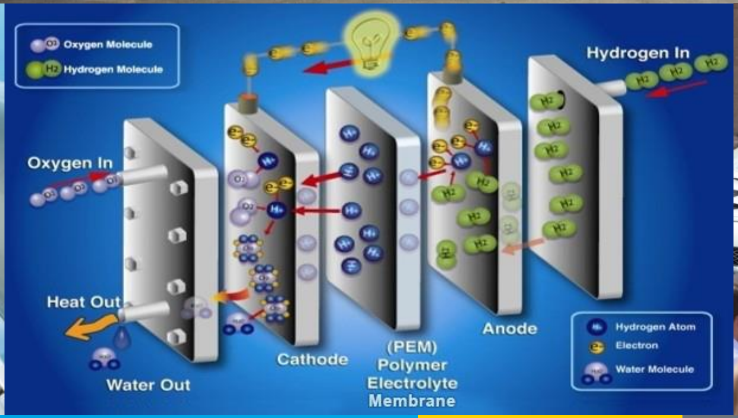
# U.S. Department of Energy Hydrogen and Fuel Cells Program

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




## Presented at National Institute of Standards and Technology Colloquium

**Gaithersburg, MD**

October 21, 2016

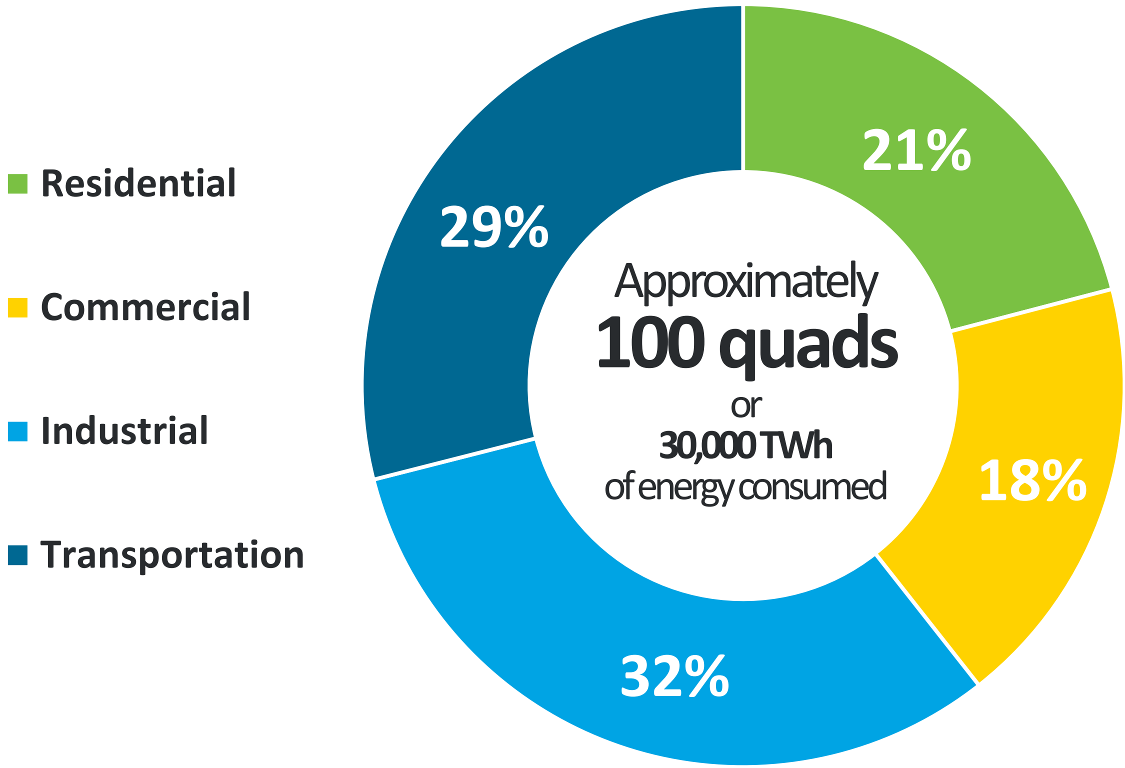
**Dr. Sunita Satyapal**

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

# We need deep decarbonization

# Energy Consumption in 2015

## U.S. Energy Consumption* in 2015



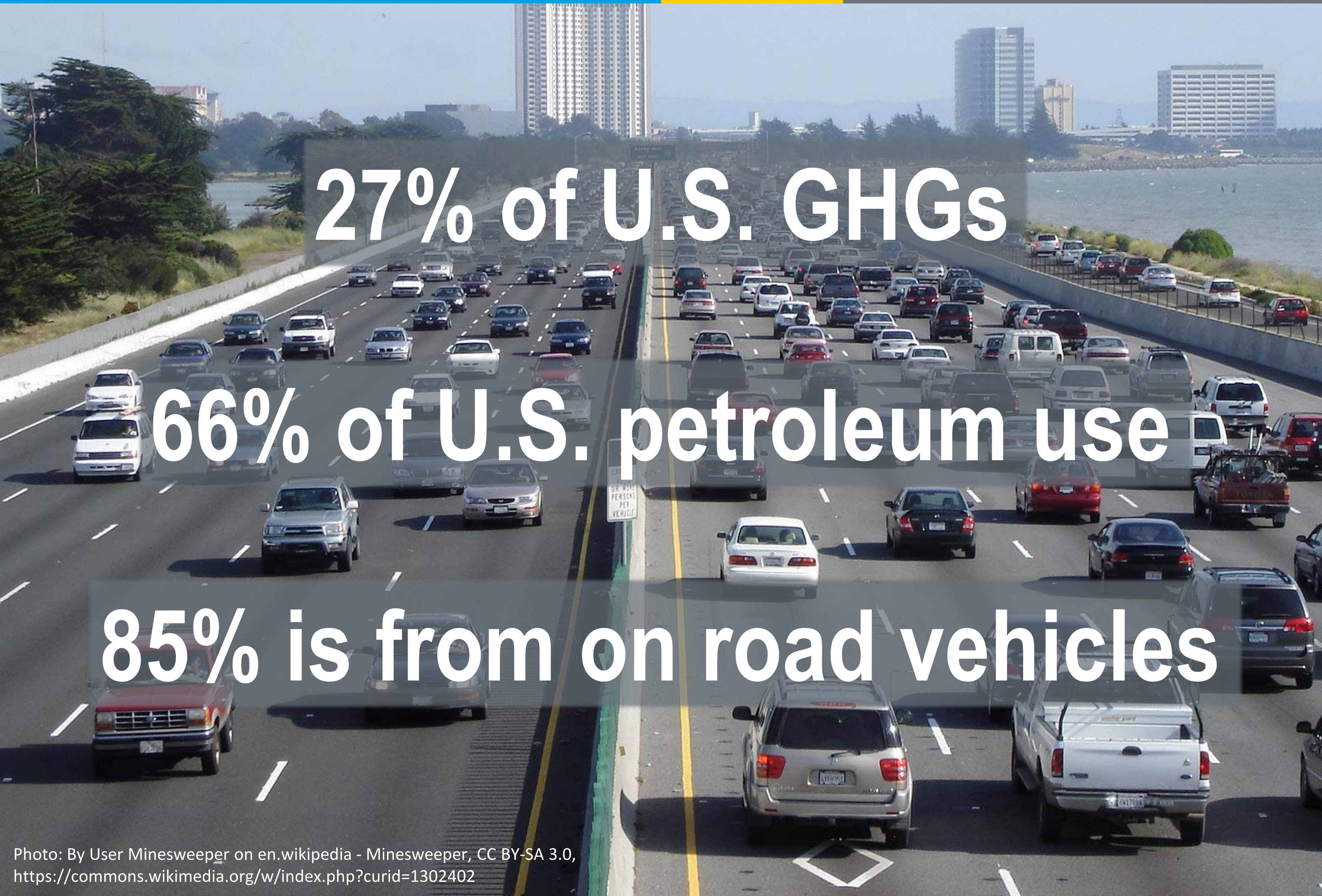

**World Energy Consumption** Approximately **600 quads or 180,000 TWh**

*Includes electrical losses

Source: EIA

***Transportation accounts for almost a third of U.S. energy consumption***

# U.S. Transportation’s Contribution



**27% of U.S. GHGs**

**66% of U.S. petroleum use**

**85% is from on road vehicles**

Photo: By User Minesweeper on en.wikipedia - Minesweeper, CC BY-SA 3.0,
https://commons.wikimedia.org/w/index.php?curid=1302402

# 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*

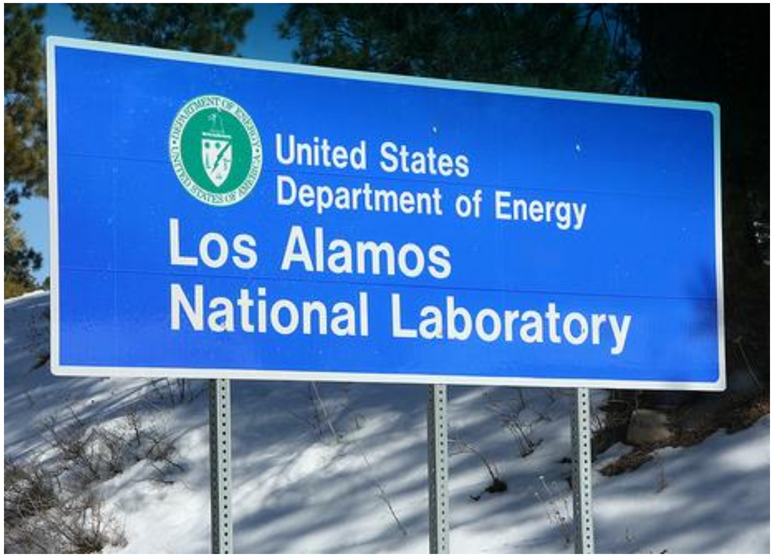
***"As part of an all-of-the-above energy approach, fuel cell technologies are paving the way to competitiveness in the global clean energy market and to new jobs and business creation across the country."***

*- Secretary Moniz,*
*U.S. Department of Energy*

Secretary Moniz at DC Auto Show

# The beginning of the DOE Fuel Cell Program…

## 1970s

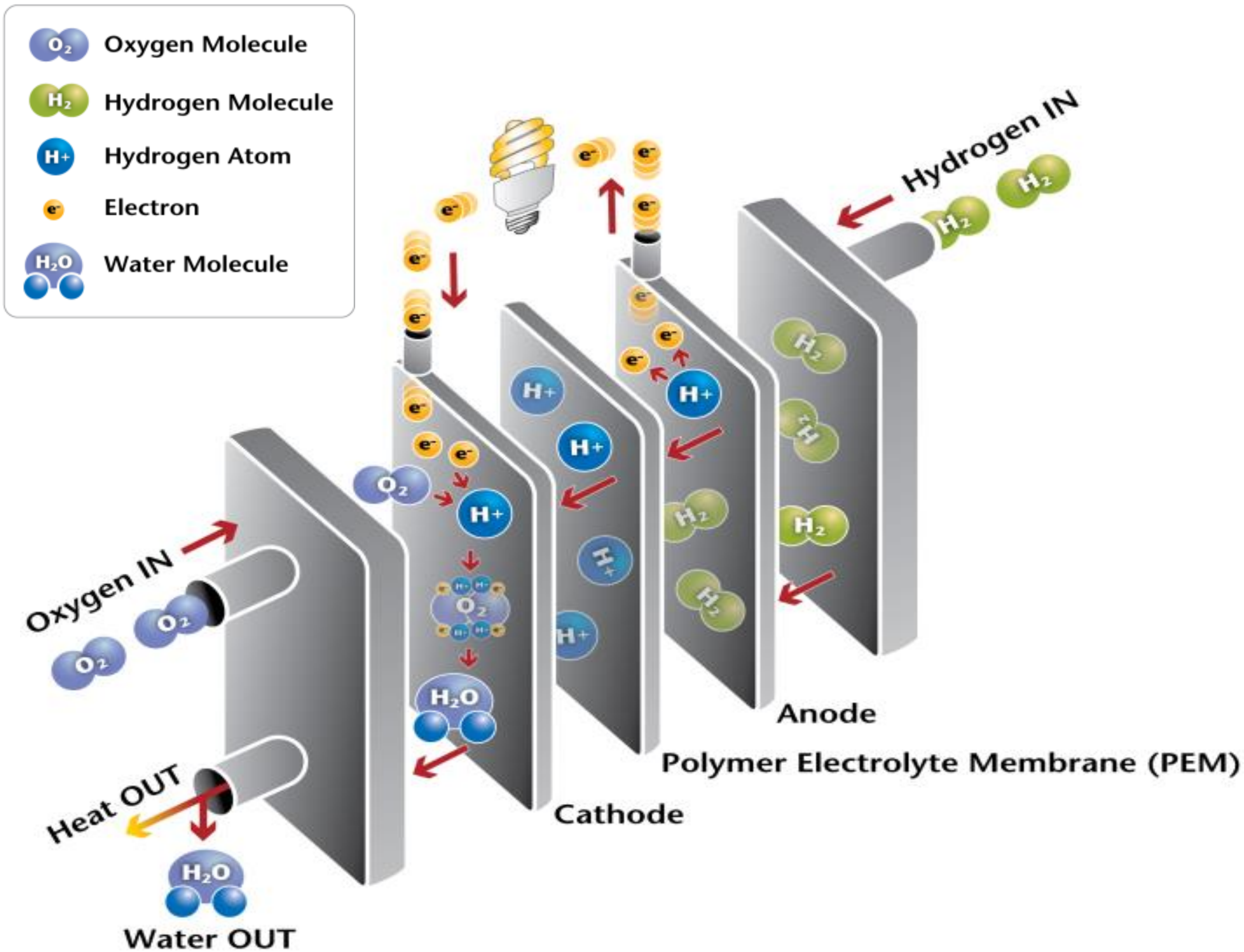



**Lab researchers taught scientists around the world how to fabricate MEAs**

**GM relocated to Los Alamos**

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

# Fuel Cells Intro




**Electricity** produced **directly**

**No combustion** involved

**No pollution** in tailpipe emissions

**Water and Heat** only byproducts

***Similar to batteries producing electricity without combustion***

# For the first time in history: Commercial FCEVs



*Hyundai Tucson Fuel Cell SUV*

*Toyota Mirai*

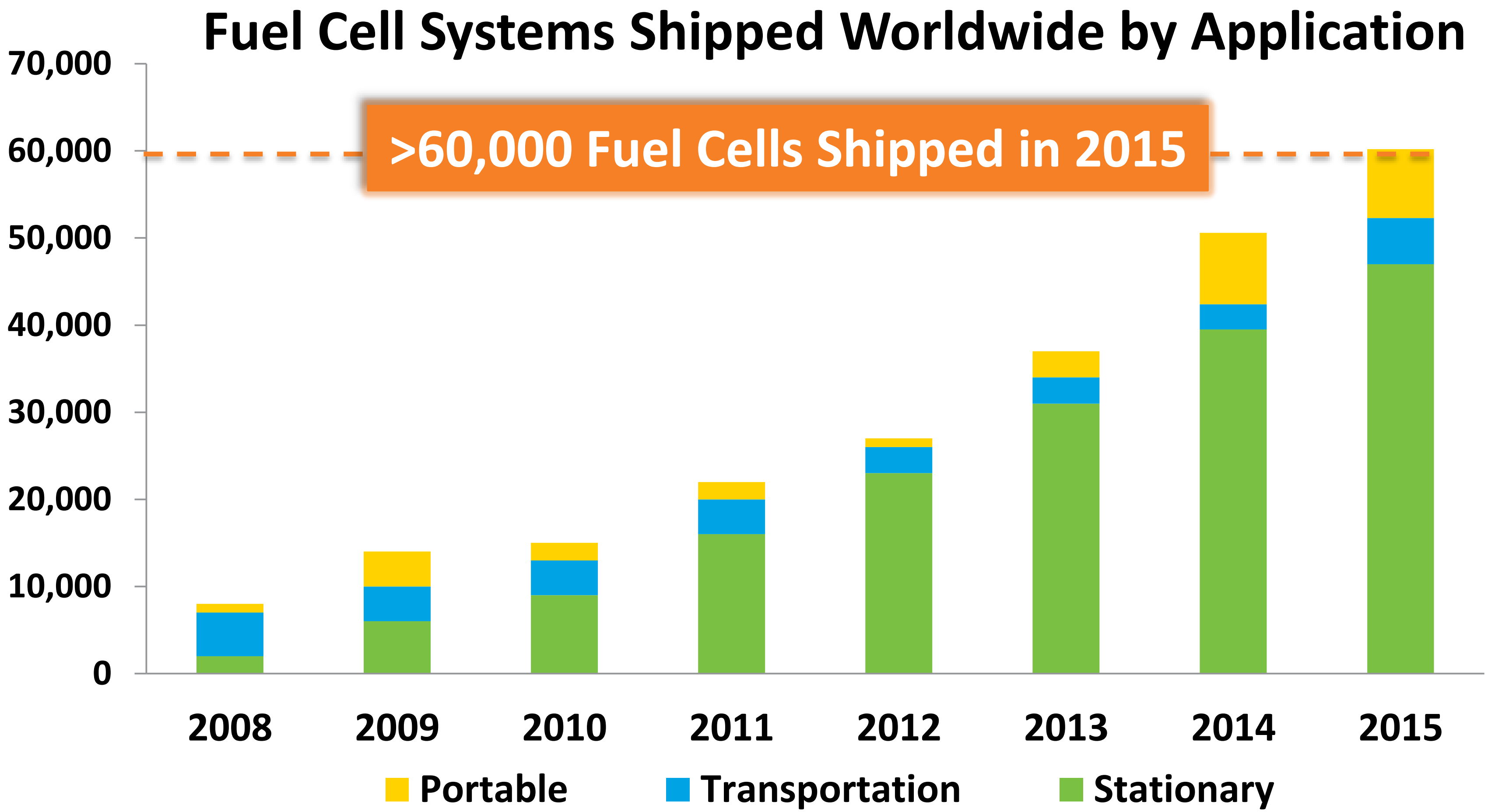
*Honda FCV*

Commercial FCEVs are here **today!**

**Can reduce total GHG emissions 50-90% vs. today's gasoline vehicles**

FCEV: Fuel Cell Electric Vehicle
GHG: Greenhouse Gases

# Market Growth in Fuel Cell Sales




Capacity shipped **in 2015** → Approximately **300 MW** & **~2X** → the capacity **in 2014**

*Source: Navigant Research (2008-2013) & E4tech (2014-2015)*

***Consistent ~30% annual growth since 2010***

# Fuel Cells: Big Leaps in the Last Year




**Fuel cell buses surpass 4 million passengers**

# Fuel Cells: Big Leaps in the Last Year




**Over 10,000 fuel cell forklifts**

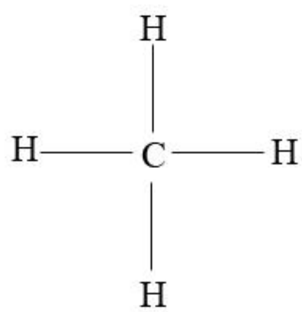
**Over 1.5 million $H_2$ refuelings**

# Hydrogen Introduction



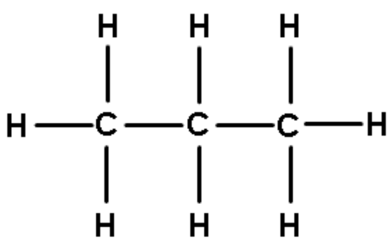
Increasing specific energy

120 MJ/kg

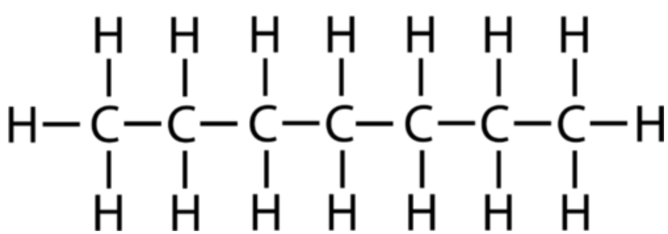


8.5 MJ/L (l)
4.8 @ 700 bar

~ 43 MJ/kg



Increasing energy density

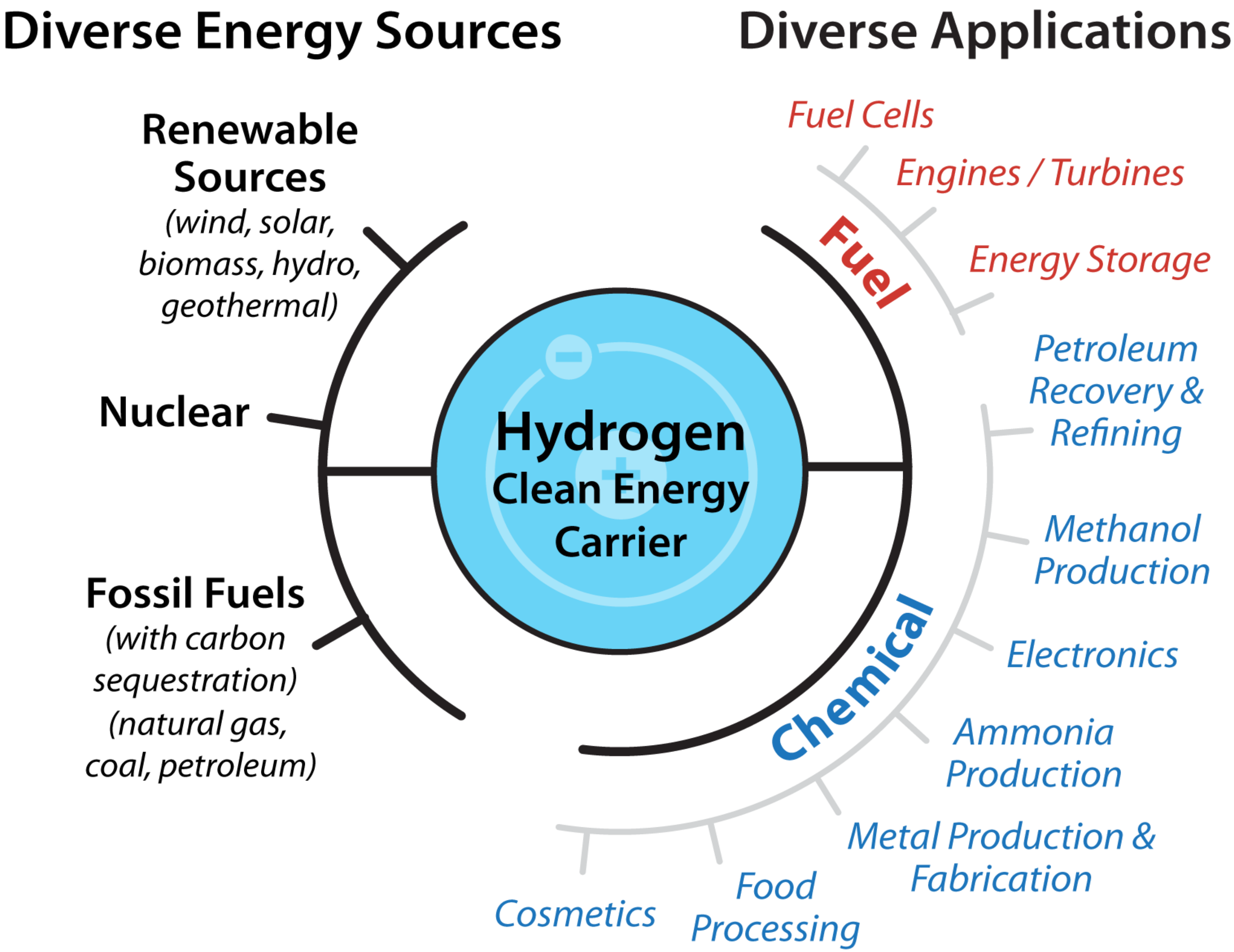


similar components in gasoline

~32 MJ/L

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

# Hydrogen- An energy carrier feedstock

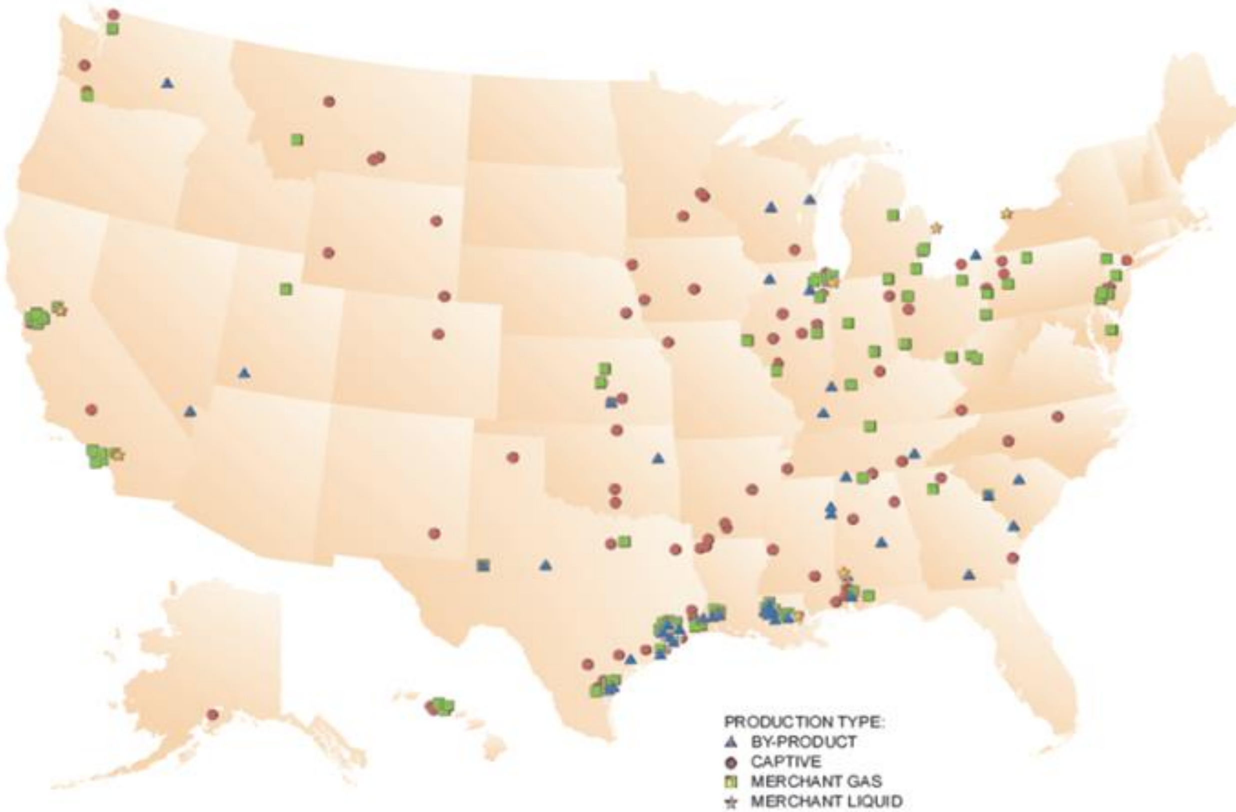



Source: DOE, NREL, Hydrogen and Fuel Cell Program

# Hydrogen Production Nationwide

We already produce **~ 10M metric tons of $H_2$** per year

Today there are **more than 1600 miles of $H_2$ pipeline**




**Centralized $H_2$ Production Facilities**

***Many states already produce many metric tons of hydrogen***

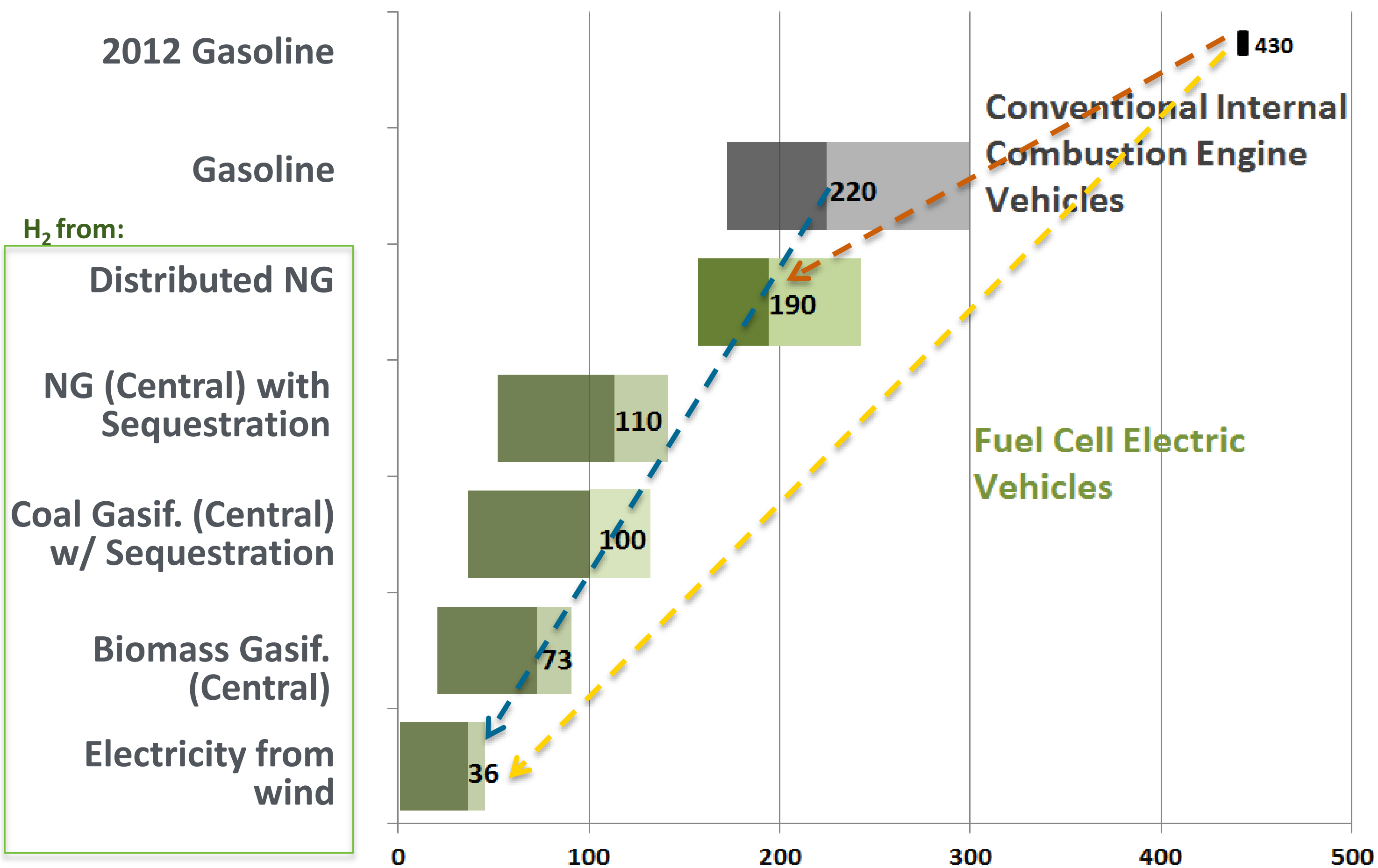
# FCEVs Reduce Greenhouse Gas Emissions

**>50%** with $H_2$ from Distributed Natural Gas*

**>80%** with $H_2$ from Renewables* (Wind)

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

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



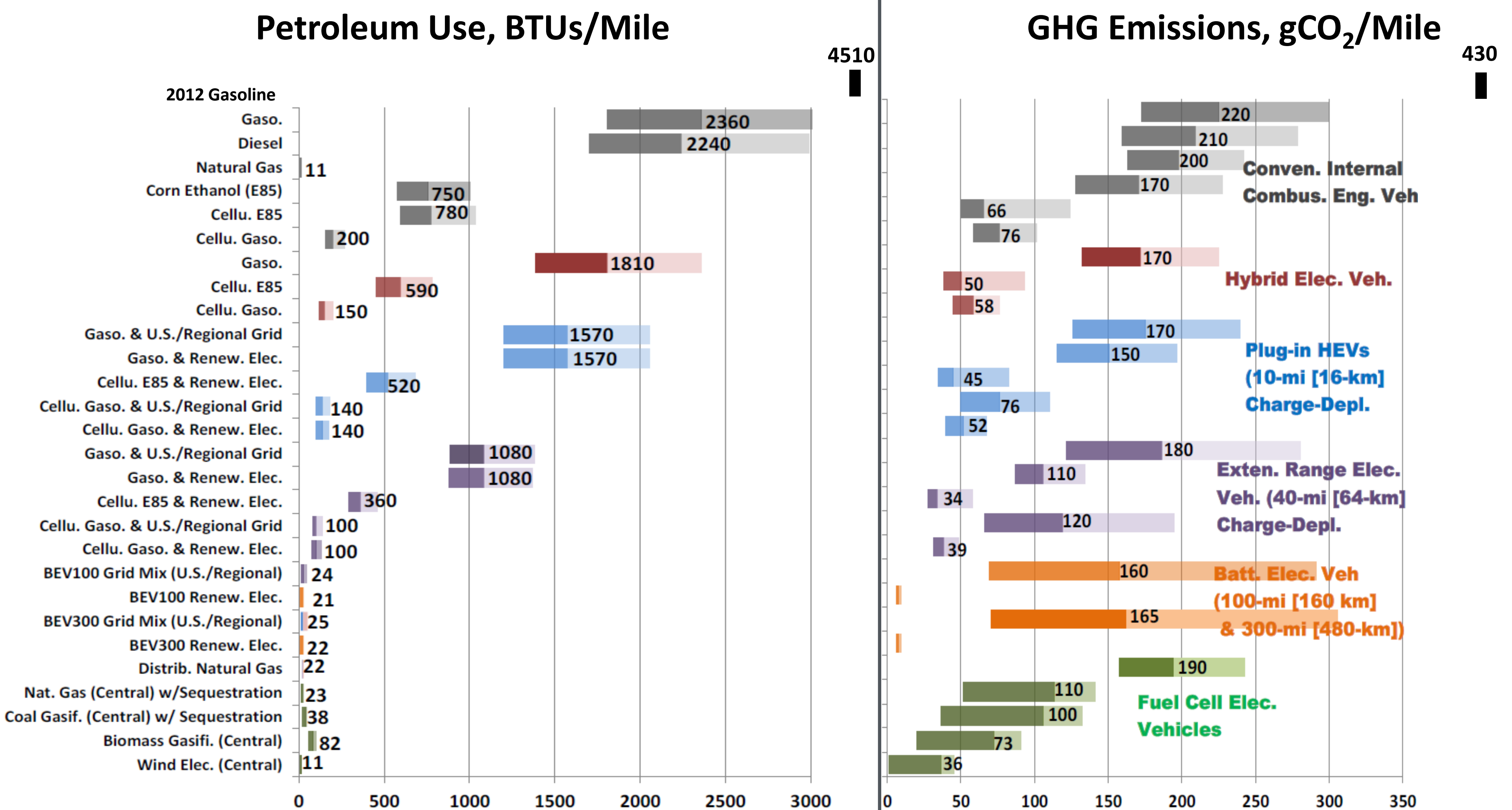

*Compared to 2035 gasoline vehicle
**Compared to 2012 gasoline vehicle

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***

# Well to Wheels Emissions and Petroleum Use*






**Program Record #13005:** http://www.hydrogen.energy.gov/pdfs/13005_well_to_wheels_ghg_oil_ldvs.pdf

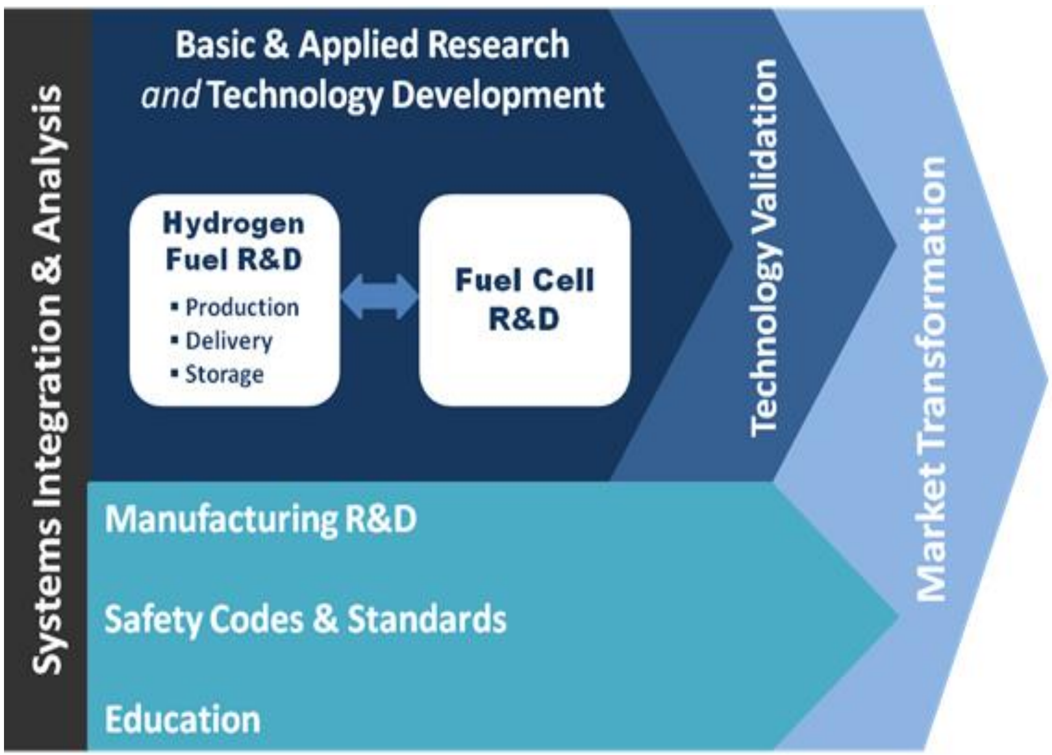
*2035 Technology except for 2012 gasoline

***Electric Drive With Low Carbon Fuels - Pathway with lowest GHG emissions and petroleum use***

# DOE Hydrogen and Fuel Cells Program

## Mission

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




## 2020 Targets by Application

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

*For Natural Gas
**For Biogas

***Integrated approach to widespread commercialization of $H_2$ and fuel cells***

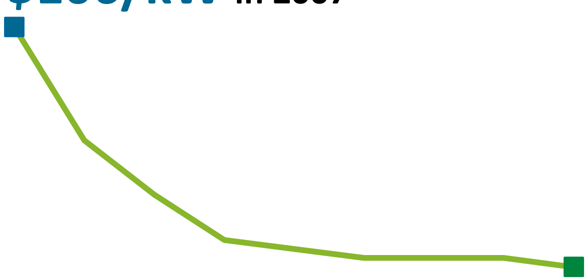
# DOE Activities Span from R&D to Deployment

## 1. Research & Development

### Fuel Cells

- Cut cost in half since 2007
- 5X less platinum
- 4X increase in durability

$106/kW in 2007



$53/kW in 2015 at high volume*

*$280/kW low volume

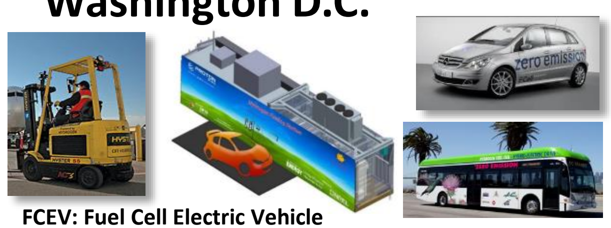
## 2. Demonstration

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

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

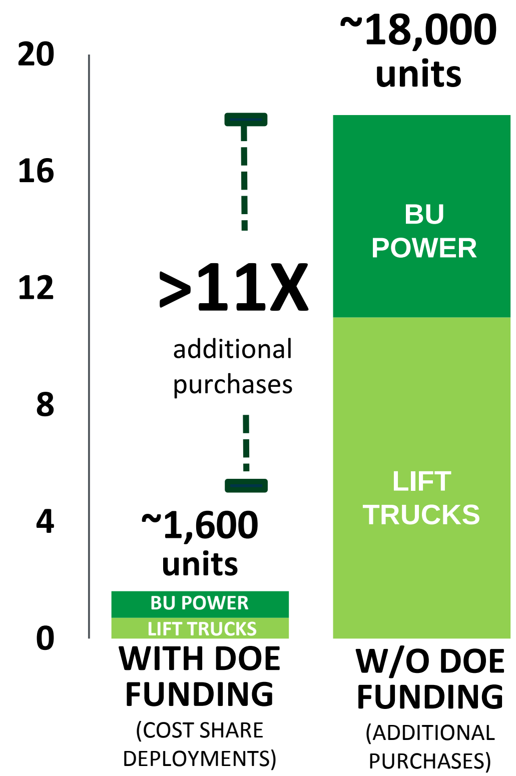
World's first tri-gen station

$H_2$ technology station in Washington D.C.




FCEV: Fuel Cell Electric Vehicle

## 3. Deployment




BU: Back Up Power

### Examples of consortia supporting R&D

- FCPAD (Fuel Cell Performance and Durability): Fuel Cell Performance & Durability
- HyMARC: Advanced $H_2$ Storage Materials
- ElectroCat (Electrocatalysis Consortium): PGM-Free Catalysts for Fuel Cells
- HydroGen (Advanced Water Splitting Materials): Renewable $H_2$ Production

### Supporting Deployment

$H_2$USA

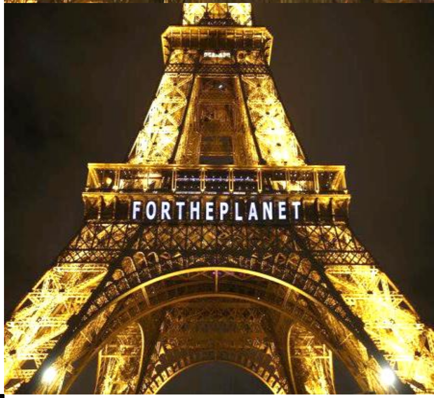
Collaboration to address $H_2$ Infrastructure Barriers

# Unprecedented global government support and growing collaboration

# 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

# $H_2$ and Fuel Cells Highlighted

## Mission Innovation Clean Energy R&D Focus Areas

| | AUSTRALIA | BRAZIL | CANADA | CHILE | CHINA | DENMARK | EUROPEAN UNION | FRANCE | GERMANY | INDIA | INDONESIA | ITALY | JAPAN | KINGDOM OF SAUDI ARABIA | MEXICO | NORWAY | REPUBLIC OF KOREA | SWEDEN | UNITED ARAB EMIRATES | UNITED KINGDOM | UNITED STATES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| INDUSTRY & BUILDINGS | ● | ● | ● | ● | | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| VEHICLES & OTHER TRANSPORTATION | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | | ● | ● | ● | ● | ● | ● | ● | | ● |
| BIO-BASED FUELS & ENERGY | ● | ● | ● | | ● | ● | ● | ● | ● | ● | ● | ● | | | ● | ● | ● | ● | ● | ● | ● |
| SOLAR, WIND & OTHER RENEWABLES | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| NUCLEAR ENERGY | ● | ● | ● | | ● | | | | | | | | | | | | ● | | ● | ● | ● |
| HYDROGEN & FUEL CELLS | ● | ● | ● | | | ● | ● | ● | ● | ● | | | ● | ● | | ● | ● | | | ● | ● |
| CLEANER FOSSIL ENERGY | | ● | ● | | ● | ● | | | ● | ● | ● | | | ● | | | ● | | | | ● |
| $CO_2$ CAPTURE, UTILIZATION & STORAGE | ● | ● | ● | | ● | ● | ● | ● | ● | | | | ● | ● | ● | ● | ● | | ● | ● | ● |
| ELECTRICTY GRID | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | | ● | ● | ● | ● | ● | ● | ● |
| ENERGY STORAGE | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | | ● | ● | ● |
| BASIC ENERGY RESEARCH | ● | | ● | | | ● | ● | ● | ● | ● | ● | ● | ● | ● | | ● | | ● | ● | | ● |

Indicators are for key areas of R&D investment, but do not imply a comprehensive representation of a country's full R&D portfolio.

# International Partnerships



IPHE
International Partnership for Hydrogen and Fuel Cells in the Economy

## IPHE is an Inter-Governmental Partnership to

- **Share policy** information on $H_2$ and fuel cells
- **Increase** international **collaboration**
- **Share information** and lessons learned

## International Energy Agency: H2 and Fuel Cells

- More than 25 countries collaborate on research in both hydrogen and fuel cell technologies

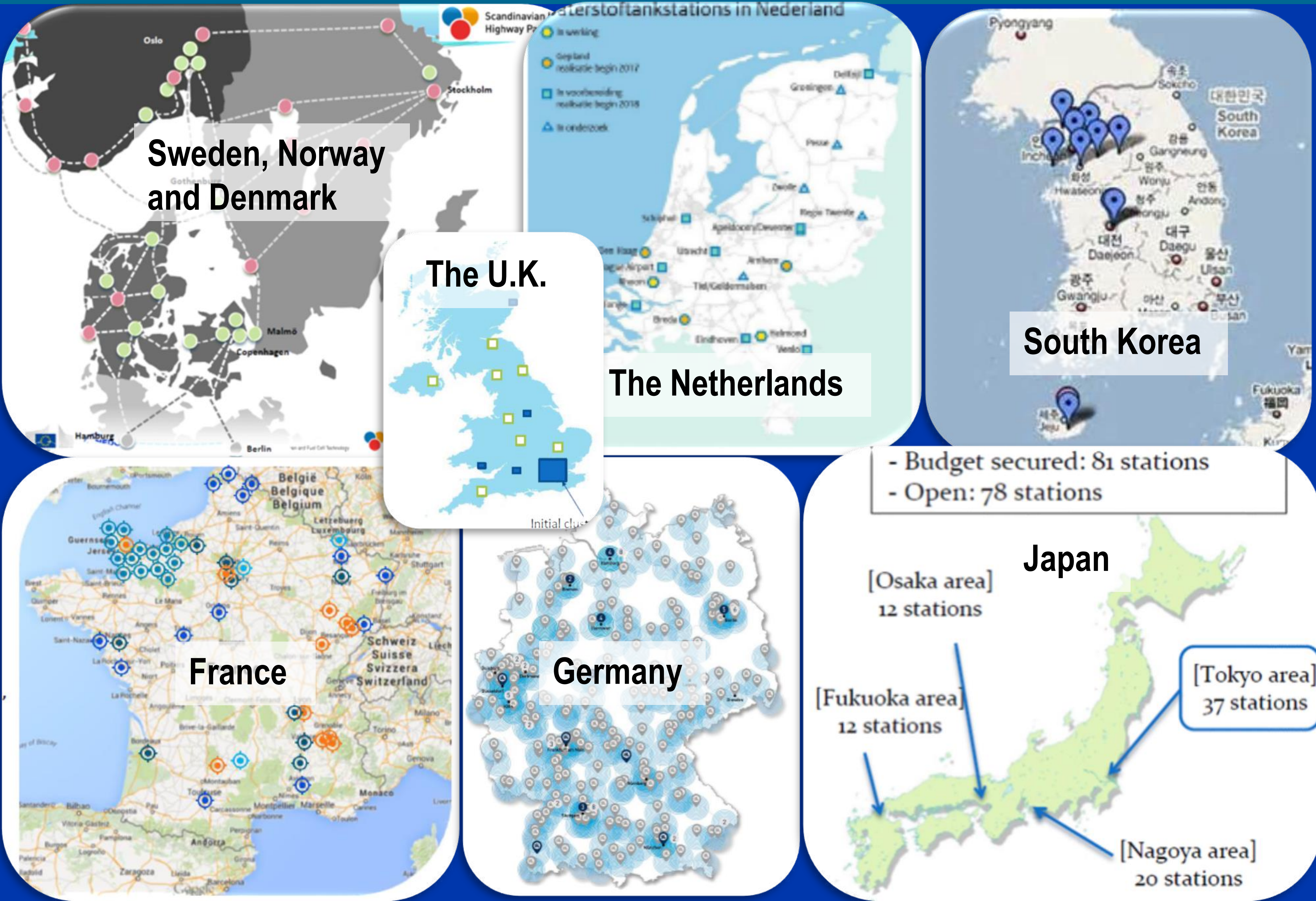
## 18 IPHE members work to advance hydrogen and fuel cell technologies

| | | |
|---|---|---|
| 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**

**World's largest town running on hydrogen in Fukuoka, Japan**

# Global Expansion of Infrastructure



# What can we learn from history?

# Henry Ford's Quadricycle in 1896 to Model T in 1908

# FORD CARS

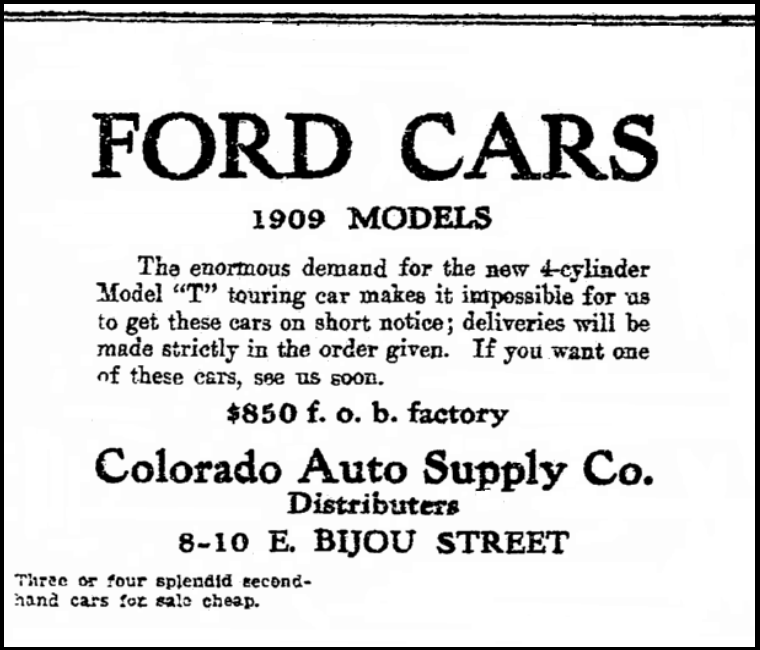
**1909 MODELS**

The enormous demand for the new 4-cylinder Model "T" touring car makes it impossible for us to get these cars on short notice; deliveries will be made strictly in the order given. If you want one of these cars, see us soon.

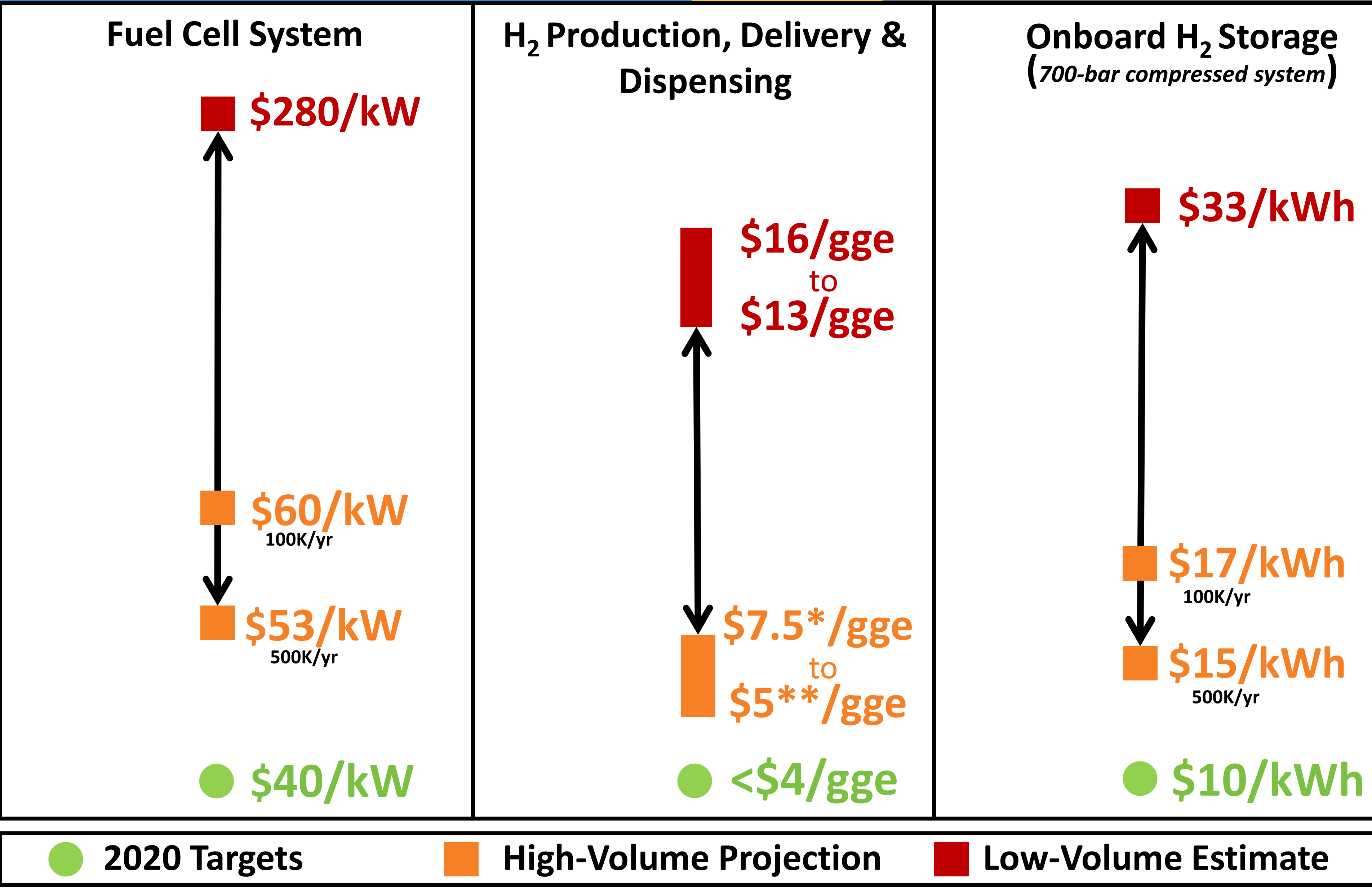
**$850 f. o. b. factory**

**Colorado Auto Supply Co.**
**Distributers**
**8-10 E. BIJOU STREET**

Three or four splendid second-hand cars for sale cheap.



# Cost Status and Targets



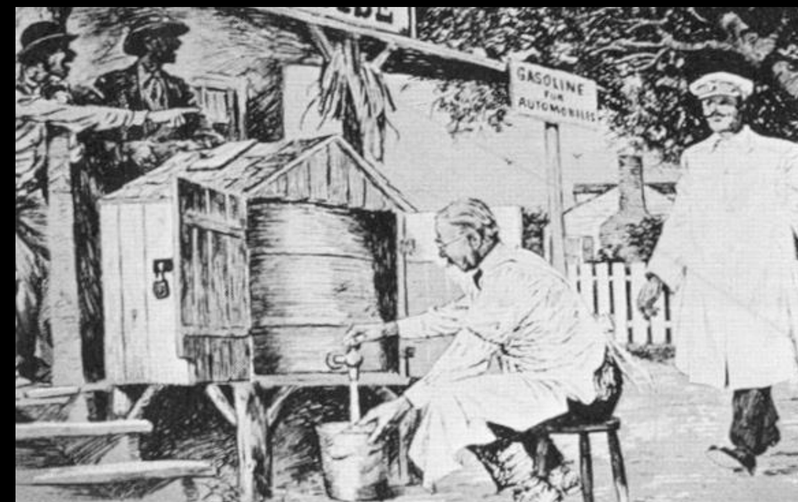

*Based on Electrolysis **Based on NG SMR

*For illustration purposes only, not drawn to scale

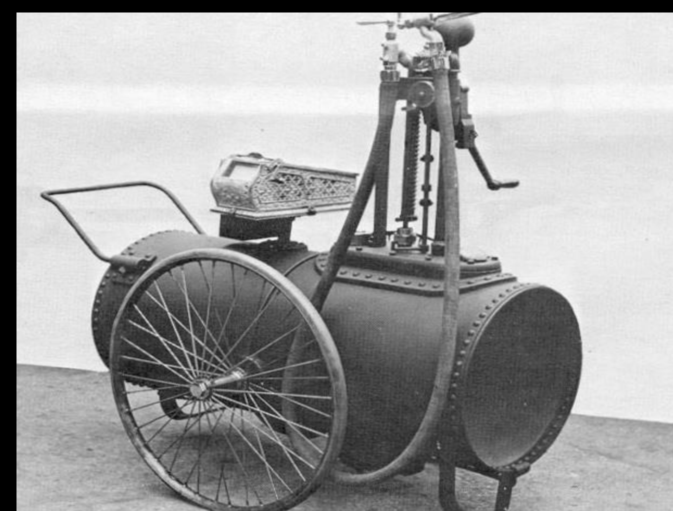
# Gasoline History: Many diverse options

## Cans, barrels, home models, mobile refuelers


Source: M. Melaina 2008.



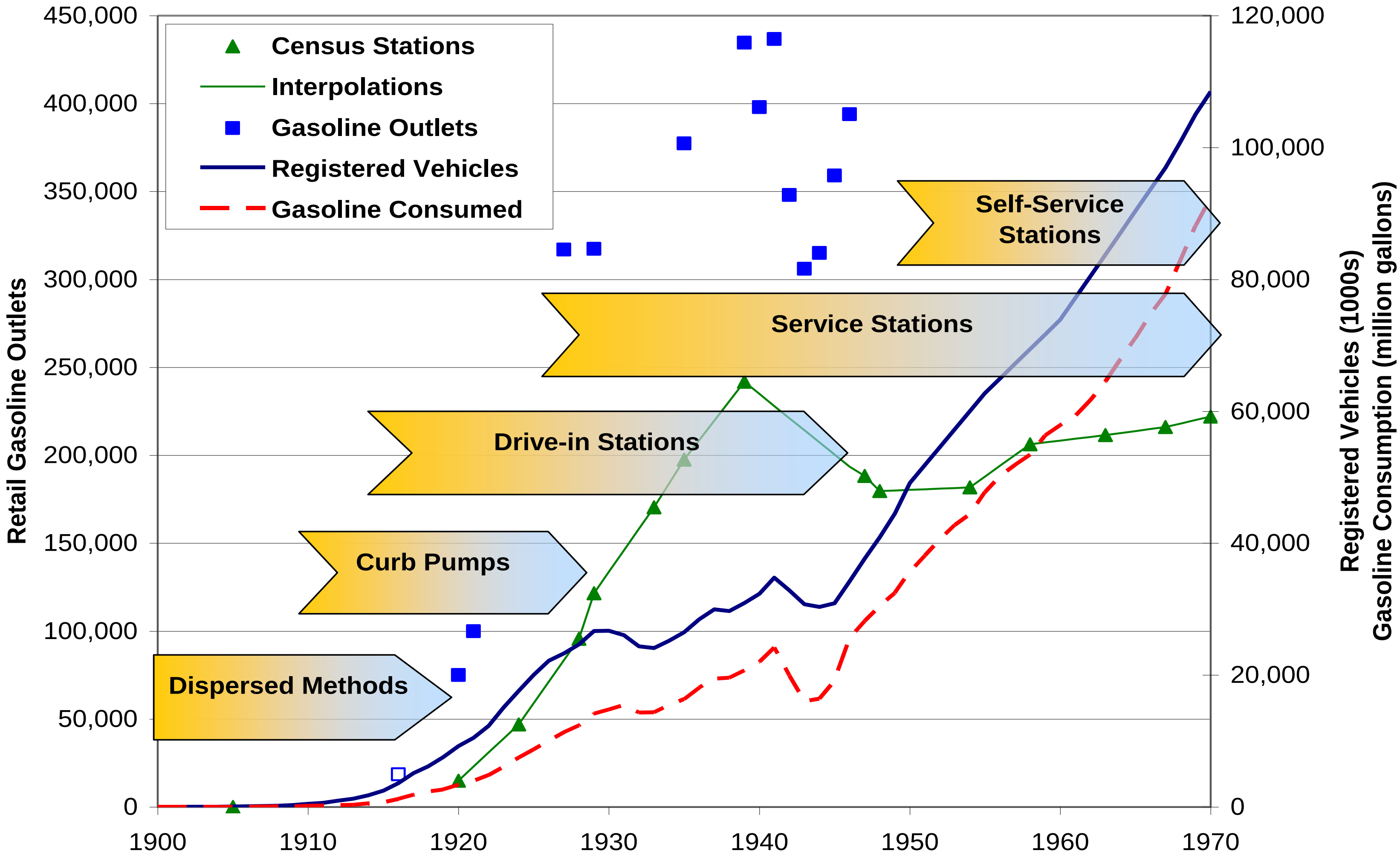

Source: Vieyra, 1979



Source: Milkues, 1978

# Refueling Methods Evolved Over Time






*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***

# $H_2$USA: Public-Private Collaboration



## $H_2$ 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

*$H_2$FIRST Coordination panel*

$H_2$FIRST

### $H_2$USA's Working Groups

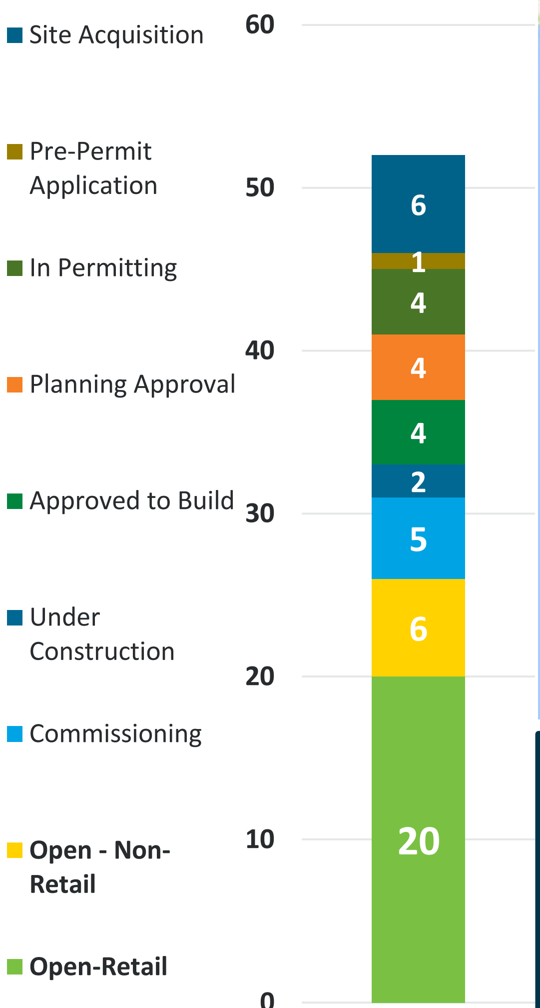
- Hydrogen Fueling Station
- Locations Roadmap
- Financing Infrastructure
- Market Support & Acceleration

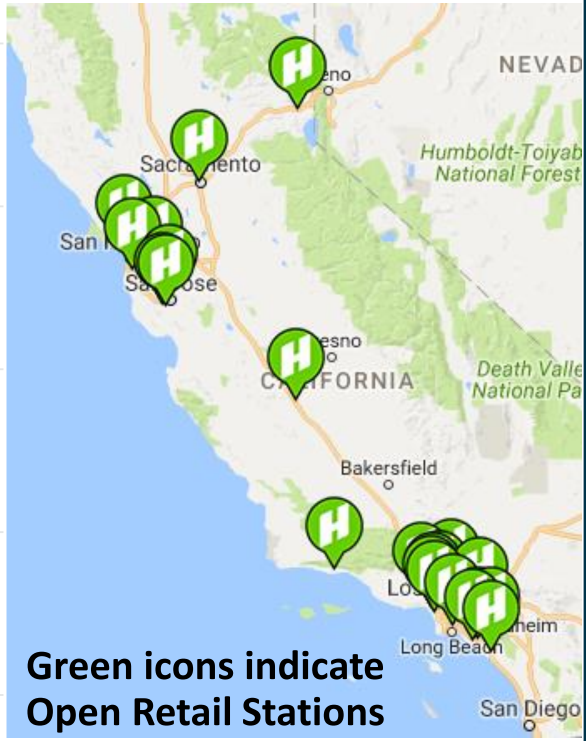
***More than 50 partners- Visit www.H2USA.org***

# Regional Landscape- Infrastructure Activities



## California




## $H_2$ Stations

**More than 20 retail**

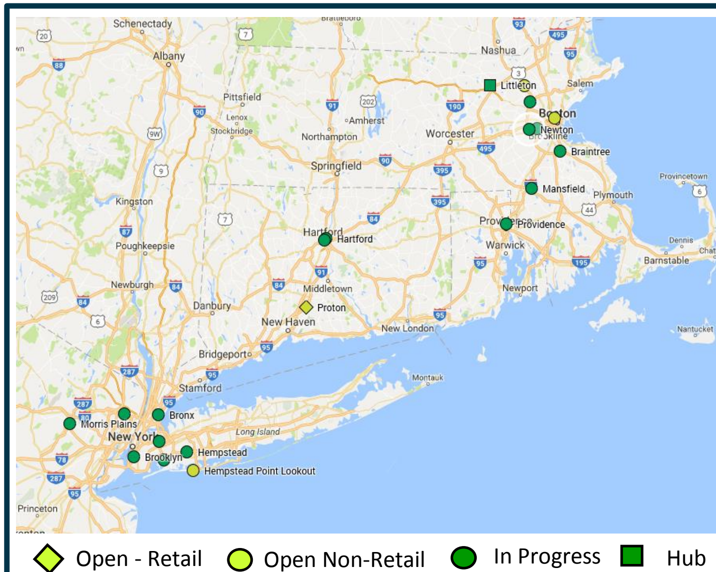
**Approx. 50 underway**

Funding for: 100

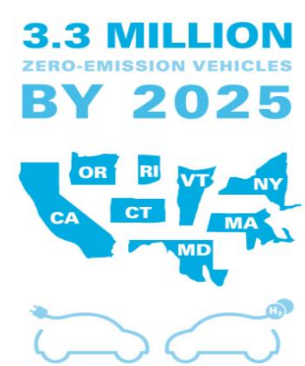
As of June 22, 2016 (Data from CaFCP June 2016 status report- http://cafcp.org/sites/default/files/h2_station_list.pdf )

# Currently offline

## Northeast




**~ 12 to 25 Planned Retail $H_2$ Stations**




- California
- Connecticut
- Massachusetts
- Maryland
- New York
- Oregon
- Rhode Island
- Vermont

# Complementing Retail Stations: $H_2$ Refuel H-Prize

H2refuel
U.S. Department of Energy

## $1M Competition: On-site $H_2$ fueling

**Finalist Team Announced!**
More at hydrogenprize.org

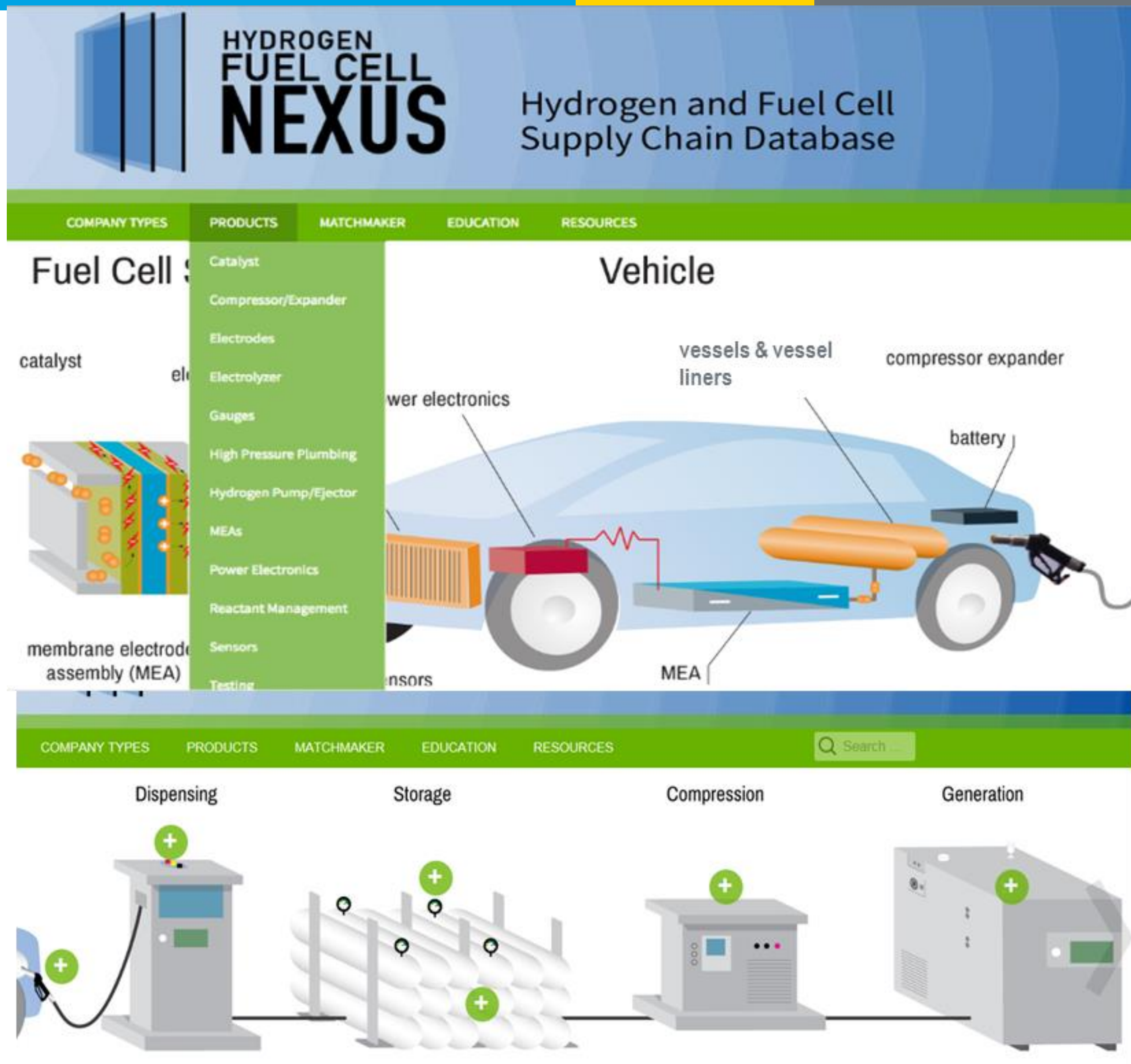
simple.fuel.™


**Innovative packaging concepts**
**Electrolysis 350 and 700 bar**


**Email your Feedback**
**info@teamsimplefuel.com**

# Online Database






www.HFCnexus.com

***Supplier engagement & collaboration & information readily and publicly accessible***

# New DOE efforts to enable robust supply chain



## Integrated Network of Regional Technical Centers

OFCC
OHIO FUEL CELL COALITION

## Activities

Hold supply chain exchanges

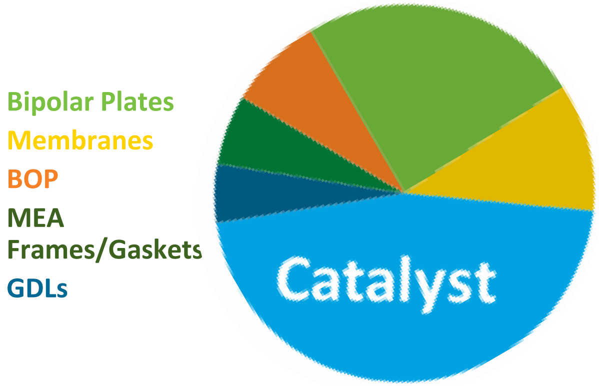
Promote cooperation between suppliers & developers, and standardization of component specifications

# Examples of technical challenges that need more work

# Techno-Economic Analysis Guides R&D Portfolio

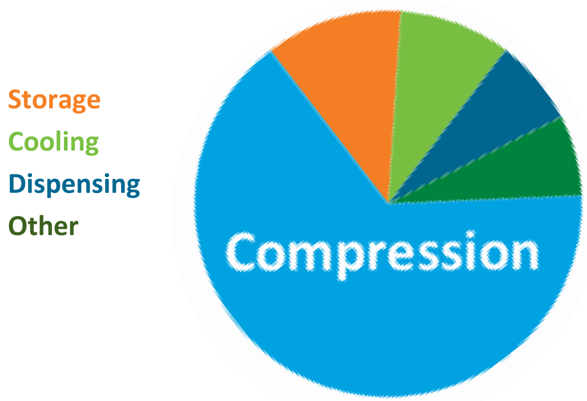
**Focusing on…**

## Fuel Cells



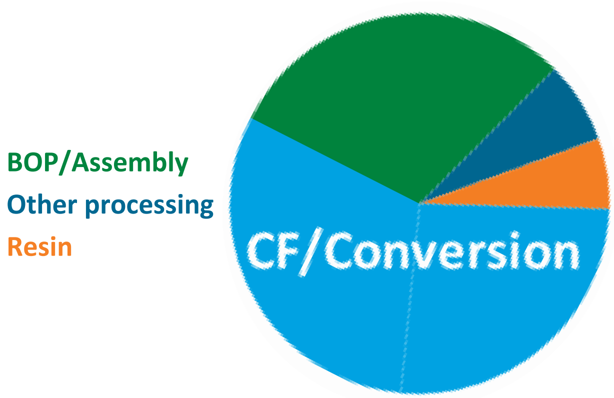

→ **Low and Non PGM Catalysts, Alkaline Membranes**

## $H_2$ Station




→ **Advanced Compression Alternate Approaches**

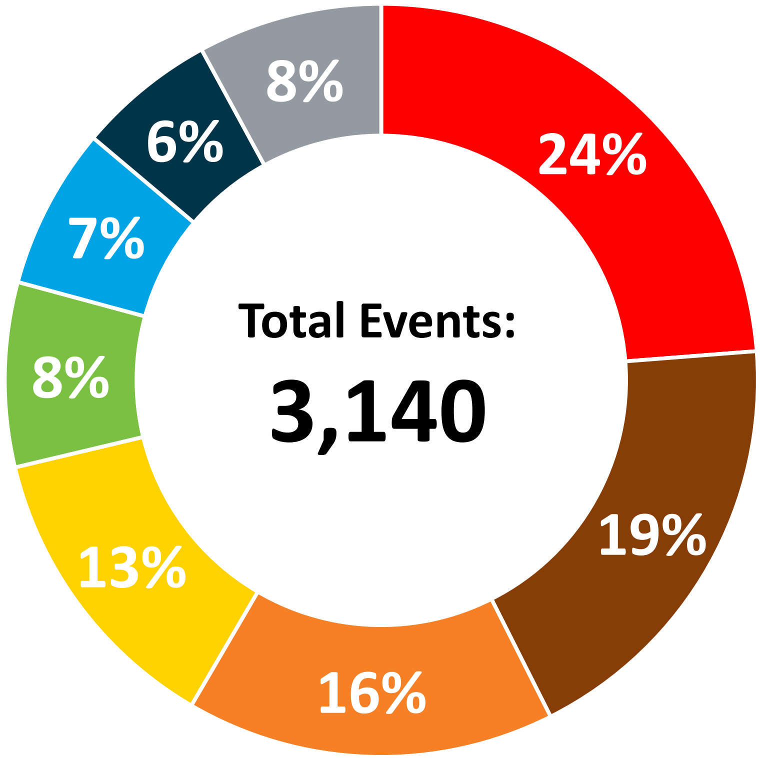
## $H_2$ Storage




→ **Low Cost Carbon Fiber (CF) Long term Materials Approaches**

# Real World Operation Data- $H_2$ Infrastructure

## Example: **Sources of $H_2$ Infrastructure Maintenance**




**Compressor**
**Dispenser**
**Entire**
**Safety**
**Storage**
**Reformer**
**Thermal Management**
**Other** Chiller, Feedwater

NREL cdp_infr_21

**Most maintenance related to compressors and dispensers**

**Contamination is a key issue:** See Database *www.nrel.gov/hydrogen/system_contaminants_data/*
**To participate: techval@nrel.gov**

***Providing insights to guide $H_2$ infrastructure activities and to maximize impact***

# FY17 Energy and Water Appropriations



## House Mark:

***"The Committee recognizes the need to support the development of alternative fueling infrastructure for U.S. consumers. Accordingly, the Department is encouraged to collaborate with the National Institute of Standards and Technology to allow accurate measurement of hydrogen at fueling stations."***

**NIST Handbook 44** requires 1.5% dispensing accuracy at initial certification; 2.0% during maintenance or in-use annual checks.

***CA adopted time-phased accuracy classes (4.0% initial certification)***

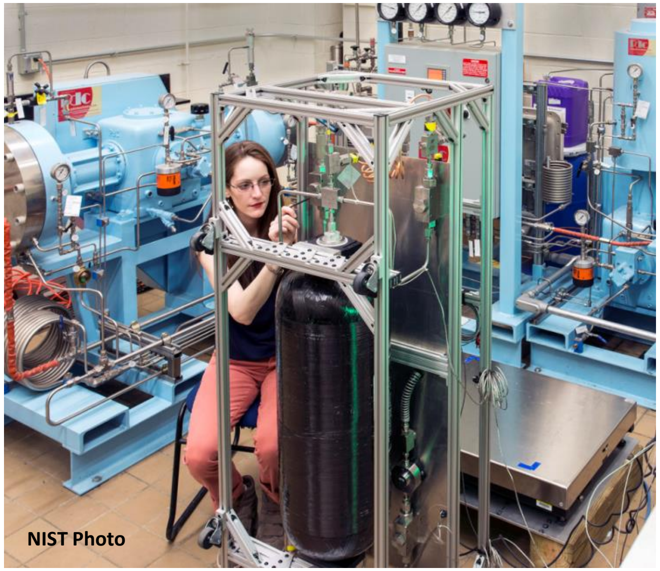
***Problem: Existing hydrogen dispensing technology in California cannot routinely meet the accuracy tolerances published in NIST HB44***

# Meter Benchmarking: Collaboration

## NIST Fluid Metrology Group – Oct. 2015

- NIST experience with $H_2$ dispensing test capability (35 MPa)
  - Could be valuable for medium/heavy duty applications
- NREL 70 MPa test device in high demand
- Potential opportunities to
  - Develop "master flow meter" device and perform calibrations
  - Address remaining issues

    (e.g. vibration, pressure, etc.)



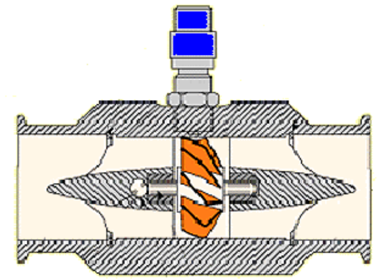
NIST Photo

NREL Photo

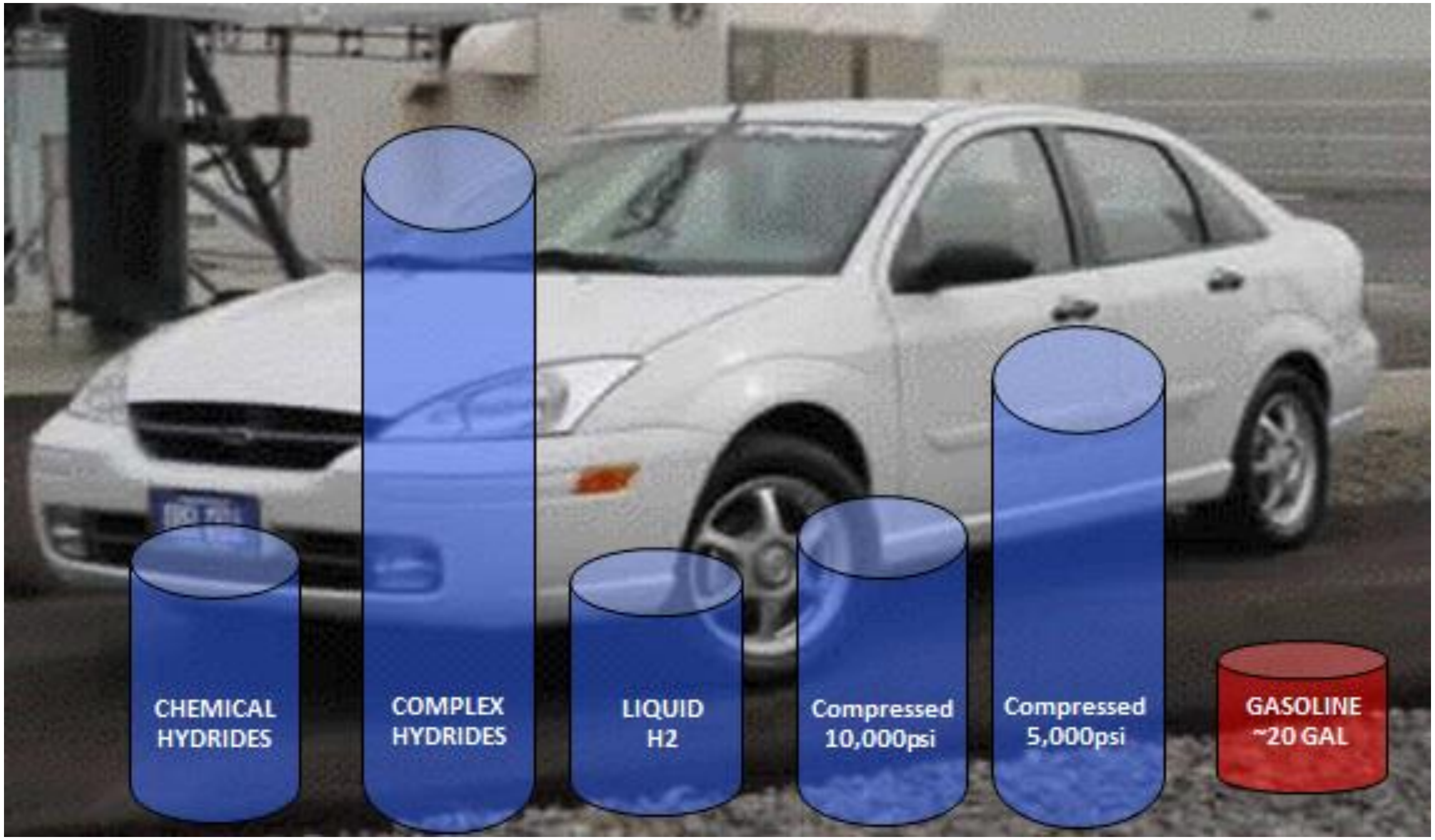
NIST participants: Jodie Pope, John Wright, Mike Moldover

# Meter Benchmarking: Meter Selection



| Type | Coriolis | Turbine |
|---|---|---|
| |  |  |
| **Output** | Mass flow rate | Volumetric flow rate |
| **Field Accuracy** | Installed meters have been certified to 5.0% CA accuracy class | Not field vetted yet |
| **Pros** | • Current industry standard<br>• No data conversion required | • Low component cost<br>• Higher turndown ratio |
| **Cons** | • Not routinely achieving NIST HB 44 accuracy levels | • Not vetted for HRS use<br>• Conversion to mass flow required |

***Broader tolerances must be established until commercial meters are able to routinely meet NIST HB44 accuracy levels***




**“Tank” Volume Estimates- Based on 5 kg hydrogen**

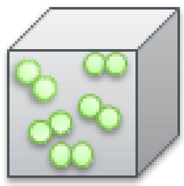
Data based on R&D projections for storage systems

***High-pressure hydrogen tanks are a viable option for onboard hydrogen storage. FCEVs have already demonstrated >400-mile range with compressed hydrogen.***

# Materials Based Hydrogen Storage: Potential for Higher $H_2$ Densities



## Physical Storage



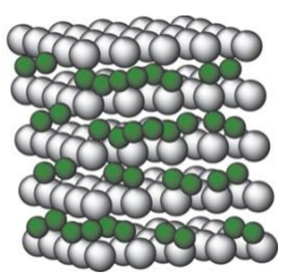
700 bar (70 Mpa)
Gen 2 vehicles
40g/L

| Storage Targets | Gravimetric kWh/kg (kg $H_2$/kg system) | Volumetric kWh/L (kg $H_2$/L system) | Cost $/kWh ($/kg $H_2$) |
|---|---|---|---|
| 2020 | 1.8 (0.055) | 1.3 (0.040) | $10 ($333) |
| Ultimate | 2.5 (0.075) | 2.3 (0.070) | $8 ($266) |

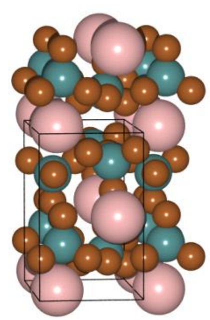
**Theoretical limitations prevent 700 bar from meeting all onboard targets**

**7.5 wt% and 70 g/L**

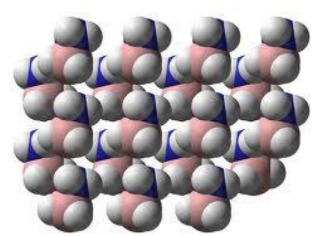
## Materials Storage



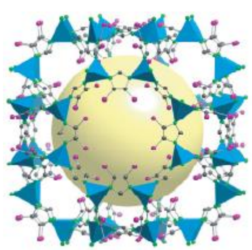
interstial hydrides
~100-150 g $H_2$/L



complex hydrides
~70-150 g $H_2$/L



chemical storage
~70-150 g $H_2$/L



sorbents
≤ 70 g $H_2$/L

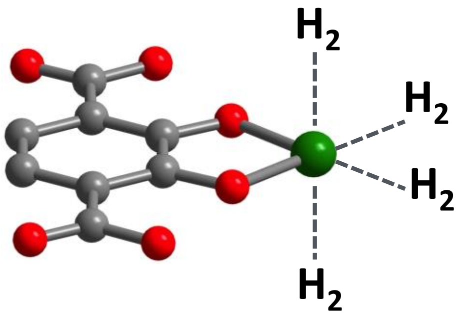
Reference

water
111 g $H_2$/L

**Higher densities = potential to meet system targets**

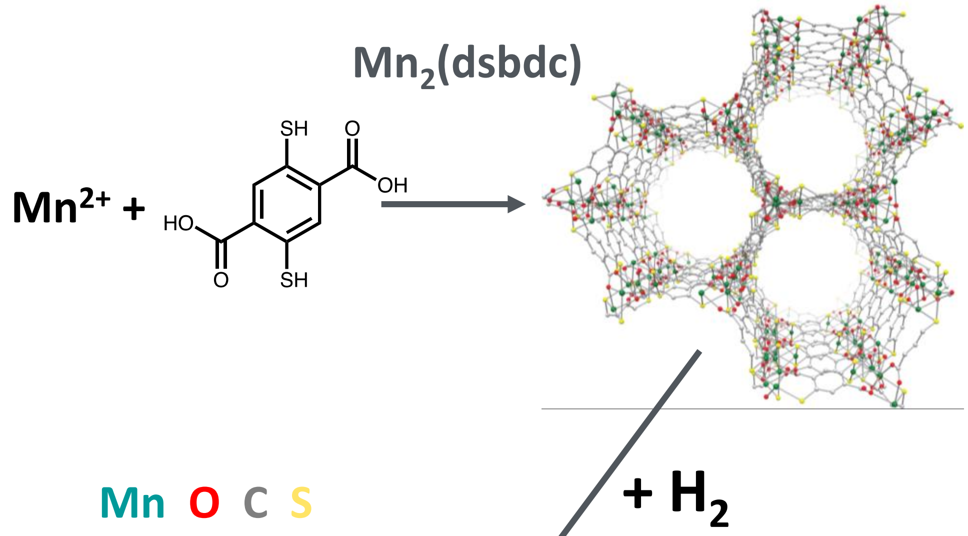
# NIST neutron data: *First example of multiple $H_2$ molecules adsorbed at a single metal center*

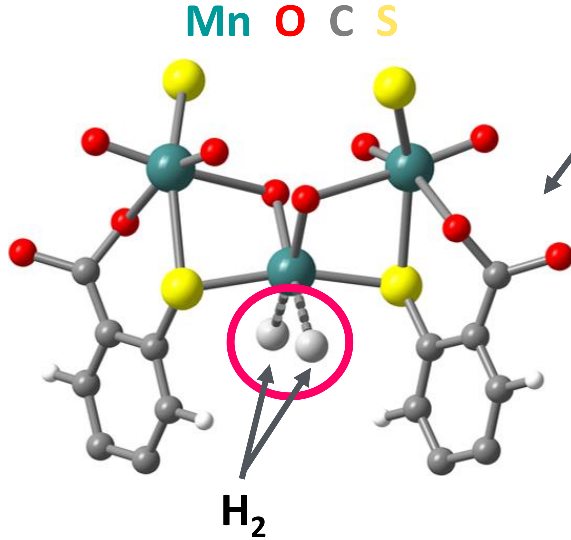





**Target Materials:**
**4 or more $H_2$ per metal cation for even more densely adsorbed $H_2$**

**DOE Annual Merit Award Winner**



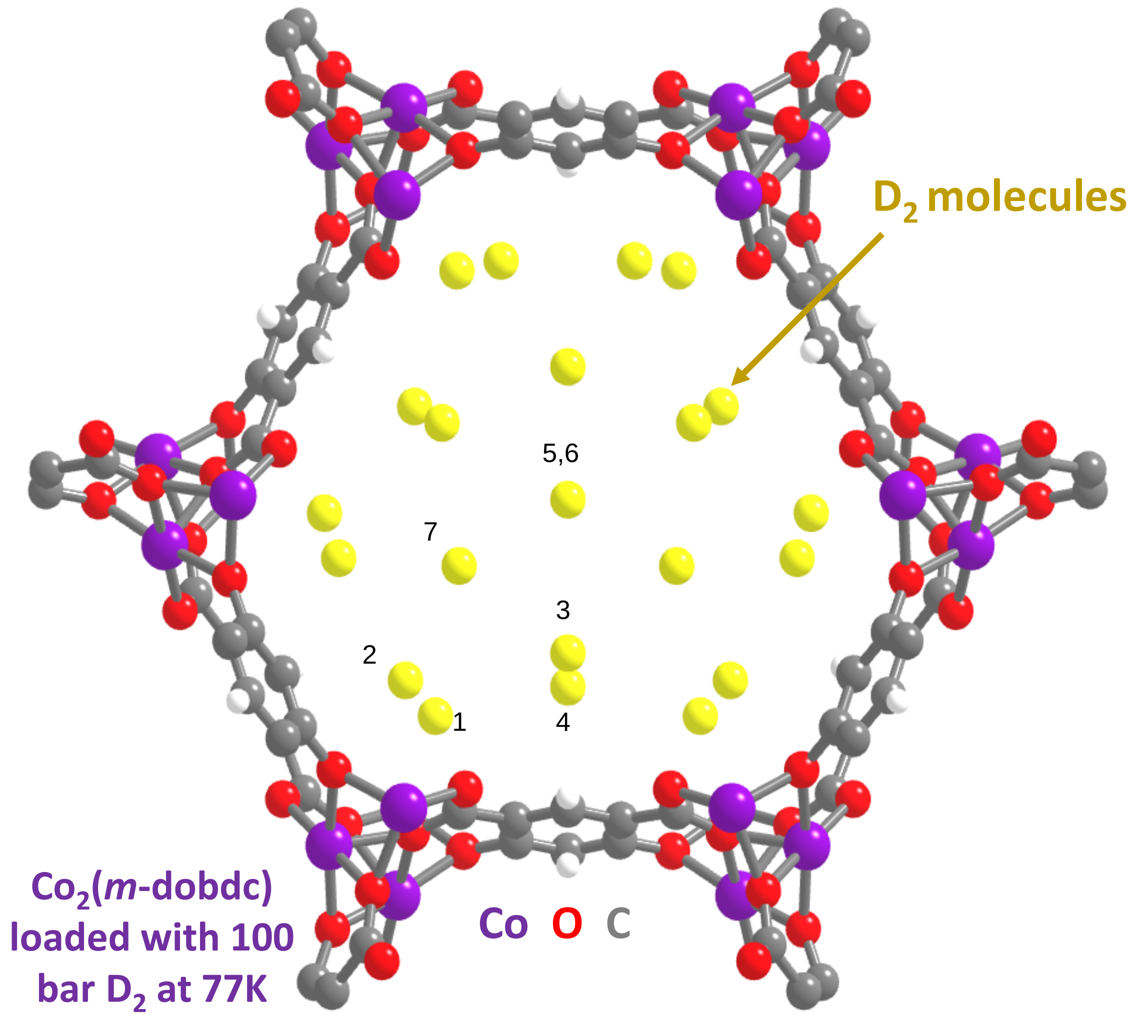

**First example of multiple $H_2$ molecules adsorbed at a single metal site**

Rončevski, T.; Kapelewski, M. T.; Torres-Gavosto, R. M.; Tarver, J. D.; Brown, C. M.; Long, J. R. *Chem. Commun.*, **2016**, *52*, 8251.

***Demonstrates a synthetic path to materials with higher densities of adsorbed $H_2$***

# NIST capabilities: Neutron diffraction of $H_2$ in MOFs

NCNR performing cutting edge experiments to determine gas adsorption sites in adsorbent materials using neutron diffraction




**$H_2$—$H_2$ distances shorter than solid hydrogen demonstrates the potential to outperform compressed gas**

| $D_2 \cdots D_2$ interaction | distance (Å) |
|---|---|
| 1···2 | 2.82(3) |
| 2···2 | 3.02(3) |
| 3···4 | 3.09(5) |
| 4···5 | 3.48(3) |
| solid $H_2$ | 3.20 |
| liquid $H_2$ | 3.61 |

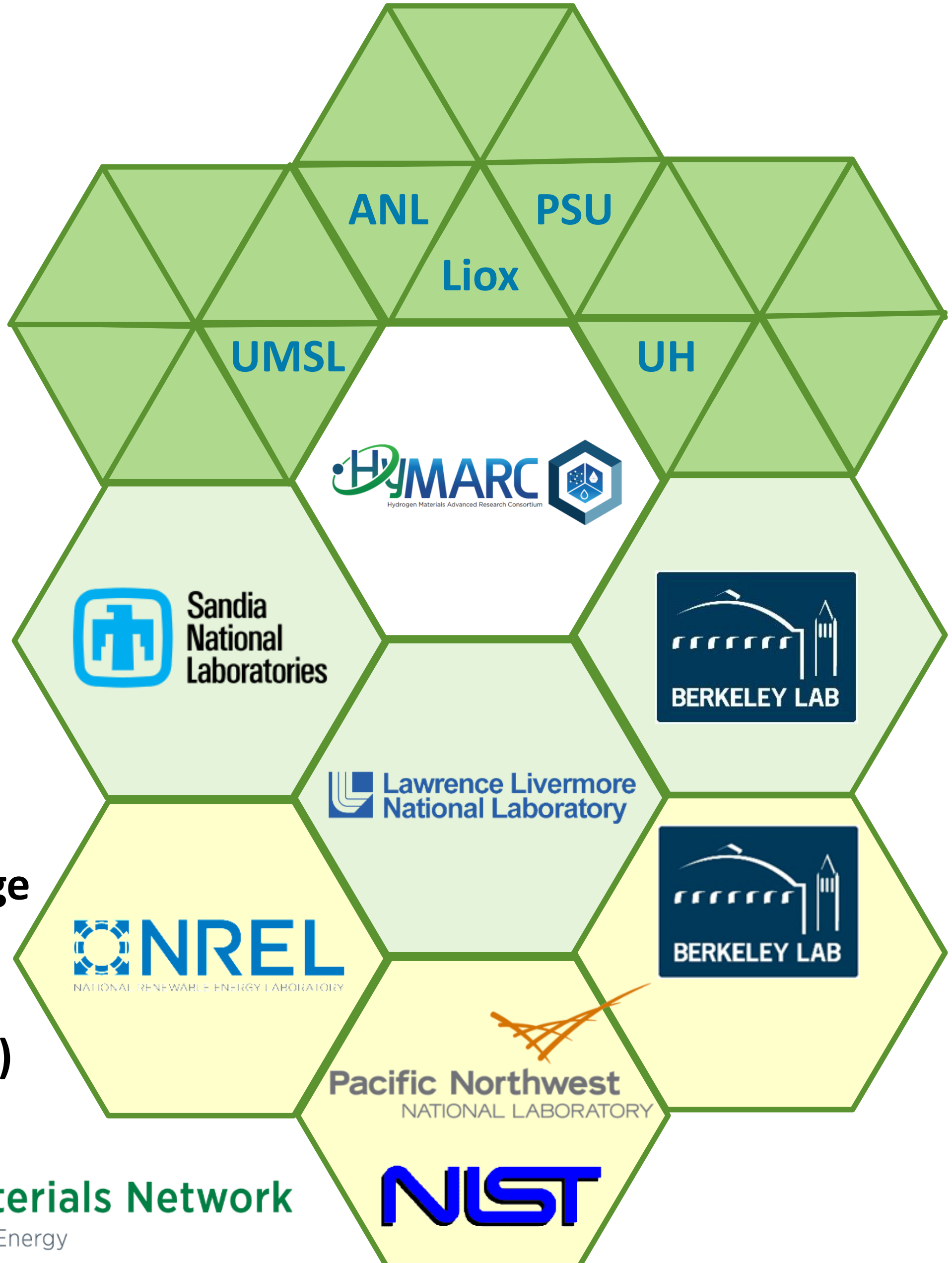
# Hydrogen Materials – Advanced Research Consortium (HyMARC)

HyMARC
Hydrogen Materials Advanced Research Consortium

**Individual projects**

**Core National Laboratory Team**

**Hydrogen Storage Characterization Optimization Effort (HySCORE)**




- **Applied material development**
  - Novel material concepts
  - High-risk, high-reward
- **Concept feasibility demonstration**
- **Advanced development of viable concepts**

- **Material development tools**
  - Foundational R&D
  - Computational modeling development
  - Synthetic/characterization protocol development
- **Guidance to FOA projects**
- **Database development**

- **Characterization Resources**
  - Validation of Performance
  - Validation of "Theories"
- **"User-facility" for FOA projects/HyMARC**
- **Characterization Method Development**

**Part of the**

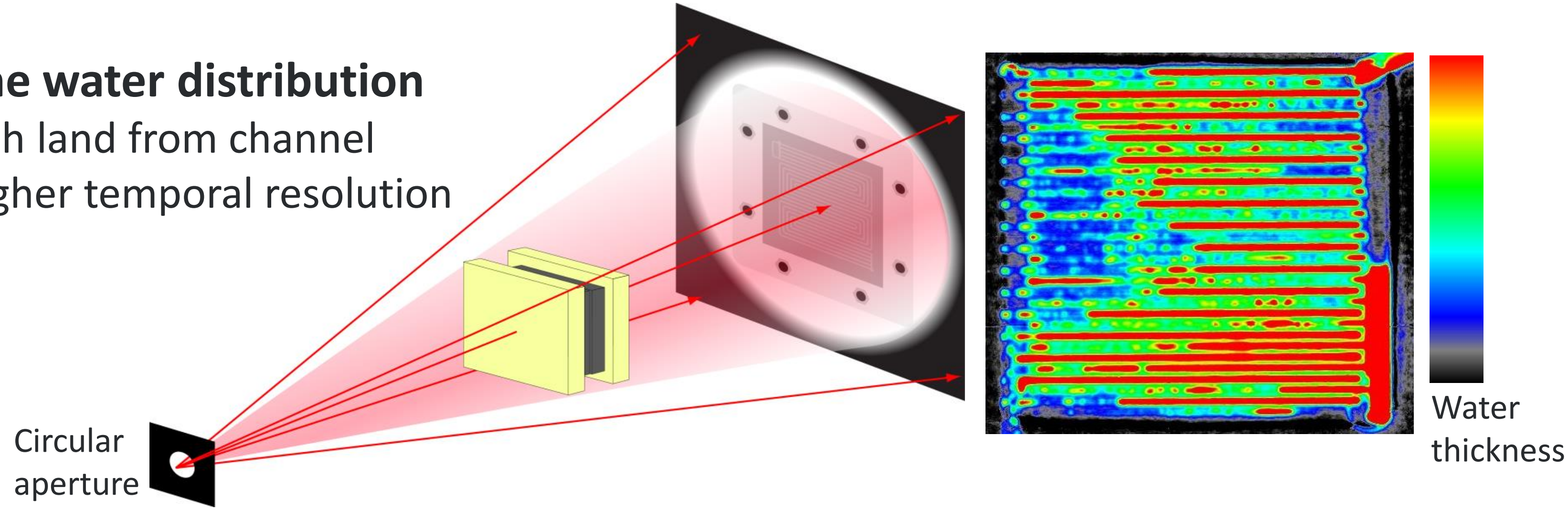
Energy Materials Network
U.S. Department of Energy

# Neutron Imaging of Water Distribution in Fuel Cells

Water content (thickness) is always integrated along the beam direction

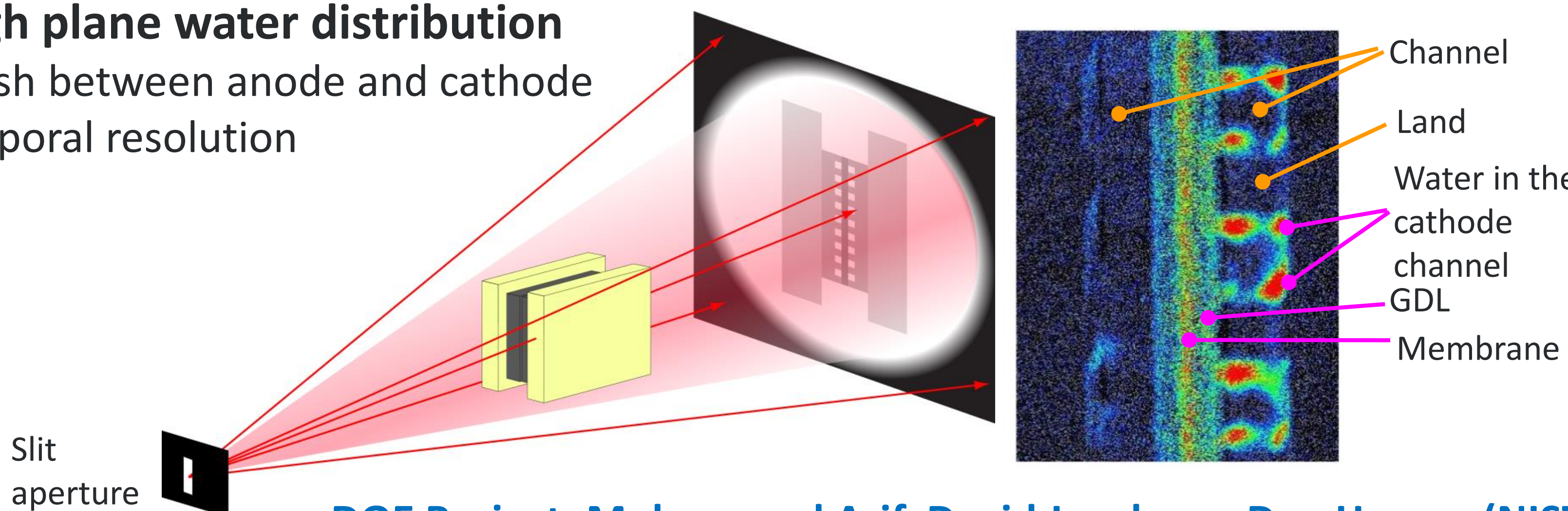
## In-plane water distribution

- Distinguish land from channel
- Allows higher temporal resolution



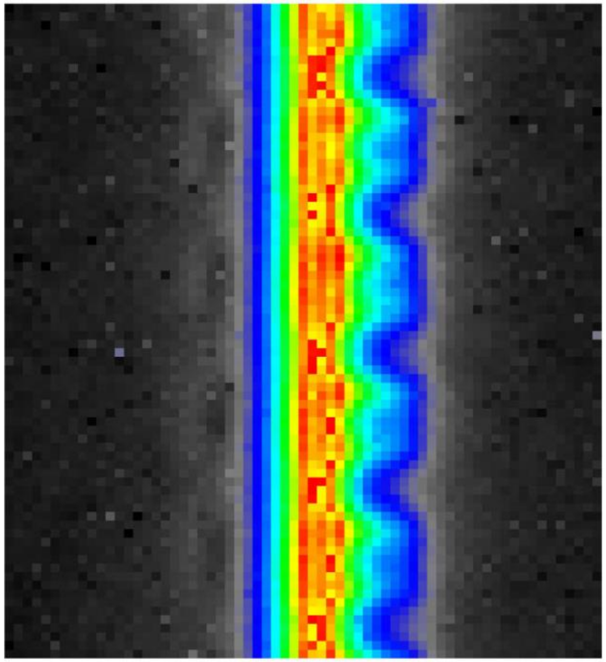

## Through plane water distribution

- Distinguish between anode and cathode
- Low temporal resolution

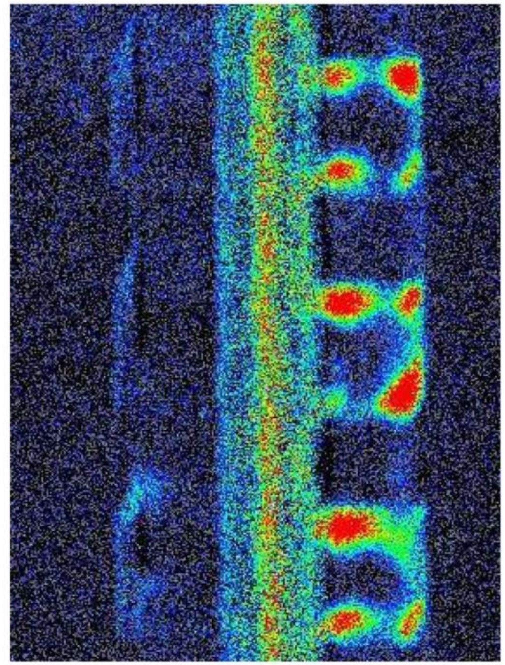



**DOE Project: Muhammad Arif, David Jacobson, Dan Hussey (NIST)**

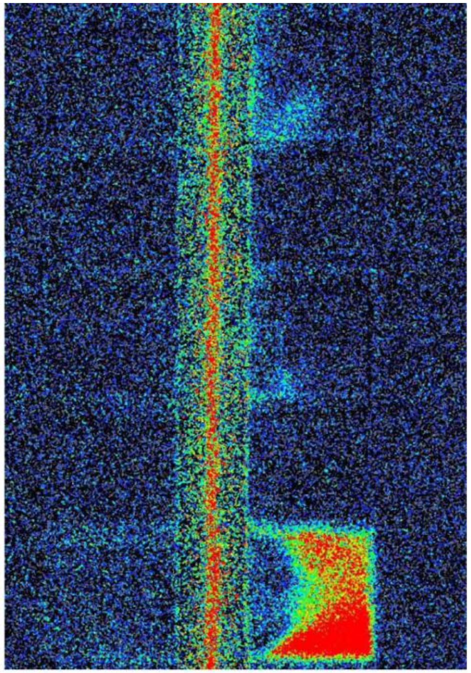
# Spatial resolution improving but we need more!



Scintillator 250 µm



MCP 25 µm



MCP 13 µm

**Resolution** → **1 µm**

- Easily resolve water content in gas diffusion layer at 25 µm resolution

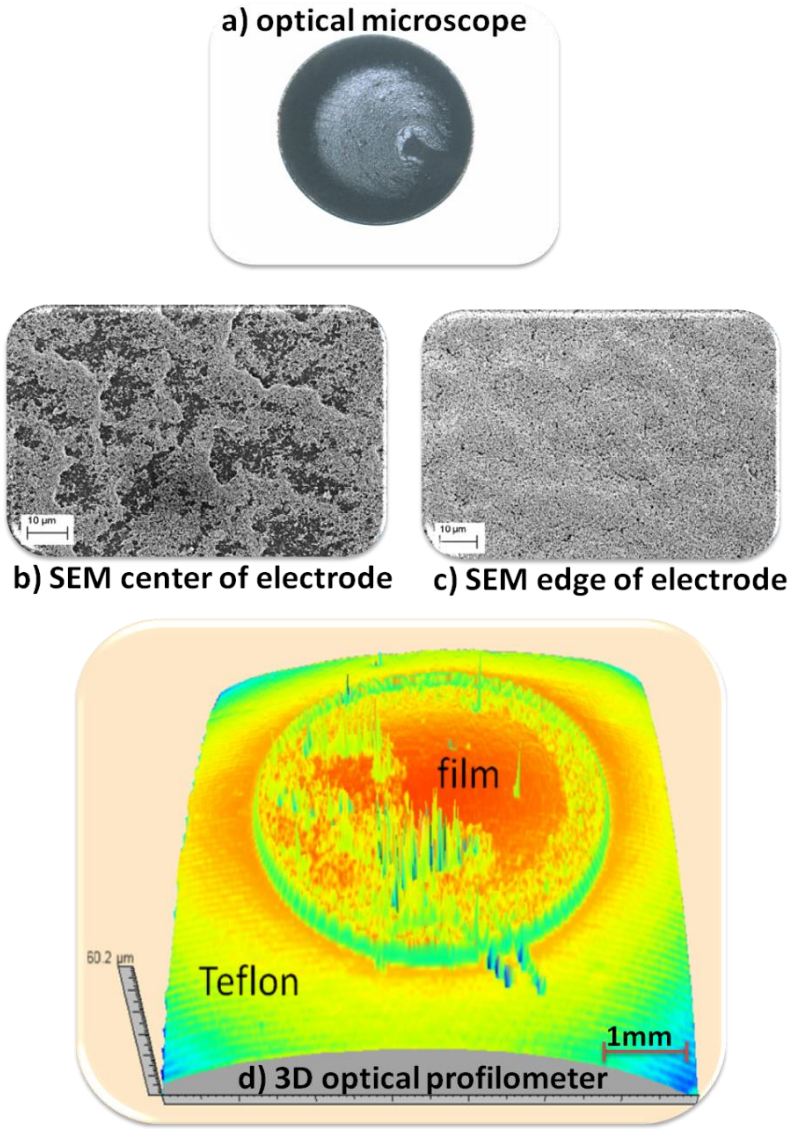
  25 µm is insufficient to resolve water in membrane for autos

**We need even higher resolution! Current NCNR goal is 1 µm!**

**DOE Project: Muhammad Arif, David Jacobson, Dan Hussey (NIST)**

# Electrocatalysts: Challenges in Technique



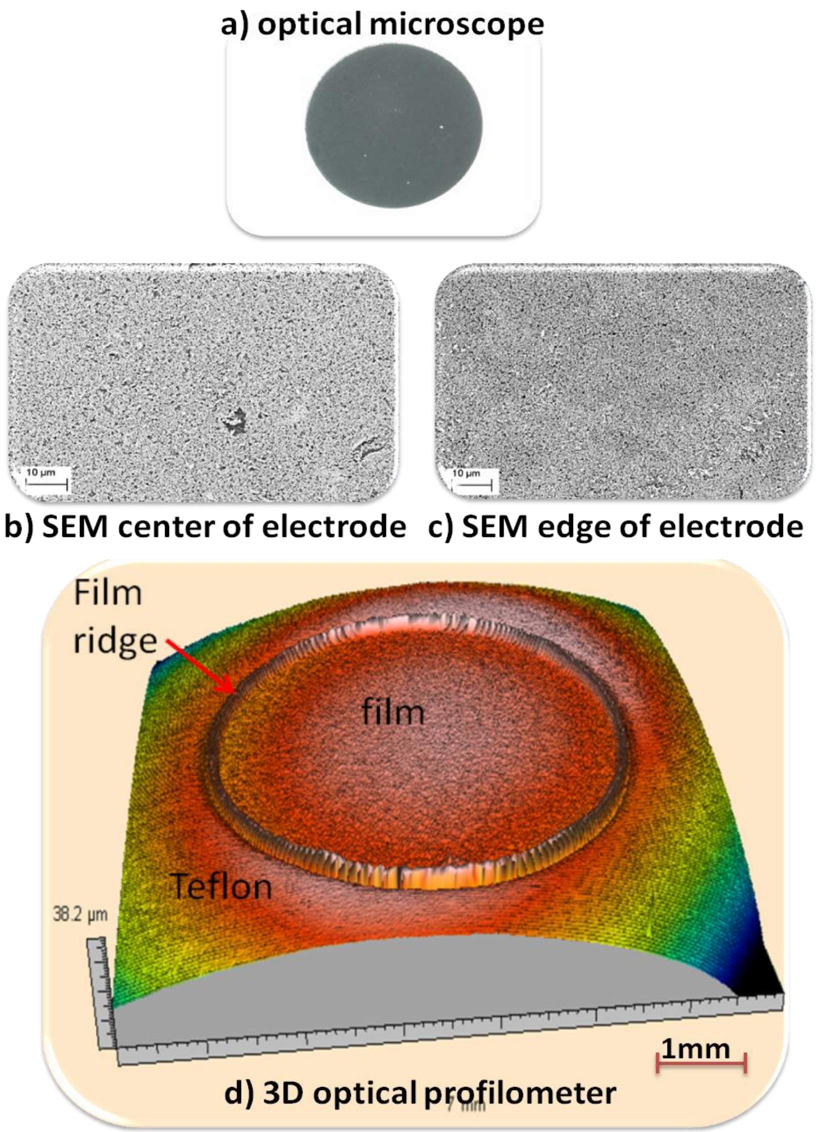



## Stationary drying method thin-film morphology

- Fairly uniform on the edge of electrode
- Thinner region towards the center of electrode
- Coffee ring structure at the edge

Y. Garsany, I.L. Singer, K.E. Swider-Lyons, S.S. Kocha, Impact of film drying procedures on the RDE characterization of Pt/VC electrocatalyst, J. Electroanal. Chem. 662 (2011) 396-406.

# Example of Technique Improvement




## Rotational drying method thin-film morphology

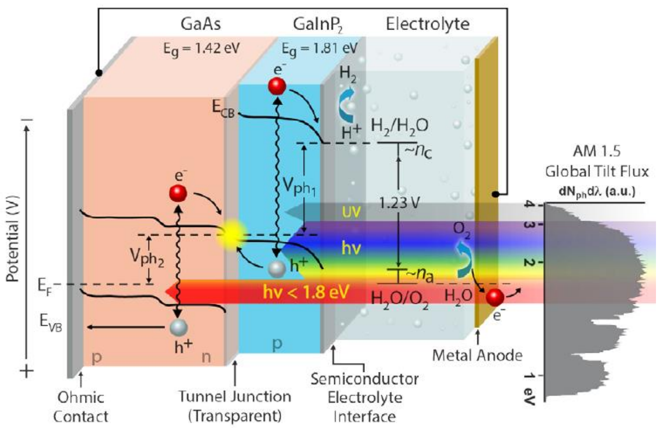
- **Very uniform over the entire surface**
- **No Coffee ring structure visible**

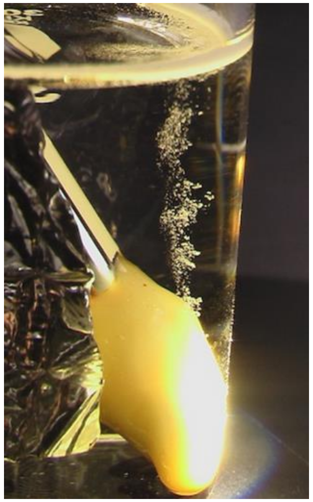
**Y. Garsany, I.L. Singer, K.E. Swider-Lyons, S.S. Kocha, Impact of film drying procedures on the RDE characterization of Pt/VC electrocatalyst, J. Electroanal. Chem. 662 (2011) 396-406.**

# Photoelectrochemical (PEC) Water Splitting

## EERE Applied R&D

**NREL set benchmark for efficient direct solar water splitting in a III-V semiconductor PEC device.**



Young, J. Deutsch, T, et. al. *Publication submitted*.

**New Solar to Hydrogen Efficiency Benchmark >16%**

## EERE PEC Working Group

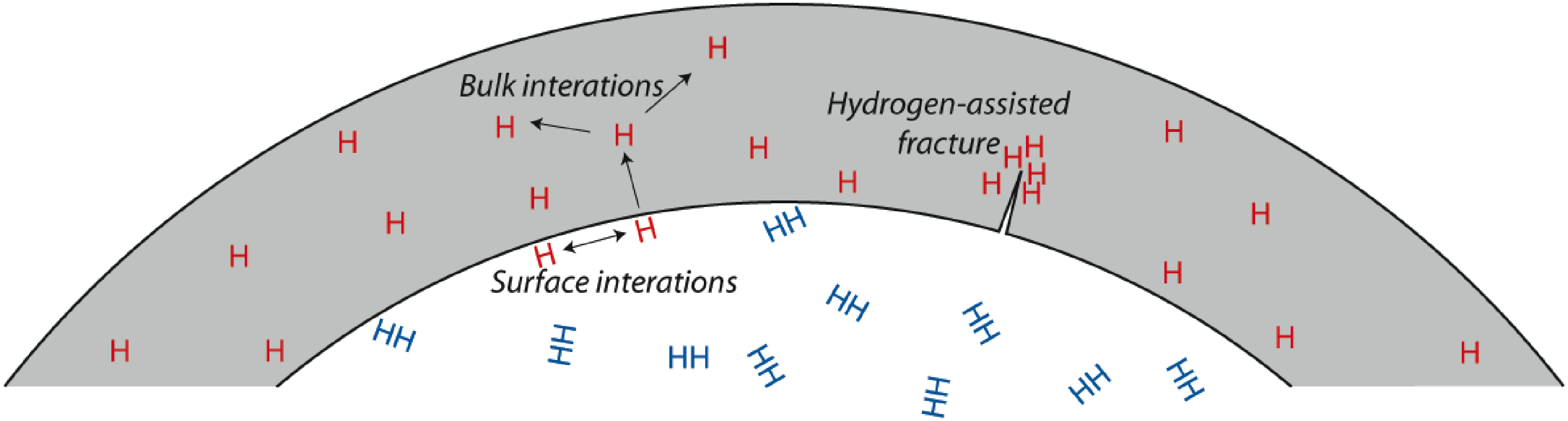
**Technology advancement by publishing standards, protocols and reviews.**


**Technology Standards to Facilitate Commercialization**

***Standard protocols for characterizing PEC performance are needed***

# Materials Compatibility – $H_2$ Embrittlement

1) ***Hydrogen-surface interactions:*** molecular adsorption and dissociation producing atomic hydrogen chemisorbed on the metal surface
2) ***Bulk metal-hydrogen interactions:*** dissolution of atomic hydrogen into the bulk and segregation to defects in the metal (i.e., transport and trapping)
3) ***Hydrogen-assisted cracking:*** interaction of hydrogen with defects changes local properties of the metal leading to embrittlement and possibly failure



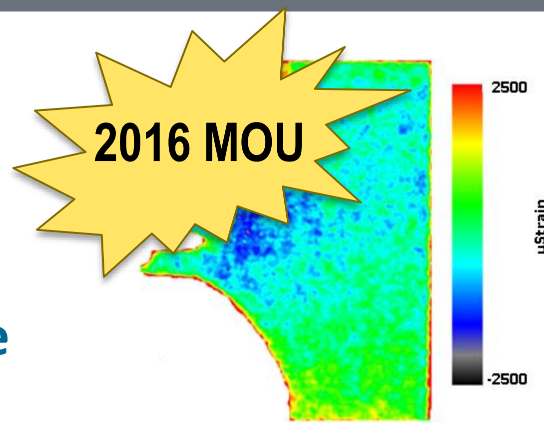

***DOE-NIST collaborations will result in up to 25% reduction in cost of pipelines!***

# $H_2$ Steels and Polymer RD&D Needs



**Metallics**

- Sandia/Oak Ridge: Fatigue testing, and development of novel microstructures.
- NIST: Neutron diffraction to characterize hydrogen interactions with steel, multi-specimen testing, and physics-based modeling.




**Andy Slifka, NIST**

*Predictive modeling of fatigue in hydrogen*

**Non-Metallics**

- PNNL/SNL/ORNL: World-first extensive R&D project on polymer compatibility in hydrogen.
- NIST: NCNR, soft materials manufacturing, strong industry collaborations.

nSoft

**Eric Lin, NIST**

*Soft materials consortium*

*Collaborative projects needed to coordinate NIST/DOE work on vessels and polymers.*

# Energy Materials Network

U.S. Department of Energy

LightMAT
Lightweight Materials CONSORTIUM

ElectroCat
Electrocatalysis Consortium

DuraMAT
Durable Module Materials Consortium

ChemCatBio
Chemical Catalysis for Bioenergy

CaloriCool™
CALORIC MATERIALS CONSORTIUM

HydroGEN
Advanced Water Splitting Materials

HyMARC
Hydrogen Materials Advanced Research Consortium

*1. World Class Materials Capability Network*

| | | | |
|---|---|---|---|
| Predictive Simulation Across Scales | Synthesis & Characterization | Rapid Screening | End Use Performance |
| Process Scalability | Process Control | Real-time Characterization | Reliability Validation |

Data Management & Informatics

*2. Clear Point of Engagement*
*3. Streamlined Access*
*4. Data & Tools Collaboration*

*Exploring compatibilities between NIST informatics framework and EMN needs*

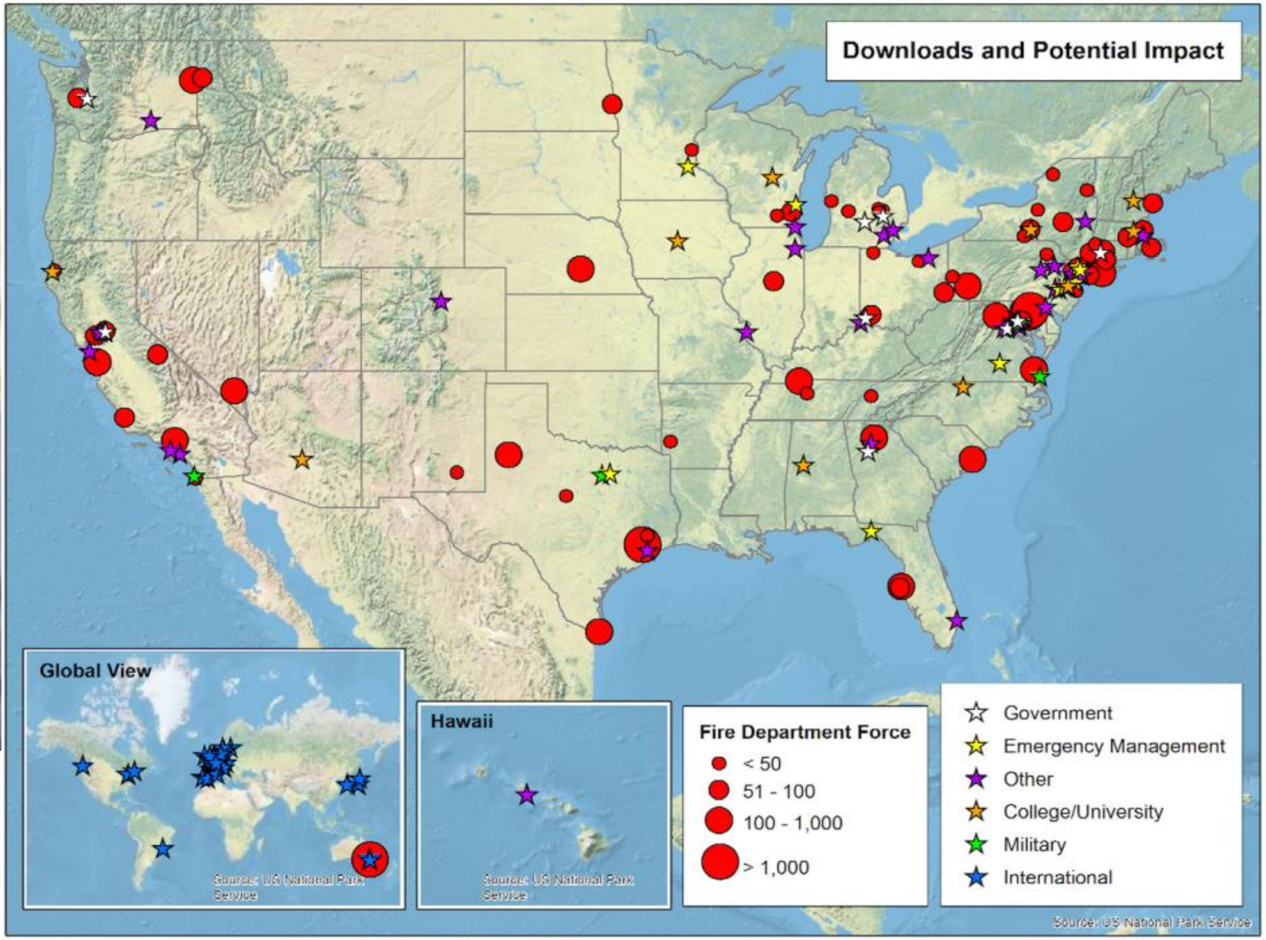
***New Material Innovations for Clean Energy 2X Faster and 2X Cheaper***

# Information sharing and outreach are critical

# $H_2$Tools: One-stop for $H_2$ safety knowledge

h2tools.org

- 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***

# Portfolio Approach: The Narrative

**Batteries <u>and</u> Fuel Cells**

**Electricity <u>and</u> Hydrogen**

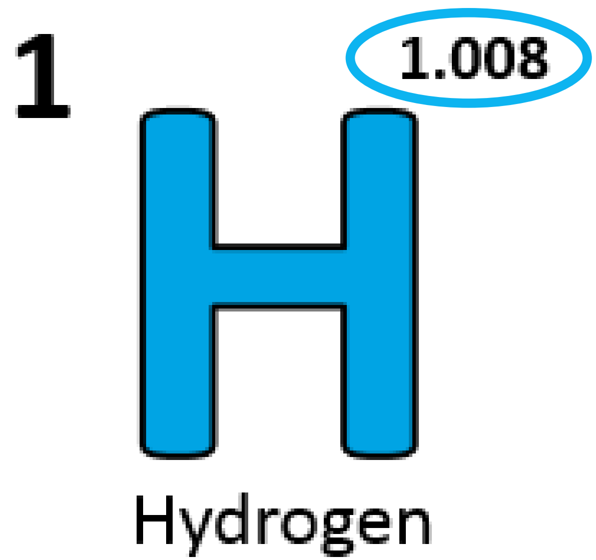
**… and Net Zero Carbon Fuels (Solar2Fuels, etc.)**

***Low carbon electrons to electrified powertrains***

# What can you do? Spread the Word



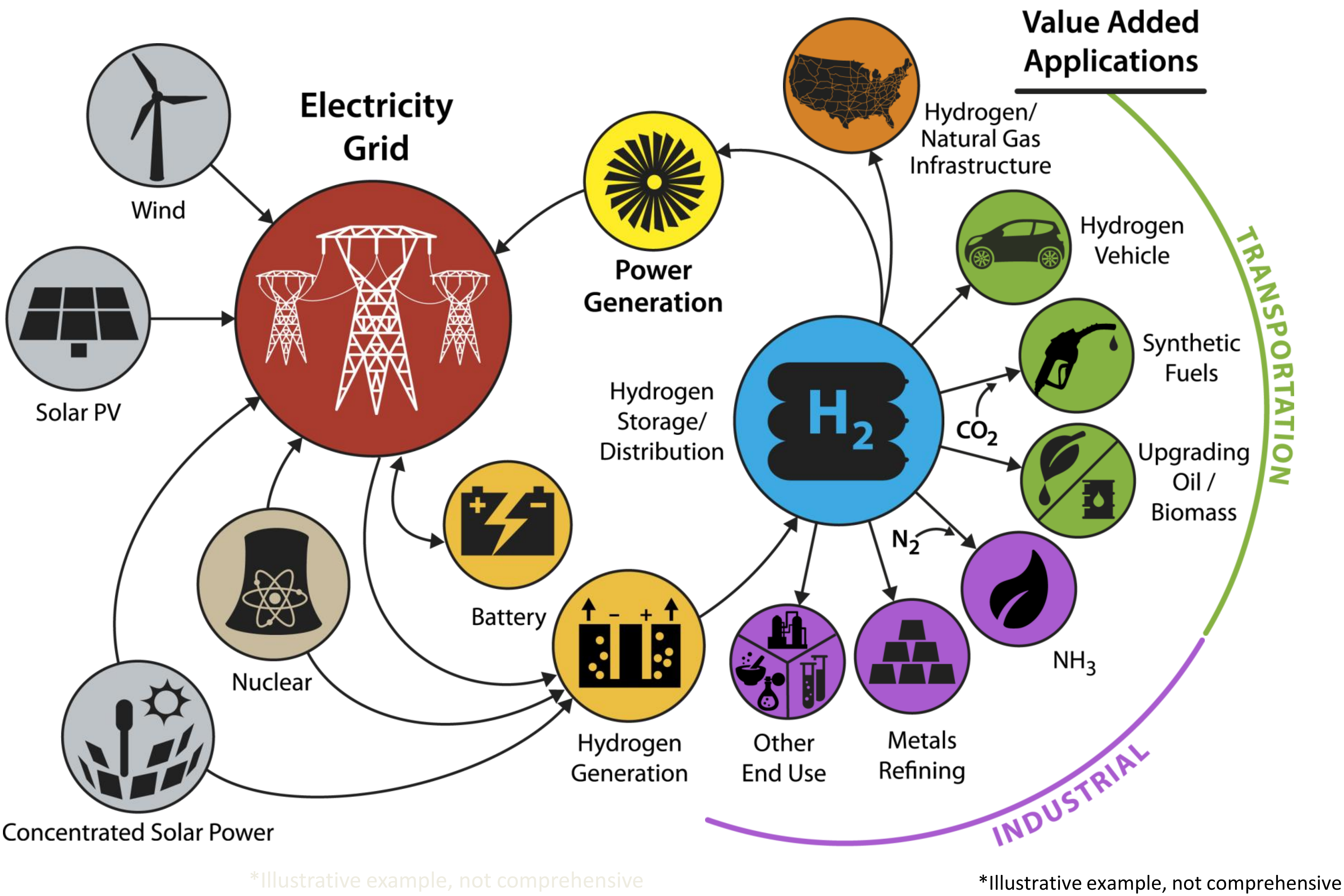
National Hydrogen & Fuel Cell Day | 10·08




**Celebrate National Hydrogen & Fuel Cell Day on 10/8** (Held on its very own atomic- weight- day)

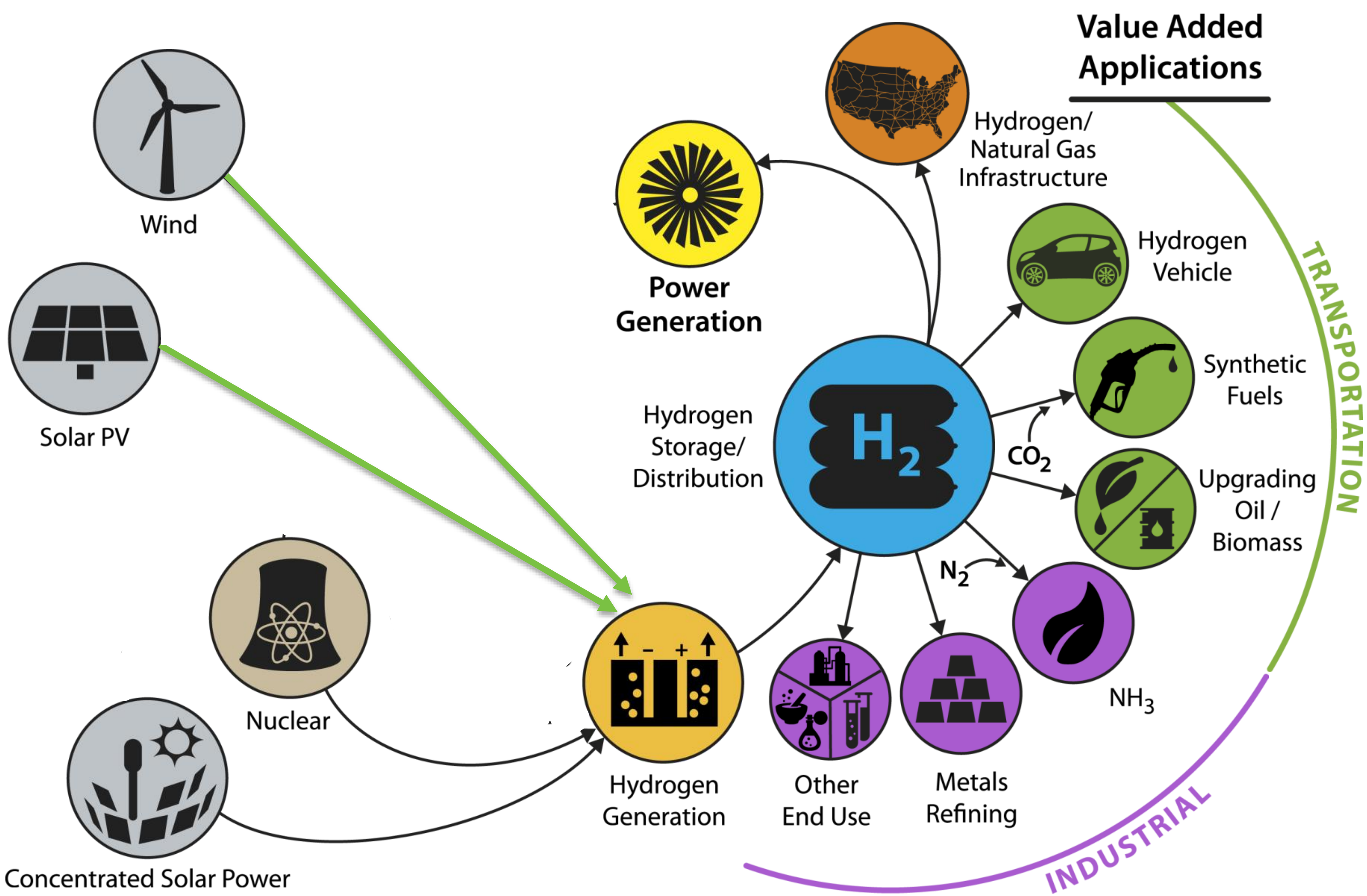
**Learn more: energy.gov/eere/fuelcells**

# $H_2$ at Scale Energy System Vision




*Illustrative example, not comprehensive
Source: NREL

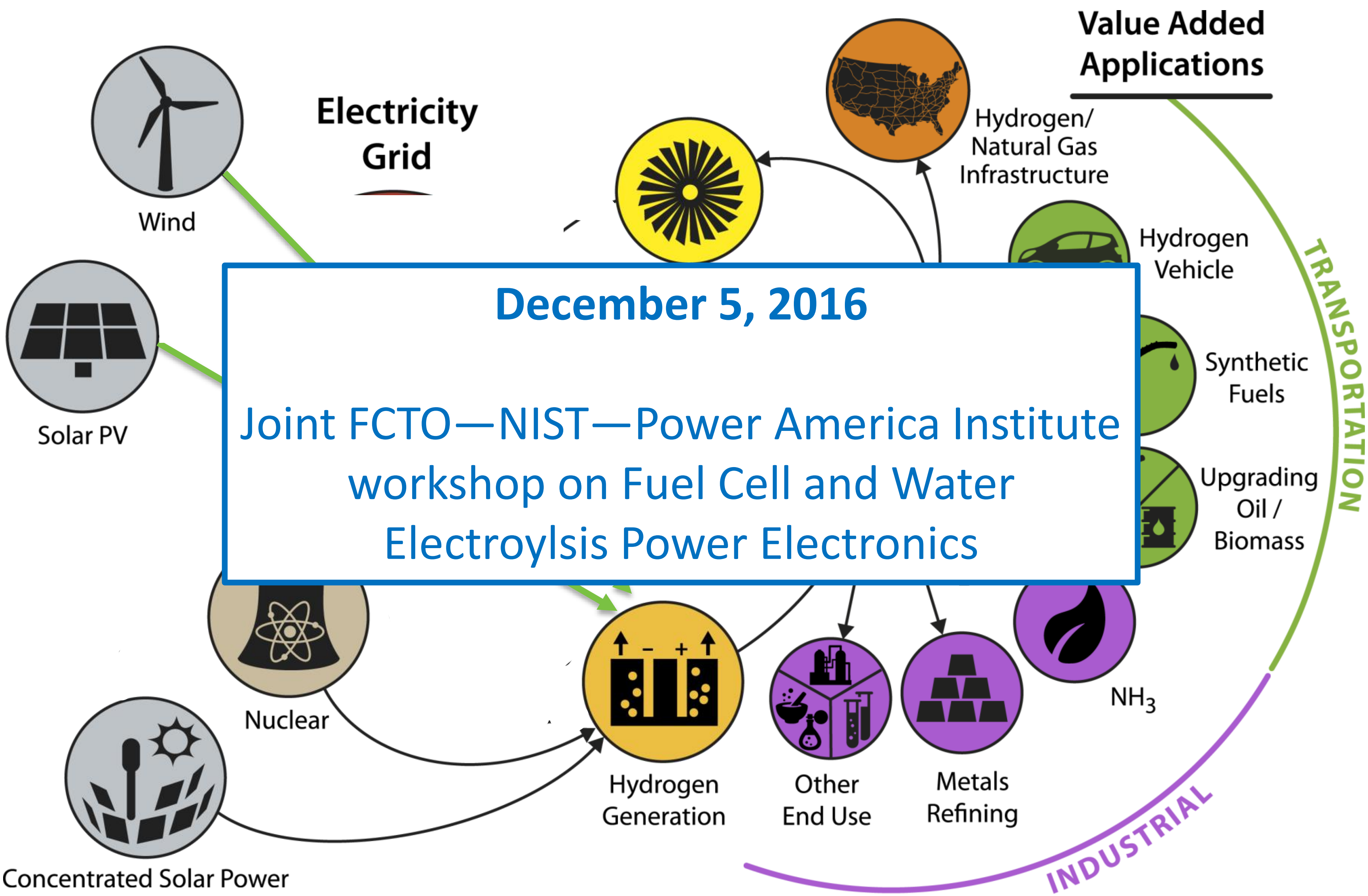
# Conceptual $H_2$ at Scale Energy System




*Illustrative example, not comprehensive

# Conceptual $H_2$ at Scale Energy System






**December 5, 2016**

Joint FCTO—NIST—Power America Institute workshop on Fuel Cell and Water Electroylsis Power Electronics

*Illustrative example, not comprehensive

Napoleon Hill

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

# Additional Information

**Dr. Sunita Satyapal**

**Director**

**Fuel Cell Technologies Office**

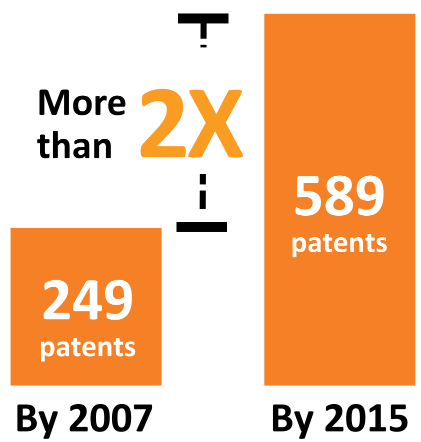
**Sunita.Satyapal@ee.doe.gov**

**hydrogenandfuelcells.energy.gov**

# Program Impact: $H_2$ and Fuel Cells

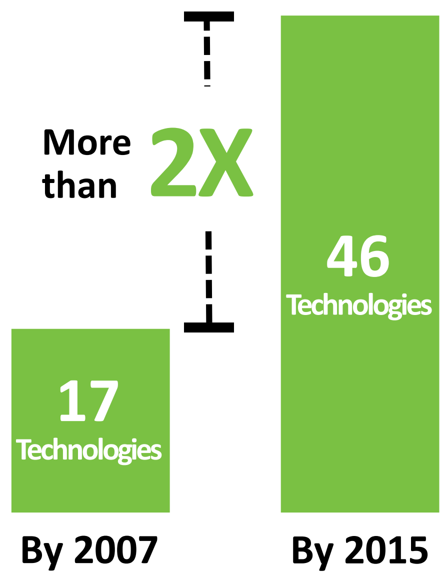
## Innovation

**Cumulative Number of Patents due to DOE funds**




## Commercialization

**Cumulative Number of Commercial Technologies Entering the Market**




## Economy and Environment

### U.S. Job Potential*

**360K to 675K jobs** in fuel cells and hydrogen

**Job gains** across **41 industries**

* 2008 DOE Employment Study currently being updated

### GHG Emission Reduction

$CO_2$

More than **50% - 90%** per vehicle

GHG: Greenhouse Gases

## Examples of Commercial Technologies

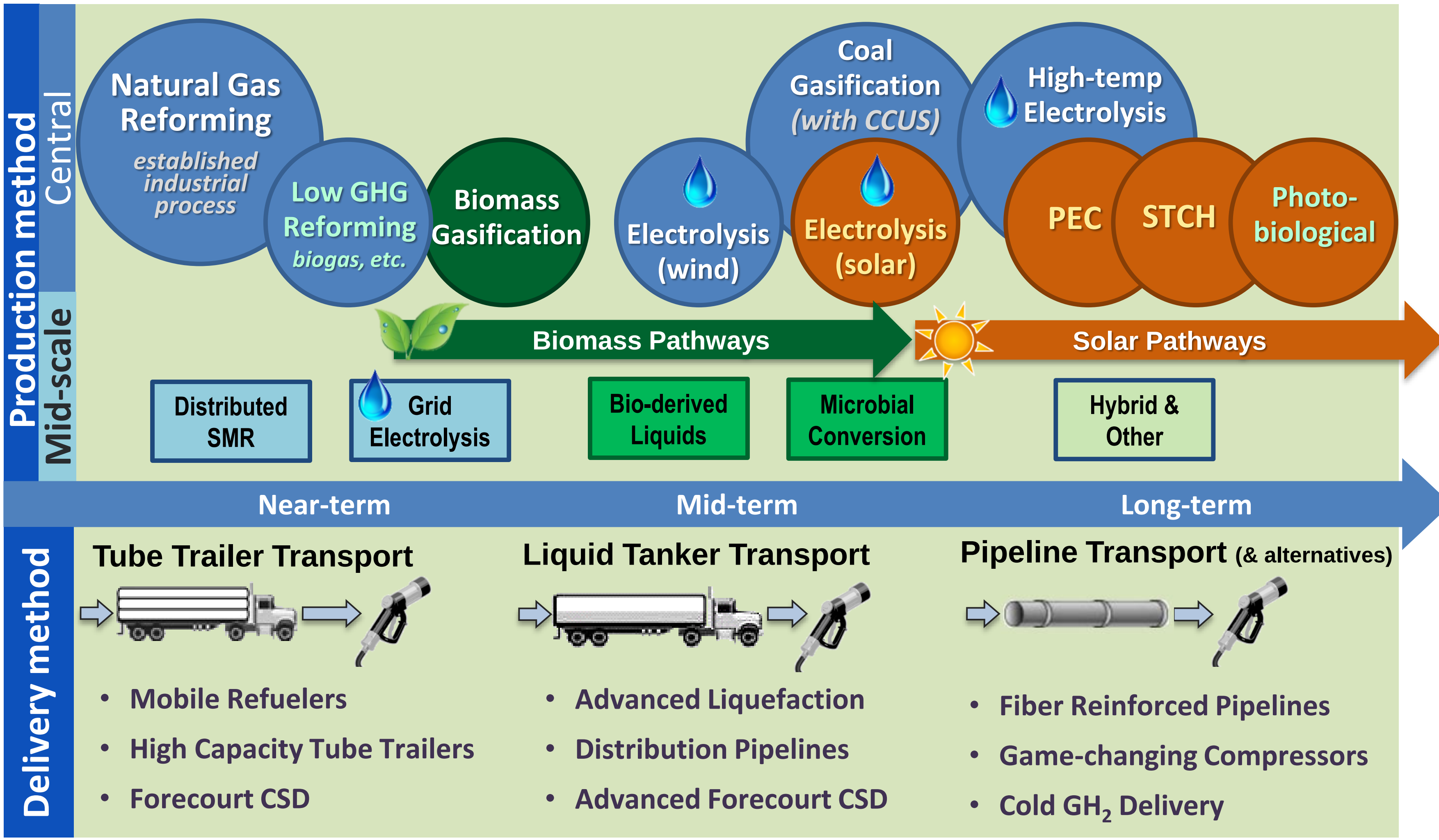
- Catalysts
- Tanks
- Fuel Cell System Components
- Electrolyzers

## Impact of DOE Investment on Industry

| Revenues | Additional Investment |
| --- | --- |
| More than 7X the DOE Investment | More than 5X the DOE Investment |

*for selected companies

# Hydrogen Production & Delivery Roadmap




***Goal: Affordable $H_2$ from diverse renewable domestic resources***