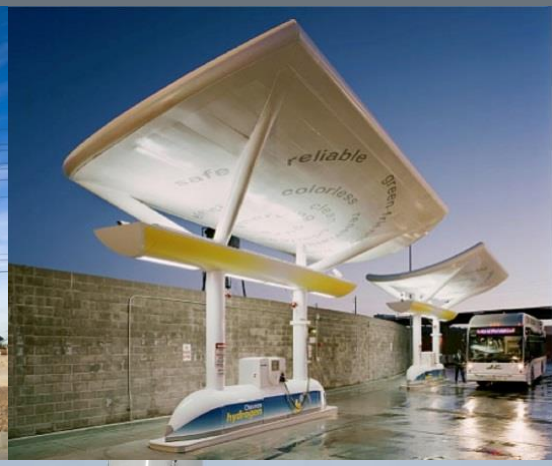
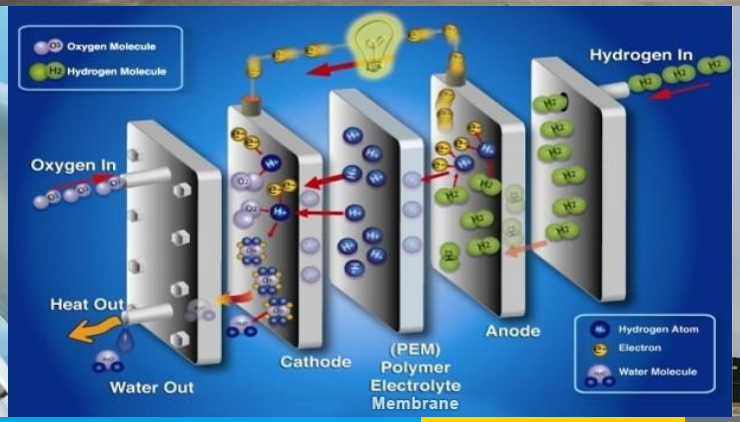
U.S. Department of Energy
Fuel Cell Technologies Office

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





Hydrogen and Fuel Cells Overview

DLA Worldwide Energy Conference
National Harbor, MD

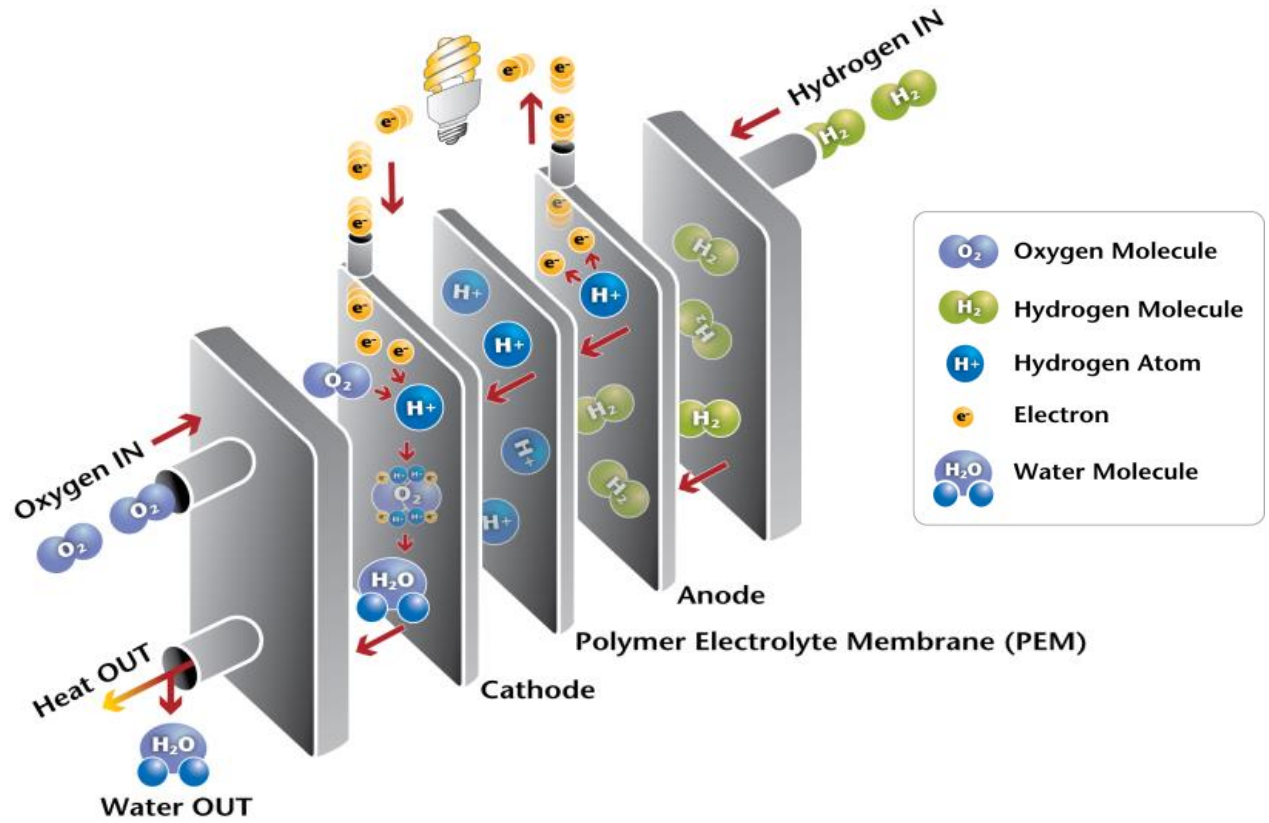
April 12, 2017

Dr. Sunita Satyapal

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

Fuel Cells Introduction

The Basics:



Highlights

Electricity produced **directly**

No combustion involved

No pollution from tailpipe

Water and Heat only byproducts

In Cars: >2X as efficient as today's gasoline engine

60 MPG
Fuel Cell

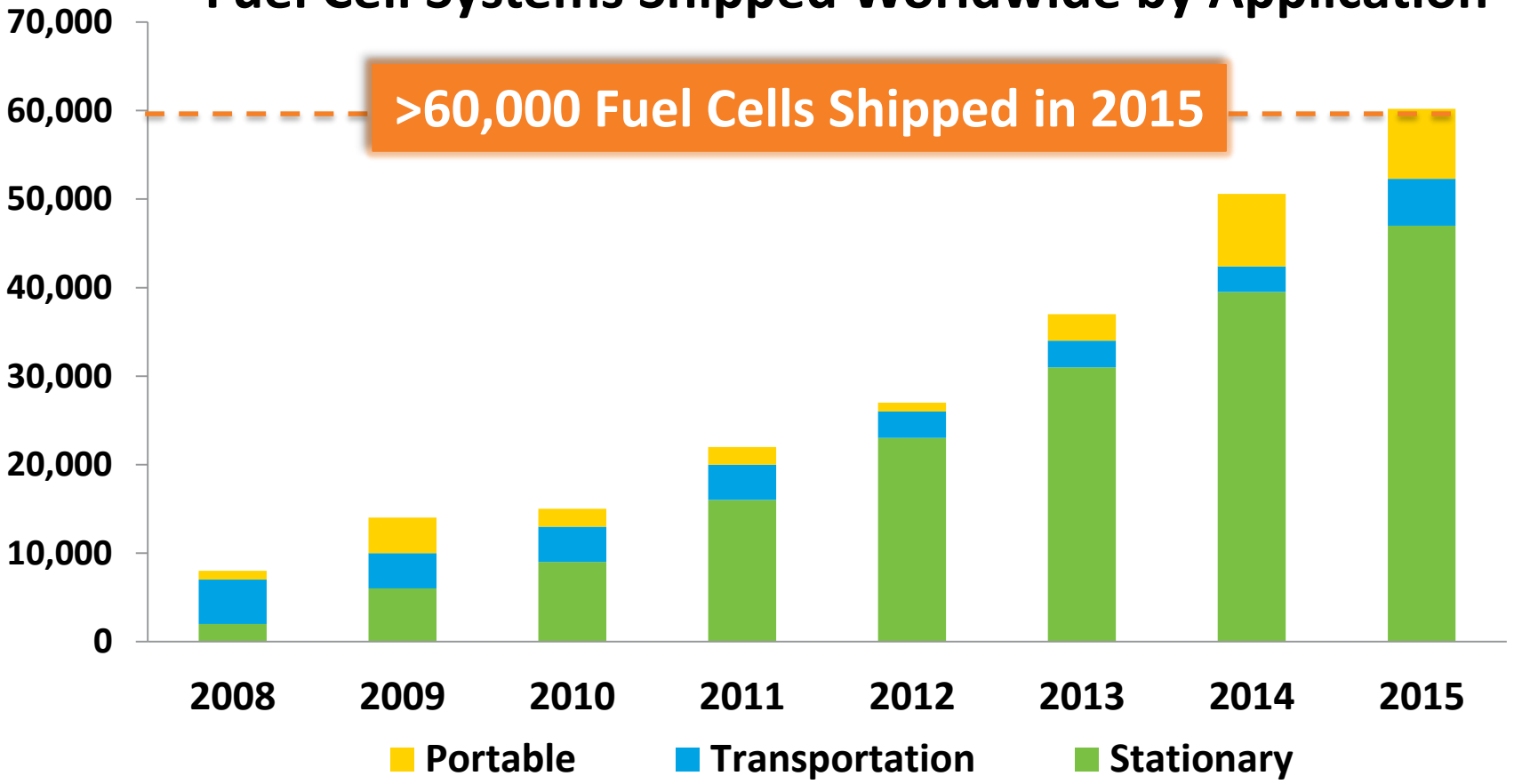
vs.

<30 MPG
Gasoline Engine

Similar to batteries producing electricity without combustion

Market Growth in Fuel Cell Sales

Fuel Cell Systems Shipped Worldwide by Application



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

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

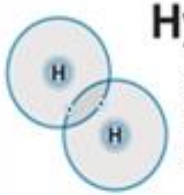
Consistent ~30% annual growth since 2010

Many Fuel Sources and Applications for Fuel Cells

DIVERSE ENERGY SOURCES & FUELS

- Natural Gas
- Propane
- Diesel
- Biomass
- Other
- Hydrocarbons
- Methane
- Methanol

Hydrogen



From renewables or low carbon resources like water splitting

CLEAN, EFFICIENT ENERGY CONVERSION

Fuel Cells

- Alkaline
- Direct Methanol
- Molten Carbonate
- Polymer Electrolyte Membrane (PEM)
- Phosphoric Acid
- Solid Oxide

DIVERSE APPLICATIONS

Stationary Power

Transportation

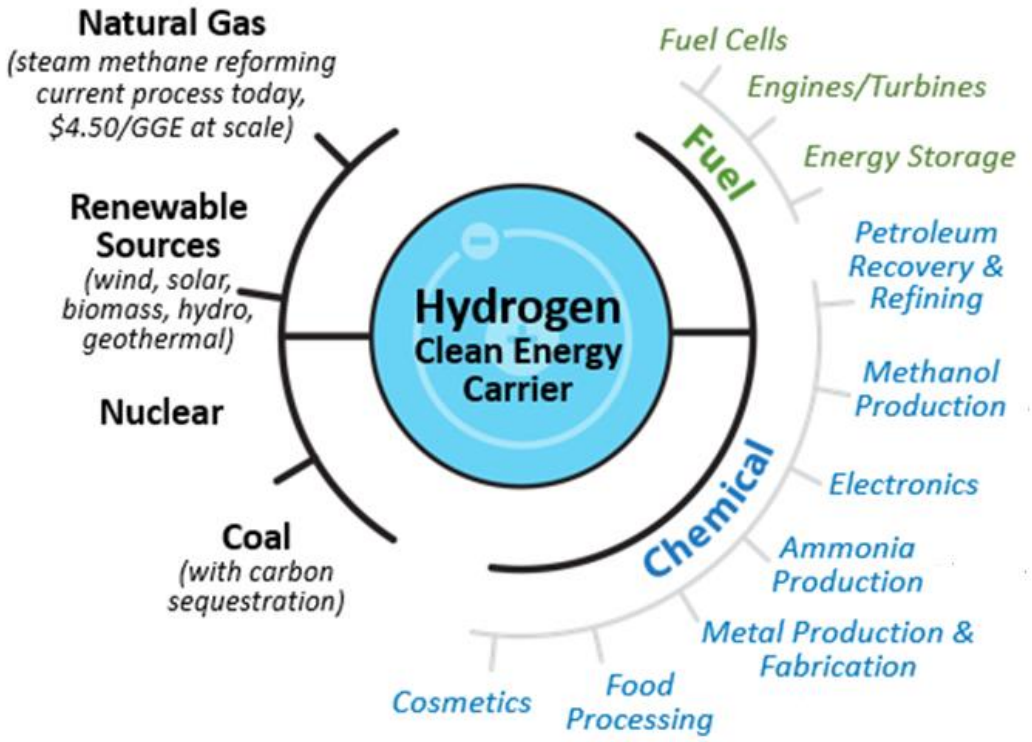
Portable Power

Fuel cells can be supported by different fuels and used in many applications

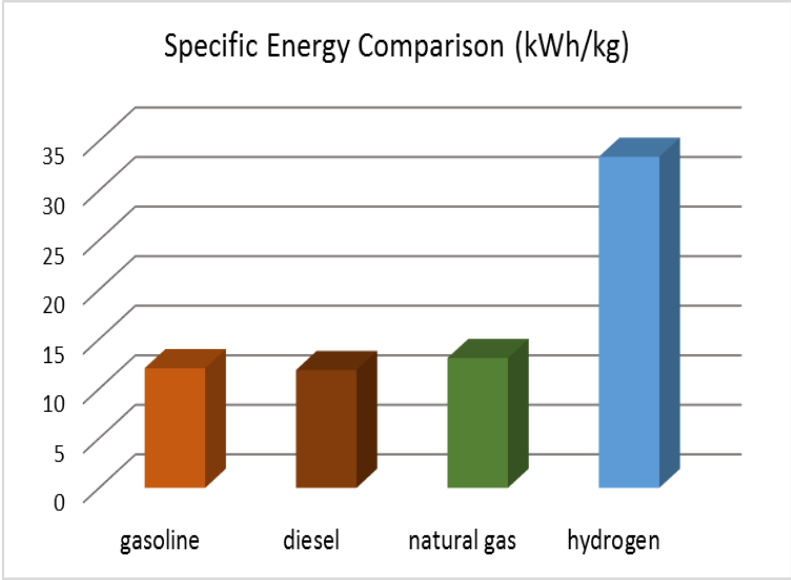
Advantages of hydrogen as an energy carrier

A multitude of sources can be used to produce H_2

Many applications rely on or could benefit from H_2



Very High Specific Energy

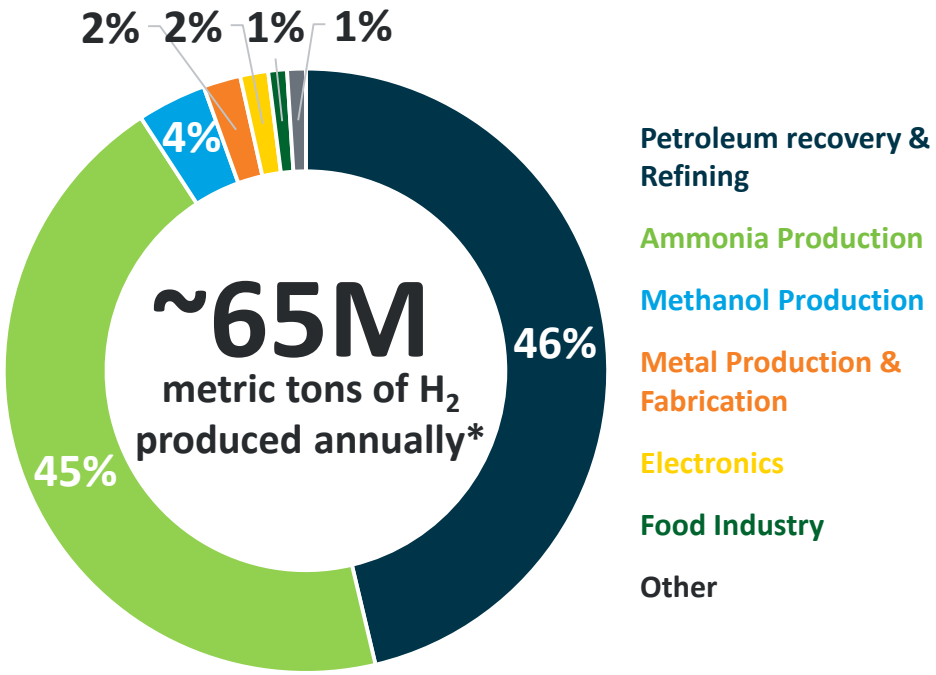


About *three times* more energy by mass than most other fuels!

Hydrogen is a clean , sustainable, versatile, and efficient energy carrier

H_2 Production & Infrastructure: Current Status

Global Annual H_2 Production/Demand



Steam methane reforming of natural gas (SMR): currently most cost-competitive process to produce H_2

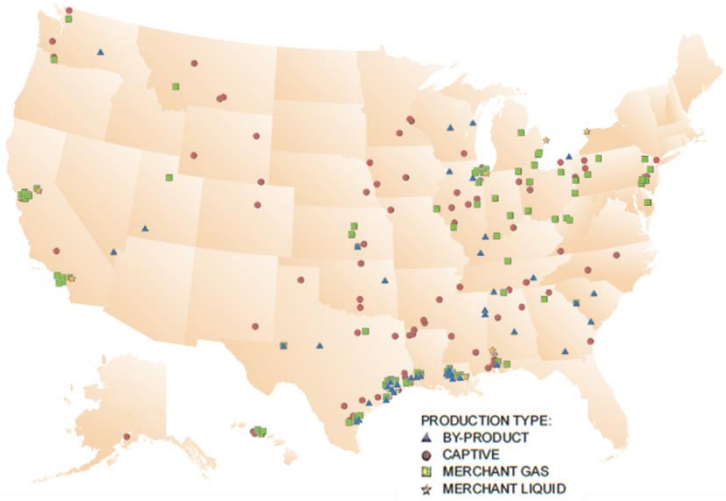
*CryoGas International. Hydrogen Production and Consumption in the US- the last 25 years (Sep 2015).

Current H_2 Infrastructure:

1,600 miles of H_2 pipeline

~50 H_2 Stations (~25 public)

Centralized H_2 production facilities in the U.S.



10 million metric tons of H_2 produced every year in the U.S.

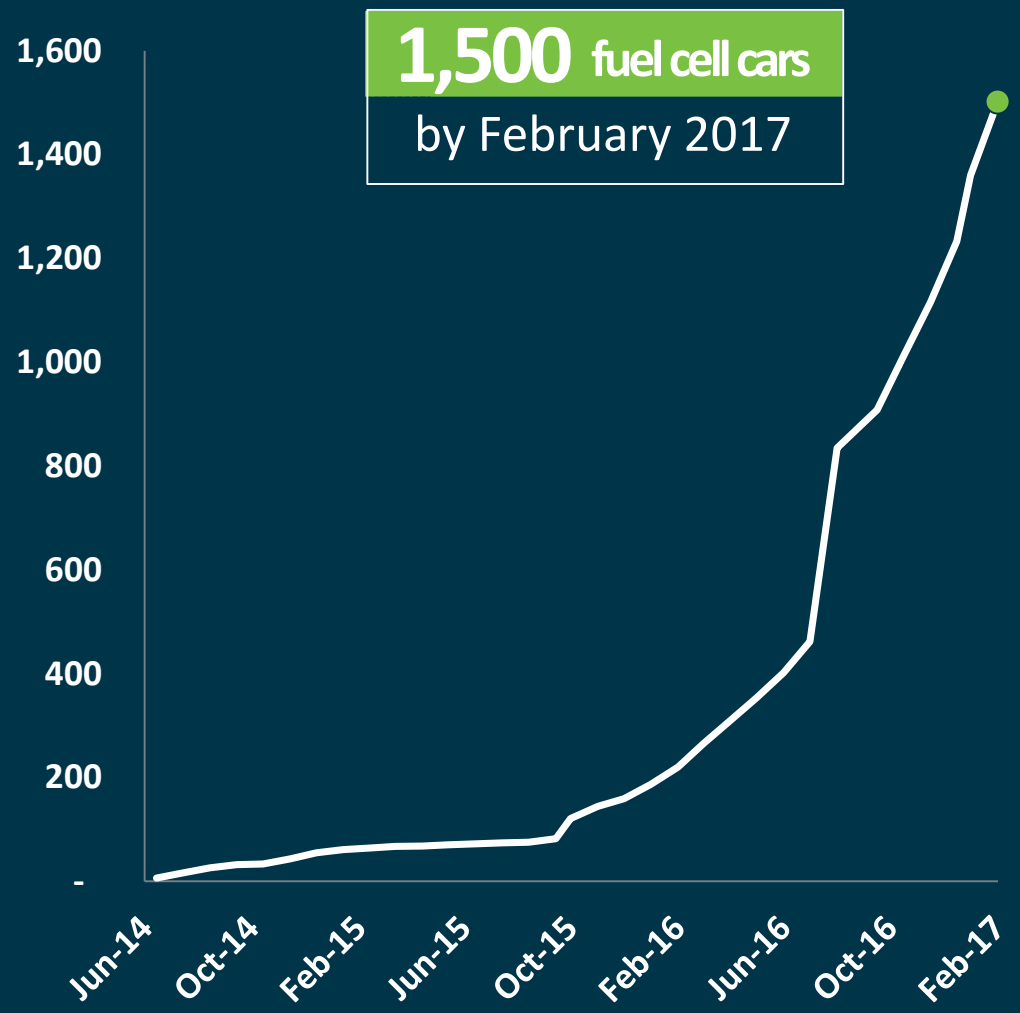
Near-Term Strategy

Cost- Competitive H_2 Fuel

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

Commercial Fuel Cell Cars are Here

Fuel Cell Cars Sold/Leased in the U.S



Note: Cumulative number of vehicles sold/leased. Source: hybridcars.com


Hyundai Tucson


Toyota Mirai


Honda Clarity

Power, Performance & Petroleum-Free

Fuel Cell Electric Vehicles can:

- ✓Refuel in minutes
- ✓Have a 366 driving range
- ✓Get more than 66 miles per gallon (equivalent)
- ✓High power (torque and acceleration)

And all with no gasoline on board and zero pollution from the tailpipe- only clean water vapor

And the cars don't need to be plugged in to charge

Fuel Cells: Recent Progress

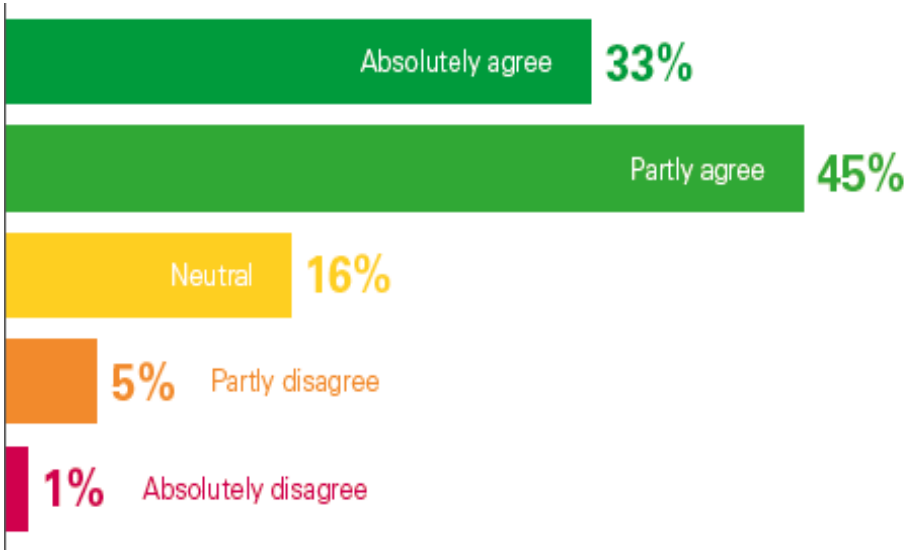
ZH2: TARDEC and GM collaboration
First of its kind

Executive Opinions Worldwide- Jan 2017

Fuel Cell Electric Vehicles (FCEVs)

78% of executives

Absolutely or partly agree that **FCEVs will be the real breakthrough for electric mobility**



Source: KPMG, Global Automotive Executive Survey 2017 (Jan. 2017)

Fuel Cells: Recent Progress

Fuel cell buses surpass 15 million passengers

Fuel Cells: Material Handling Applications

Over 10,000 fuel cell forklifts

~ 5 million H_2 refuelings

Fuel Cell Benefits - Forklifts

Value Proposition - Example

- **Commercial warehouses**
- Operation of **2-3 shifts per day**

Benefits

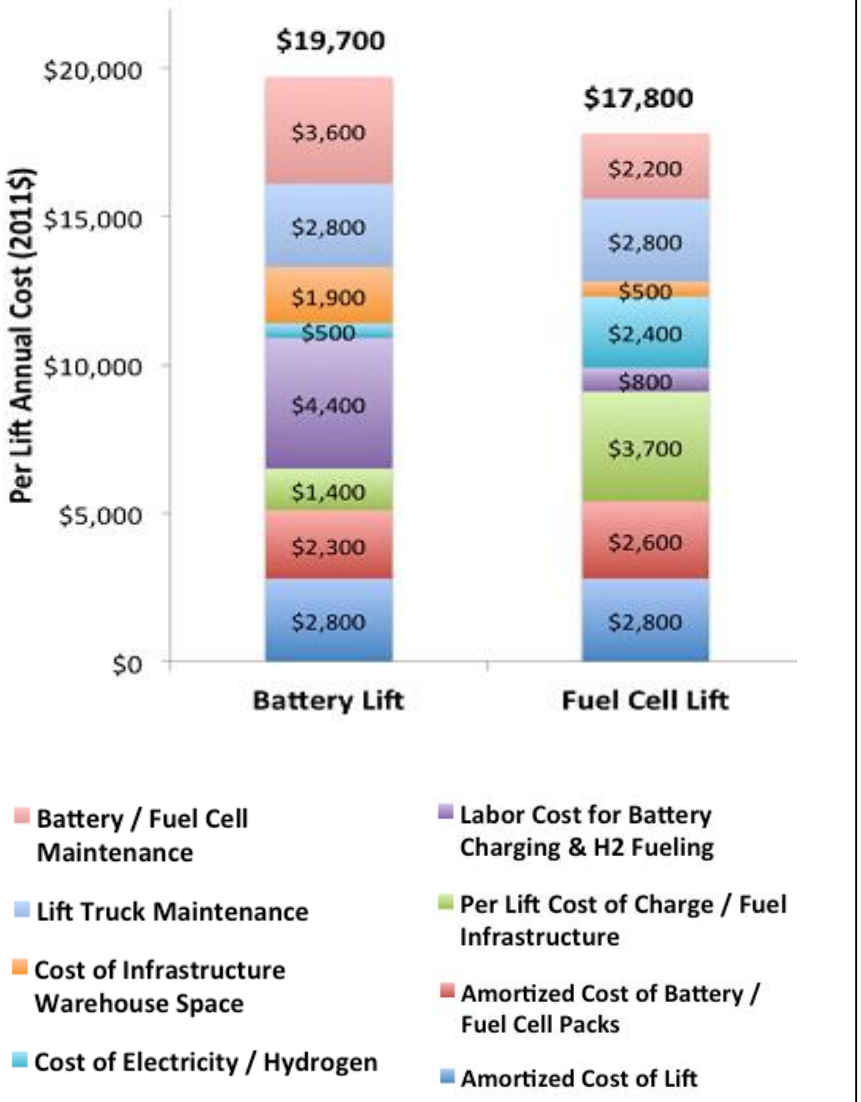
- **Lower total cost** of ownership than comparable battery forklifts
- **Can operate for more than 12 hrs**.
- **No performance degradation**
- **Fuels in minutes**
- **No emissions**

Performance Validation- Examples

- **Over 100 forklifts deployed in Defense Logistics Agency** distribution warehouses*
- **Over 700 forklifts** cost-shared through DOE (Recovery Act) led to more than 11,000 forklift orders from industry**

**Source: DOE Program Record #1602 (https://www.hydrogen.energy.gov/pdfs/16012_industry_deployed_fc_powered_lift_trucks.pdf)

Annualized Cost Example



MHE: Material Handling Equipment (MHE), Type I and II

*Source: NREL.. An Evaluation of the Total Cost of Ownership of Fuel Cell –Powered MHE (2013)

Fuel Cells: New Applications Demonstrated

World's first hydrogen fuel cell train in Germany

World's first 4-seater fuel cell plane takes off at German Airport

Fuel Cells: New Applications Demonstrated

1st fuel cell cargo tow trucks at U.S. airport

Aircraft and Ship Auxiliary Power

Reduced Acquisition & Life Cycle Costs

- Greater System Efficiencies
- Reduced Maintenance Costs
- Enables Spiral Development

Enhanced Survivability

- Reduced IR & Acoustic Signature
- Distributed Power Generation

Design Flexibility

- Modular Approach to Ship Power
- Multi Platform Applicable

- **Increased efficiency**
- **Reduced emissions**
- **On-board water generation**
- **Combined-heat-and-power opportunities**
- **Reduced generator size & weight**

Fuel Cells: New Applications Demonstrated

World's first fuel cell for maritime ports

Fuel Cells: New Applications Demonstrated

Fuel cell powered lights at the Super Bowl

Fuel Cells: Stationary Power

Fuel cells for back up and emergency power for hospitals, telecommunications towers, supermarkets and more!

Stationary Fuel Cells- Opportunities Emerging

Data centers require non-stop electrical power

Reliable power is vital at hospitals

Supermarkets- growing interest for reliable power

Fuel Cell Stationary Power in the U.S.

Installations

More than
235 MW
in at least
43 states

Top States

- **By unit size:** DE (30 MW) and CT (14.9 MW)
- **By number of units** CA (480 systems)

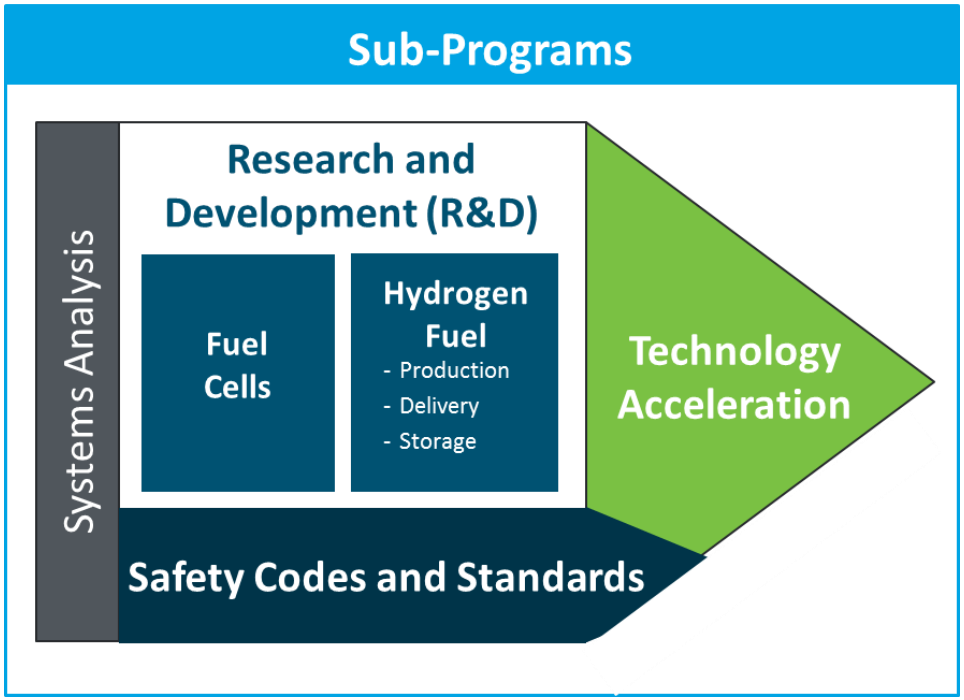
Source: DOE Fuel Cell Technologies Office. State of the States Report (2016)

New World Trade Center using fuel cells

DOE Hydrogen and Fuel Cells Program

Focus

Applied research, development and innovation of hydrogen and fuel cell technologies that enable **energy security, resiliency, and a strong domestic economy** in emerging markets.



2020 Targets by Application

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)	

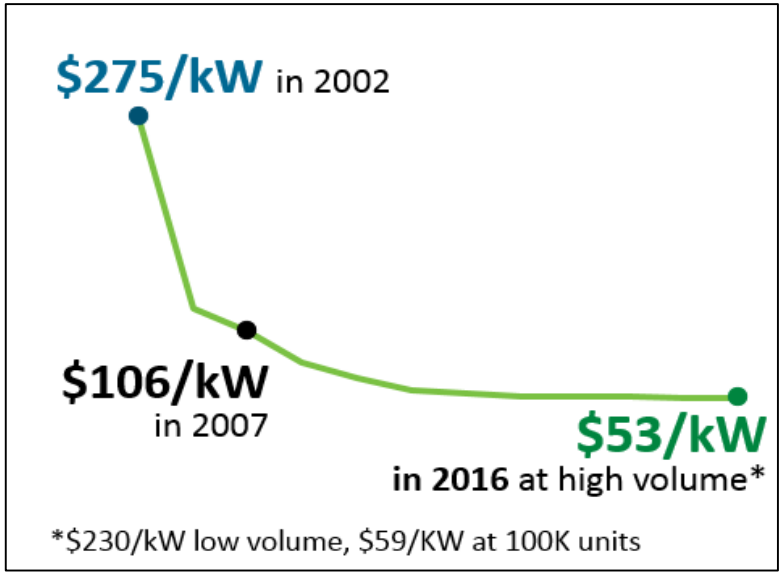
*For Natural Gas
**For Biogas

Strengthening U.S. energy security and the economy through R&D on hydrogen and fuel cells

The Role of the Government Enabling Progress

Technology Innovation

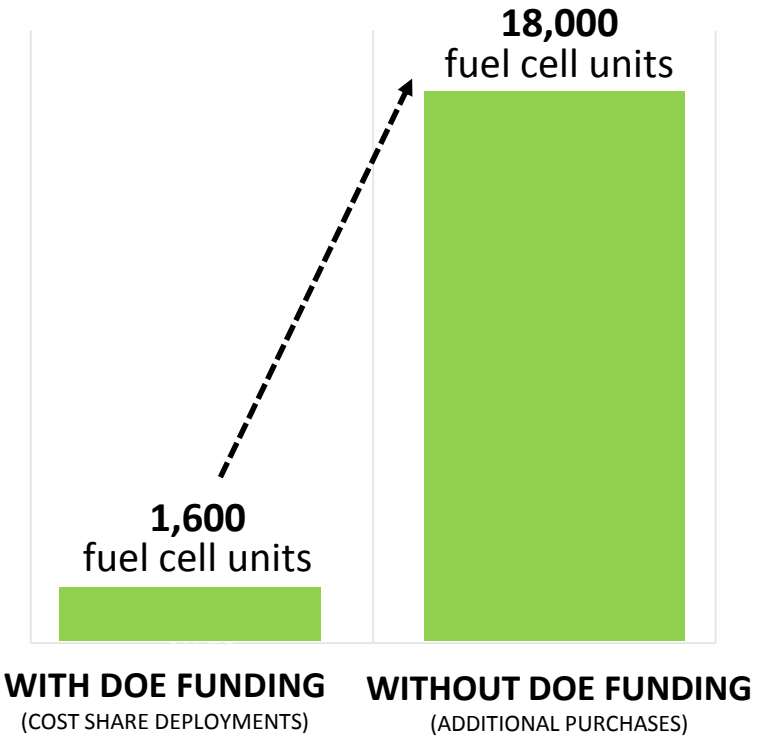
- **Cut fuel cell cost by 80%**



- **Quadrupled fuel cell durability**
- **Validated Research Advances**
  - More than **220 fuel cell cars**
  - Driving over **6 million miles**
  - **>360 mi** range, >**2X** efficiency of gasoline vehicles

Market Impact

- **Jumpstarted early markets by magnitude of more than 11X**



- **Catalyzed Additional Private Investment**

DOE Hydrogen and Fuel Cells Impact

Innovation

More than 580 patents H_2 and fuel cells enabled by FCTO funds

Market Impact

More than 30 Technologies available in today's market enabled by FCTO funds

FCTO: Fuel Cell Technologies Office

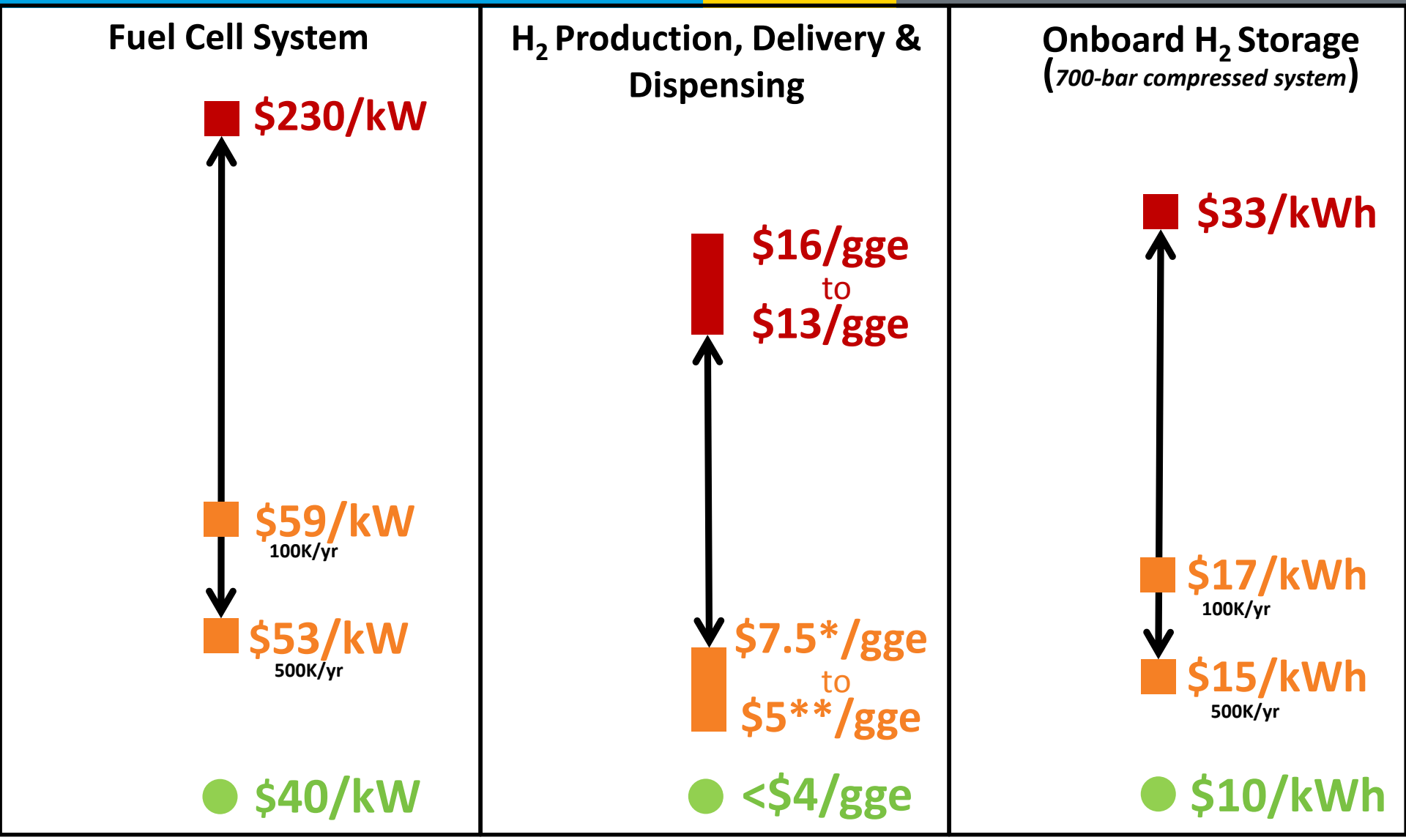
Job Potential*

360,000 to 675,000 Jobs in fuel cells and hydrogen

Job gains across 41 industries

*2008 DOE Employment Study currently being updated

DOE Cost Status and Targets



*Based on Electrolysis **Based on NG SMR

*For illustration purposes only, not drawn to scale

Techno-Economic Analysis Guides R&D Portfolio

Fuel Cells

Bipolar Plates
Membranes
BOP
MEA
Frames/Gaskets
GDLs

Focusing on…

Low and Non PGM Catalysts,

Alkaline Membranes

H_2 Station

Storage
Cooling
Dispensing
Other

Advanced Compression

Alternate Approaches

H_2 Storage

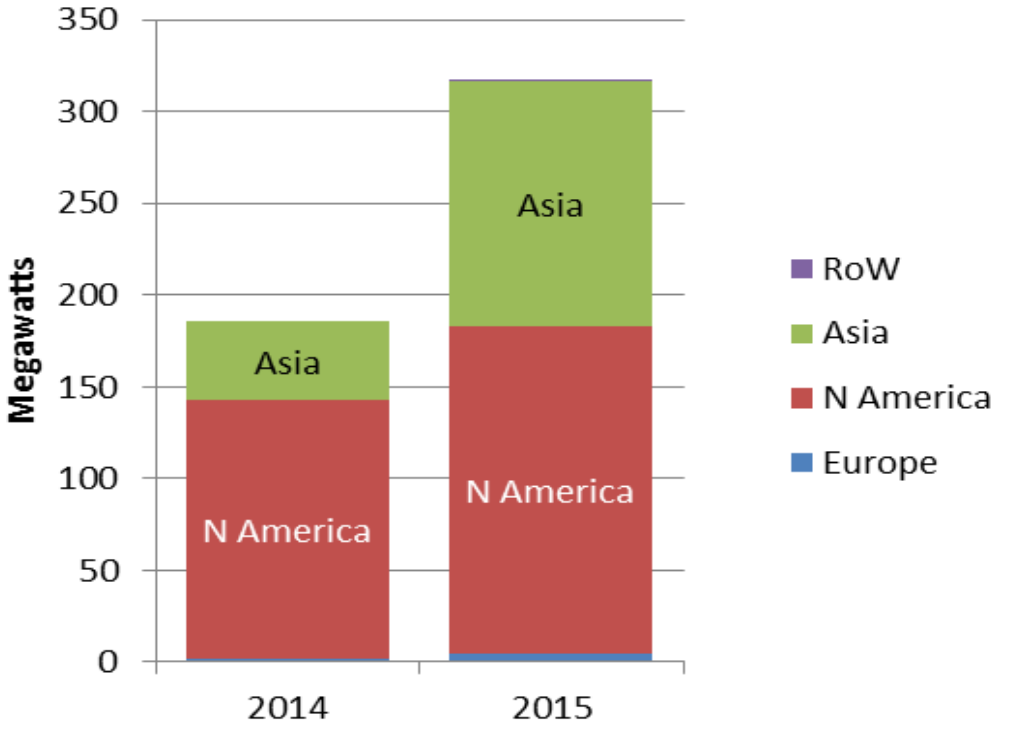
BOP/Assembly
Other processing
Resin

Low Cost Carbon Fiber (CF)

Long term Materials Approaches

Global Landscape: Recent Trends

Growth in Foreign Manufacturing in Just one Year



Preliminary

International RD&D Commitments in H_2 and Fuel Cells- Examples

Japan: $850M (total) including $350M to showcase H_2 and FCs at the 2020 Olympics

Source: 2014 HTAC Report

EU: $1.5B covered by FC 2 JU, including EU contribution of up to $800M

Source: European Union 2014 http://ec.europa.eu/research/press/jti/factsheet_fch2-web.pdf

Need to strengthen efforts and enable domestic leadership

Collaboration
is
Critical

Tools, Models and Databases Online

Resources

"Toolbox" online:

- HyRAM
- HDSAM
- H2FAST
- H2A
- JOBS and more

Available now at:
http://energy.gov/eere/fuelcells/hydrogen-analysis-toolbox

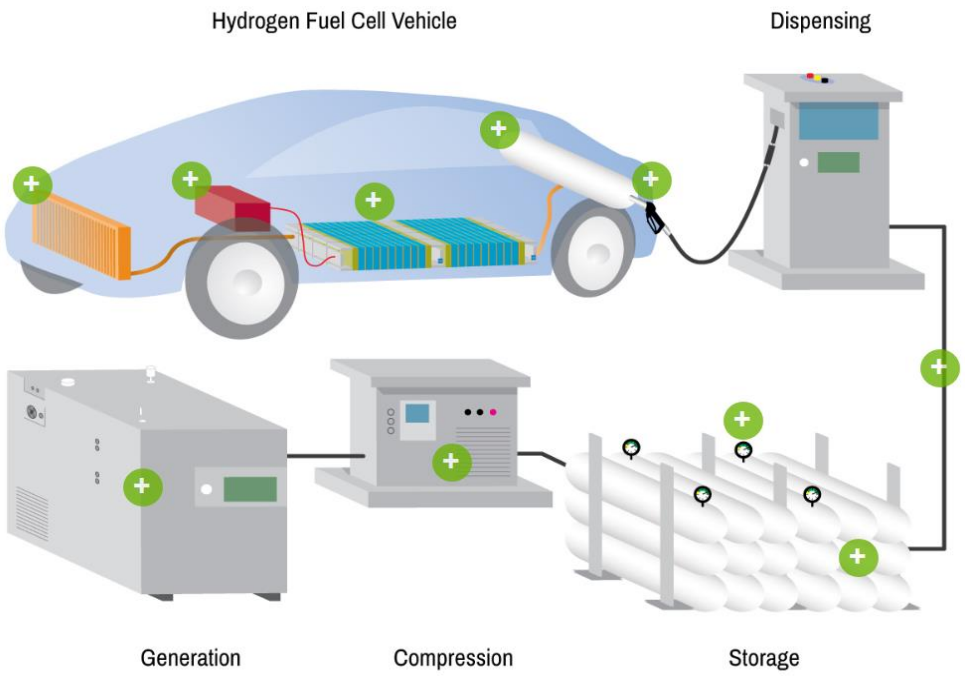
H2Tools.org

Hydrogen Safety Resources

HYDROGEN FUEL CELL NEXUS

The US Hydrogen and Fuel Cell Directory

COMPANY TYPES | PRODUCTS | US MAP | MATCHMAKER



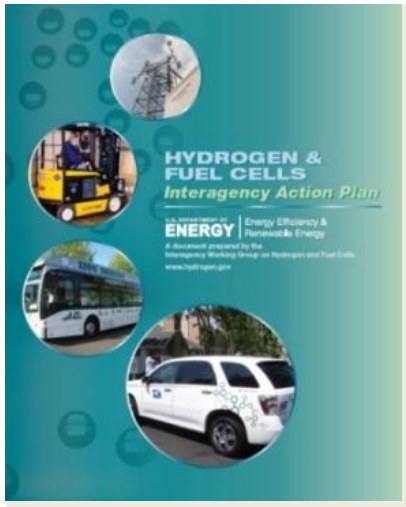
www.HFCnexus.com

Supplier engagement & collaboration & information readily and publicly accessible

DOE - DOD Coordination

Coordination

- Interagency Task Force
- Interagency Action Plan
- Interagency Working Group
- Workshops
- Hawaii Hydrogen Initiative (H2I)



Developed Interagency Action Plan* with 10 Federal Agencies (Interagency Working Group)

September 2010

*http://www.hydrogen.gov/pdfs/hydrogen_fuelcell_interagency_action_plan.pdf

DOD Partners

- Defense Logistics Agency
  - Nearly 100 FC lift trucks deployed
- Office of Naval Research
  - Grid management and utility scale renewable hydrogen generation for transportation fuel
- Army/Marine Corps
  - Soldier power: battery rechargers for forward operation bases
- Navy, Army, Air Force
  - Deploy fuel cell vehicles and infrastructure at bases in Hawaii.
- Army/AF (Joint Base Lewis McCord)
  - Biogas reforming and material handling equipment.

Interagency Collaborations: Technology

Completed: Validation of fuel cell forklifts

Collaboration: Dept. of Defense- The Defense Logistics Agency (DLA)

Ongoing: Analysis and Testing of Emergency urban power and fuel cell buses

Collaboration: NREL and Dept. of Transportation- Federal Transit Administration (FTA)

Potential: Light duty vehicles for military applications

Potential collaboration: Army

Potential: Unmanned Underwater Vehicles (UUV)

Potential collaboration: Navy

Potential: Unmanned Aviation Vehicles (UAV)

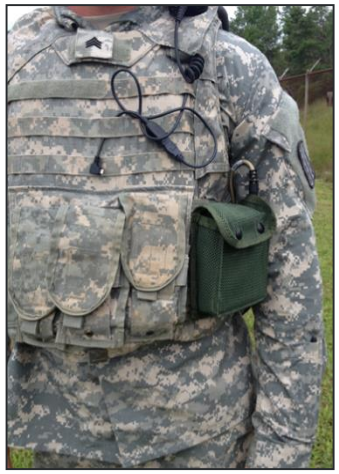
Potential Collaboration: DOT - Pipeline Management

DOD-DOE R&D Collaboration: Portable Power

- **Application:** Wearable Soldier Power
- **R&D Focus** Low cost alane-based hydrogen storage
- **Broader impact:** portable power, back up power, UAVs and vehicles
- **Collaboration:** Ongoing US Army-DOD FCTO Hydrogen Production and Storage R&D Initiative

Actual Image of WPS20 System

System cartridge containing alane



Soldier portable power weight: fuel cells vs. battery

- PRC 154A Rifleman Radio Batteries
- 12 Batteries per Soldier for 72hrs
- **14.4 lbs**

- Conformal Wearable Battery
- 3 Batteries per Soldier for 72hrs
- 7.86lbs

- Wearable Power System
- 1 System with 6 fuel cartridges per Soldier for 72hrs
- **3.52 lbs**

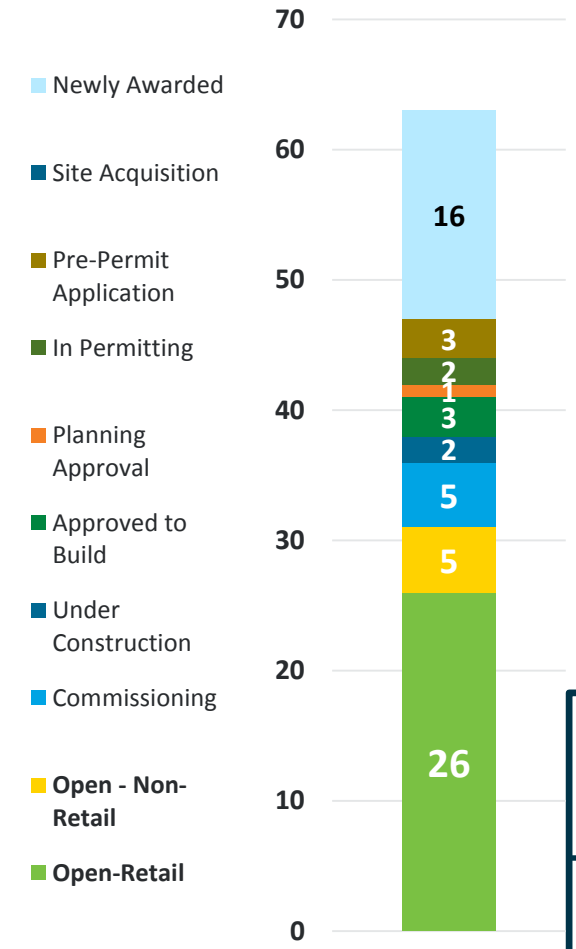
Over **70% weight savings** with fuel cells

Source: AEWE 2016

Enabling low cost alane-based hydrogen storage for military portable power devices

Hydrogen Infrastructure Activities- Status

California



As of November 30 (Data from CaFCP June 2016 status report- http://cafcp.org/sites/default/files/h2_station_list.pdf

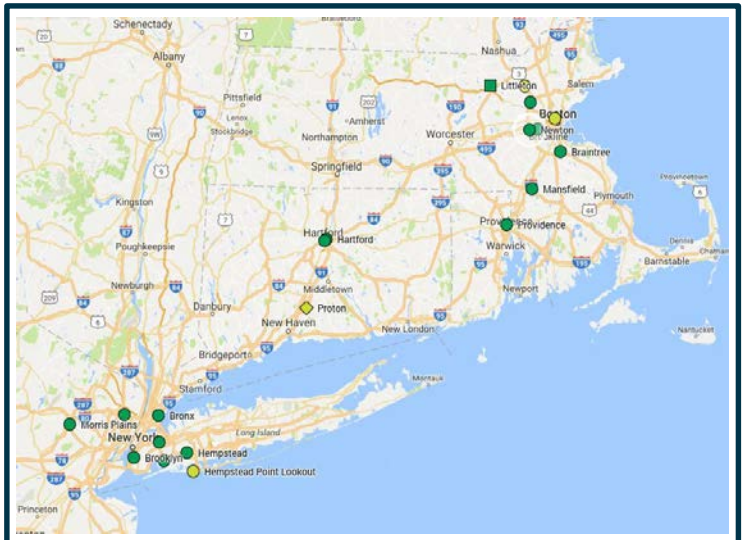
H_2 Stations

26 retail

Approx. 60 underway

Funding for: 100

Northeast



~ 12 to 25 Retail H_2 Stations (planned)

California
Connecticut
Massachusetts
Maryland
New York
Oregon
Rhode Island
Vermont

To find a H_2 station near you: **afdc.energy.gov/locator/stations/**

Complementing Retail Stations: H_2 Refuel H-Prize

H2refuel
U.S. Department of Energy

$1M Competition: On-site H_2 fueling

Winner Announced:
More at hydrogenprize.org

simple.fuel.™

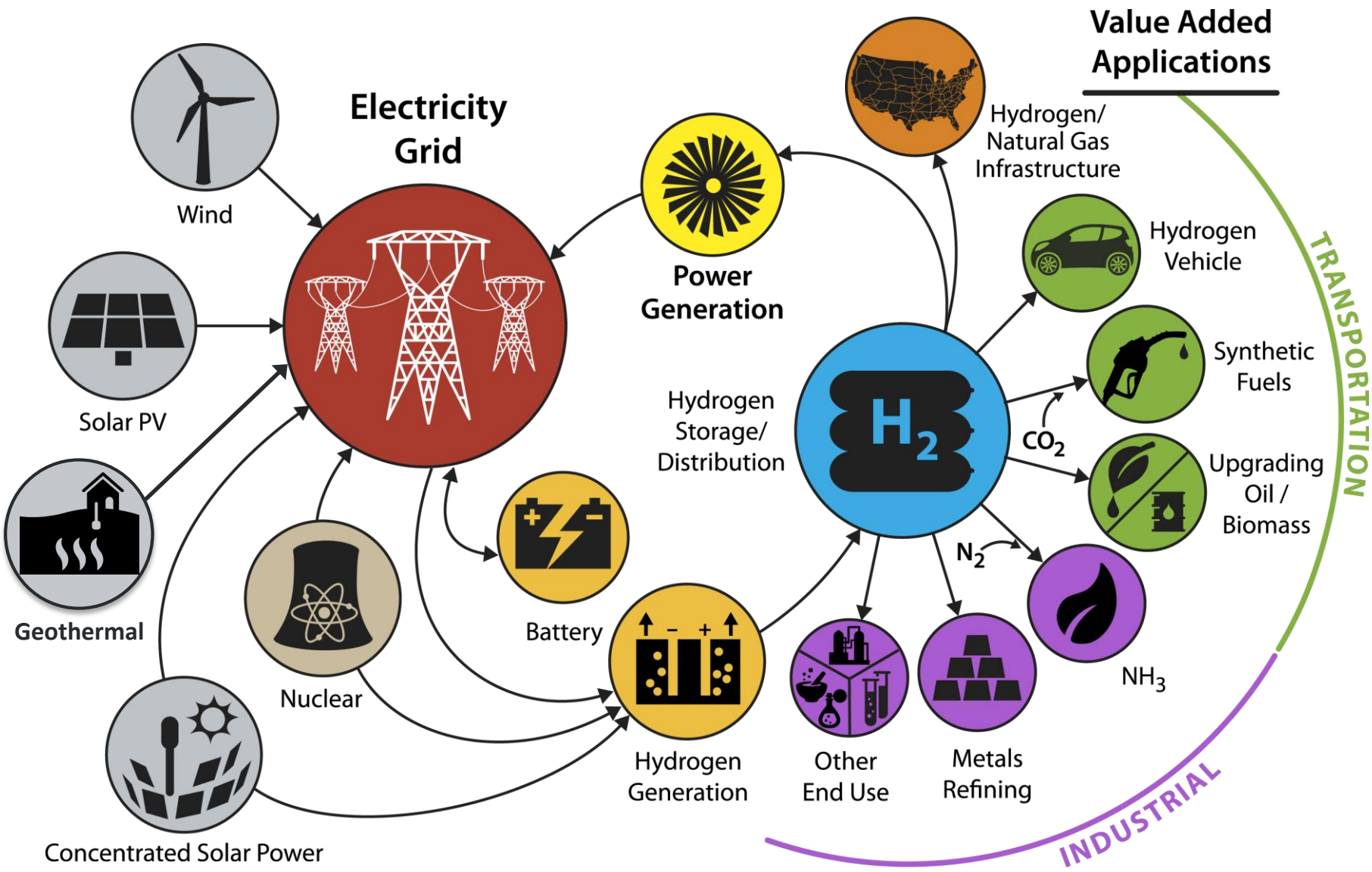
Competition Timeline

- Launched- Oct. 2014
- Testing phase completed- Dec. 2016
- Winner announced- Jan. 2017

System Details

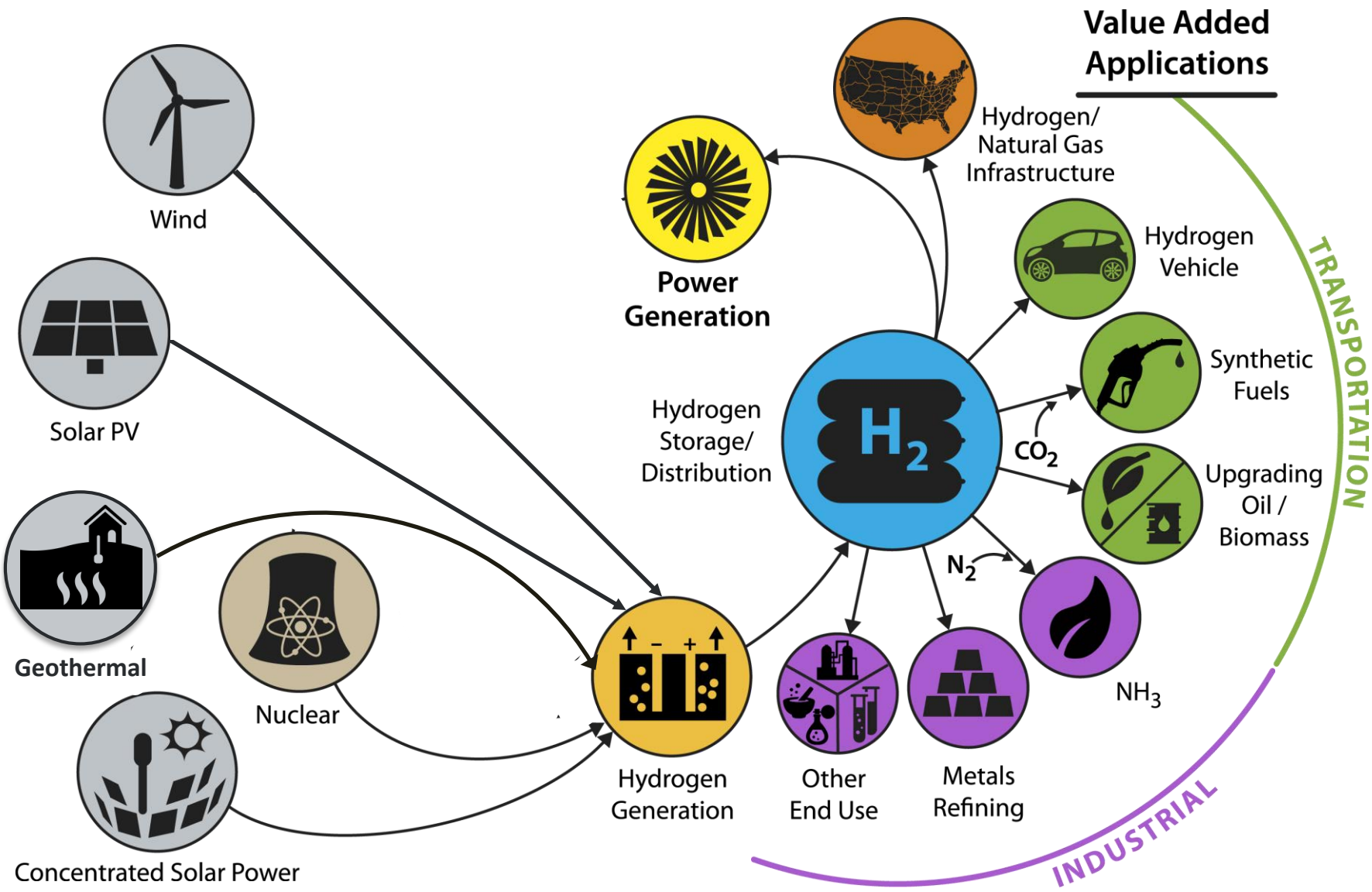
- Hydrogen produced via **electrolysis**
- **Up to 10 kg H_2 per day**
- **700 bar** refueling

Conceptual H_2 at Scale Energy System



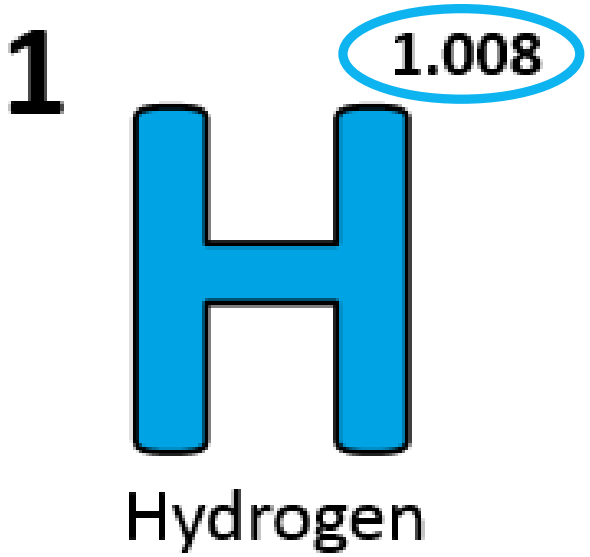
*Illustrative example, not comprehensive
Source: NREL

Conceptual H_2 at Scale Energy System



Increasing outreach and visibility…

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

Strategic Direction

- **Early R&D innovation and accelerate Tech to Market**
  - **Key Focus: H2@Scale, technology advancement**
  - **Safety, fuel cells & hydrogen R&D, and enable infrastructure**
- **Strengthen supply chain- infrastructure components**
- **Leverage activities to maximize impact**
  - **U.S. and global partnerships, H_2USA, States**
  - **Strengthen collaboration on safety and information sharing**

Save the date: Annual Merit Review (AMR)

June 5-9, 2017- Washington DC

2018 Summer: AMR + Industry Expo!

Thank You

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Fuel Cell Technologies Office, DOE Energy Efficiency and Renewable Energy

hydrogenandfuelcells.energy.gov