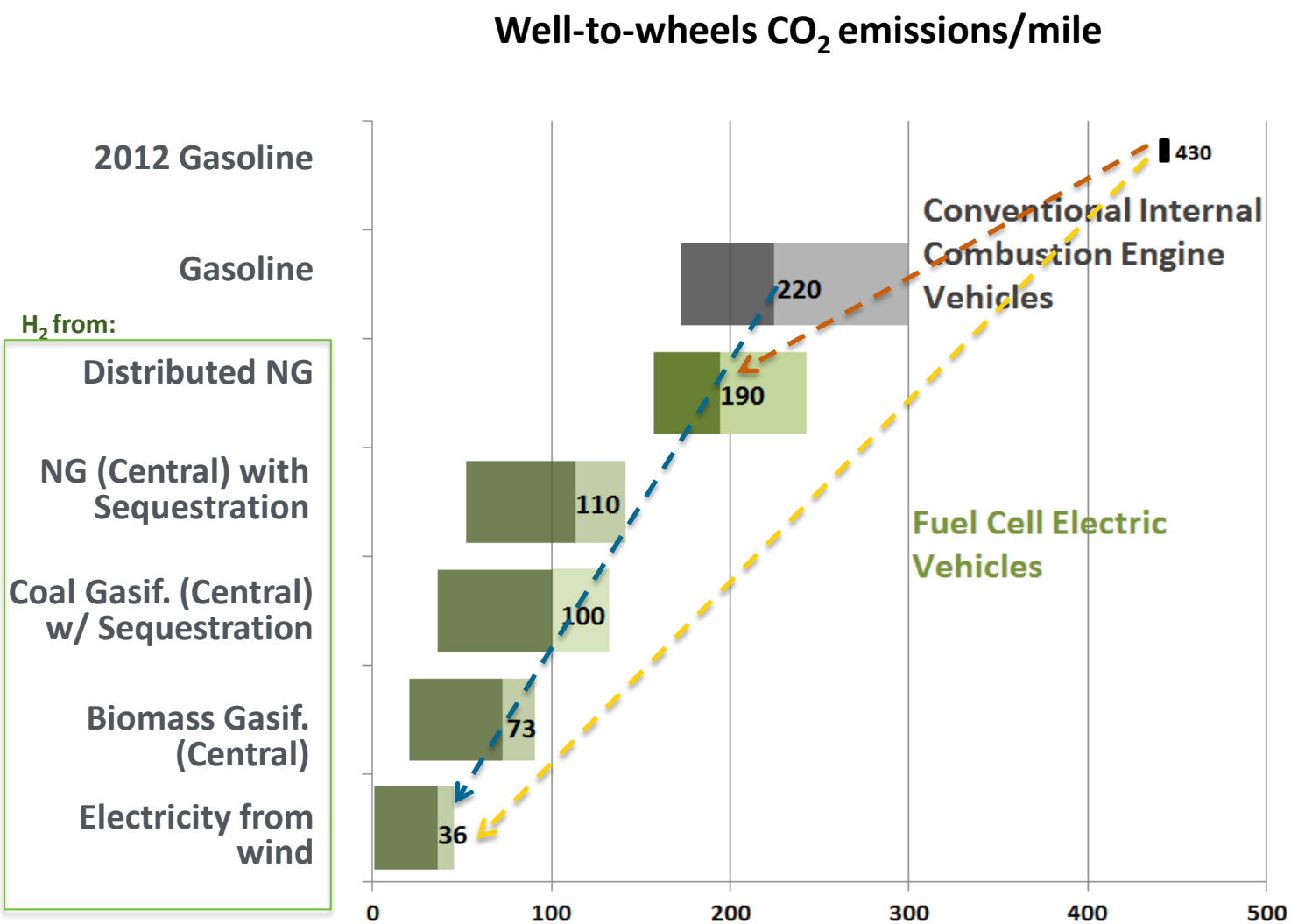
FCEVs Reduce Greenhouse Gas Emissions

>50% with H_2 from Distributed Natural Gas*

>80% with H_2 from Renewables* (Wind)

>90% with H_2 from Renewables** (Wind)

*Compared to 2035 gasoline vehicle
**Compared to 2012 gasoline vehicle



Source: http://hydrogen.energy.gov/pdfs/13005_well_to_wheels_ghg_oil_ldvs.pdf
Advanced 2035 technologies

Substantial GHG reductions with H_2 produced from renewables

Examples of Global Infrastructure Activities

Hydrogen Supply/Utilization Technology (HySUT)

- 18 companies (including 3 auto companies), have announced plans to commercialize FCEVs and provide infrastructure by 2015.
- **100** H_2 stations and FCEVs launched in **4** urban areas by 2015

H2Mobility

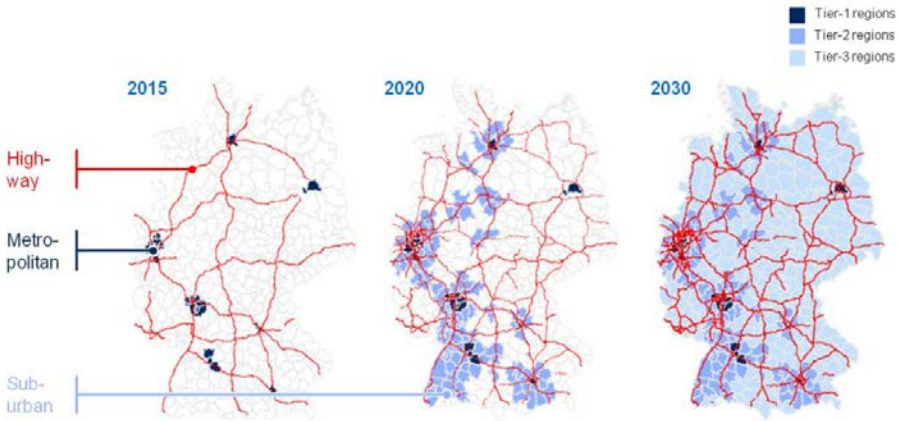
- Public-private initiative for nationwide H_2 infrastructure—will develop into joint venture to install stations.
- **50** H_2 stations (public-private funds committed); and **5,000** FCEVs expected on the road by 2015

UKH2Mobility

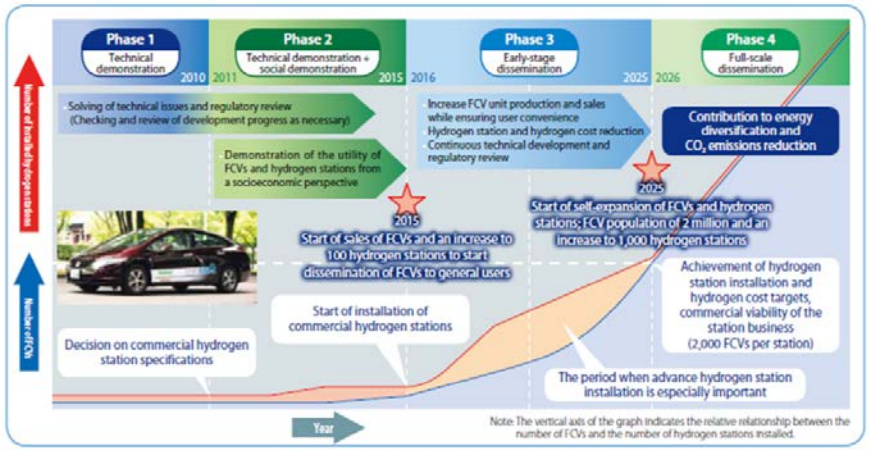
- Evaluating anticipated FCEV rollout in 2014-2015
- Will develop action plan to make UK a leading market for FCEVs

Scandinavian H2 Highway Partnership (SHHP)

- Partnership of Hydrogen Link (Denmark), HyNor (Norway) and Hydrogen Sweden.
- 45 H_2 stations and a fleet of ~1K vehicles. Projects include H2Moves Scandinavia and Next Move
- 2012 MOU signed between auto & infrastructure companies and NGOs to introduce FCEVs and H_2 infrastructure within 2014 and 2015 timeframe.



	2015	2020	2030
No. of FCEVs Thousands	~ 5	~ 150	~ 1,800
No. of HRS	~ 100	~ 400	~ 1,000
Total population covered by HRS Percent	~ 20	~ 60	~ 100



International partnerships established to accelerate hydrogen infrastructure

H_2USA: Public-Private Partnership

H2 USA

Partners

~ 45 Partners in 2015

Mission

To address hurdles to **establishing hydrogen fueling infrastructure**, enabling the **large scale adoption of fuel cell electric vehicles**

Structure

4 Working Groups coordinated by the **Operations** Steering Committee

H_2FIRST Coordination panel

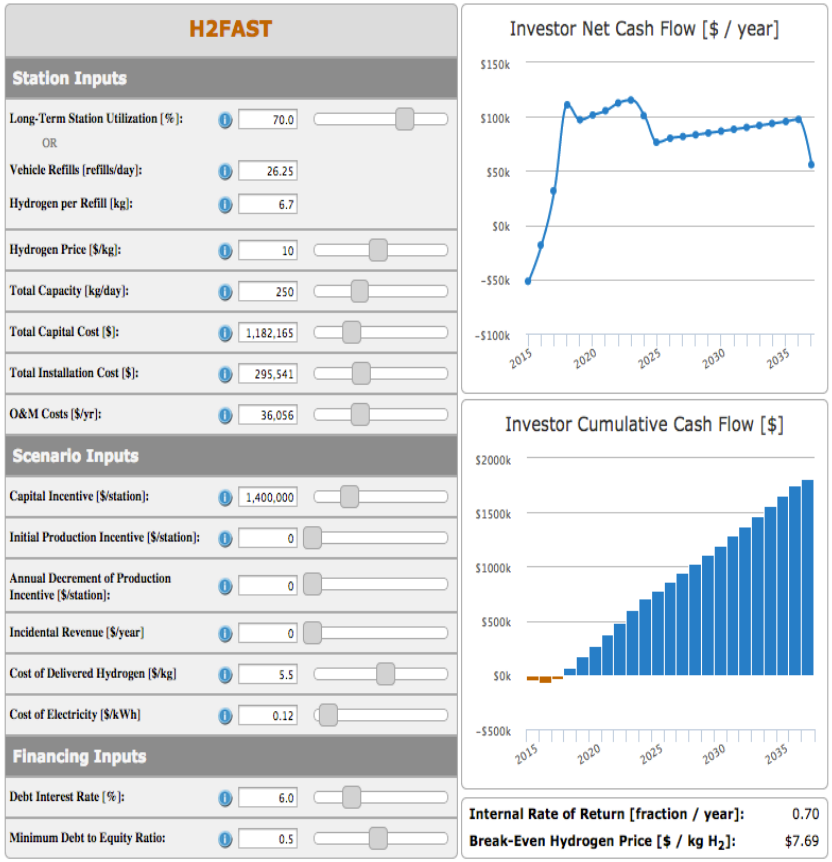
H_2FIRST

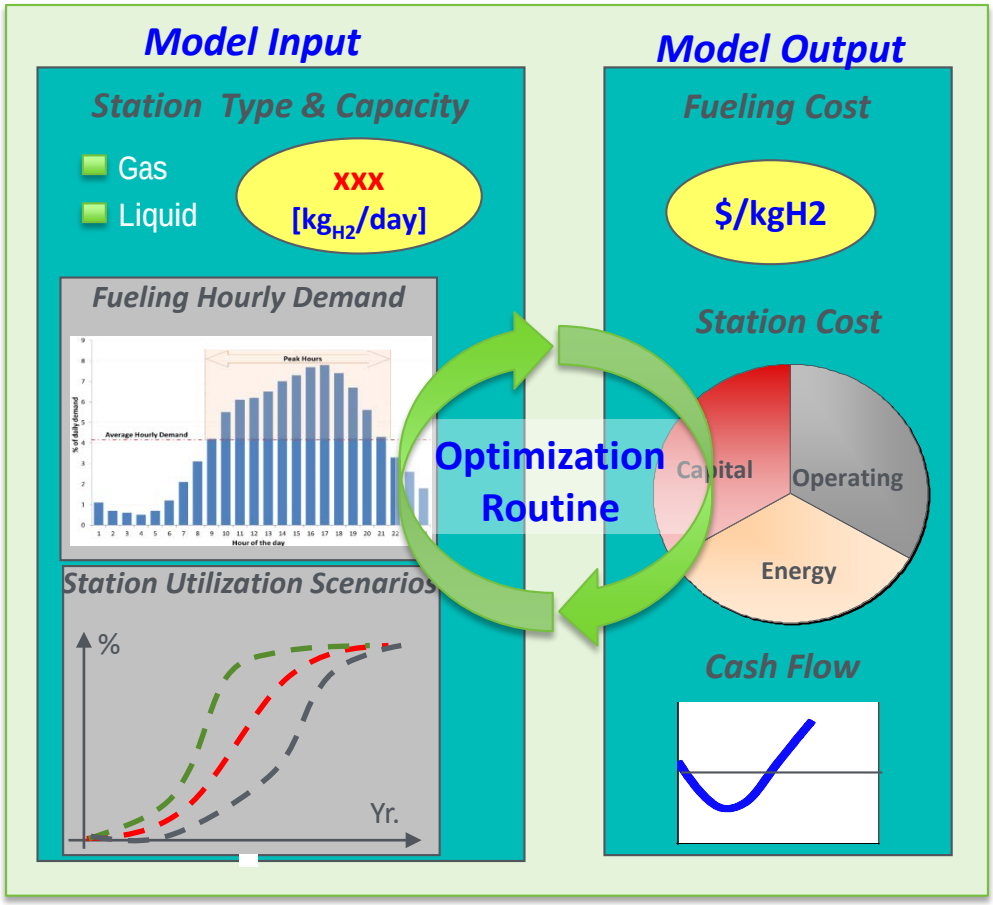
H_2USA's Working Groups

- Hydrogen Fueling Station
- Locations Roadmap
- Financing Infrastructure
- Market Support & Acceleration

More than 45 partners working towards adoption of FCEVs and H_2

Modeling and Online Tool Development for Stations





H2FAST- H2 Financial Analysis Scenario Tool
Web-based online calculator (NREL)

HRSAM- Hydrogen Refueling Station Analysis Model (ANL)

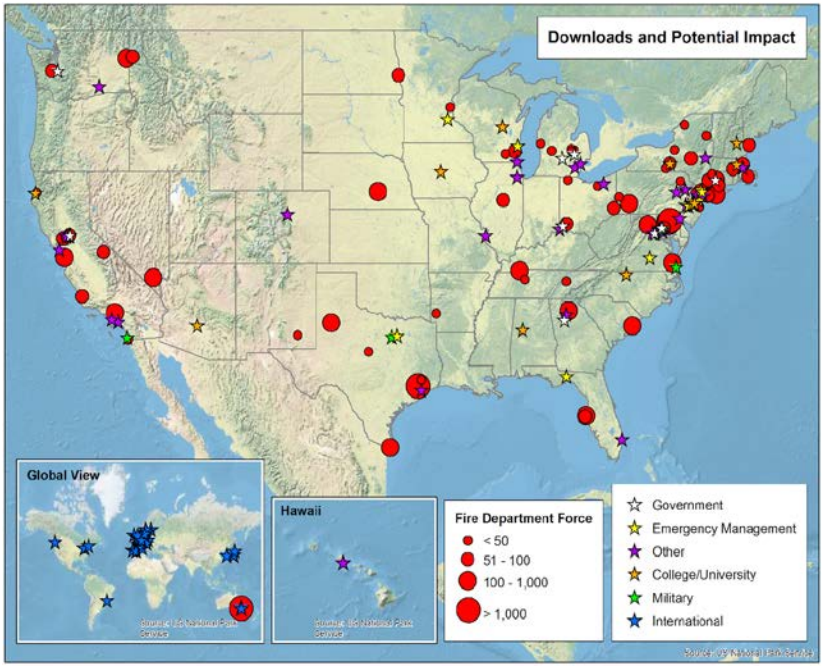
Station cost, optimized configurations, and cash flow and ROI analyses to optimize financial viability of station options

Safety Codes and Standards Highlights

H2Tools

Consolidated safety and knowledge resources into a central location, alongside newly added functionality and content

Safety Training for First Responders



Tracking interest in first responder training resources across the country, including along the northeast corridor

Reached more than 35,000 code officials and first responders

Examples of zero-emission MD and HD truck and bus demonstrations include…

Heavy Duty Vehicles

Full-size buses

Drayage Trucks

Waste Hauling Trucks

Medium Duty Vehicles

Shuttle buses

Baggage Tow Tractors

Delivery Vehicles

These H_2-fueled fleet vehicles can replace diesel engines with limited infrastructure

Accomplishments: Progress Toward Targets

Data Summary for 2015

Specifications for FCEBs included in data summary

FCEB Identifier	ACT ZEBA	SL AFCB
Transit Agency	AC Transit	SunLine
Location	Oakland, CA	Thousand Palms, CA
Number of Buses	12	3
Bus OEM	Van Hool	ElDorado National
Bus length/height	40 ft / 136 in	40 ft / 140 in
Fuel Cell OEM	US Hybrid	Ballard
Model	PureMotion 120	FCvelocity–HD6
Power (kW)	120	150
Hybrid System	Siemens ELFA, integrated by Van Hool	BAE Systems HybriDrive
Design strategy	FC dominant	FC dominant
Energy Storage—OEM	EnerDel	A123
Type	Li-ion	Nanophosphate Li-ion
Capacity	17.4 kWh	11 kWh
# cylinders	8	8
Capacity (kg) / Pressure (Bar)	40 / 350	50 / 350

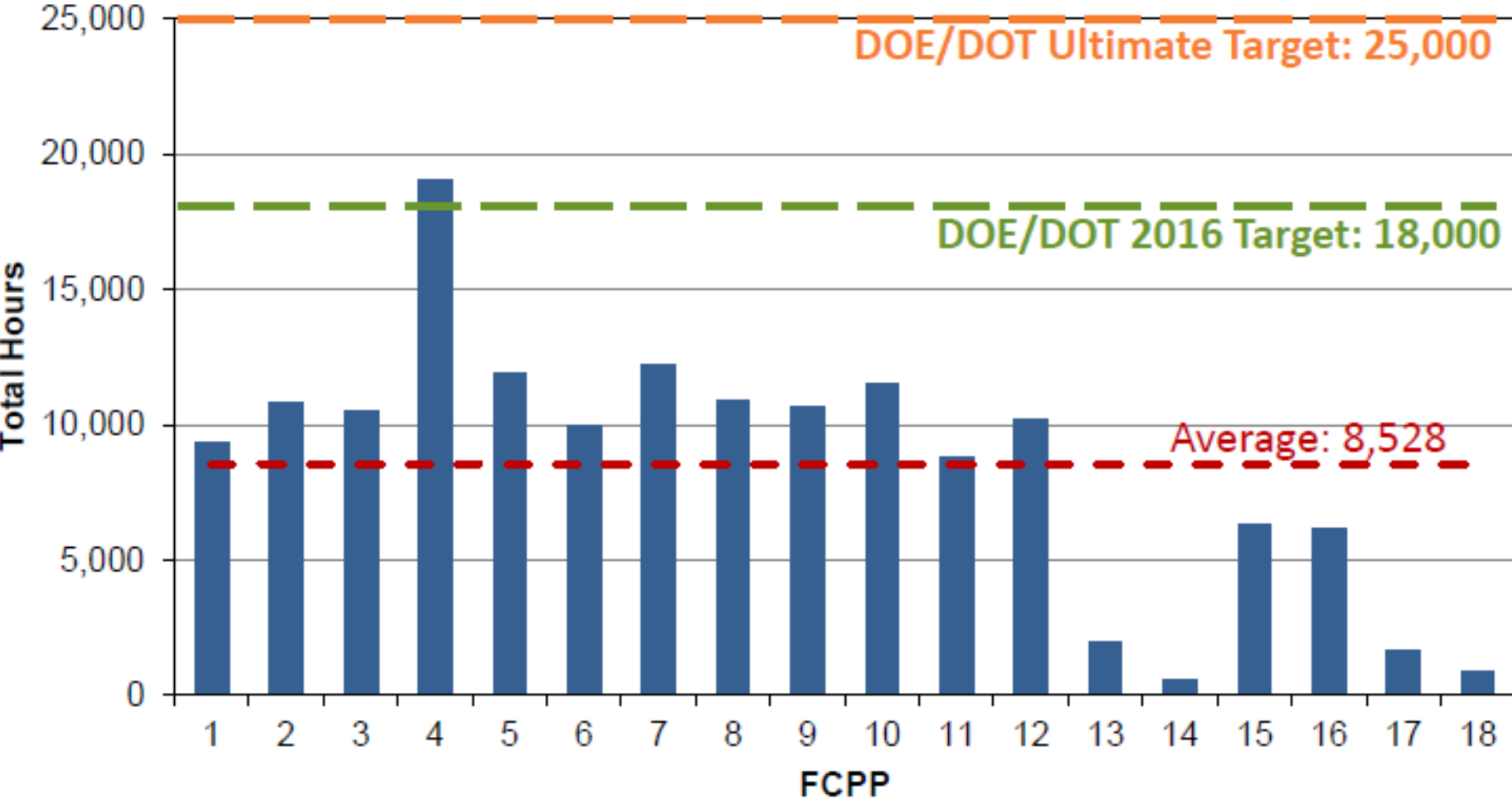
ACT ZEBA

SL AFCB

OEM = original equipment manufacturer
ACT ZEBA = AC Transit Zero Emission Bay Area
SL AFCB = SunLine American Fuel Cell Bus
FC = fuel cell

Top Fuel Cell Powerplant exceeds 19,000 Hours

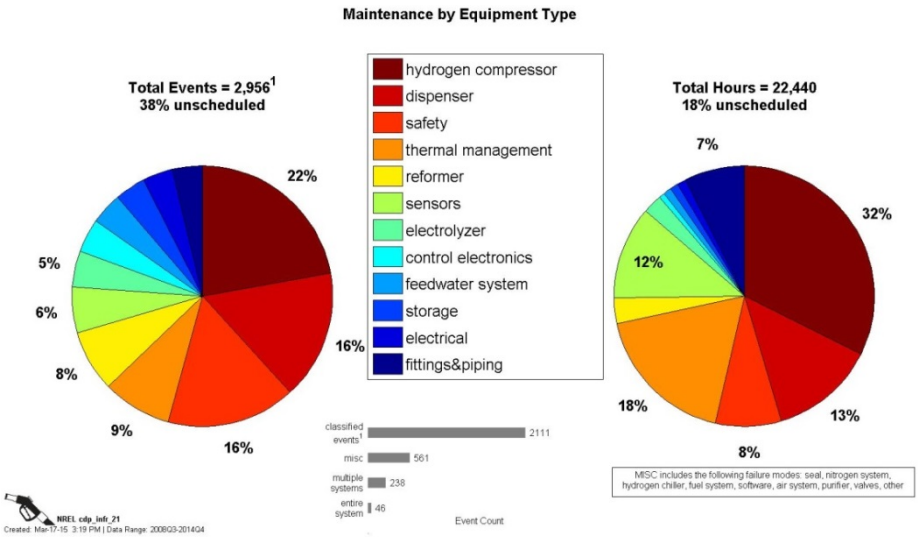
Top FCPP > 19,000 hours, surpassing DOE/DOT target; 67% of FCPPs over 8,000 hours

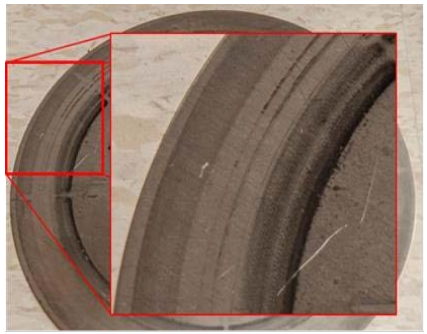


Total hours accumulated on each FC powerplant (FCPP) as of 3/31/15

Highlights from Real World Operation

- CSULA- First in U.S. to receive seal of approval for sale of H_2 Jan 2015
- New **data collection** projects with OEMs (Toyota, Hyundai, Honda, Nissan, Daimler, GM)
  - **2.4 million miles**
  - >**50% of FCEVs on road showed 50-55 mpgge fuel economy**
- Determined **causes for >2,900** maintenance events
- Developed **safety and contaminant sensor** technologies at LANL
- Developed and **tested fuel cell power system** for pier-side and auxiliary sea vessel power



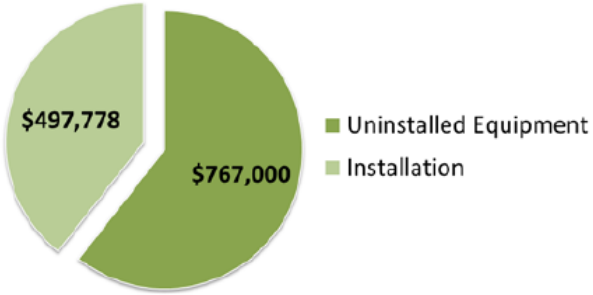


Determined contaminant source (siloxane) & identified potential substitutes (e.g. PTFE-based grease can be suitable replacement with minimal effects)
Fuel cell system contaminants material screening databased (NREL):
www.nrel.gov/hydrogen/system_contaminants_data/

H2FIRST Results on Station Designs & Cost

Reference Station Design Report

(a) Gaseous, 300 kg/day, 6 consecutive fills, 1 hose



Total: $1,264,778

- ✓ Analyzed 120 station permutations and selected four high-priority, near-term station concepts based on economics, technical feasibility, and market need
- ✓ Produced spatial layouts, bills of materials, and piping & instrumentation diagrams and detailed cost estimates

Station Number	H_2 Delivery Method	Daily Capacity	Target Market	Installed Capital Cost ($K)	Fuel Cost ($/kg)
1	Gaseous	300 kg	High use	$1,265	$6.03
2	Gaseous	200 kg	Low use	$1,179	$5.83
3	Gaseous	100 kg	Intermittent	$1,098	$13.28
4	Liquid	300 kg	High use	$2,007	a
5	Future Liquid	300 kg	High use	$1,551	$7.46

[a]This station type was not available for modeling in HRSAM at the time of the analysis.

Report available: http://www.nrel.gov/docs/fy15osti/64107.pdf

Station capital and O&M adds $6-$8/kg to the cost of 700 bar hydrogen in the near-term

The Key Pieces of the FCEV-H_2 Puzzle

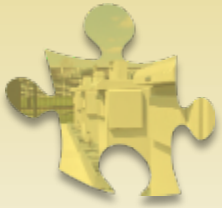
1. FCEV and H_2 Station Incentives

2. Communities of Interest

3. FCEV Fleet Strategy

4. Initial H_2 Infrastructure

5. Enabling Affordable Hydrogen



6. Planning for Smart Refueling

7. Take Advantage of Financing Options

8. Gaining Public Acceptance

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We are getting there

Thank You

Pete Devlin

Market Transformation Manager

Fuel Cell Technologies Office

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hydrogenandfuelcells.energy.gov

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DE-FOA-0001349 "Medium and Heavy Duty Vehicle Powertrain Electrification and Dual Fuel Fleet Demonstration"

EERE released an $11M Funding Opportunity Announcement for Medium and Heavy Duty Vehicles (Vehicle Technologies Office)

Area of Interest 1 – Medium and Heavy Duty Vehicle Powertrain Electrification

- **The objective of this area of interest is to research, develop, and demonstrate electric-drive powertrain technologies for medium and heavy duty Plug-in Hybrid Electric Vehicles (PHEV) and Electric Vehicles (EV) that reduce fuel consumption by at least 50% when compared to an equivalent vehicle with a conventional internal combustion engine powertrain driven on a comparable duty cycle.**
- **Total $10M Federal funds, 1 – 3 Awards**

Area of Interest 2 – Dual Fuel Heavy Duty Vehicle Fleet Demonstration

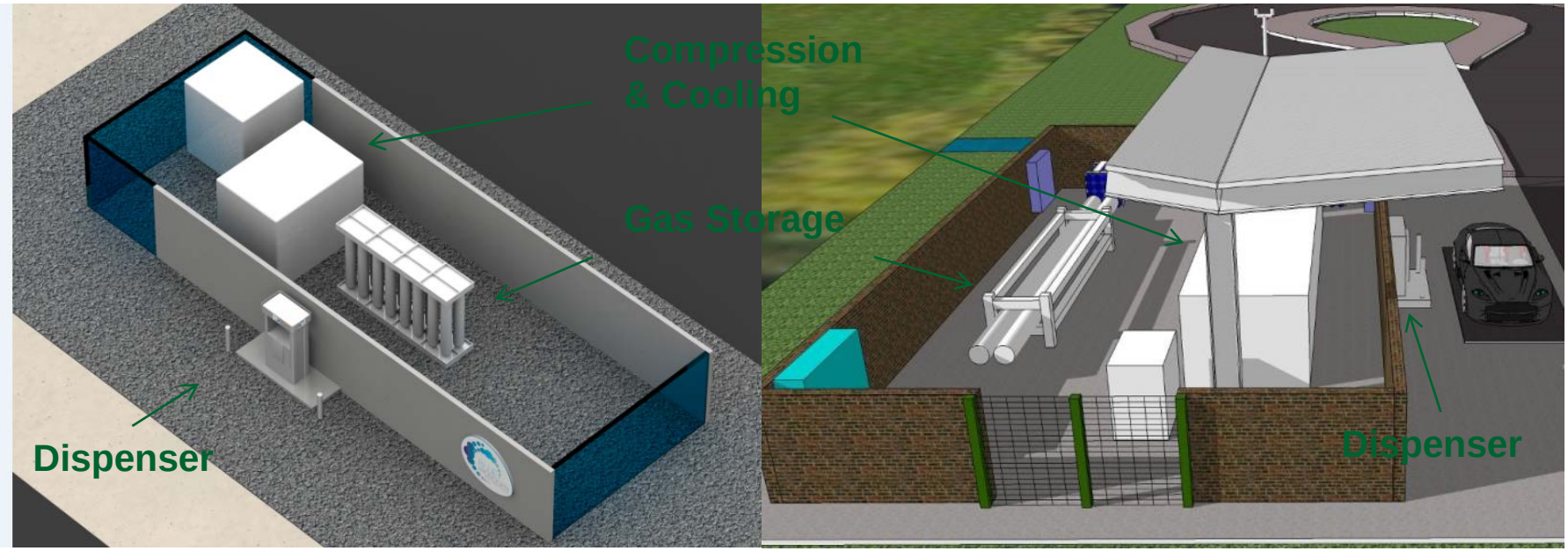
- The objective of this area of interest is to demonstrate and evaluate the performance and emissions systems of dual fuel heavy-duty vehicles equipped with engines capable of operation using a mixture of diesel fuel and gaseous fuels (natural gas, propane or natural gas derived fuels such as DME).
- Total $1M Federal funds, 1 – 2 Awards

Full requirements are outlined in the FOA **https://eere-exchange.energy.gov**

FOA Issue Date:	**09/08/2015**
Submission Deadline for Concept Papers:	**10/08/2015**
Submission Deadline for Full Applications:	11/19/2015

Station Design

- Small foot print 1500-2000 ft2
- All equipment modular, above ground and expandable
- Fueling time 3-5 minutes
- NFPA 2 and CGA compliant



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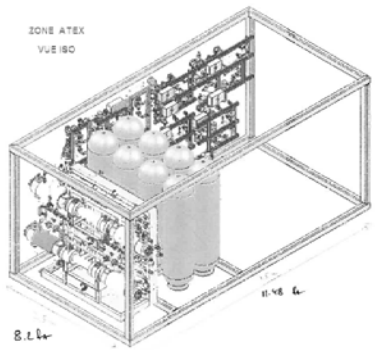
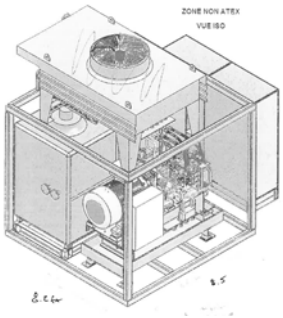
Station Components

Compression and Cooling





- Conditions H2 for achieving high density and SAE compliant fills

Dispensers

- Standard retail point of sale system or customized fleet systems
- SAE fueling nozzle and protocol
- Metering systems advancing to weights & measures approvals
- Station status broadcast to the cloud or internet

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Hydrogen Supply and Distribution

Large Scale Production

H2 Gaseous Source:
- Steam Methane Reformation
- Waste gas purification
- Electrolysis

200-450 bar

Liquefaction

Onsite Production

SMR

Electrolysis

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H_2 Delivery Options and Stations

H_2 Delivery Infrastructure

- **Current: 1,500 miles of H_2 pipeline**

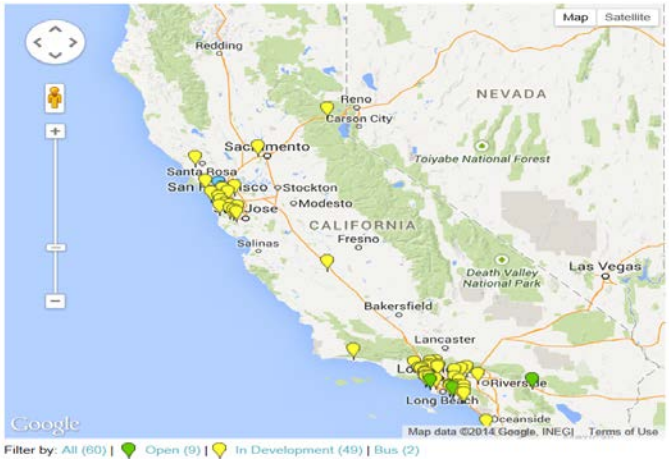
H_2 Station Options

- **H_2 from central site:**
  - **~$1M** for stations*
  - **~$7/gge** for H_2
- **Distributed production:**
  - Natural gas
  - Electrolysis

*~200-300 kg/day (range of cost)

H_2 Stations in the U.S.

- **Current: ~50 total** (~10 public)
- **State Plans:**
  - **CA- 100 stations, ~$100M** planned through 2023
  - **Northeast States & Hawaii**
  - **8 State MOU- 3.3M ZEVs** by 2025



H_2 stations in CA (source: CAFCP)

H_2 delivery options present opportunities for expanding H_2 infrastructure

Hydrogen & Fuel Cells Budget

Key Activity	FY 15 Request ($ in thousands)	FY 15 Approp. ($ in thousands)	FY 16 Request ($ in thousands)
Fuel Cell R&D	33,000	33,000	36,000
Hydrogen Fuel R&D[1]	36,283	35,200	41,200
Manufacturing R&D	3,000	3,000	4,000
Systems Analysis	3,000	3,000	3,000
Technology Validation	6,000	11,000	7,000
Safety, Codes and Standards	7,000	7,000	7,000
Market Transformation	3,000	3,000	3,000
NREL Site-wide Facilities Support	1,700	1,800	1,800
Total	$92,283	$97,000	103,000

Office	FY 2015
EERE	$97M
Basic Science[2]	~$20M
Fossil Energy, SOFC	$30M

FY 2015 DOE Total: **~$150M**

Number of Recipients funded from 2008-2015	
Industry	>110
Universities	>100
Laboratories	12

[1]Hydrogen Fuel R&D includes Hydrogen Production & Delivery R&D and Hydrogen Storage R&D
[2]Estimated from FY14 appropriation

More stable R&D funding requests and appropriations in recent years
> 20 new projects including 11 new Incubator projects (2014-2015)