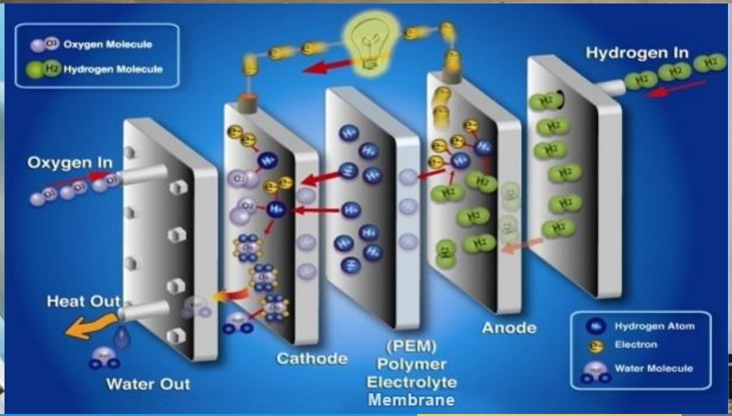
U.S. Department of Energy Hydrogen and Fuel Cell Overview

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



FC EXPO 2016

Tokyo, Japan

March 2, 2016

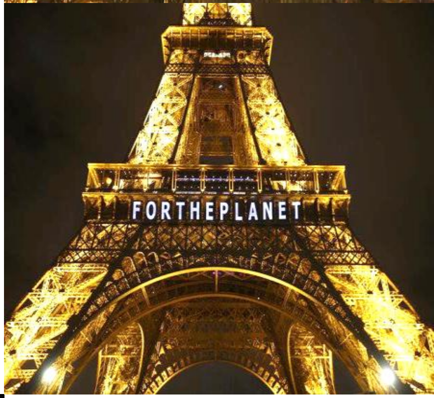
Dr. Sunita Satyapal

Director
Fuel Cell Technologies Office
U.S. Department of Energy

Key Driver- Paris Agreement at COP 21

"Let that be the common purpose here in Paris. A world that is worthy of our children. A world that is marked not by conflict, but **by cooperation**; and not by human suffering, but by human progress. A world that's safer, and more prosperous, and more secure, and more free than the one that we inherited. **Let's get to work.**"

- President Barack Obama at the launch of COP21



PARIS2015
UN CLIMATE CHANGE CONFERENCE
COP21·CMP11

Major Administration Energy Goals

Reduce GHG emissions by 17% by 2020, 26-28% by 2025 and 83% by 2050 from 2005 baseline Climate Action Plan

By 2035, generate 80% of electricity from a diverse set of clean energy resources Blueprint Secure Energy Future

Double energy productivity by 2030 Department of Energy

Reduce net oil imports by half by 2020 from a 2008 baseline Blueprint Secure

Reduce CO_2 emissions by **3 billion metric tons** cumulatively by 2030 through efficiency standards set between 2009 and 2016 CAP Progress Report

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

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

The beginning of the DOE Fuel Cell Program…

1970s

Lab researchers taught scientists around the world how to fabricate MEAs

A group of scientists and DOE managers set the foundation for DOE fuel cell programs

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!

Toyota Mirai Fuel Cell Vehicle

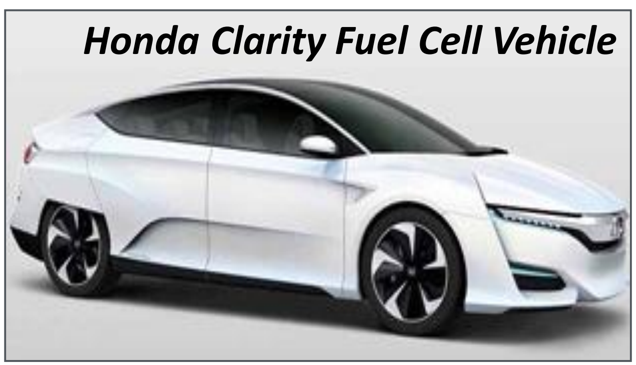
Available for Commercial Sale

- **$57,500 MSRP**
- 67 mi/gge
- 312 mi range, ~5 min refuel
- 114 kW stack
- US:200 2015, 3000 by 2017

Hyundai Tucson Fuel Cell SUV

Available for Lease

- **$499/month lease**
- 50 mi/gge
- 265 mi range
- 100 kW stack
- US: 70 thru May '15 (237 overall)



Honda Clarity Fuel Cell Vehicle

Just Announced at Auto Shows

- **$60,000 MSRP**
- **$500/month lease** for initial launch
- +300 mi range*
- 100 kW stack
- Initial launch planned for late 2016

*Preliminary range estimate determined by Honda

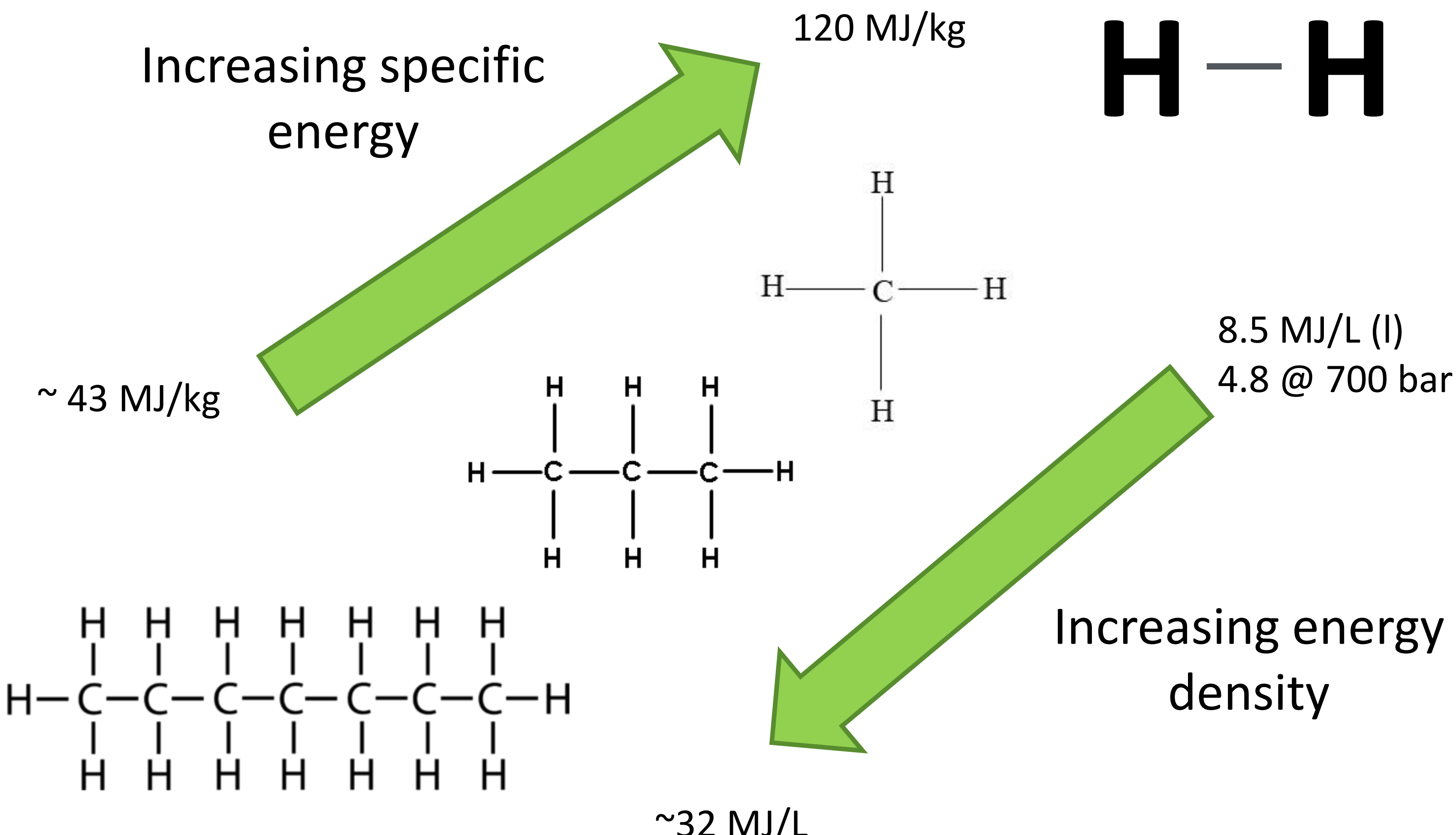
Additional OEMs planning FCEVs in soon

FCEV Ride-n-Drive at DOE Headquarters

Watch Secretary Moniz driving the Mirai!

http://energy.gov/eere/fuelcells/test-driving-toyota-mirai

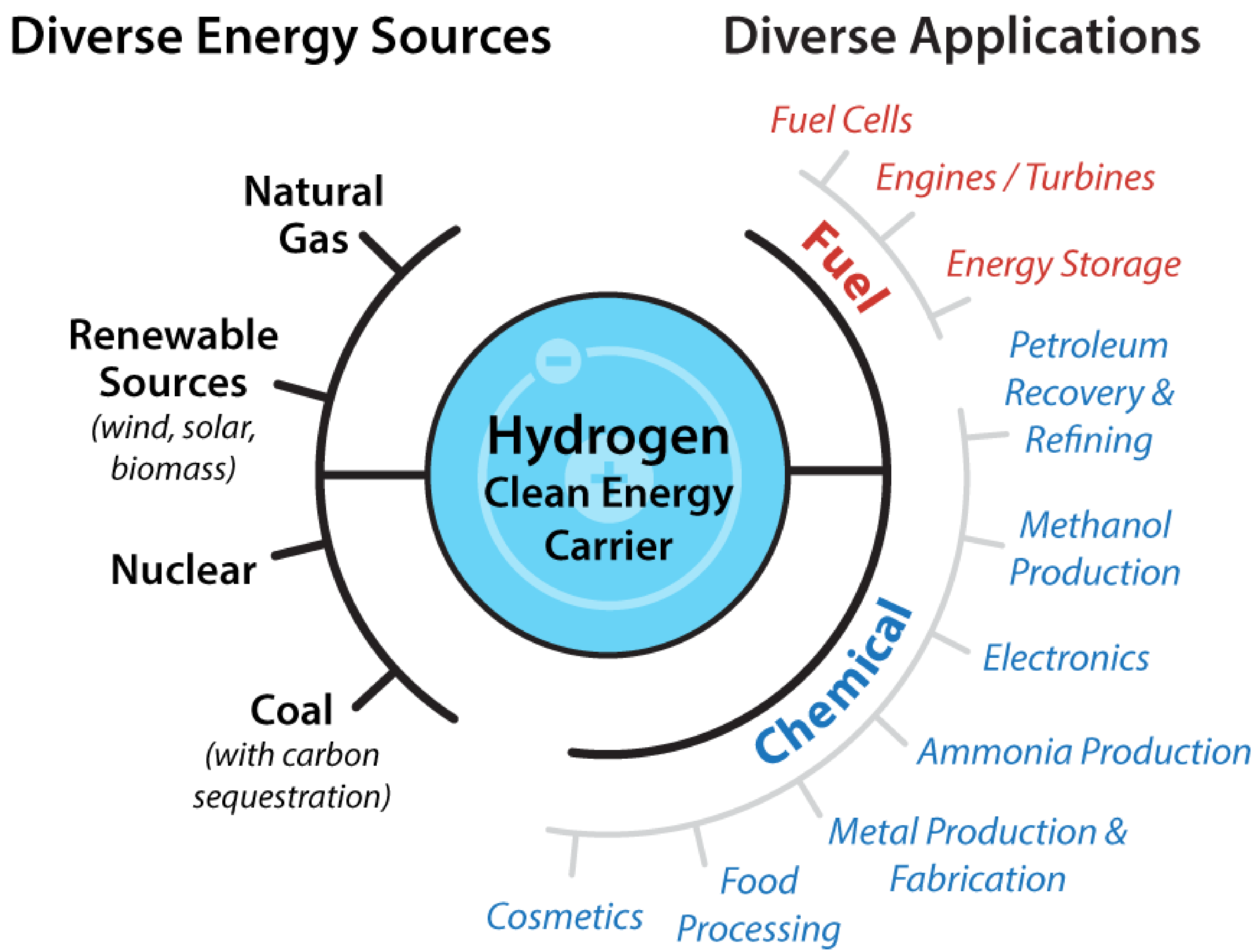
Hydrogen and Hydrocarbons



similar components in gasoline

Hydrogen has the highest energy content by mass but low energy density

Hydrogen- An energy carrier feedstock



Source: DOE, NREL, Hydrogen and Fuel Cell Program

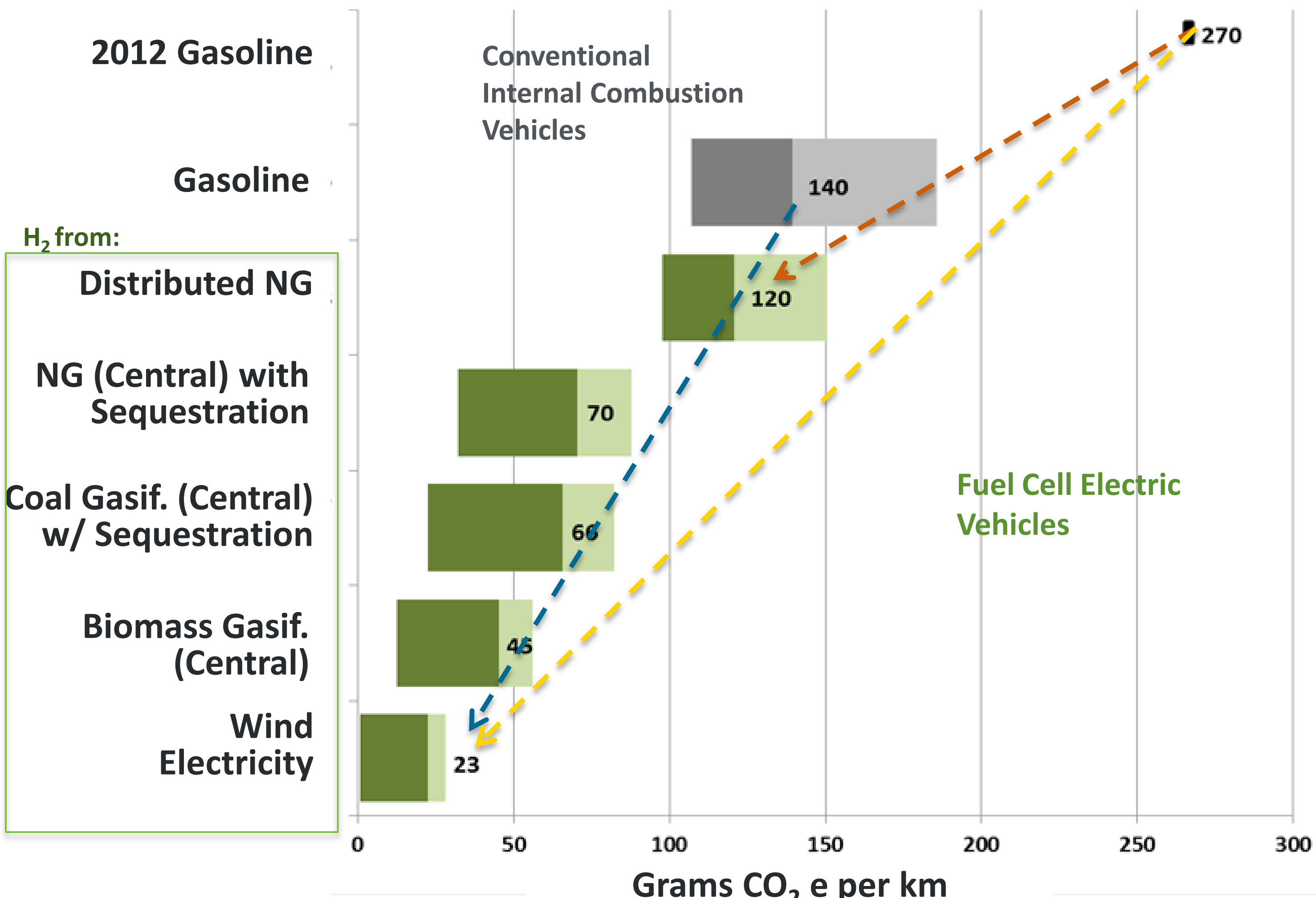
FCEVs Reduce Greenhouse Gas Emissions

>50% from Distributed Natural Gas*

>80% from Renewables** (Wind)

>90% from Renewables* (Wind)

Well-to-Wheels CO_2 Emissions (in grams per km) **for 2035 Vehicles Technologies,** *except were indicated*



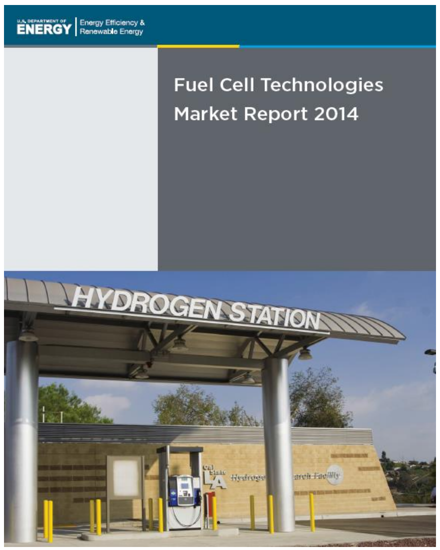
*Compared to 2012 gasoline vehicle
**Compared to 2035 gasoline vehicle

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

Substantial GHG reductions with H_2 produced from renewables

Fuel Cells- Steady Market Growth

Market Report Just Published!



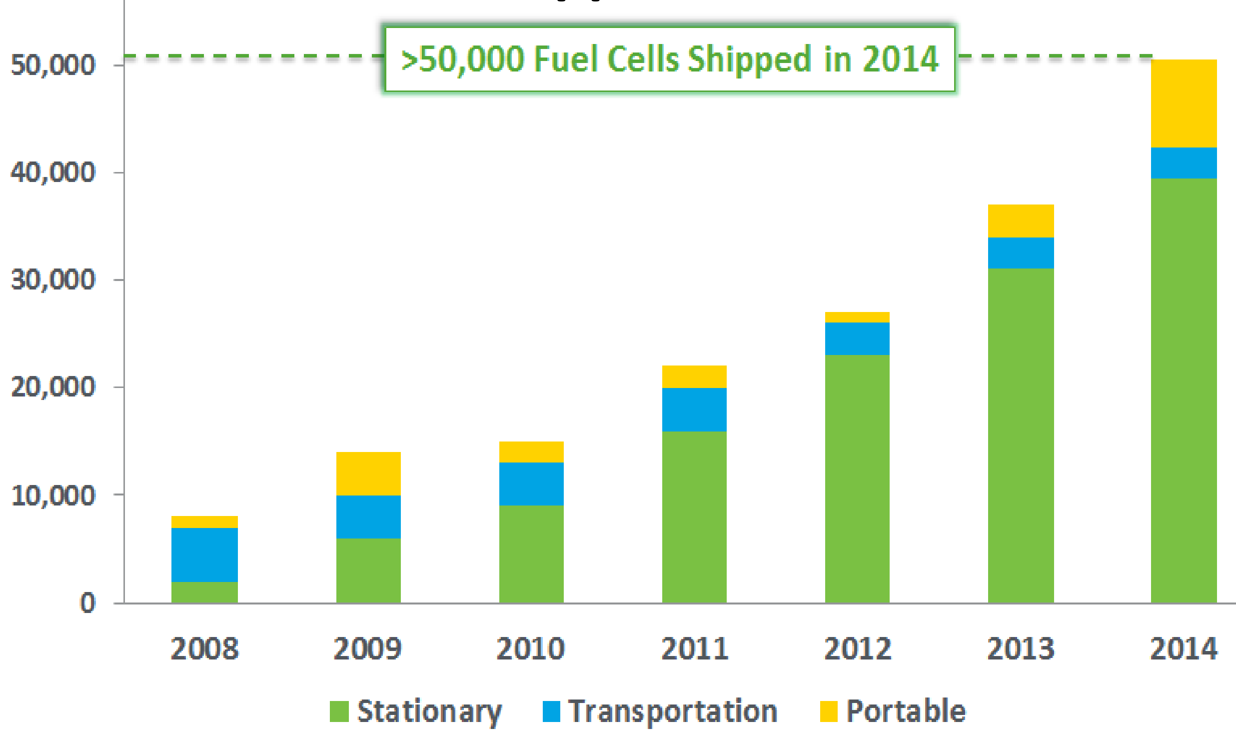
In 2014…

>$2B in revenues

>180 MW fuel cells shipped

Available at:
http://energy.gov/eere/fuelcells/downloads/2014-fuel-cell-technologies-market-report

Fuel Cell Systems Shipped Worldwide by Application



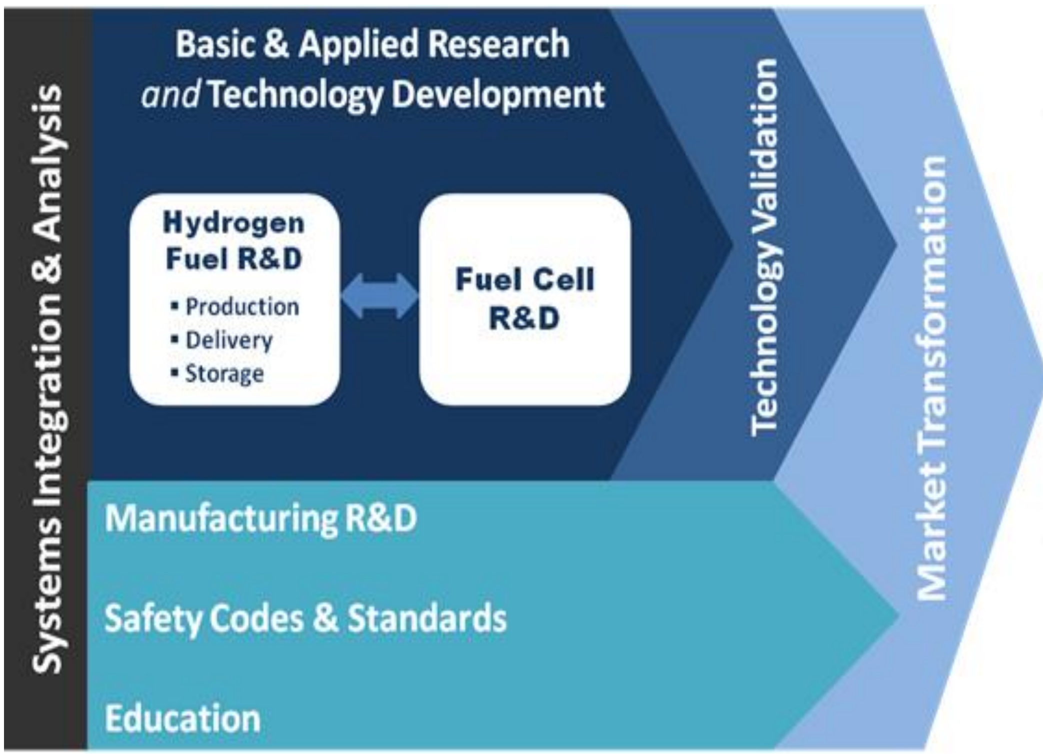
Source: Navigant & E4tech

- **Consistent ~30% annual growth since 2010**
- **Global Market Potential in 10- 20 year**
  - **$14B – $31B/yr for stationary power**
  - **$11B /yr for portable power**
  - **$18B – $97B/yr for transportation**

DOE Hydrogen and Fuel Cells Program

Mission

To enable the **widespread commercialization of hydrogen and fuel cell technologies**



2020 Targets by Application

	Vehicles	Stationary
Fuel Cell Cost	$40/kW	$1,000/kW* $1,500/kW**
Durability	5,000 hrs	80,000 hrs
H_2 Storage Cost (On-Board)	$10/kWh 1.8 kWh/L, 1.3 kWh/kg	
H_2 Cost at Pump	<$4/gge <$7/gge (early market)	

*For Natural Gas
**For Biogas

Integrated approach to widespread commercialization of H_2 and fuel cells

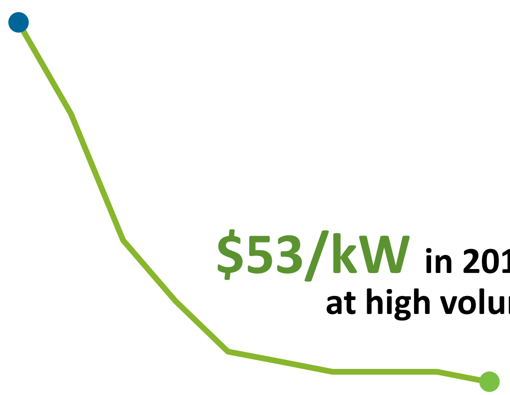
DOE Activities Span from R&D to Deployment

1. Research & Development

Fuel Cells

- **>50% decrease** in cost since 2006
- **5X less** platinum used
- **>4X increase** in durability

$124/kW in 2006



$53/kW in 2015*
at high volume

*$280/kW low volume

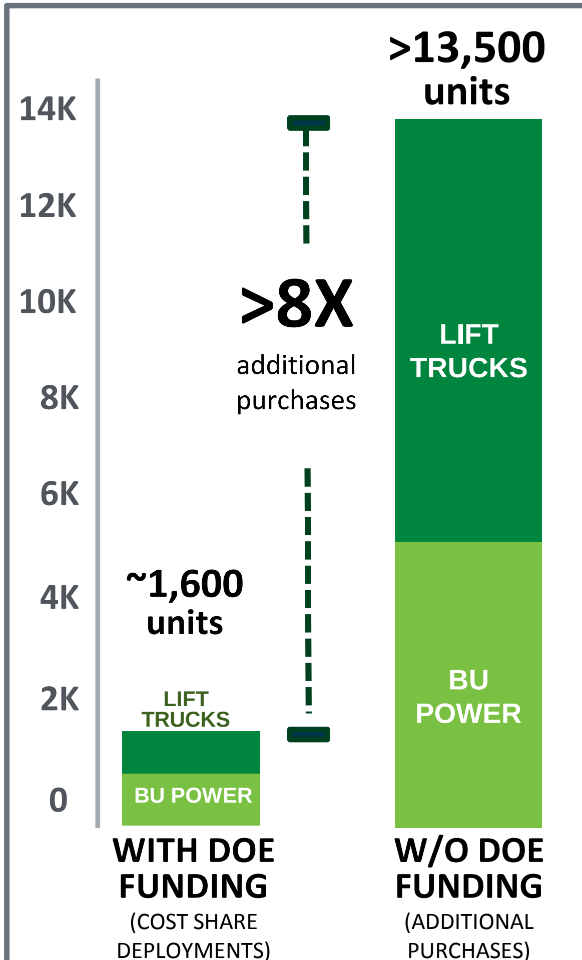
2. Demonstration

Forklifts, back-up power, airport cargo trucks, parcel delivery vans, marine APUs, buses, mobile lighting, refuse trucks

>220 FCEVs, **30** stations, **6M** miles traveled

World's **first tri-gen station**

3. Deployment



BU: Back Up Power

Hydrogen & Fuel Cells Budget

Key Activity	FY 15	FY 16	FY17
	($ in thousands)		
	Approp.	Approp.	Request
Fuel Cell R&D	33,000	35,000	35,000
Hydrogen Fuel R&D[1]	35,200	41,050	44,500
Manufacturing R&D	3,000	3,000	3,000
Systems Analysis	3,000	3,000	3,000
Technology Validation	11,000	7,000	7,000
Safety, Codes and Standards	7,000	7,000	10,000
Market Transformation	3,000	3,000	3,000
Technology Acceleration	0	0	13,000[2]
NREL Site-wide Facilities Support	1,800	1,900	N/A
Total	97,000	100,950	105,500

Office	FY 2015
EERE	$97.0M
Basic Science	$18.5M
Fossil Energy, SOFC	$30.0M

FY 2015 DOE Total: ~$150M

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

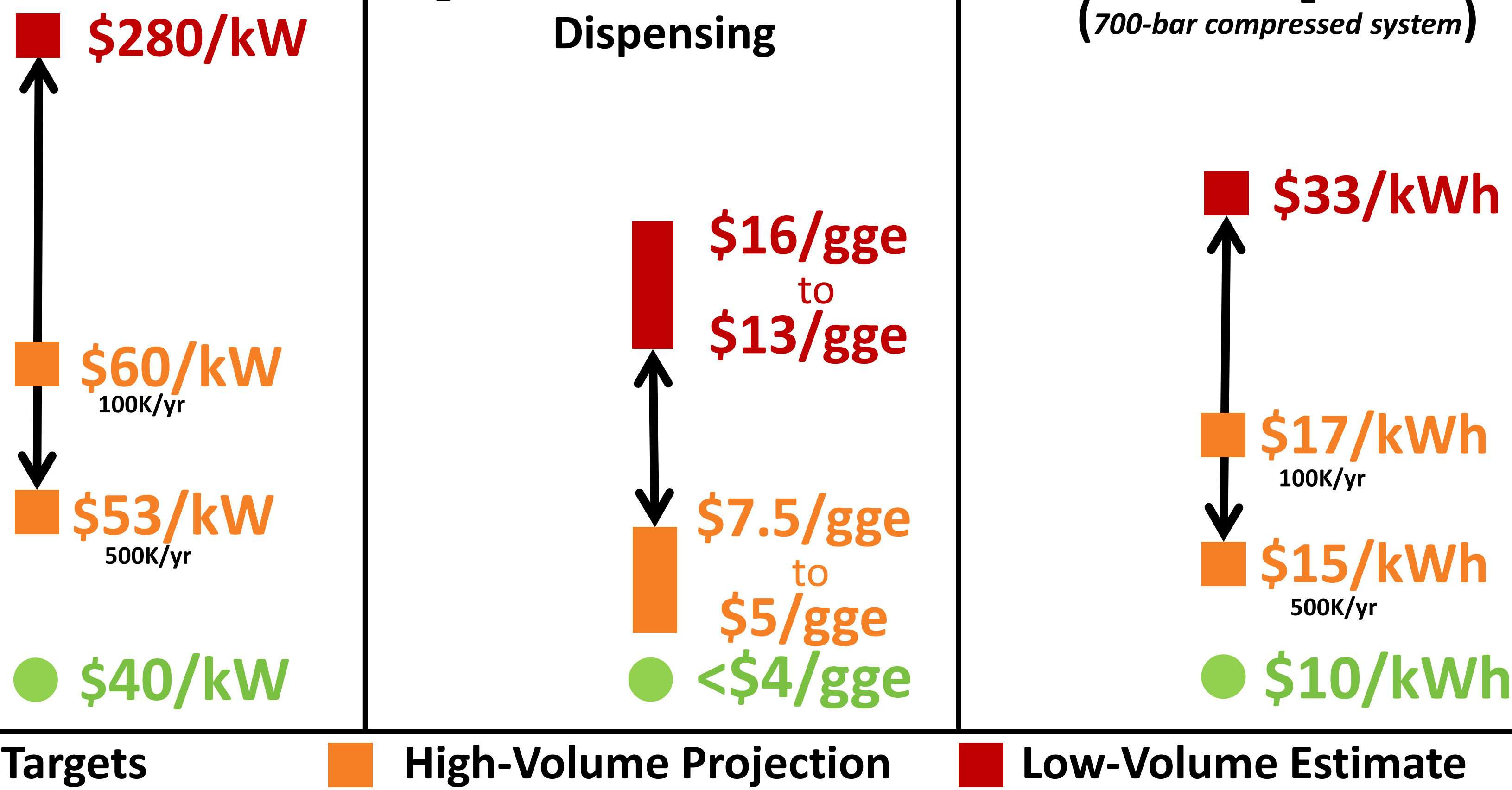
[1]Hydrogen Fuel R&D includes Hydrogen Production & Delivery R&D and Hydrogen Storage R&D

[2]Combines Manufacturing R&D, Technology Validation, Market Transformation.

Sustained, stable funding requests and appropriations

DOE Cost Targets and Status

Fuel Cell System | **H_2 Production, Delivery & Dispensing** | **Onboard H_2 Storage** (*700-bar compressed system*)



Key Challenges- Examples

Fuel Cell System
- PGM loading
- Catalyst and membrane durability
- Electrode performance and durability

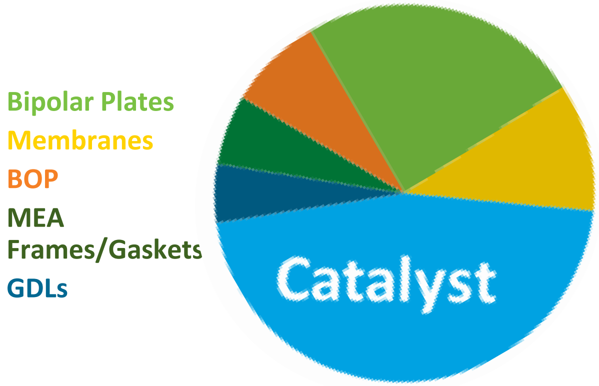
H_2 Production, Delivery & Dispensing
- Efficiency and Reliability
- Feedstock and Capital Costs
- Compression, Storage and Dispensing (CSD) Costs

Onboard H_2 Storage
- Carbon fiber precursors and conversion
- Composite/resin materials
- BOP and assembly costs

Techno-Economic Analysis Guides R&D Portfolio

Focusing on…

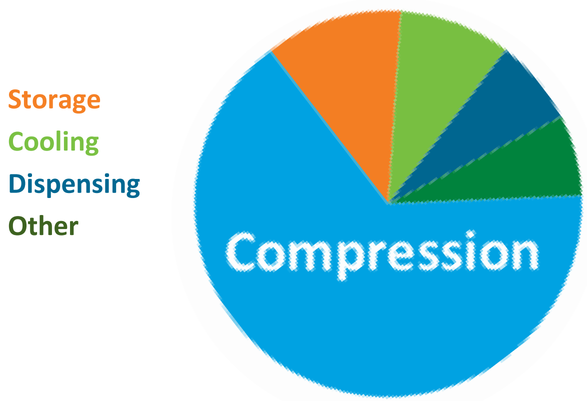
Fuel Cells



Low and Non PGM Catalysts,

Alkaline Membranes

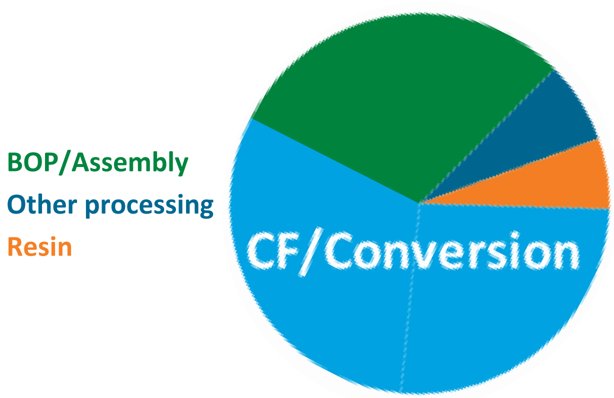
H_2 Station



Advanced Compression

Alternate Approaches

H_2 Storage



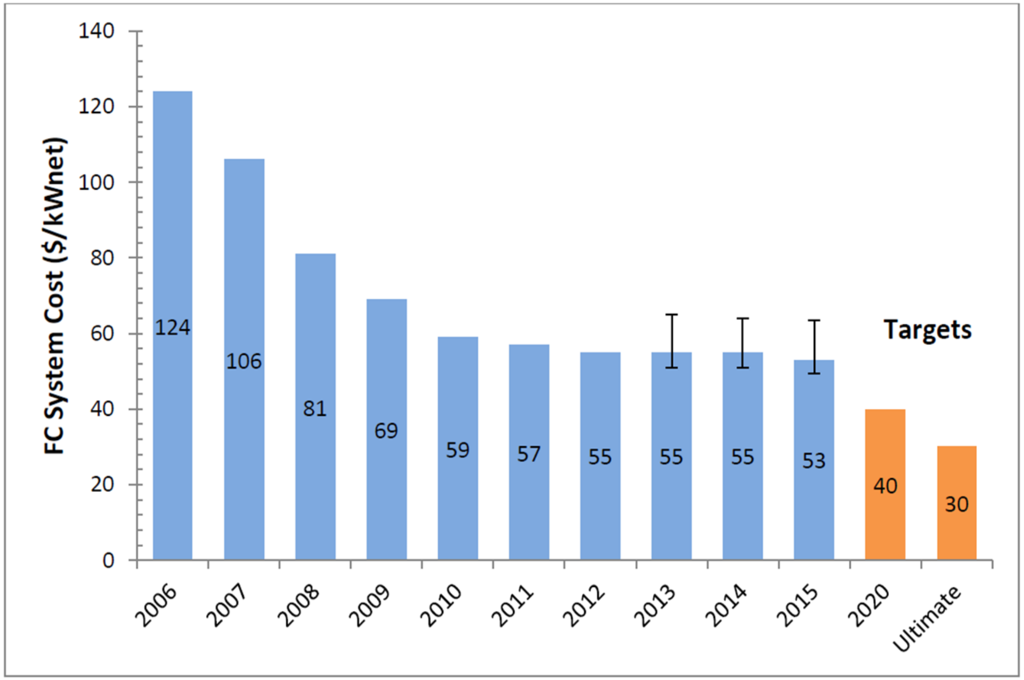
Low Cost Carbon Fiber (CF)

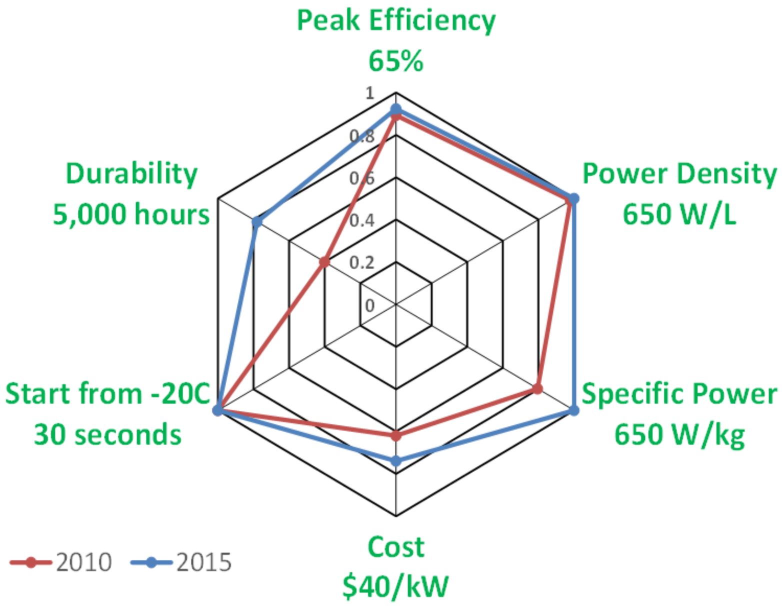
Long term Materials Approaches

Fuel Cell Progress and Status

2020 Goals: 65% peak efficiency, $40/kW, 5000 hour durability

2015 Status: 60% peak efficiency, $53/kW, 3900 hour durability





Significant progress but fuel cell cost reduction is leveling off.
Further R&D is needed to overcome challenges - durability <u>and</u> cost.

H_2 Production Pathways Cost Status

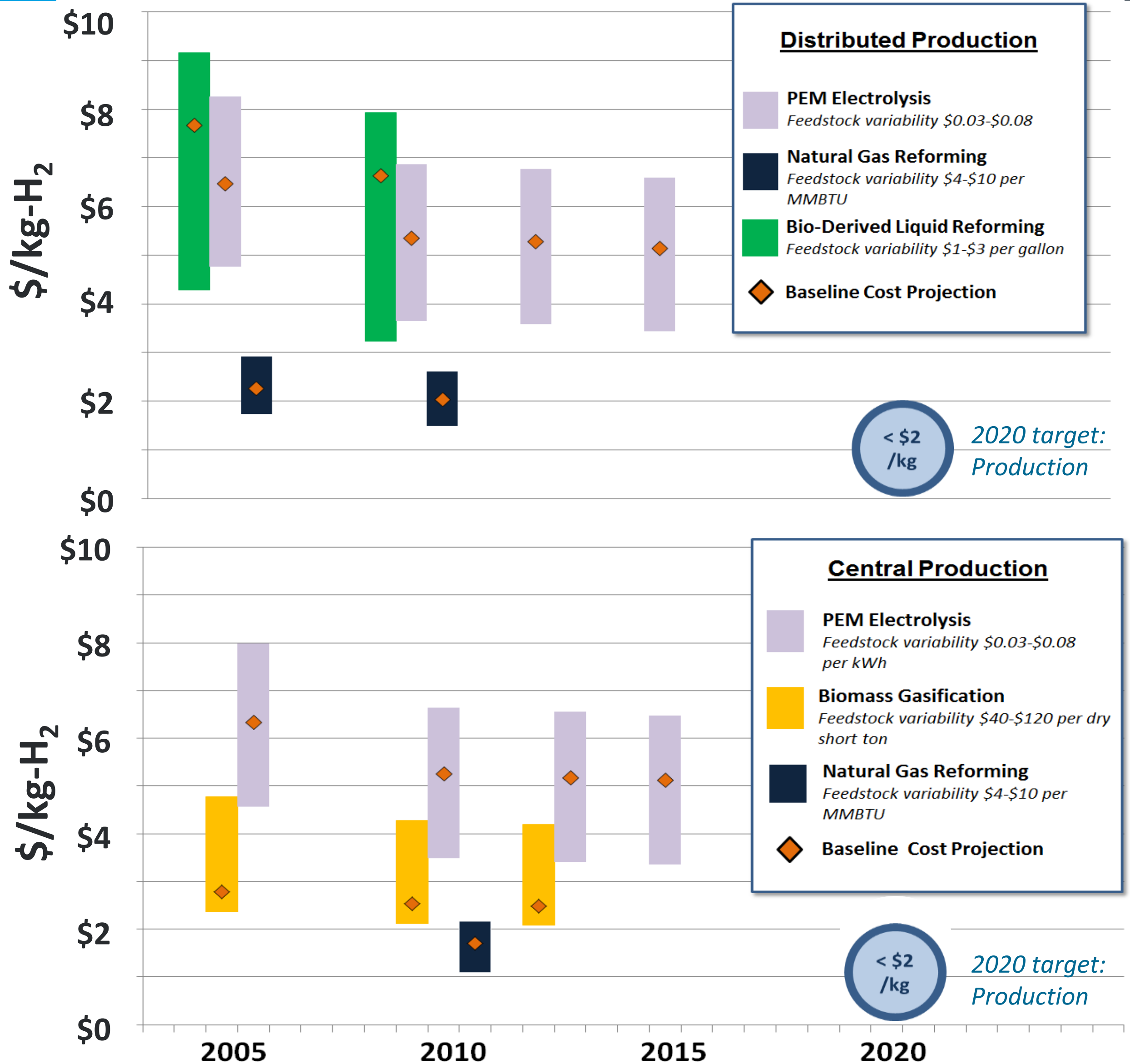
Current Technology
- Natural Gas (D/C)
- Electrolysis (D)

Near to Mid-Term:
- Electrolysis- Wind and Solar Powered (D/C)
- Bio-derived Liquids (D/C)
- Fermentation (D/C)

Long-Term (not shown):

Central Renewable H_2
- Solar-based water splitting
- Photolytic Bio-hydrogen

D- Distributed **C- Central**



H_2 from NG can be competitive today - renewables is a longer-term focus

The hardest problems of pure and applied science can only be solved by the open collaboration of the world-wide scientific community

Kenneth G. Wilson

Nobel Prize, 1982 in Physics

Lab Consortia Approach

Activities

Consortia Core

- **Fuel Cells: FC-PAD** (Fuel Cell Performance and Durability)
- **Storage: HyMARC** (Hydrogen Storage Materials Advanced Research Consortium)
- **ElectroCat (planned)**
- **Renewable H2 Production (planned)**

Projects added through FOAs

- Companies, universities, labs
- 2-4 yrs/project
- May include seedling projects

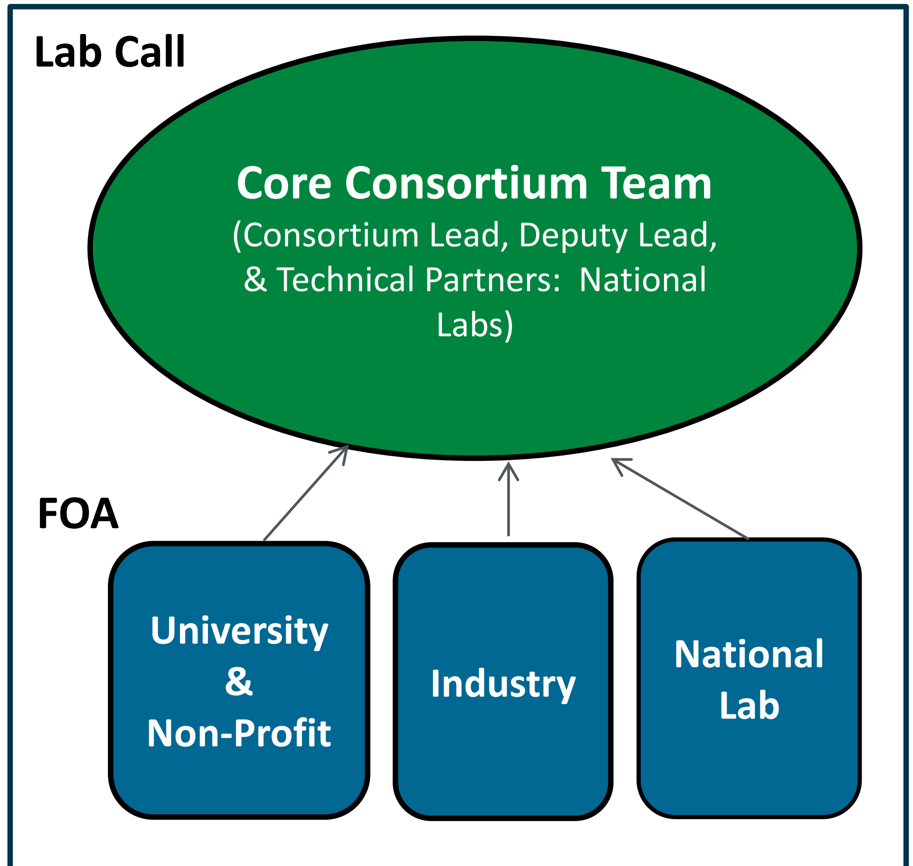
* Subject to appropriations

Potential Future Collaborations

Relevant Offices and other Agencies (e.g. Office of Science , Advanced Manufacturing Office, etc.)

Strategy and Structure

Multi-Lab team with Lab Call to competitively select core team

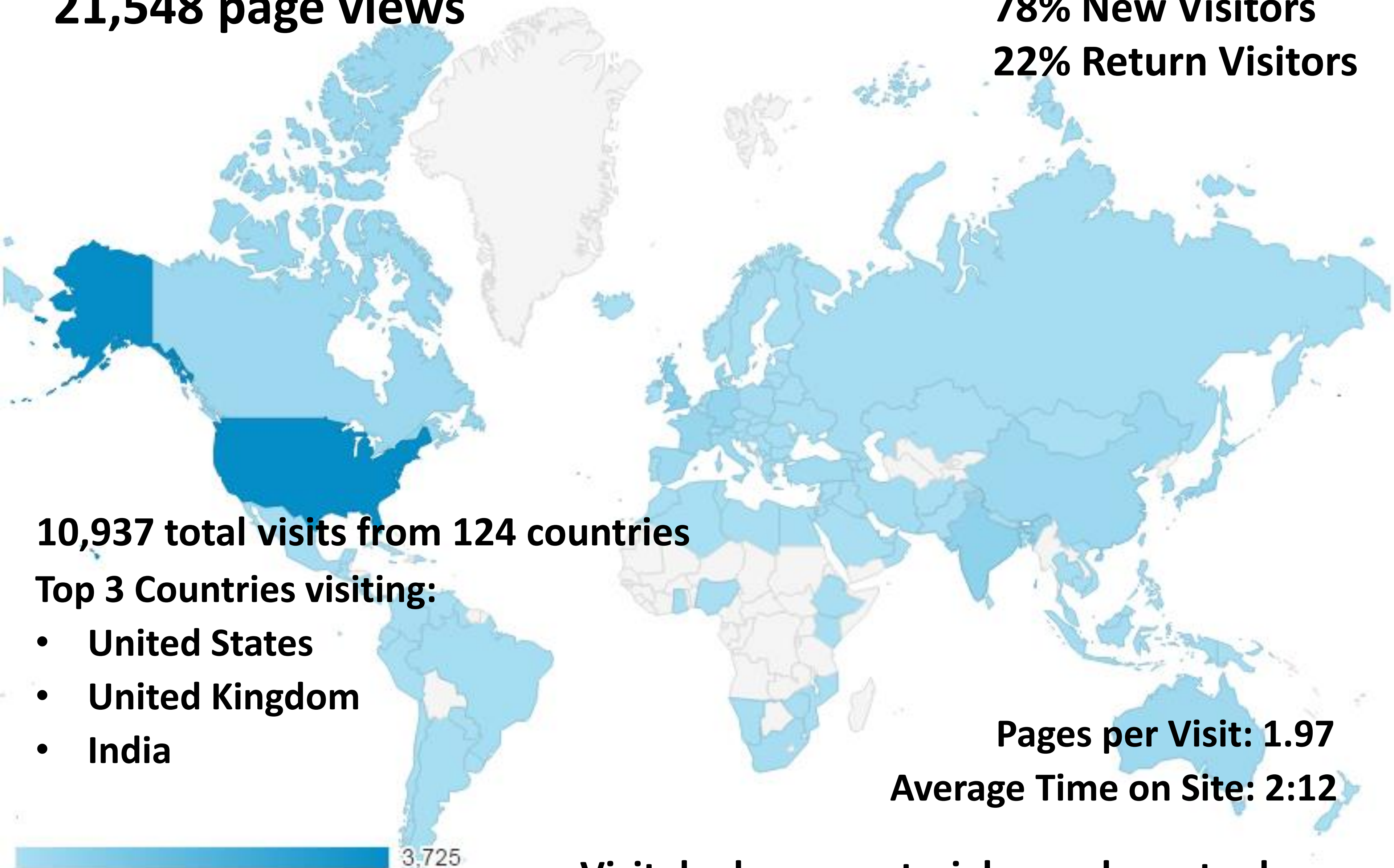


Materials Based Storage Database Analytics

21,548 page views

78% New Visitors

22% Return Visitors



10,937 total visits from 124 countries

Top 3 Countries visiting:

- **United States**
- **United Kingdom**
- **India**

Pages per Visit: 1.97

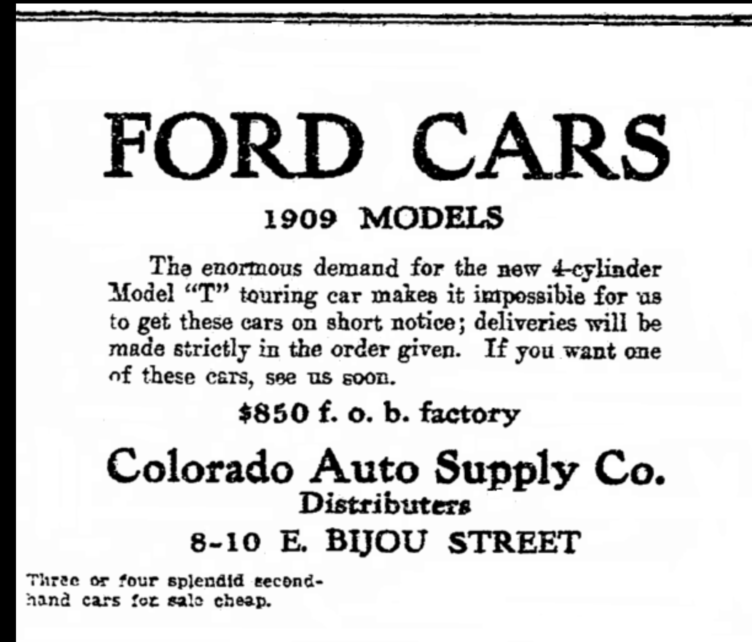
Average Time on Site: 2:12

Visit: hydrogenmaterialssearch.govtools.us

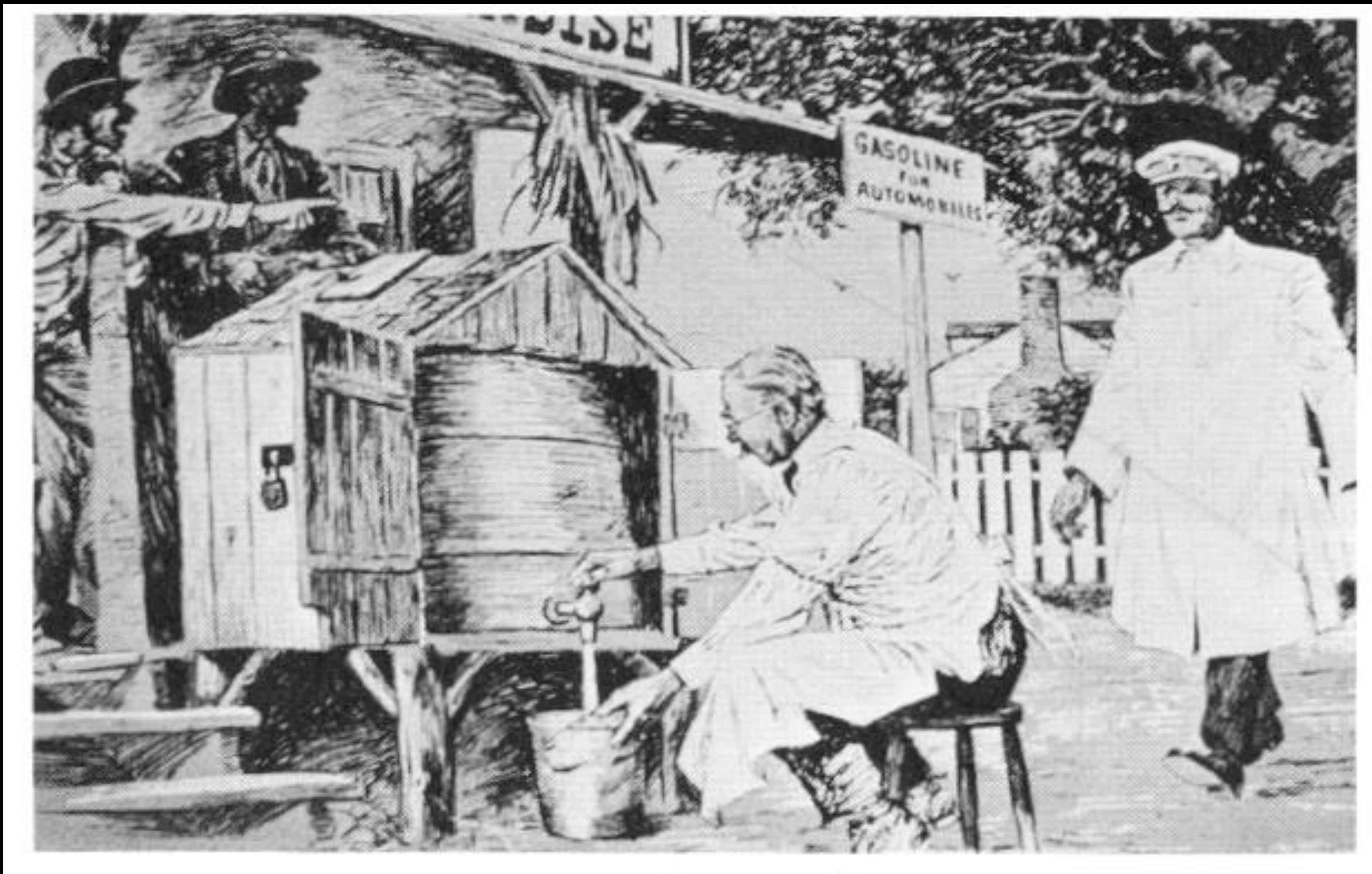
*Data courtesy of Google Analytics for data through June, 2015

What can we learn from history?

Henry Ford and his first car, the Quadricycle, built in 1896

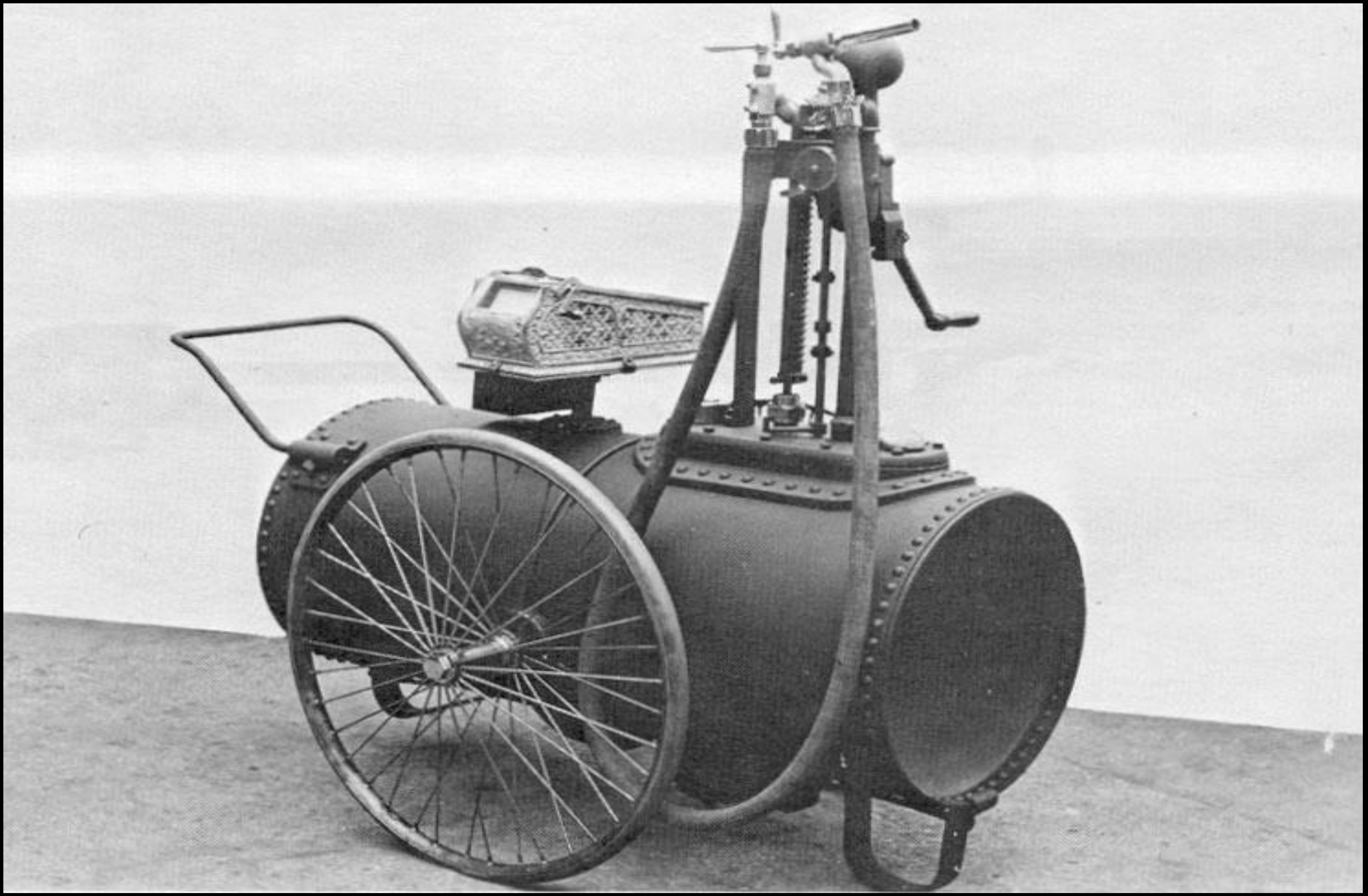


What Does Early History of Gasoline Refueling Tell Us?



Source: M. Melaina et al

Many diverse options, makes and models



Source: M. Melaina et al

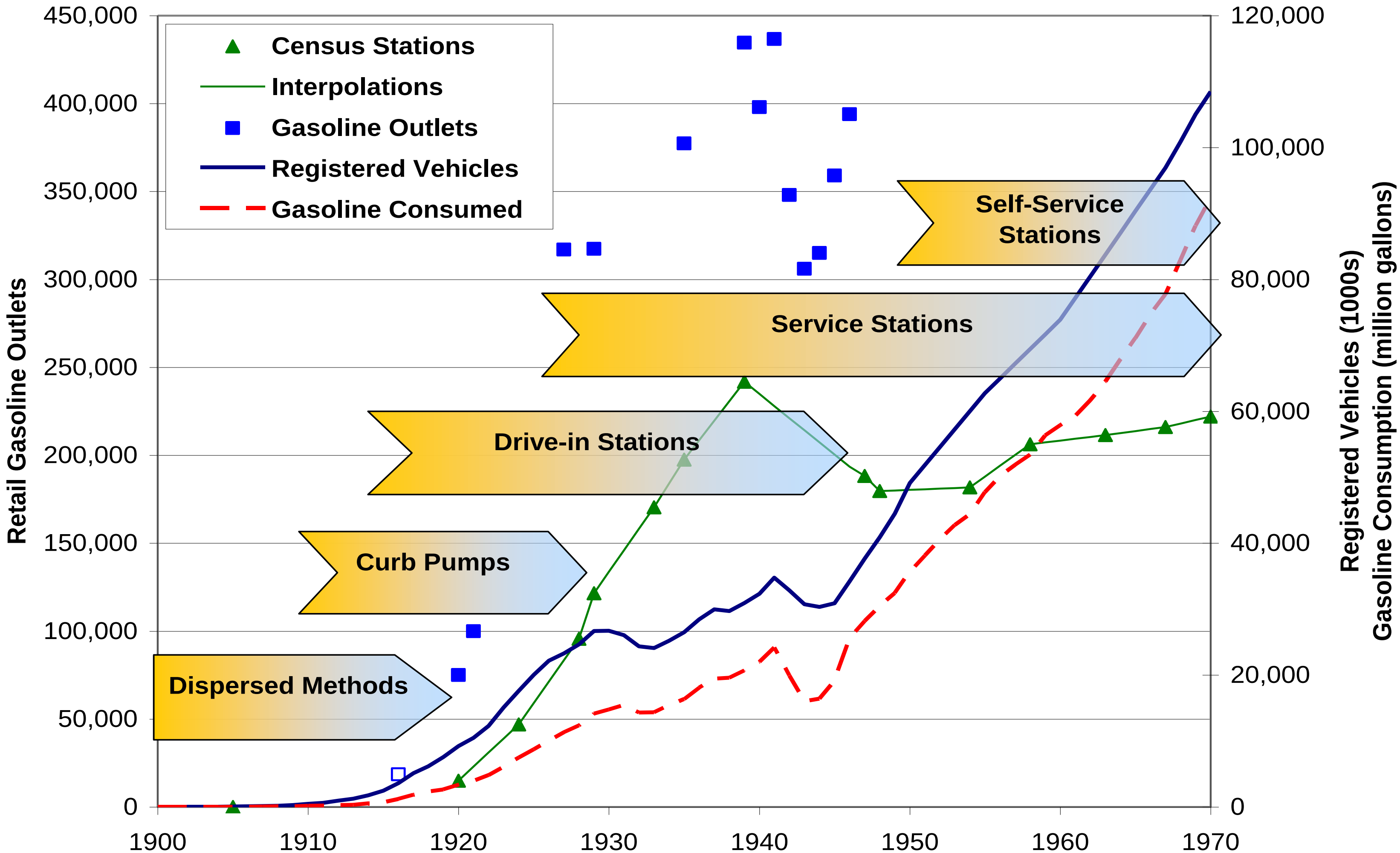
Options for accessibility to fuel

Source: M. Melaina et al

Mobile refuelers bring fuel to you

Source: M. Melaina et al

Examples of Gasoline Refueling Methods



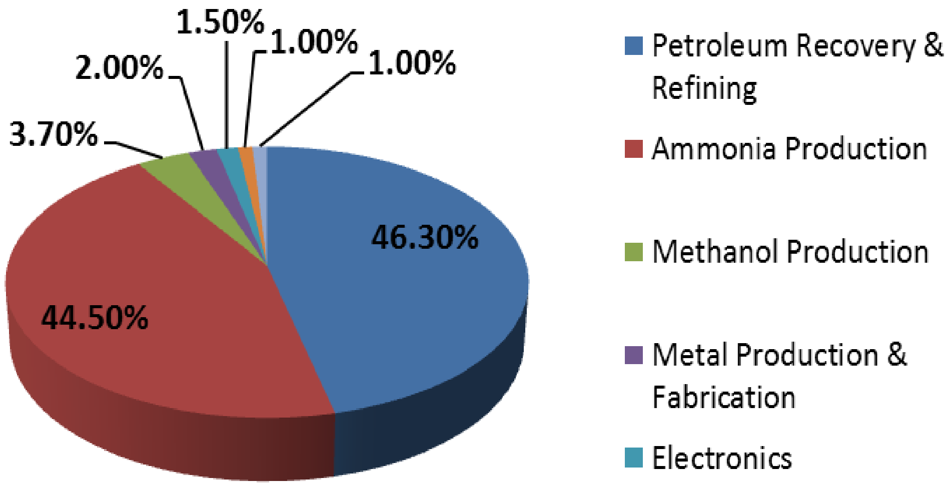
Source: Turn of the Century Refueling: A Review of Innovations in Early Gasoline Refueling Methods and Analogies for Hydrogen (Melaina 2007)

History shows phased introduction of different refueling methods

H_2 Production: Current Status

~10 million* metric tons of H_2
mostly from:

- **Steam methane reforming of natural gas (SMR)**

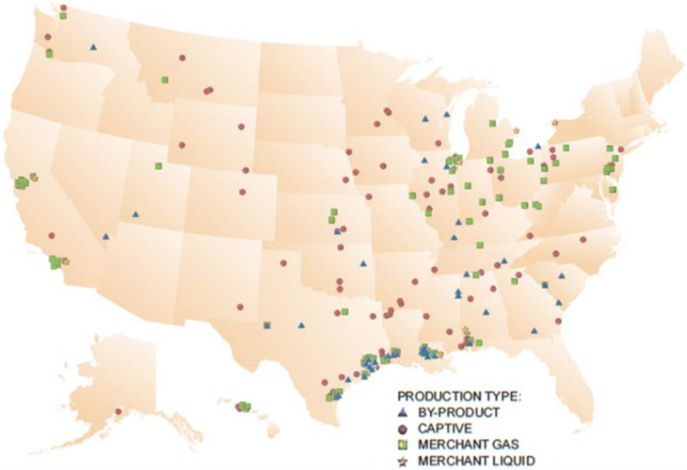


H_2 consumption market share by application

*CryoGas International. Hydrogen Production and Consumption in the US- the last 25 years (Sep 2015).

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)

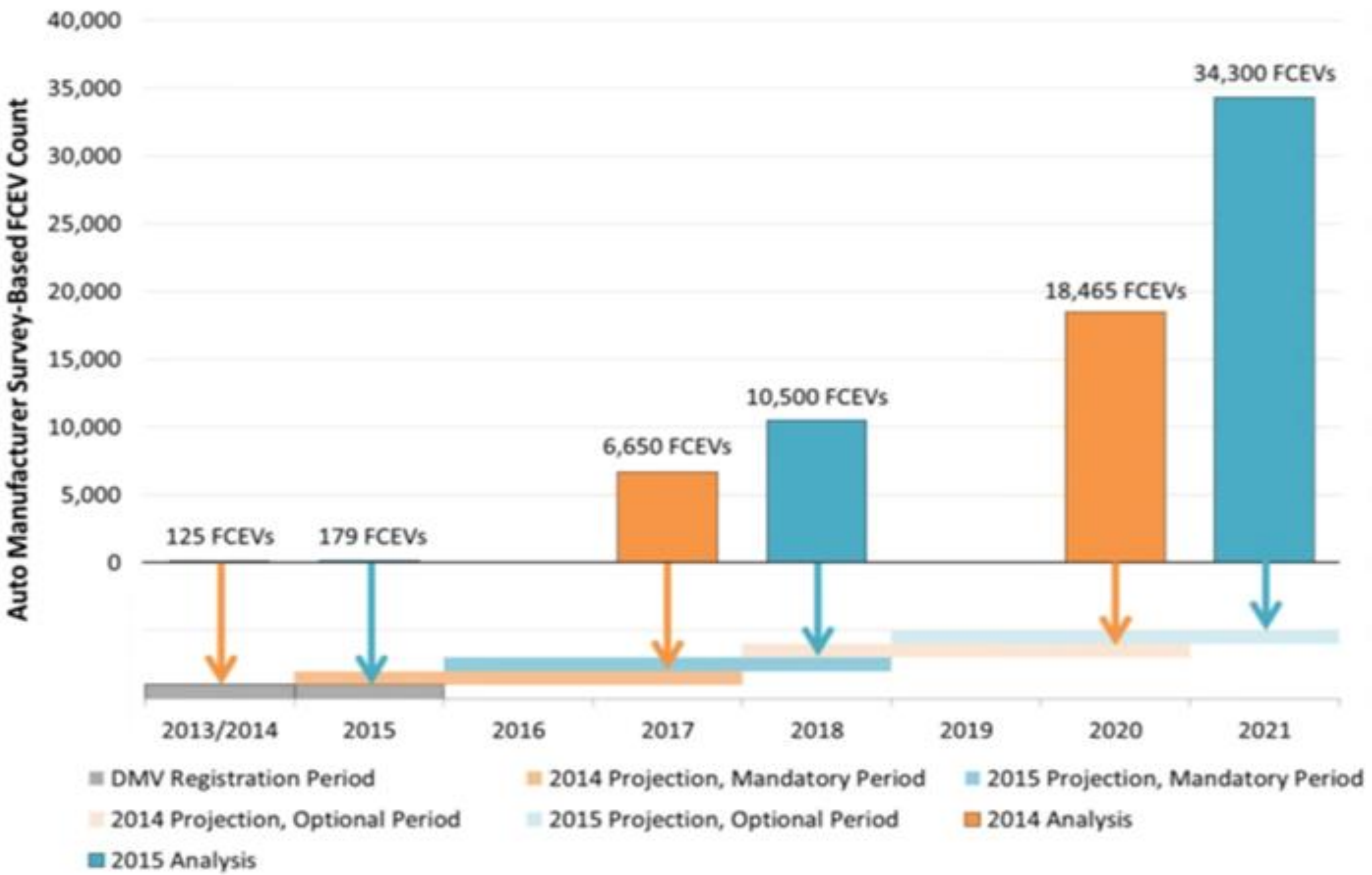


Centralized H_2 production facilities

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

FCEV Deployment Projections in California

Post-2018 FCEV deployment is anticipated *to accelerate* more rapidly than previously projected



Source: CARB 2015 AB 8 Report (July, 2015)

Rapid innovation is critical.
Collaboration is critical.

Public-private, regional
and global partnerships.

H_2USA: Public-Private Partnership

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_2USA's Working Groups

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

More than 45 partners- Visit www.H2USA.org

H_2 Infrastructure Status

H_2 Delivery Infrastructure

- **Current: 1,600 miles of H_2 pipeline**

H_2 Station Options

- **H_2 from central site:**
  - **>$1-2 M** for stations*
  - **~$7-$16/gge** for H_2
- **Distributed production:**
  - Natural gas
  - Electrolysis

*~100-300 kg/day (range of cost)

H_2 Stations in the U.S.

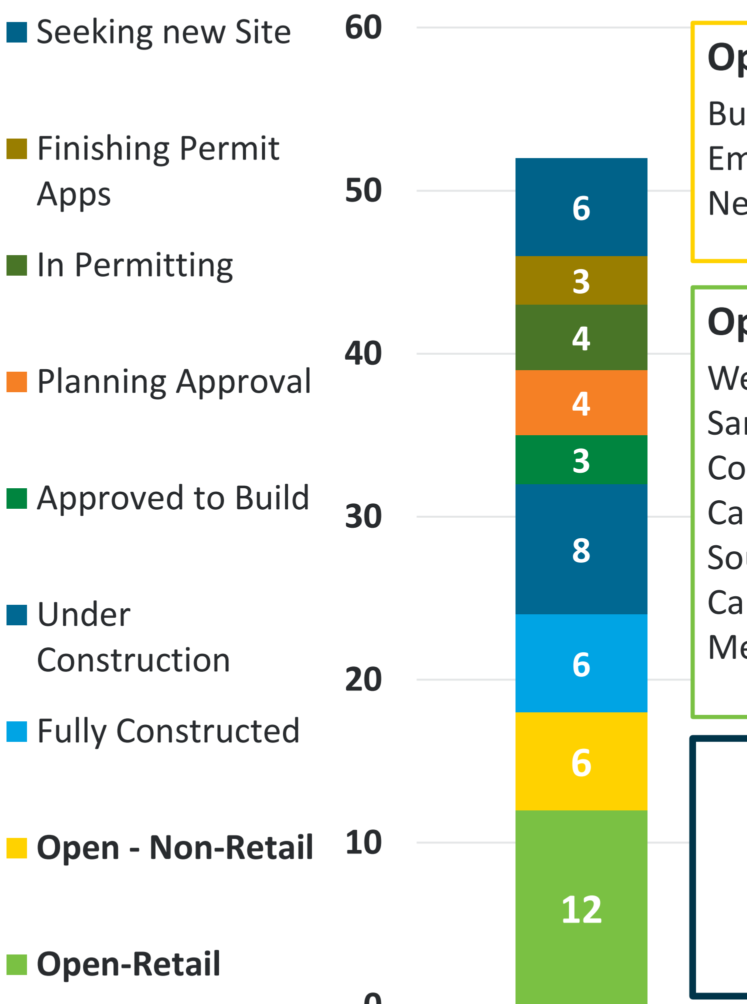
- **Current: ~50 total** (~10 public)
- **State Plans:**
  - **CA- 100 stations, ~$100M** planned through 2023
  - **Northeast States & Hawaii**
  - **8 State MOU- 3.3M ZEVs** by 2025

California
Connecticut
Massachusetts
Maryland
New York
Oregon
Rhode Island
Vermont

H_2 delivery options present opportunities for expanding H_2 infrastructure

California- H_2 Station Status

How Many?

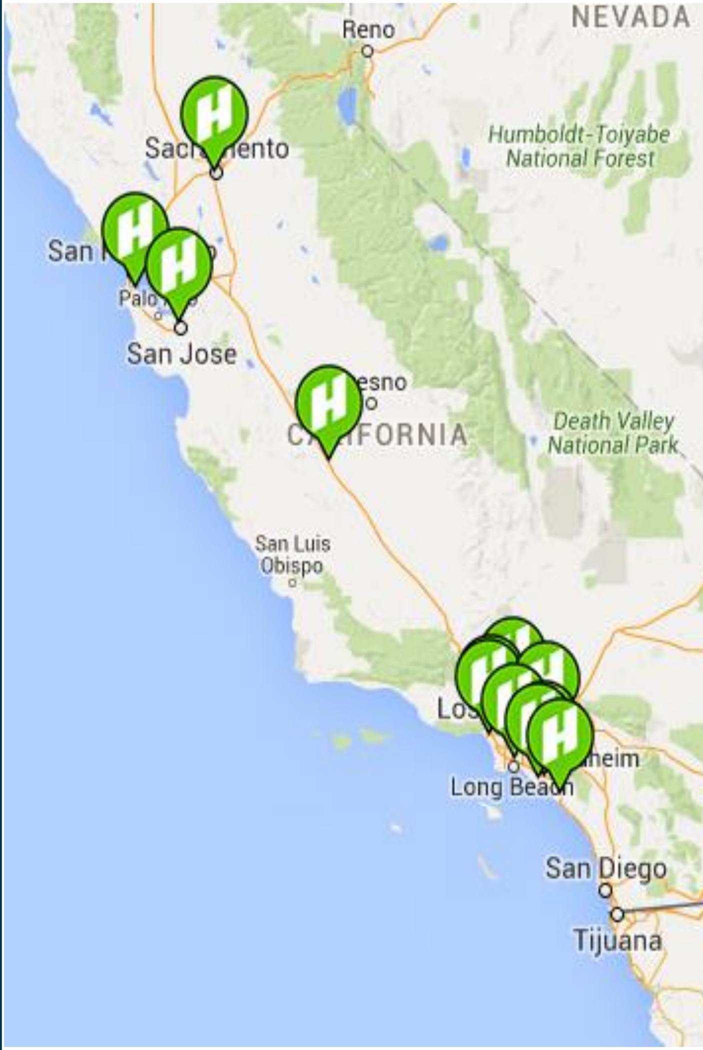


Open – Non-Retail:
Burbank, Torrance#, Emeryville*, Harbor City*, Newport Beach*, OCSD*#

Open – Retail:
West Sac, Diamond Bar, LA Santa Monica Blvd#, UCI, Coalinga, San Juan Capistrano#, Long Beach, South SF, San Jose, La Canada Flintridge, Costa Mesa, Santa Monica

Total:
52
H_2 Stations

Where?



Green icons indicate
Open Retail Stations

As of February 25, 2016 (Data from CARB). * Stations in need of extension or upgrade
Currently Torrance (H70 only), Santa Monica, San Juan Capistrano, and OCSD are offline (01/15/16 CaFCP SOSS)

Hydrogen Fueling Infrastructure Research Station Technology

Leveraging Expertise of National Labs

H2FIRST In support of

H2USA and tasked to deliver:

NREL NATIONAL RENEWABLE ENERGY LABORATORY & Sandia National Laboratories

Outstanding Partnership Award

By the Federal Laboratory Consortium (FLC) for efforts toward deployment of hydrogen fueling infrastructure

Reference Station Design

✓ Report Delivered with Detailed Station Designs and Cost Estimates

Fuel Contaminant Detection

✓ Market Survey and Gap Analysis Complete

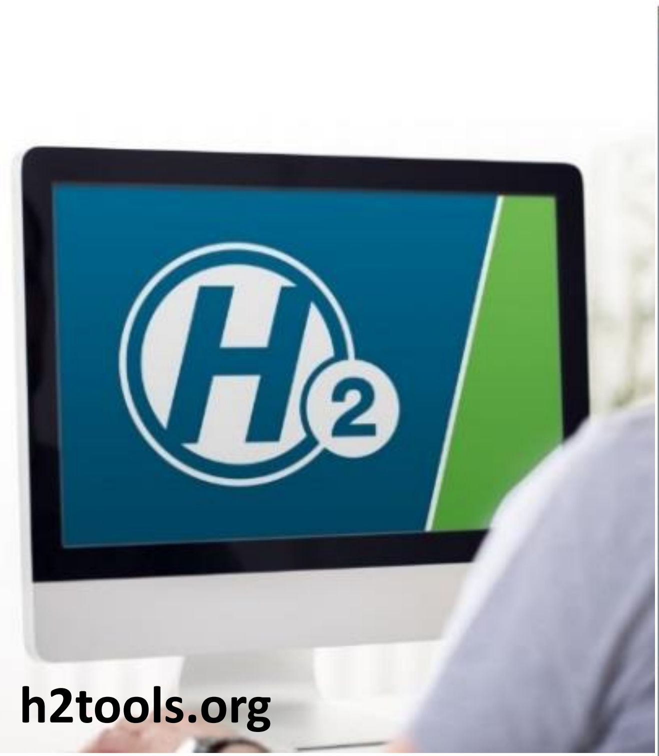
HyStEP (H_2 Station Equipment Performance Device)

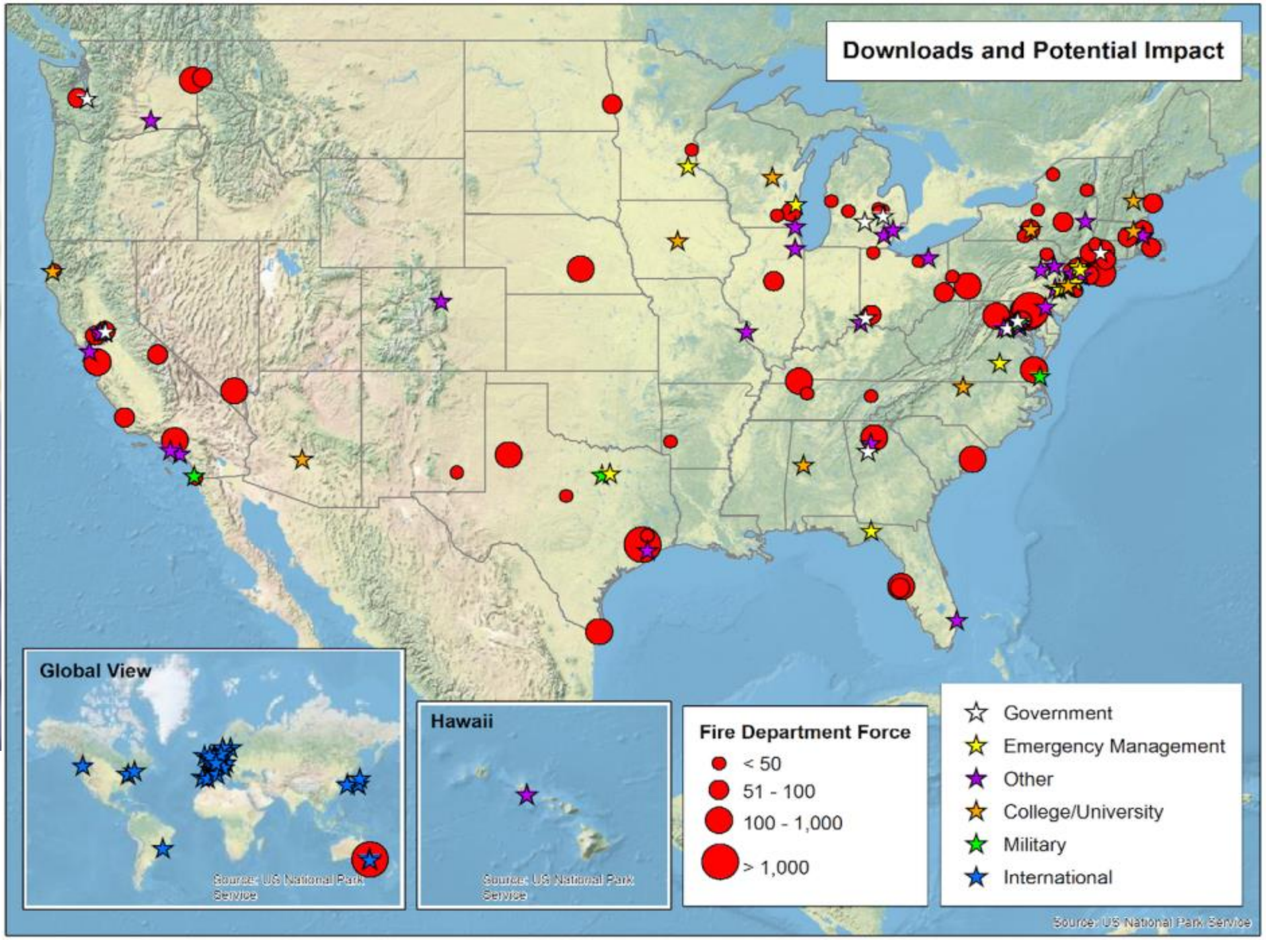
✓ Design Complete

✓ Testing Complete

DOE's H_2FIRST project supports H2USA goals to address infrastructure

H_2Tools: One-stop for H_2 safety knowledge





- Includes resources on **safety** best practices, **first responder training**, and **H_2 codes & standards**

- Tracked downloads from **Europe and Japan**
- Resource **translated in Japanese**
- **50%** of visits are **international!**

Enabling dissemination of safety information around the world

International Partnership

International Partnership for Hydrogen and Fuel Cells in the Economy

IPHE is an Inter-Governmental Partnership to

- **Advance policies** supportive of H_2 and fuel cells
- **Increase** international **collaboration**
- **Share information** and lessons learned

Recent and Upcoming IPHE Events

- 24th IPHE Steering Committee Dec 2015, in Grenoble France
- New: **May 20th- IPHE Workshop in California USA**

18 members working together to advance hydrogen and fuel cell technologies

Australia	France	Republic of Korea
Austria	Germany	Norway
Brazil	Iceland	Russian Federation
Canada	India	South Africa
China	Italy	United Kingdom
European Commission	Japan	United States

Visit www.iphe.net for more information

IPHE 24th Steering Committee Meeting- Grenoble, France

Japan- US Collaboration in Action!

20th Steering Committee Meeting City of Fukuoka, Japan *(left)*

2015 US DOE Annual Merit Review (AMR) Washington D.C. , USA *(lower left)*

2015 FC Expo Tokyo, Japan *(lower right)*

Outreach and Communication Efforts

- **Publications- ~100/yr**
  - Monthly Newsletter
  - Success Stories
  - News Alerts, Blogs
- **Educated:**
  - **>12,000** teachers
  - **>35,000** code officials & first responders
- **Investor Days**
- **Congressional Caucus Events**
- **Annual Merit Review**

  June 2015- >1,800 attendees
- **Ride-n-Drives**

U.S Department of Energy Secretary Ernest Moniz test driving the Toyota Mirai

Increasing public awareness and understanding about fuel cells and H_2

2015: Big year for Hydrogen and Fuel Cells

The U.S. joined celebrating the <u>1st ever</u> Hydrogen and Fuel Cells Day

Going Forward

- R&D and accelerate Tech to Market (Lab impact)
  - Key Focus: Renewable H_2
  - Consortia, high throughput materials, safety, fuel cells, H_2
- Strategic, selective demonstrations
- Key analyses to guide RD&D and path forward
  - Life cycle cost; infrastructure, economic & environmental analyses, sustainable pathways, etc.
- Leverage activities to maximize impact
  - U.S. and global partnerships, H_2USA, States

Save the date: Annual Merit Review (AMR)
June 6-10, 2016- Washington DC

Napoleon Hill

“It is literally true that you can succeed best and quickest by helping others to succeed”

Thank You

Dr. Sunita Satyapal

Director

Fuel Cell Technologies Office

Sunita.Satyapal@ee.doe.gov

hydrogenandfuelcells.energy.gov