U.S. DEPARTMENT OF
ENERGY
Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

U.S. Department of Energy Hydrogen and Fuel Cell Technologies Office Opening Remarks

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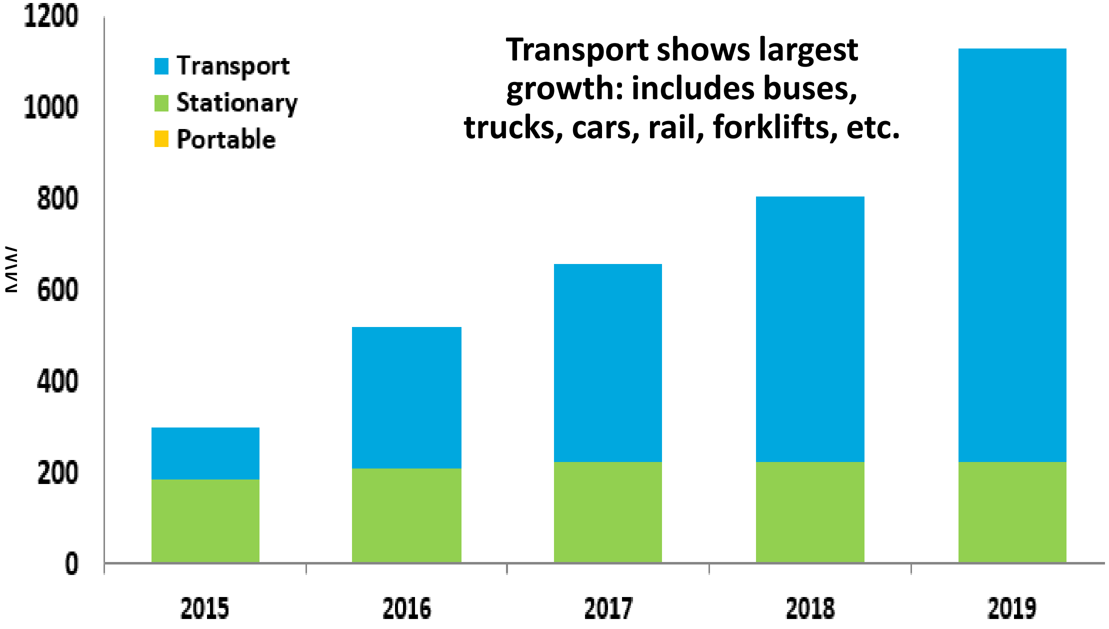
H2@Airports Workshop

November 4, 2020

Hydrogen and Fuel Cell Technology Growth Worldwide

Global fuel fell shipments surpass 1 GW



Source: E4tech for DOE analysis project

25-fold increase in electrolyzers deployed in the last decade

<1MW in 2010 to >25 MW by the end of 2019

Global FCEVs doubled to >25,200 >12.3K sold in 2019 vs. 5.8K in 2018

470 H_2 fueling stations worldwide

> 20% increase from 2018

Source: IEA (2020), Hydrogen, IEA, Paris, https://www.iea.org/reports/hydrogen

Snapshot of Hydrogen and Fuel Cells Applications in the U.S.

Examples of Applications

>500MW
Stationary Power

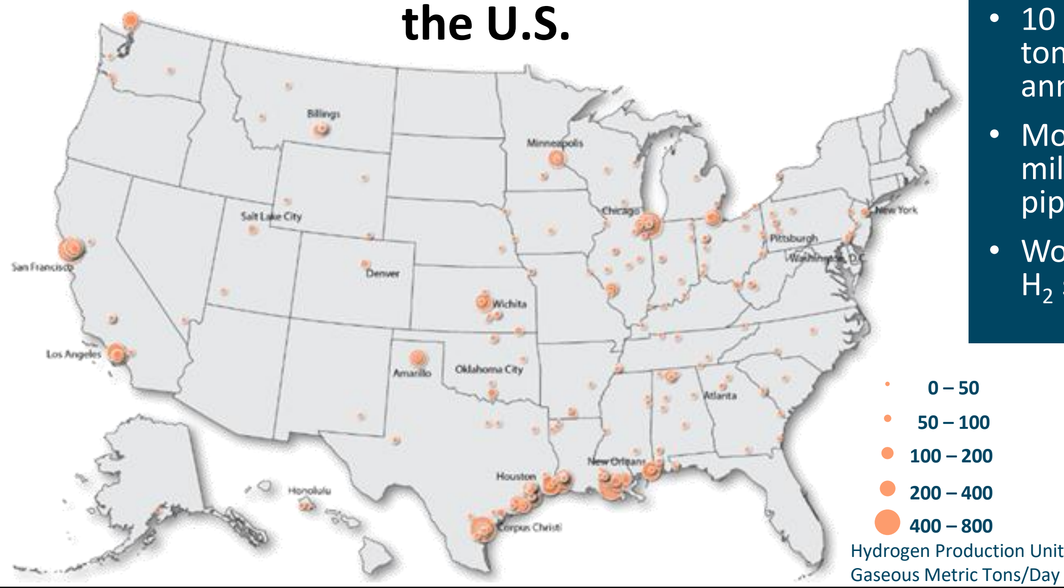
>35,000
Forklifts

>60
Fuel Cell Buses

>45
H_2 Retail Stations

>8,800
Fuel Cell Cars

Hydrogen Production Across the U.S.



- 10 million metric tons produced annually
- More than 1,600 miles of H_2 pipeline
- World's largest H_2 storage cavern

Hydrogen Stations: Examples of Plans Across States

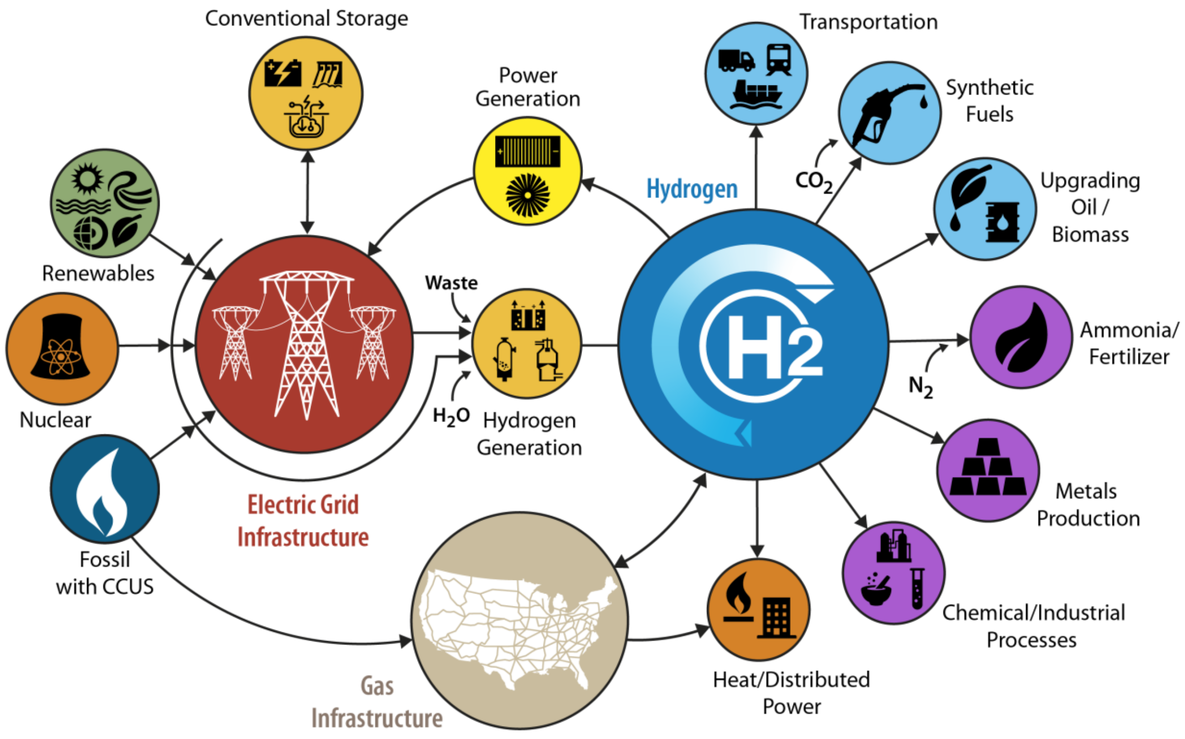
California
200 Stations Planned
CAFCP Goal

Northeast
12 – 20
Stations Planned

HI, OH, SC, NY, CT, MA, CO, UT, TX, MI
And Others

Hydrogen is one part of a Comprehensive Energy Portfolio

H2@Scale: Enabling affordable, reliable, clean, and secure energy across sectors



Source: U.S. DOE Hydrogen and Fuel Cell Technologies Office, https://www.energy.gov/eere/fuelcells/h2scale

- **Hydrogen can address specific applications across sectors that are hard to decarbonize**
- **Today: 10MMT H_2 in the U.S.**
- **Economic Potential: 2 to 4x more**

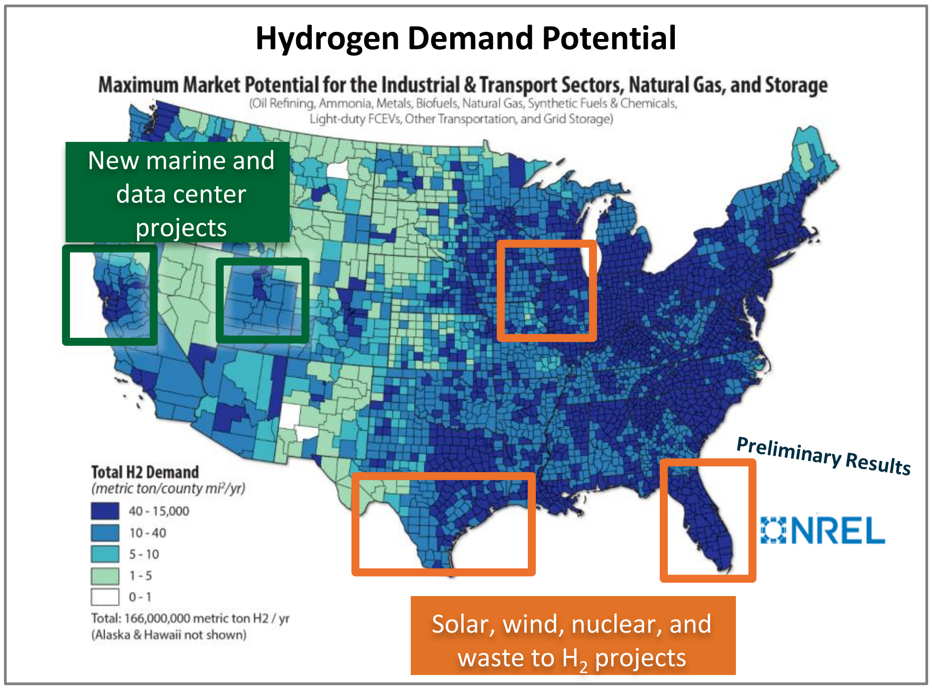
Strategies

- Scale up technologies in key sectors
- Continue R&D to reduce cost and improve performance, reliability
- Address enablers: harmonization of codes, standards, safety, global supply chain, workforce development, sustainable markets

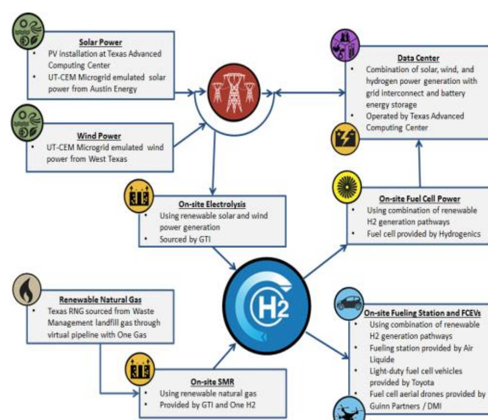
Examples of H2@Scale Demonstration Projects

New H2@Scale demonstration projects cover range of applications and regions

H2@Scale clean H_2 production, end uses and integration demonstrations (~$ 70M)



- **Sites include: Texas, Florida, California, Utah, Ohio***
- **H_2 from: Wind, solar, renewable NG/waste, and nuclear**
- **Stationary and transportation uses include: Data centers, vehicles, maritime applications, and enabling H_2 for steel manufacturing**



*** Nuclear project in collaboration with Office of Nuclear Energy***

DOE Hydrogen and Fuel Cell Technologies Office Focus Areas

Mission	Research, development, and innovation in hydrogen and fuel cell technologies leading to:	• Energy security • Energy resiliency • Strong domestic economy

Enabling H2@Scale — U.S. Department of Energy

Key R&D Sub-Programs and Focus Areas

Fuel Cells
- Cost, durability, efficiency
- Components (catalysts, electrodes) & systems
- Focus on heavy duty applications (trucks, marine, data centers, rail, air, etc.)

Hydrogen
- Hydrogen production, infrastructure/delivery, storage (for transport and stationary storage)
- Cost, efficiency, reliability & availability.

Systems Development & Integration
- Hybrid, grid integrated systems, energy storage
- Safety, codes & standards
- Technology acceleration, workforce development

Data, Modeling, Analysis: Assess pathways, impacts; set targets, guide R&D

Key Goals by 2030

Reduce the cost of:
- Heavy duty fuel cells by 2X to \$80/kW
- Electrolyzers by 3 to 5x to \$300/kW
- Storage tanks by over 40% to \$9/kWh
- H_2 delivery and dispensing by 4 to 5x to \$2/kg
- H_2 production by 2 to 3x to \$2/kg

Improve fuel cell durability 5x to 25,000 hours

Double energy density for onboard storage to **1.7 kWh/L**

Budget: \$150M in FY2020

Budget and Focus Areas in EERE H_2 and Fuel Cell Technologies Office

EERE HFTO Activities	FY 2020 ($K)
Fuel Cell R&D	**26,000**
Hydrogen Fuel R&D	**45,000**
Hydrogen Infrastructure R&D (included in Hydrogen Fuel in FY21)	25,000
Systems Development & Integration (Technology Acceleration)	**41,000**
Safety, Codes, and Standards (included in Systems Development & Integration in FY21)	10,000
Data, Modeling and Analysis	**3,000**
Total	**$150,000**

Hydrogen and Fuel Cells Breakdown FY 2020

- **Production:** Water splitting – electrolysis (high and low temperature), PEC, STCH, biomass/biological
- **Infrastructure:** Materials, delivery, components & systems
- **Storage**: materials-based, carriers, tanks, liquid
- **Fuel cells**: materials, components, systems, reversible FCs
- **Systems Development & Integration:** Tech Acceleration includes hybrid/grid integration, new markets, heavy duty, energy storage, manufacturing industrial applications (e.g. steel) safety, codes, standard, workforce development

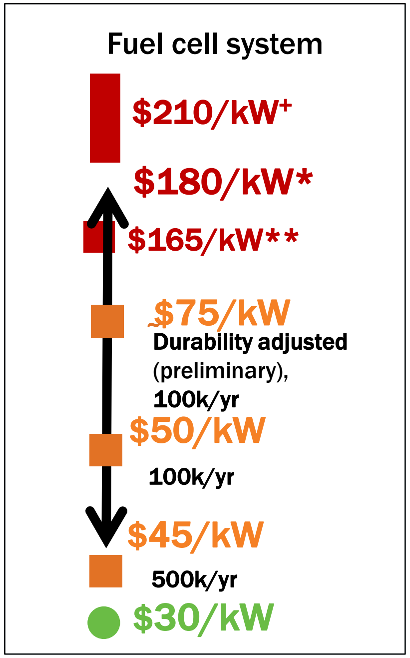
**Will be moved under Hydrogen Fuel R&D in FY 2021*

Note: Office of Fossil Energy covers fossil fuels to H_2

R&D focus is on Affordability and Performance: DOE Targets Guide R&D

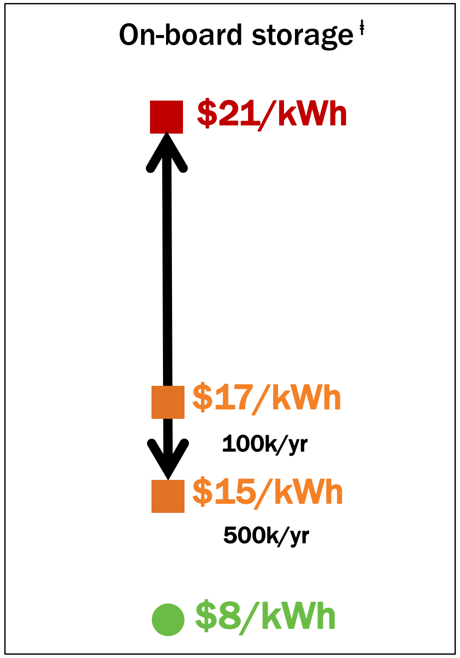
Key Goals: Reduce the cost of fuel cells and hydrogen production, delivery, storage, and meet performance and durability requirements – guided by applications specific targets

Fuel Cell R&D

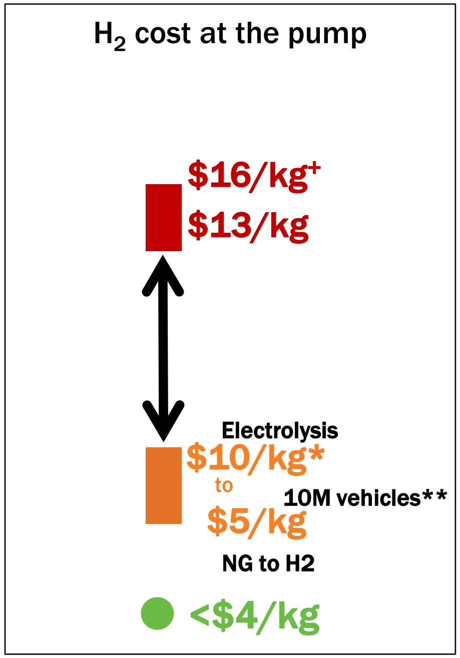


†Based on commercially available FCEVs
*Based on state-of-the-art technology
**Based on commercial FCEV analysis at 3,000/yr

Hydrogen R&D



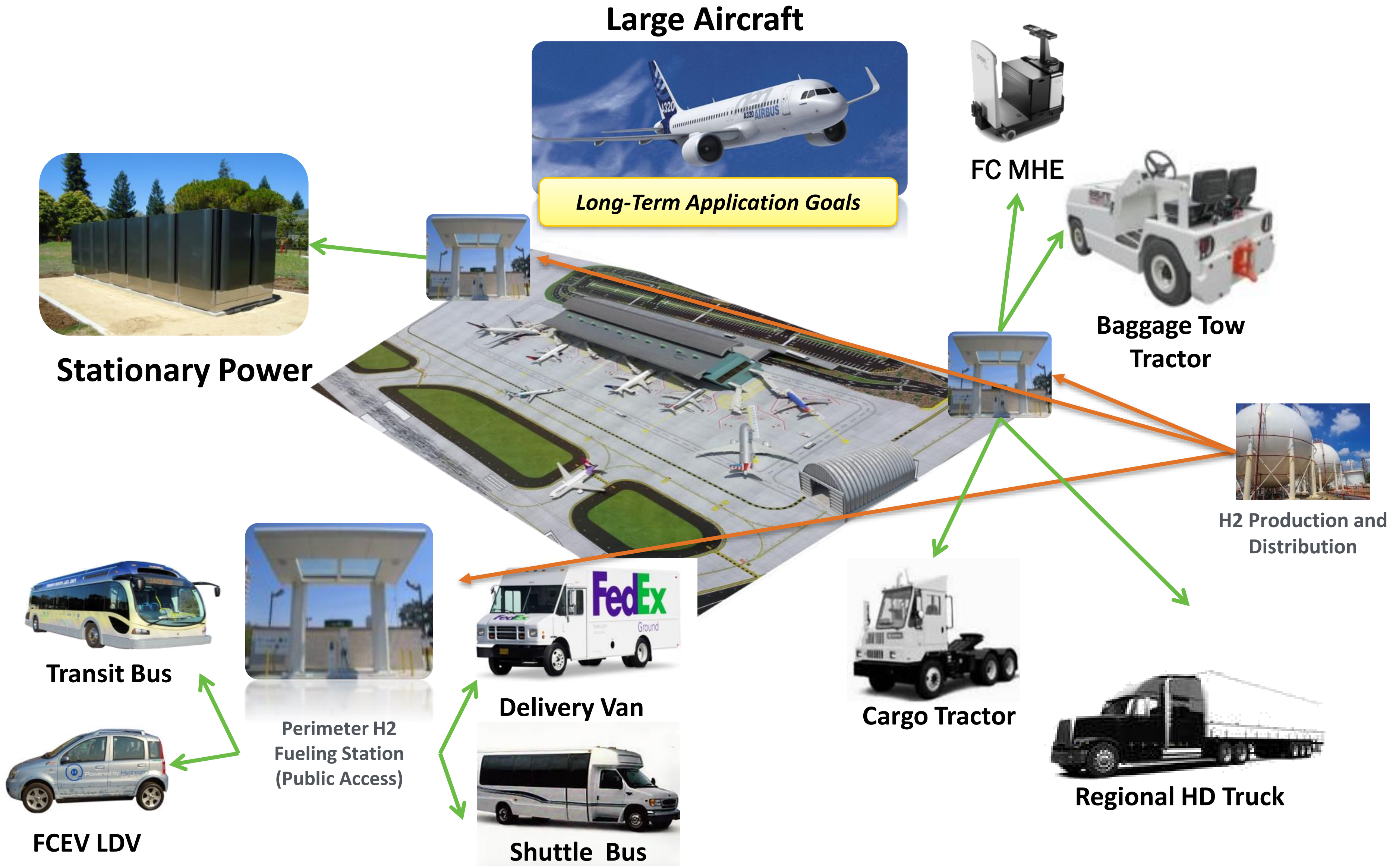
ǂ Storage costs based on preliminary 2019 storage cost record



†For range: H2 production from natural gas (NG), delivered dispensed at today's (2018) stations (~180kg/d)
*For range: Assumes high volume manufacturing in 1) H2 production costs ranging from $2/kg (NG) to $5/kg (electrolysis manufactured at 700 MW/year), and 2) Delivery and dispensing costs ranging from $3/kg (advanced tube trailers) to $5/kg (liquid tanker or advanced pipeline technologies).
** Range assumes >10,000 stations at 1,000 kg/day capacity, to serve 10 million vehicles

H2@Airports to Scale up Hydrogen

The Opportunity: Clustering Fuel Cell Applications To Drive H2 Demand At Airports



Fuel cells may be promising for UAVs, UAM-air taxis, UAM-helicopters, and regional planes

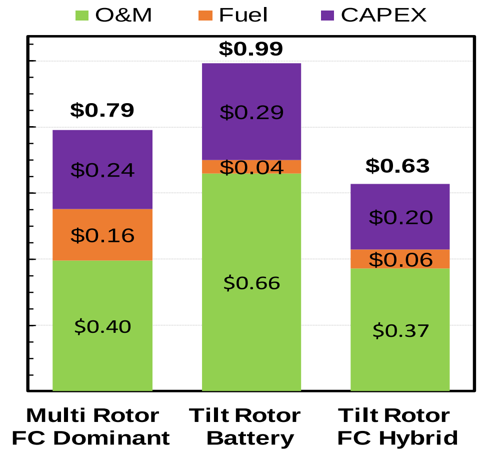
H_2 fuel cells can provide competitive TCO in UAV, UAM-air taxis, UAM-helicopters, and regional planes

UAVs
- Longer lifetime and lower maintenance cost than ICE and battery-powered UAV
- Longer mission times than batteries, allowing for a smaller fleet and lower TCO

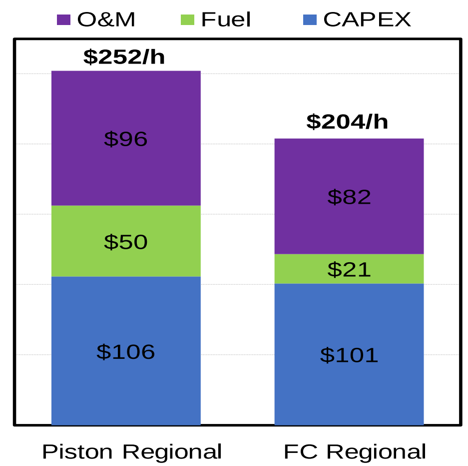
UAMs
- Air taxis: Fuel cells provide longer durability than batteries as the duty cycle has rapid charge and discharge rates
- Helicopters: Can replace aviation gasoline and piston engines on the basis of gravimetric energy density

Small regional planes
- Can replace aviation gasoline and piston engines on the basis of gravimetric energy density
- Fuel cells have lower specific power (W/kg) than turbine engines, but hydrogen can replace aviation gasoline
- Hydrogen has lower volumetric energy density than aviation gasoline

TCO ($/PAX.mile) for battery powered UAM more expensive than FC versions



TCO ($/h) for FC regional plane less than that for piston engine plane




Collaboration

Examples of Global Collaboration

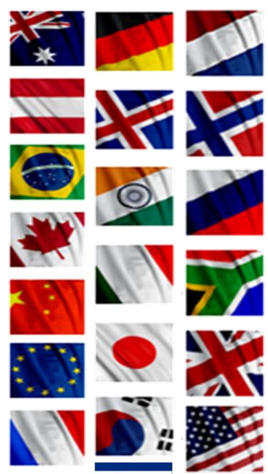
Coordinating across global partnerships: IPHE, Ministerials, Mission Innovation, IEA, etc.
Global Center for Hydrogen Safety established to share best practices, training resources and information

The International Partnership for Hydrogen and Fuel Cells in the Economy

Enabling the global adoption of hydrogen and fuel cells in the economy

Elected Chair and Vice-Chair, 2018
New Chair: Dec 2020: The Netherlands
Vice Chairs: U.S. Japan

Key Activities: Harmonization of codes & standards, Information sharing on safety, policies, regulations, analysis, education. Task force on developing H_2 production analysis methodology to facilitate international trade, global RD&D monitoring



Formed 2003

19 Countries and EC

- **Hydrogen and Clean Energy Ministerials**
- **Mission Innovation Hydrogen Challenge**
- **International Energy Agency**

www.aiche.org/CHS

CENTER FOR Hydrogen SAFETY 水素安全センター

Connecting a Global Community

Includes over 40 partners from industry, government and academia

Access to >110 countries, 60,000 members

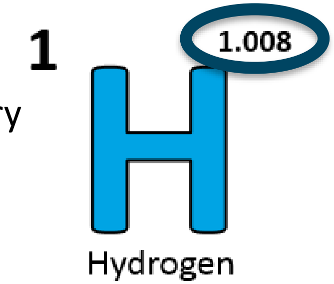
Resources and Events

Save the Date

June 8-10, 2021 Annual Merit Review and Peer Evaluation Meeting for the Hydrogen and Fuel Cells Program in Arlington, VA

Oct 8 - Hydrogen and Fuel Cells Day

(Held on its very own atomic weight-day)



Resources

INCREASE YOUR H2IQ

Join Monthly
H2IQ Hour Webinars

energy.gov/eere/fuelcells/fuel-cell-technologies-office-webinars

Download
H2IQ For Free

energy.gov/eere/fuelcells/downloads/increase-your-h2iq-training-resource

Visit H2tools.Org For Hydrogen Safety And Lessons Learned

https://h2tools.org/

Sign up to receive hydrogen and fuel cell updates

Learn more: www.energy.gov/eere/fuelcells/fuel-cell-technologies-office-newsletter

Learn more at: energy.gov/eere/fuelcells AND www.hydrogen.energy.gov

Workshop Objectives

Identify needed research to accelerate technology development and address barriers to industry commercialization.

Goals:

- Assess the state of the art for electric aircraft and airport applications specifically using hydrogen fuel cells
- Discuss operational requirements and lessons learned on early fuel cell aviation and airport projects
- Understand current technology gaps and identify collaborative R&D opportunities
- Identify codes, standards, safety and regulatory challenges and actions to address them

Workshop Agenda

Day 1 – Nov. 4

- Session I – Government Perspectives
- Session II – Aviation Safety, Codes, and Standards

Day 2 – Nov. 5

- Session III - UAVs Development & Refueling
- Session IV – Electric Aircraft Development
- Session V - Hydrogen Aviation Research and Assessments

Breakout Session No. 1

Day 3 – Nov. 6

- Session VI - Airport Ground Equipment Perspectives
- Session VII - Airport Ground Transportation Perspectives
- Session VIII - Airport Refueling Systems

Breakout Session No. 2

Thank You

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Back Up

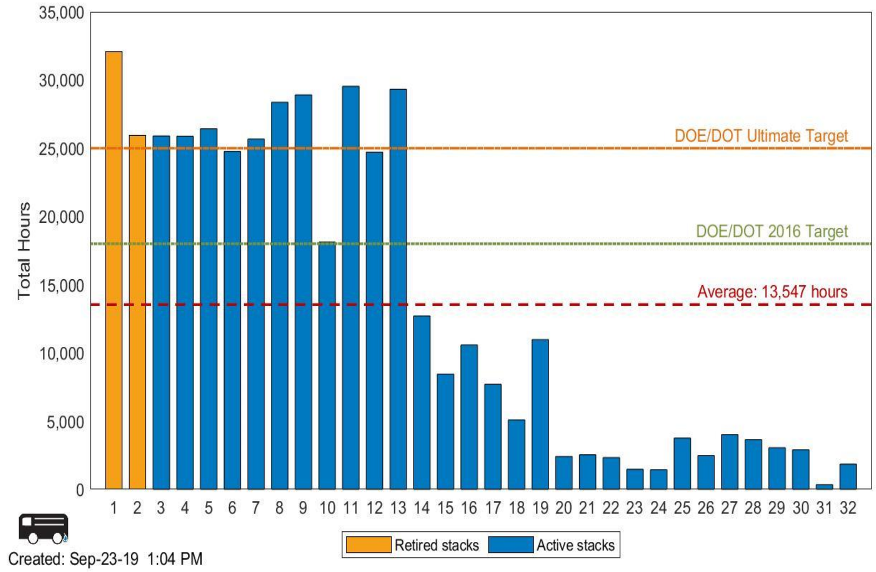
Fuel Cell Electric Buses (FCEB) in U.S. Transit Fleets

- DOE-HFTO and DOT-FTA set targets for FCEB to compete with conventional alternatives
- NREL collects data from five transit authorities to assess FCEB performance compared to baseline conventional buses
- Remaining challenges include
  - Fuel Cell BOP components
  - FCEB supply chain – parts supply
  - Hydrogen stations – low MD/HD refueling rates, equipment performance
  - Hydrogen cost

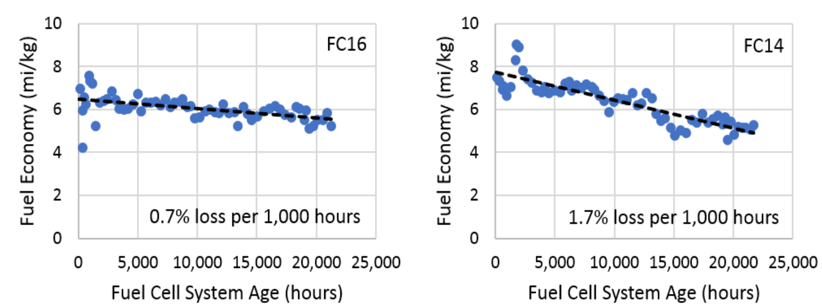
FCEB Performance Compared to DOE/FTA Targets (2018)

	Units	Current Status[a]		2016 Target[1]	Ultimate Target[1]
		Range	Average		
Bus lifetime	years/miles	0.2–8/ 6,000–222,000[b]	4.5/ 119,790	12/500,000	12/500,000
Power plant lifetime[c]	hours	500–29,000[b,d,e]	13,236	18,000	25,000
Bus availability	%	55–88	72	85	90
Fuel fills[f]	per day	1	1	1 (<10 min)	1 (<10 min)
Bus cost[g]	$	1,270,000–2,400,000[h]	1,920,000	1,000,000	600,000
Roadcall frequency (bus/fuel cell system)	miles between roadcalls	2,500–5,700/ 13,000–36,800	4,239/ 24,406	3,500/ 15,000	4,000/ 20,000
Operation time	hours per day/ days per week	7–21/ 5–7	11.8/ 6	20/7	20/7
Scheduled and unscheduled maintenance cost[i]	$/mile	0.22–0.73	0.49	0.75	0.40
Range[j]	miles	199–348	266	300	300
Fuel economy	miles per diesel gallon equivalent	5.83–7.82	7.01	8	8

Total hours accumulated on each FCPP through July 31, 2019.



Average 20% fuel economy degradation after 17,000 hr



Fuel Cell-Powered Airport GSE (Ground Support Equipment) Deployment

Technology Summary

Demonstration of hydrogen fuel cell-based solution as a cost-competitive and more energy-efficient airport tug as compared to the incumbent internal combustion engine-powered vehicles.

Specific goals included:

- Reduction of petroleum consumption at airports
- Reduction of airport emissions
- Operation up to 10 hours per day
- Towing capacity of 5000 lbs
- Acceleration of fuel cell powered GSE development

Two tuggers operated at the Albany airport.

Project Partners

Plug Power, Charlatte, Fed Ex

Program Summary

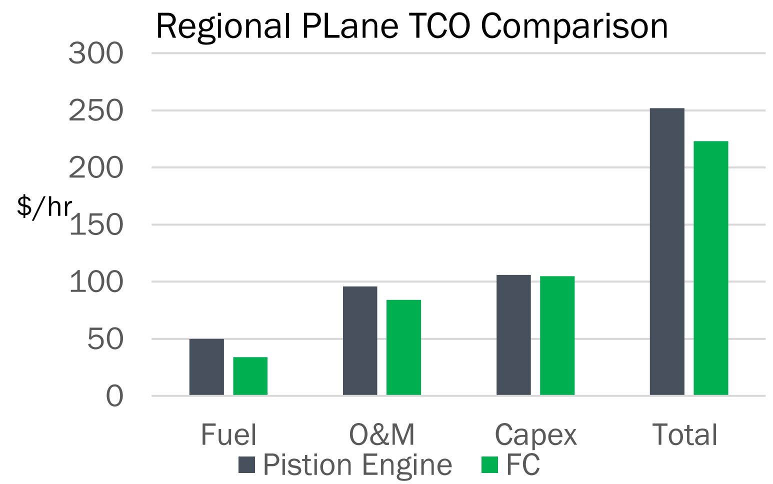
	Project Phases
Phase1	Development phase - Plug Power developed, built and tested the 80V (~20 kW) fuel cell system for the tug application.
Phase 2	Demonstration Phase - a fleet of tugs were integrated into electric tow tugs and deployed at the Memphis airport under real world conditions.
Phase 2+	Demo Phase Continued - Due to decommissioning of the hydrogen system, the project demo at Memphis was terminated early. Two of the hydrogen powered tugs were redeployed at the FedEx operation at the Albany, NY airport to continue demonstration, including cold weather operation.

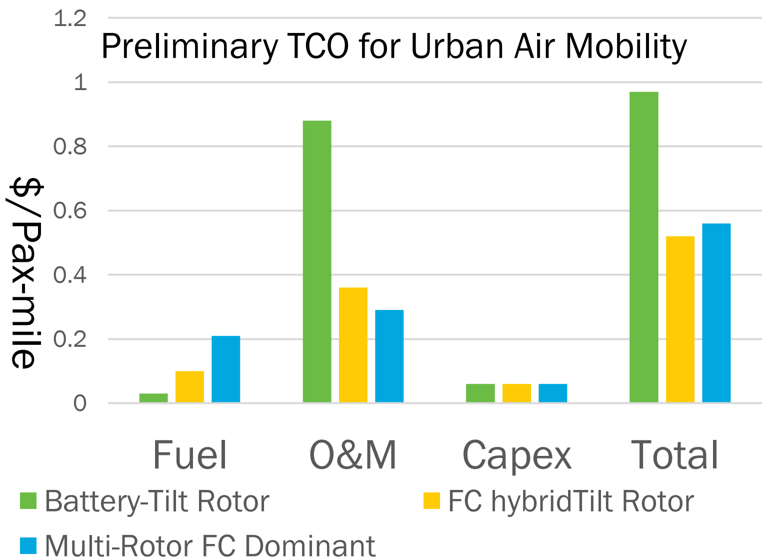
Technology Impact

The project demonstrated the viability of hydrogen powered ground support equipment. The hydrogen powered tugs were able to meet all operational demands in the FedEx freight operation. The project provided valuable technical, economic, and operational learning toward using hydrogen power for ground support equipment applications.

Fuel Cells for Aviation-Preliminary Total Cost of Ownership

- Compared TCO for H_2 fueled PEMFC to piston engine for small (4 seat) regional plane and helicopter and to battery electric for Urban Air Mobility and Unmanned Aerial Vehicles
- FCS can compete with piston engines and batteries on a TCO basis
  - CAPEX can be competitive with piston engine and battery
  - Cost sensitivity analysis suggests fuel cell systems can be competitive in regional planes with H_2 costs of up to \$9.50/kg and for UAM with H_2 costs of up to \$15/kg
  - Hydrogen provides longer mission times and better utilization of assets than batteries.





Source: Alaka'i

Source: Argonne National Lab