

Hydrogen and Fuel Cells: Progress and Opportunities

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Hydrail Symposium

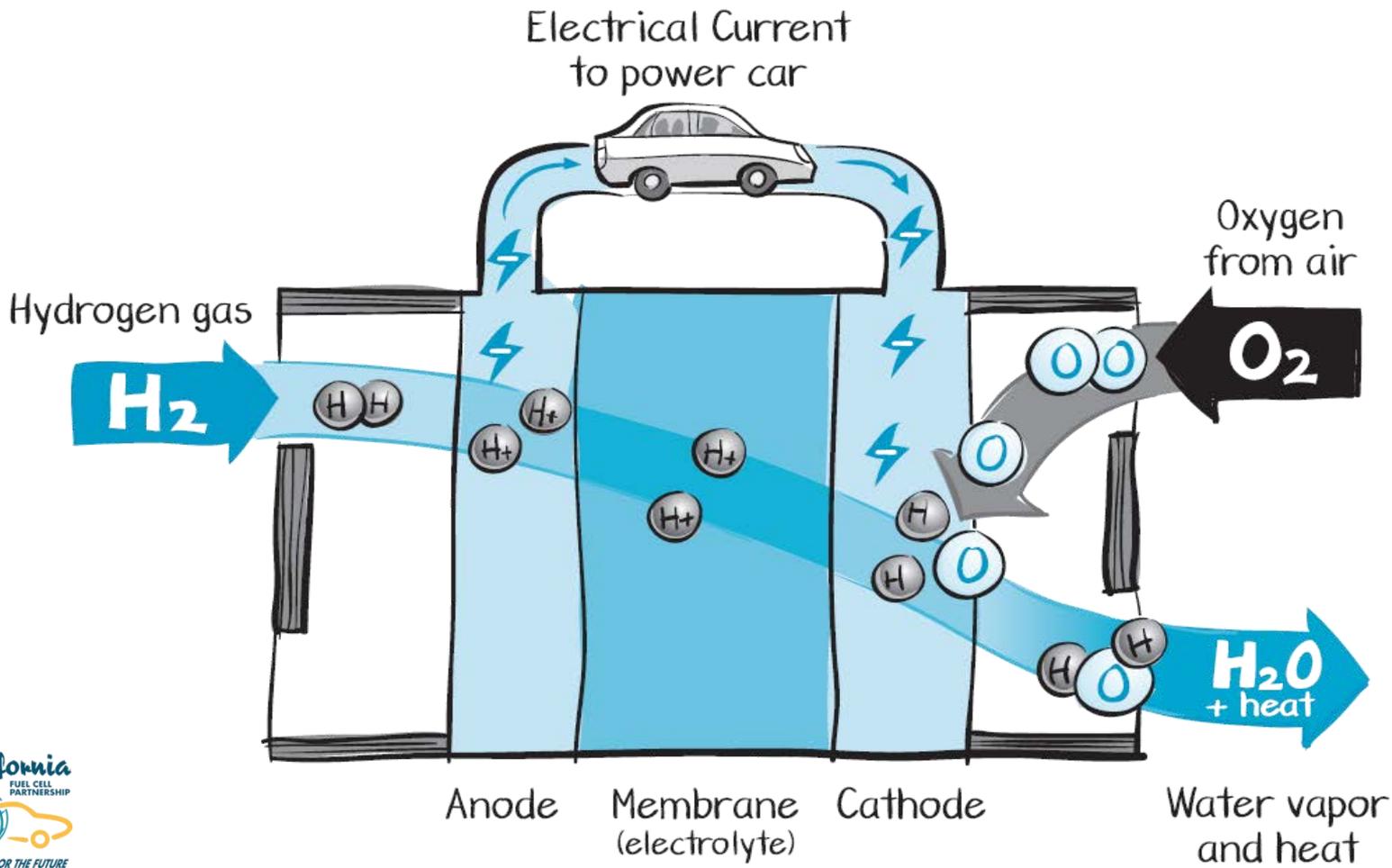
Ontario, Canada – November 16, 2017



Basics

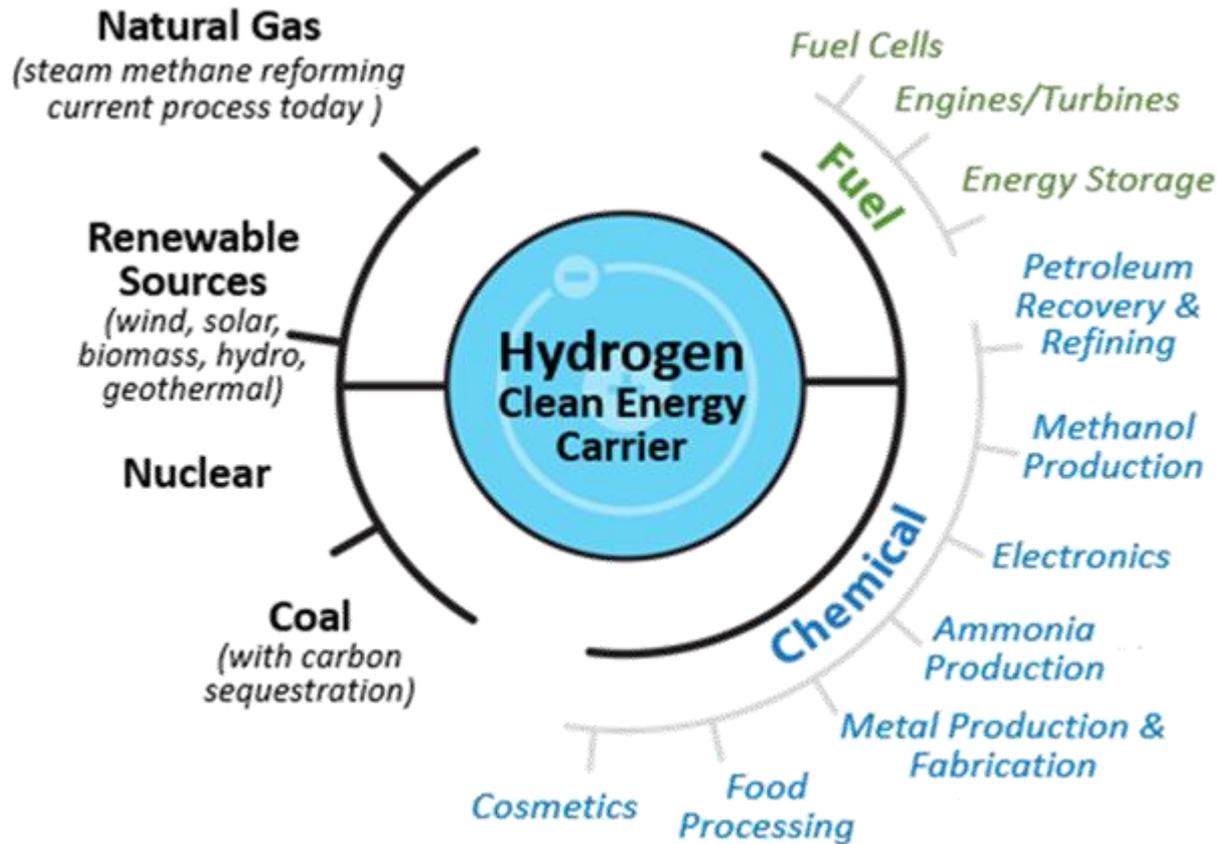
What is a fuel cell?

Takes hydrogen in and puts electricity and water vapor out



What is Hydrogen?

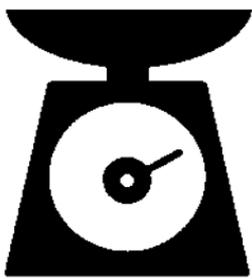
Hydrogen is an energy carrier: Used as fuel or feedstock



Produced from diverse domestic resources and used in many applications

Hydrogen's Energy Content

High Energy by Mass, Low Energy by Volume

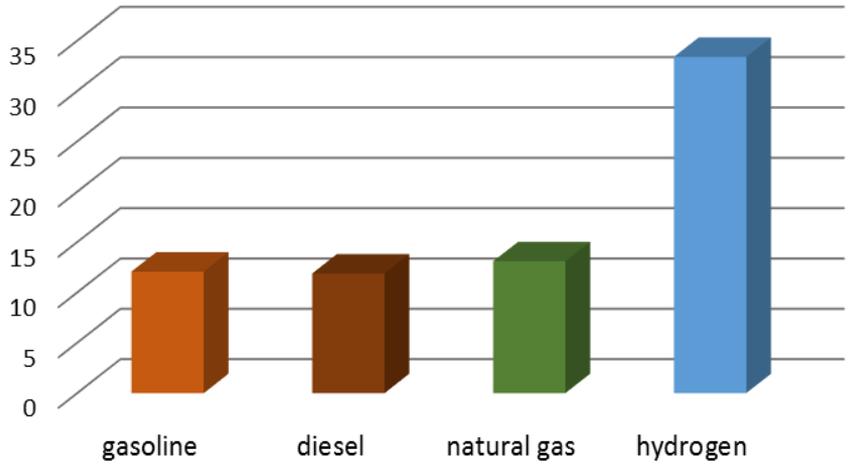


Approx. **3X more** energy content **by mass** than gasoline

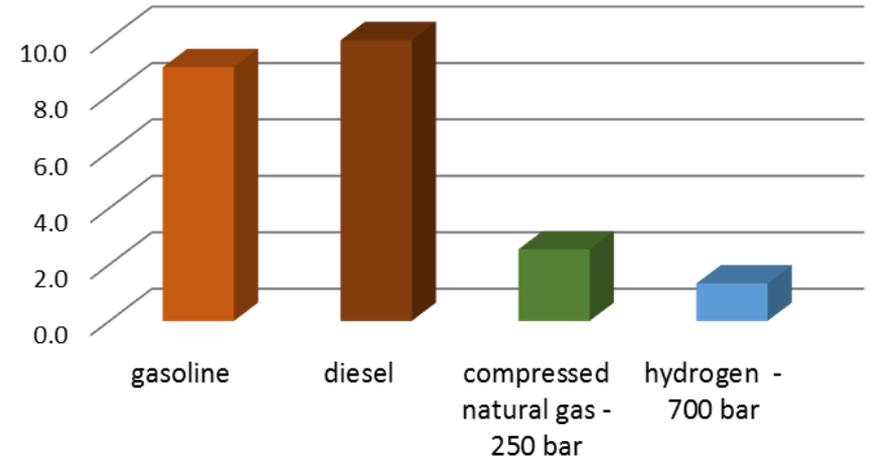


Approx. **4X less** energy content **by volume** than gasoline

Specific Energy Comparison (kWh/kg)

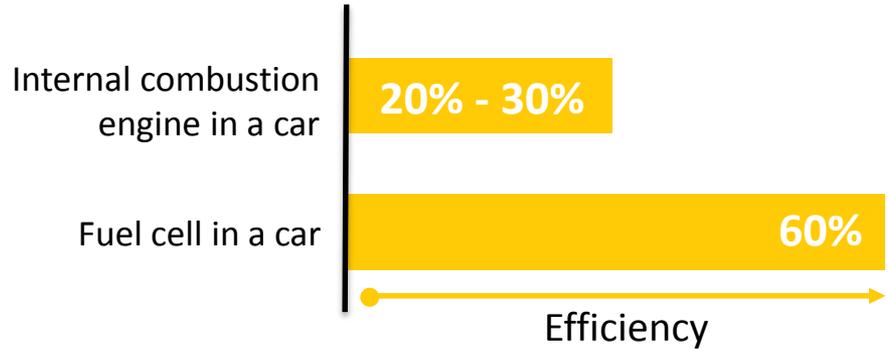


Energy Density Comparison (kWh/L)



Why Hydrogen and Fuel Cells?

Efficient Uses domestic fuels



- Natural gas
- Renewable sources (wind, solar, biomass, etc.)
- Nuclear
- Coal

Convenient Quiet Clean



Refuels in minutes



No noise in operation



Zero tailpipe emissions

Versatile and easily scalable



Transportation



Stationary

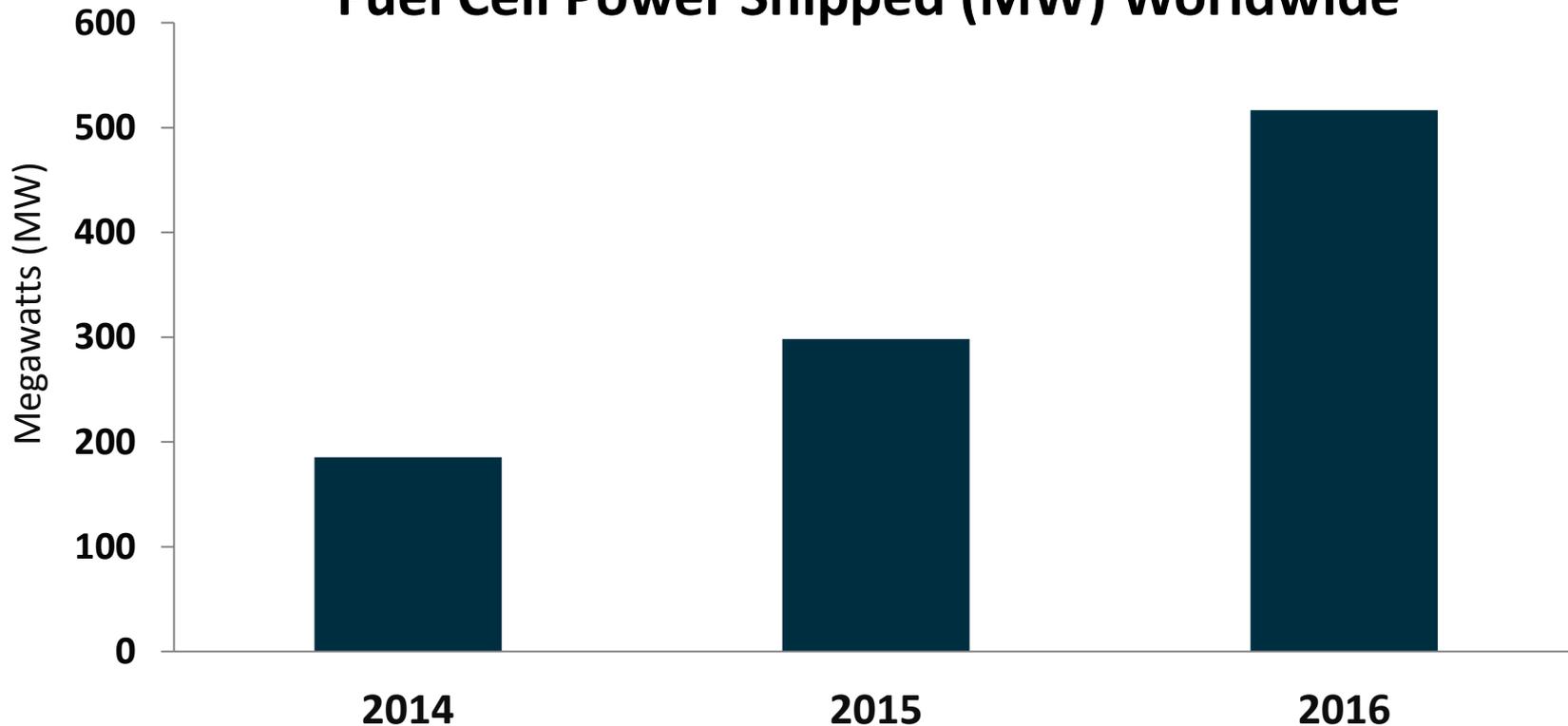


The image features a sunset sky with silhouettes of three people on a grassy hill. One person is climbing a tall pole to plant a flag, while two others pull a rope attached to the pole. The word "Progress" is written in large white letters across the center of the image.

Progress

Consistent Fuel Cell Market Growth Continues

Fuel Cell Power Shipped (MW) Worldwide



500 MW
fuel cell power
shipped worldwide



62,000
fuel cell units
shipped worldwide



Approximately
\$1.6 Billion
fuel cell revenue

Source: DOE and E4Tech

For the first time in history....



Hyundai Tucson Fuel Cell SUV



Toyota Mirai



Honda Clarity

Commercial fuel cell electric cars are here!

Nearly **3,000** | **sold or leased**
in the United States

- ✓ No petroleum, no pollution
- ✓ Refuels in minutes
- ✓ More than 360 mi driving range
- ✓ Over 60 mpgge

Life-Cycle Petroleum Use- Today's Cars

Low, Medium & High Petroleum Energy/Mile for 2015 Technology



Fuel Cell Electric



Battery Electric



Extended-Range
Electric

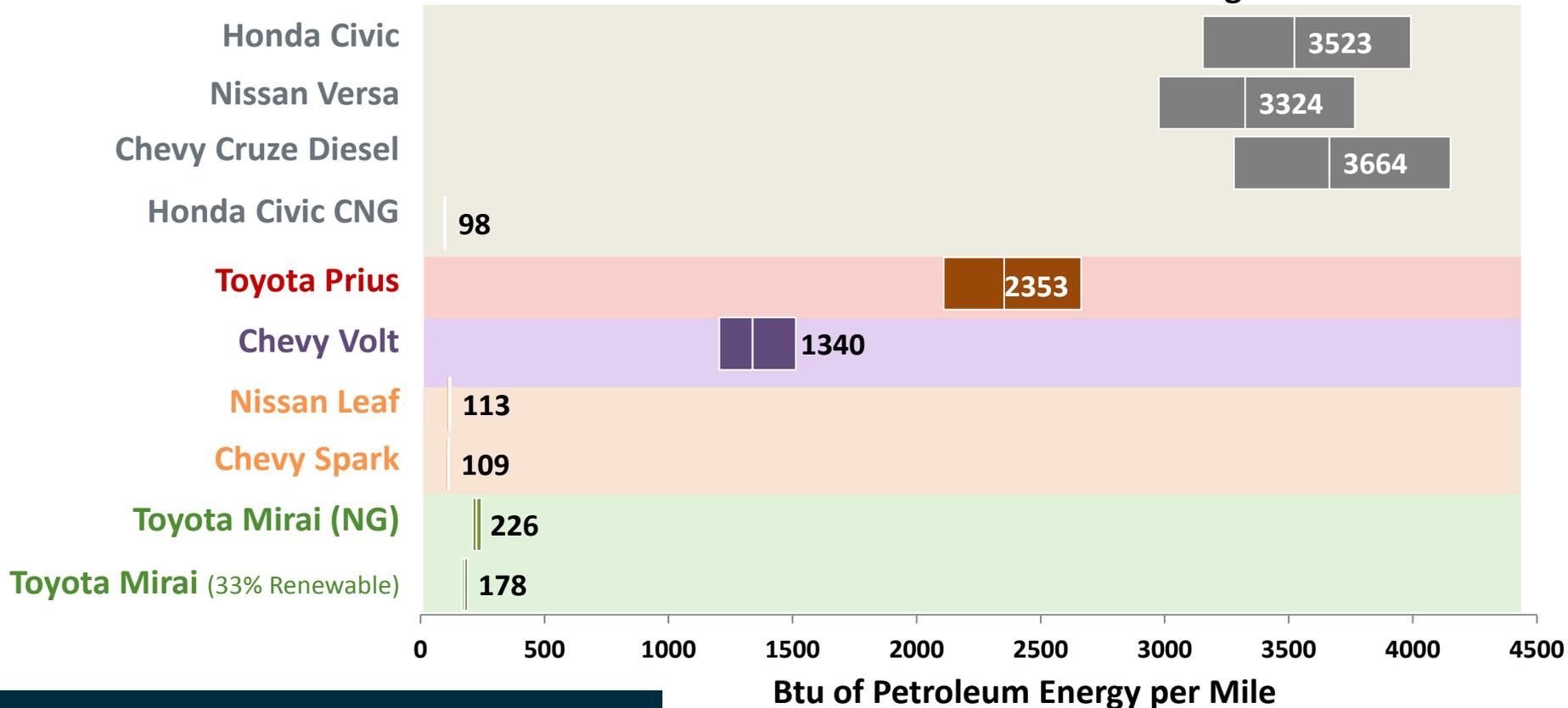


Hybrid Electric



Internal Combustion Engine

Current gasoline ICEV: 4300



Joint VTO-FCTO Analysis Example

Source: Program Record 16004 (https://www.hydrogen.energy.gov/pdfs/16004_life-cycle_ghg_oil_use_cars.pdf)

Life-cycle Emissions- Today's Cars

Low, Medium & High Emissions/Mile for 2015 Technology



Fuel Cell Electric



Battery Electric



Extended-Range
Electric

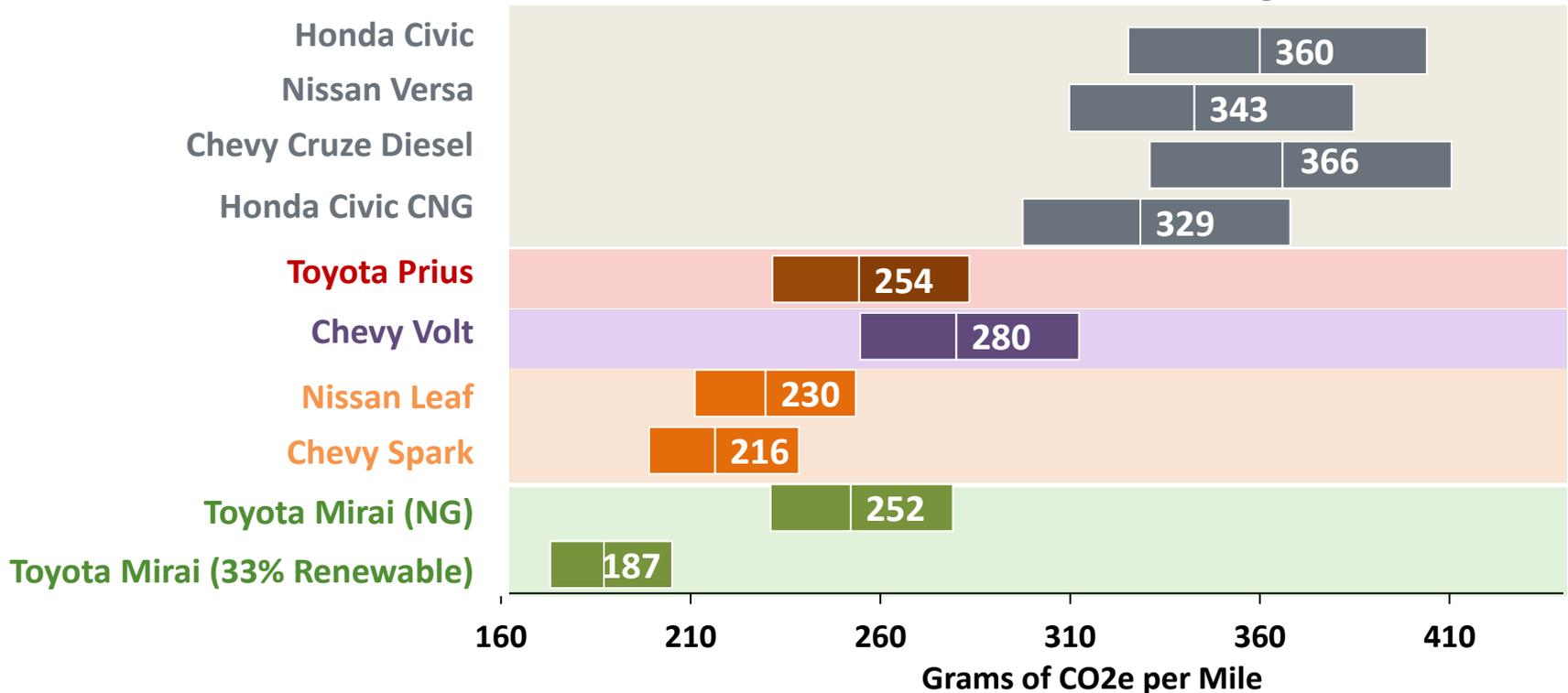


Hybrid Electric



Internal Combustion Engine

Current gasoline ICEV: ~450

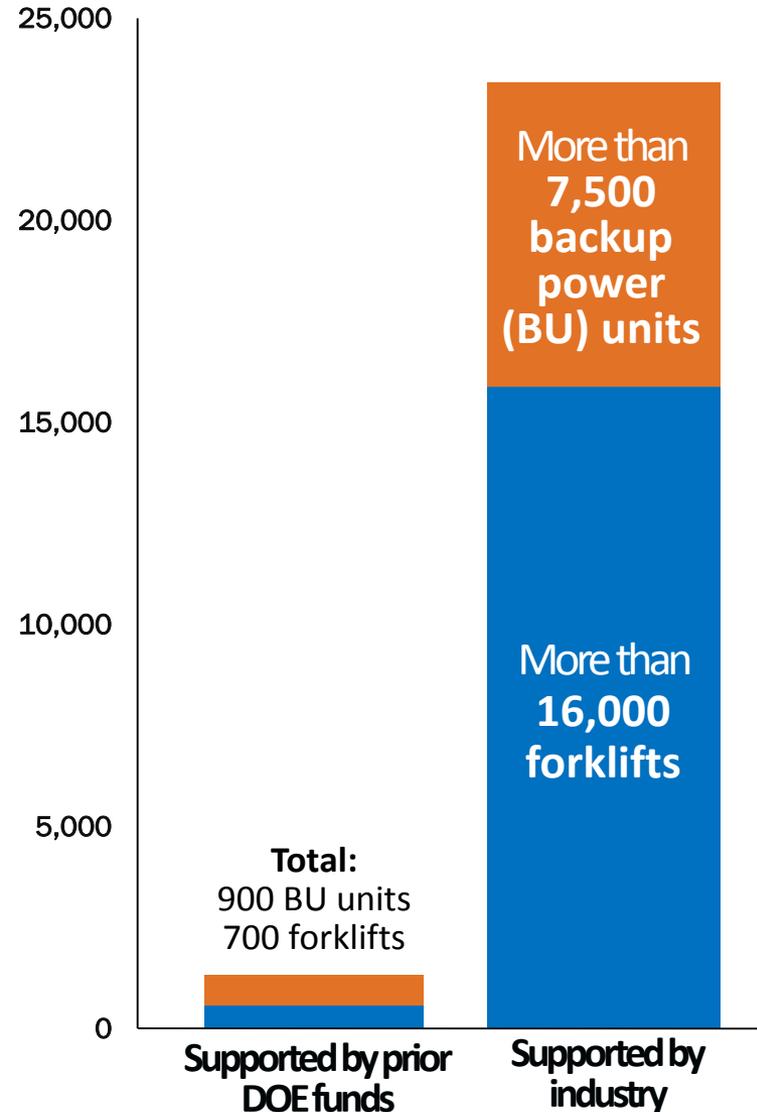


Joint VTO-FCTO Analysis Example

Source: Program Record 16004

(https://www.hydrogen.energy.gov/pdfs/16004_life-cycle_ghg_oil_use_cars.pdf)

Catalyzing Early Markets for Fuel Cells



Heavy Duty Vehicle Applications Emerging- Examples



Fuel cell delivery and parcel trucks starting deliveries in CA and NY



Industry demonstrates first heavy duty fuel cell truck in CA



Stationary Power Applications Emerging – Examples

Fuel cells provided backup power during Hurricane Sandy in the U.S. Northeast



Fuel cell power for maritime ports demonstrated in Honolulu, Hawaii



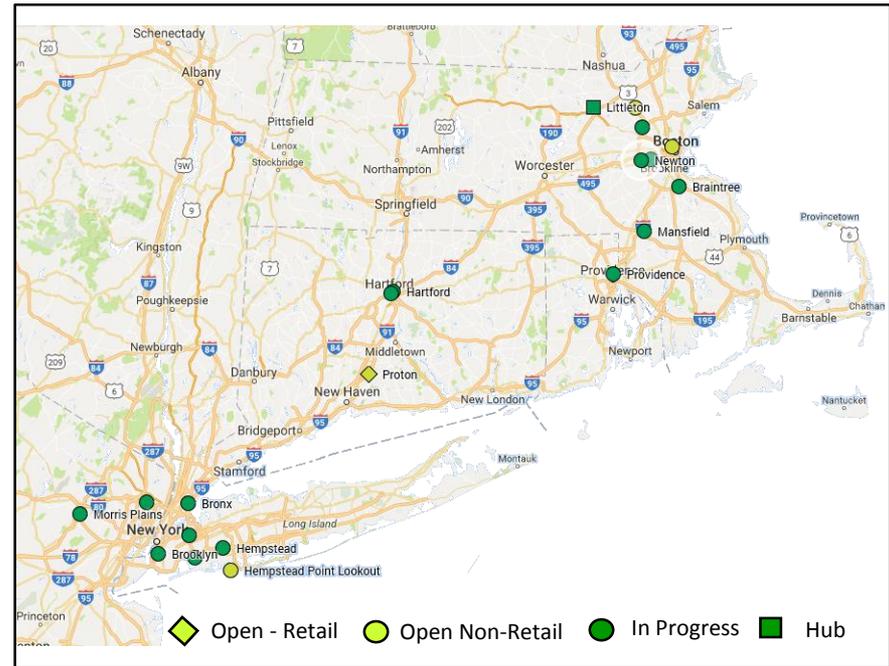
Fuel cells used to power new World Trade Center in NYC



Over 235 MW of fuel cell stationary power installed across more than 40 US states



U.S. Hydrogen Refueling Stations



Others with interest: Hawaii, Ohio, Texas, Colorado, South Carolina, and others

Global Expansion of Infrastructure

Examples:

- U.S. and Canada
- Japan
- Germany
- South Korea
- Sweden, Norway
Denmark, Netherlands
- France, UK
- China... just starting



A silhouette of a person pushing a large boulder up a hill against a sunset sky. The person is on the left, leaning forward and pushing the boulder up the slope. The sky is a mix of orange, yellow, and blue, with scattered clouds. The boulder is large and dark, and the hill it is being pushed up is also dark. The overall scene is one of struggle and perseverance.

Challenges

**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.
Distributors

8-10 E. BIJOU STREET

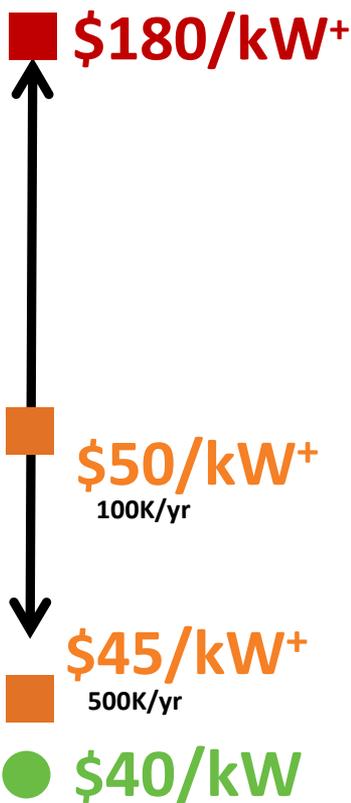
Three or four splendid second-hand cars for sale cheap.



DOE Cost Status and Targets for R&D

Fuel Cell R&D

System

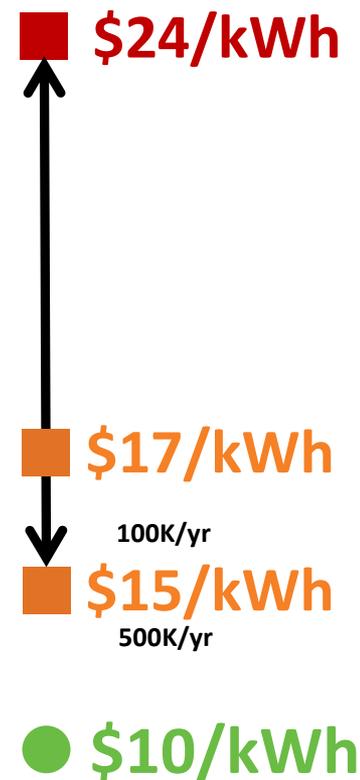


Hydrogen R&D

Production, Delivery & Dispensing



Onboard Storage (700-bar compressed system)



● **2020 Targets**

■ **High-Volume Projection**

■ **Low-Volume Estimate**

*Based on Electrolysis **Based on NG SMR + Preliminary, updates underway
 Onboard storage cost status from DOE Program Record 15013

Note: Graphs not drawn to scale and are for illustration purposes only.

Market Segmentation Analysis- DOE Study Underway

FCEV costs: favorable in larger size classes and higher driving range

Year 2040: FCEV minus PEV-X Cost

	50 mi.	100 mi.	150 mi.	200 mi.	250 mi.	300 mi.	350 mi.
Two-seaters	\$0.04	\$0.00	-\$0.04	-\$0.07	-\$0.11	-\$0.15	-\$0.19
Minicompacts	\$0.05	\$0.02	-\$0.01	-\$0.04	-\$0.07	-\$0.10	-\$0.13
Subcompacts	\$0.04	\$0.01	-\$0.02	-\$0.04	-\$0.08	-\$0.11	-\$0.14
Compacts	\$0.03	\$0.00	-\$0.03	-\$0.06	-\$0.09	-\$0.12	-\$0.15
Midsize Cars	\$0.03	\$0.00	-\$0.04	-\$0.06	-\$0.10	-\$0.13	-\$0.17
Large Cars	\$0.03	\$0.00	-\$0.03	-\$0.06	-\$0.09	-\$0.12	-\$0.16
Small Station Wagons	-\$0.01	\$0.00	-\$0.04	-\$0.06	-\$0.11	-\$0.15	-\$0.19
Pass Van	\$0.03	-\$0.01	-\$0.06	-\$0.11	-\$0.15	-\$0.20	-\$0.24
SUV	\$0.02	-\$0.03	-\$0.09	-\$0.14	-\$0.19	-\$0.25	-\$0.30
Std Pickup	\$0.14	\$0.10	\$0.07	\$0.04	\$0.01	-\$0.03	-\$0.06
Small Pickup	\$0.06	\$0.01	-\$0.03	-\$0.07	-\$0.11	-\$0.15	-\$0.19

The Hydrogen Infrastructure Challenge

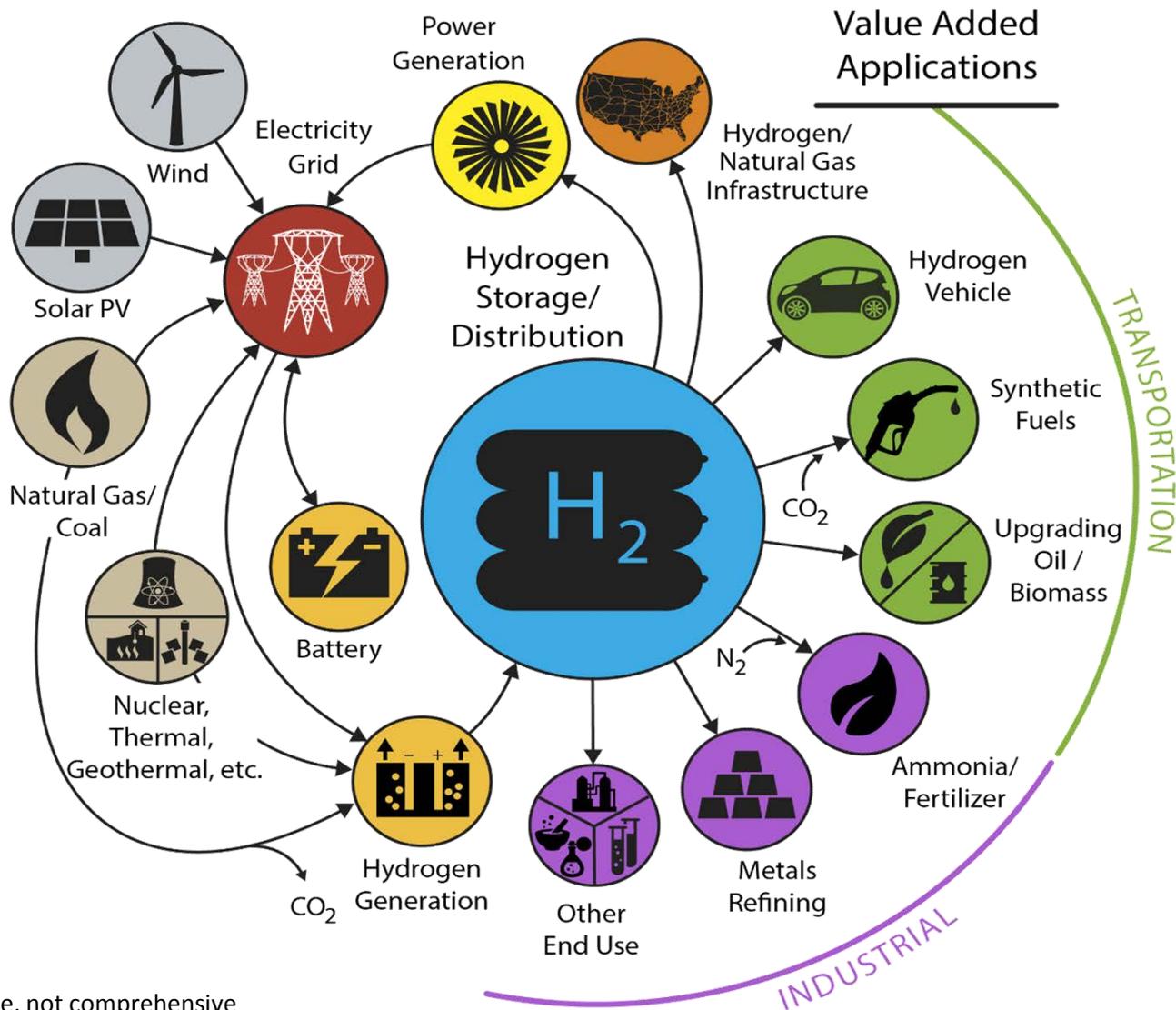
- Cost
- Reliability
- Availability

A hydrogen fueling station in San Francisco, CA. | Photo courtesy of the California Fuel Cell Partnership

The background of the slide features a silhouette of three people on a grassy hill at sunset. One person is on the right, pushing a large rock up a slope. Two other people are on the left, pulling a rope that is attached to a tall pole. The pole is leaning against the rock, and a flag is flying from the top. The sky is a mix of blue, orange, and yellow, with scattered clouds. The word "Opportunities" is written in large, white, sans-serif font across the center of the image.

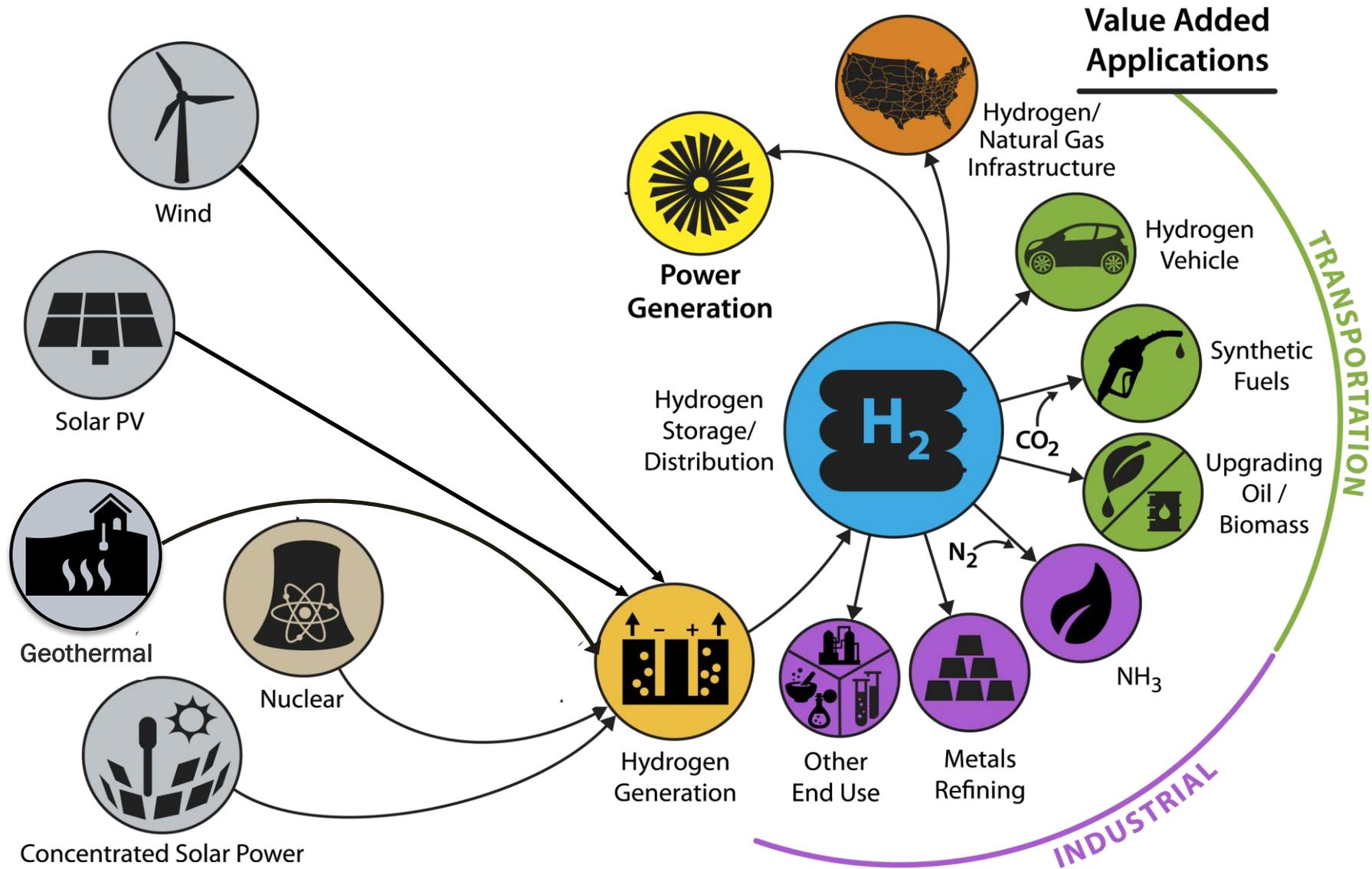
Opportunities

H₂ at Scale Energy System



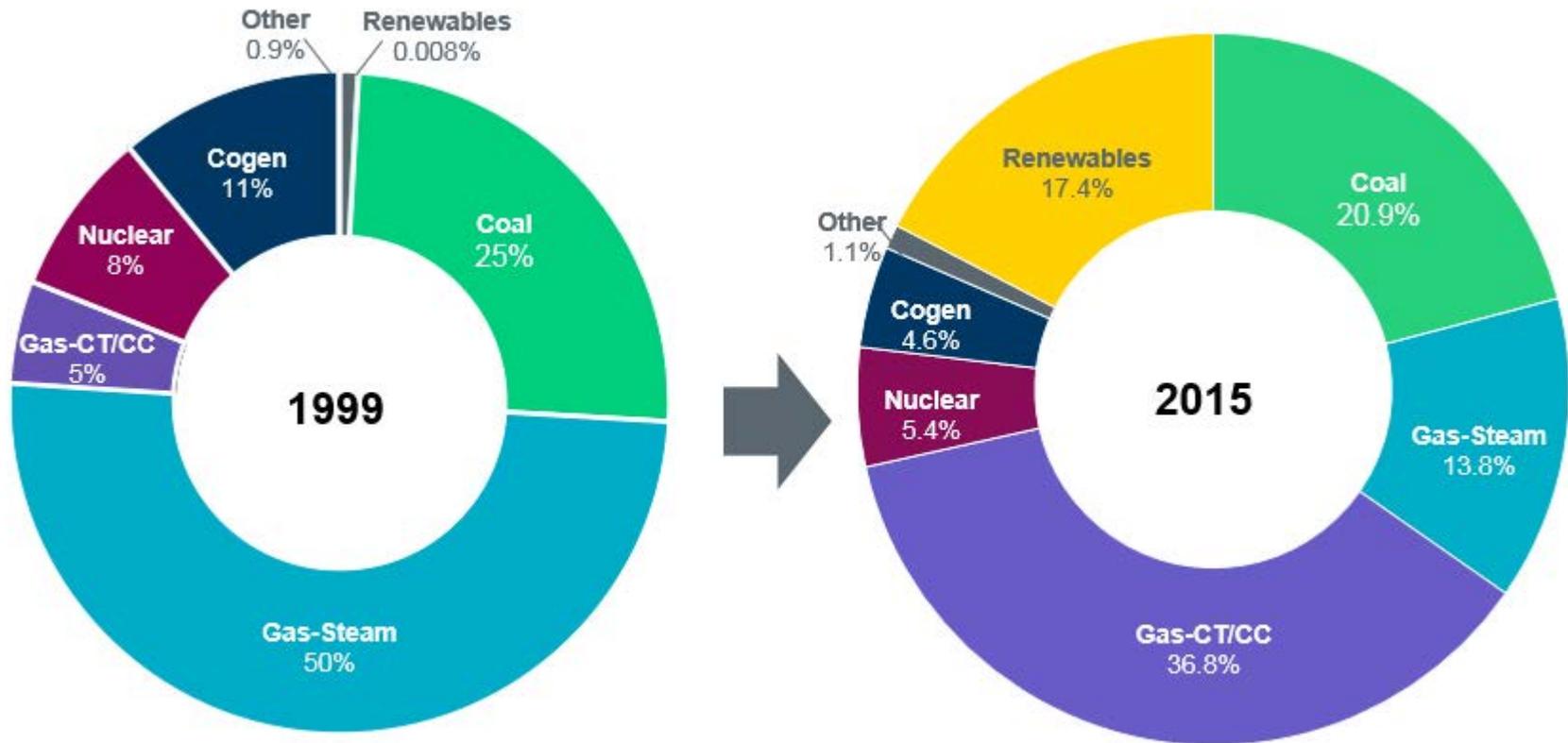
*Illustrative example, not comprehensive
Source: NREL

H₂ at Scale Energy System



Changing Energy Resource Mix for Electricity - Example

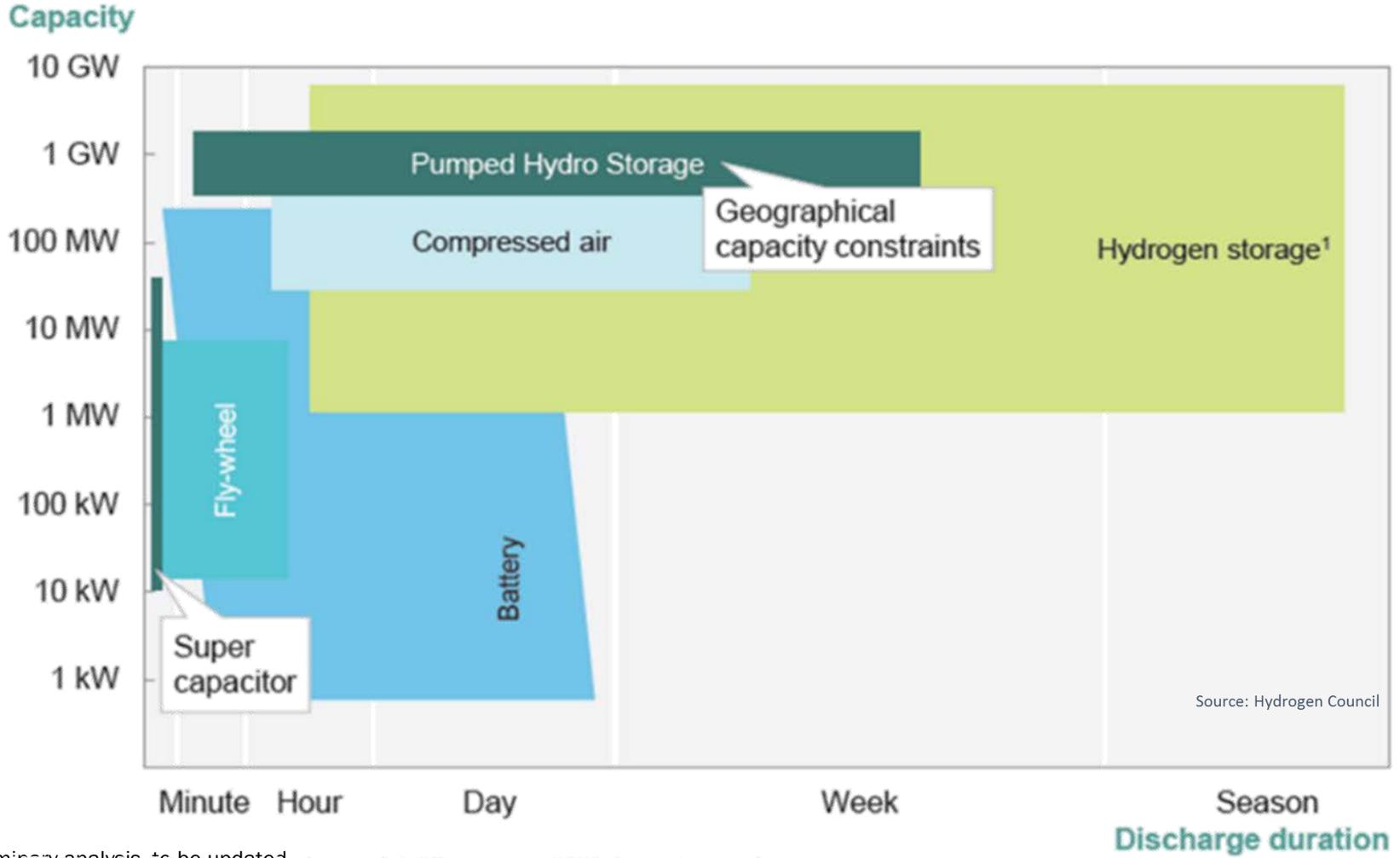
Installed Capacity in Texas



Source: ERCOT

Hydrogen as a medium for storing intermittent energy

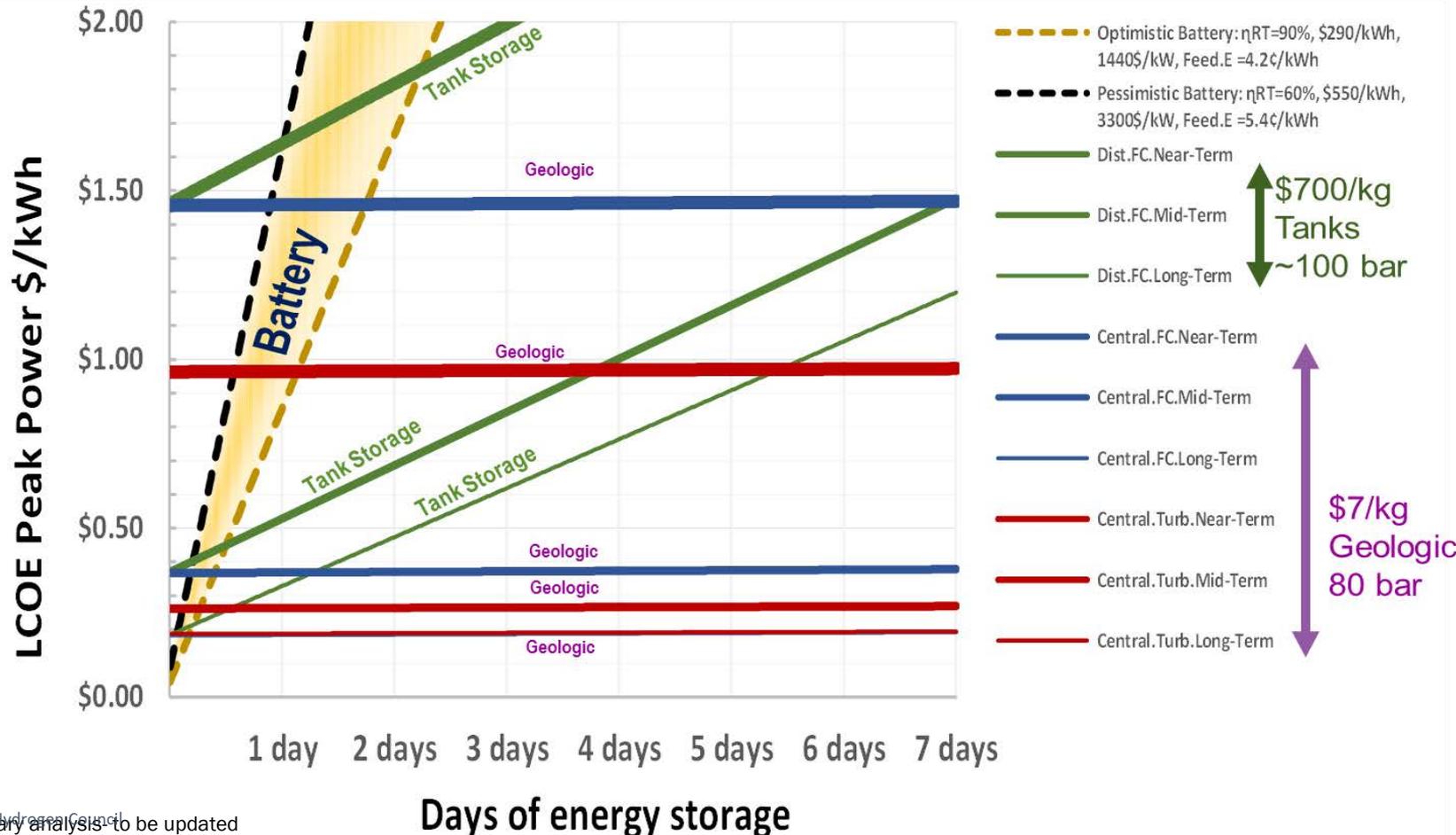
Gigawatt-scale energy storage and long discharge duration



Preliminary analysis- to be updated

Example of H₂ and Electrolyzer Benefits

H₂ can be cost effective for long duration storage



Examples: Large-scale Hydrogen Projects Worldwide



Germany 2016: 6-MW wind-to-H2 plant using electrolyzers commissioned



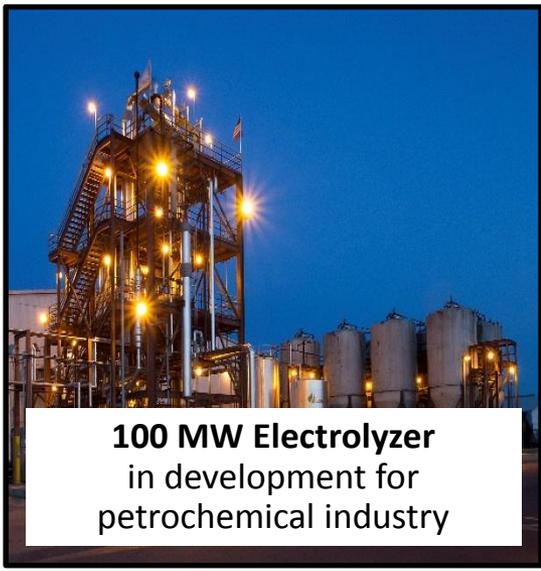
Austria 2017: 6-MW electrolyzer for steel plant



Electrolyzer for ammonia production at U. Minnesota



60-MW fuel cell park in South Korea- world's largest!



100 MW Electrolyzer in development for petrochemical industry



World's largest salt cavern for hydrogen storage commissioned in TX in 2017

A Global Initiative Supporting H₂

The Hydrogen Council



Investment

Over \$10B

towards
**hydrogen and
fuel cells**



Members

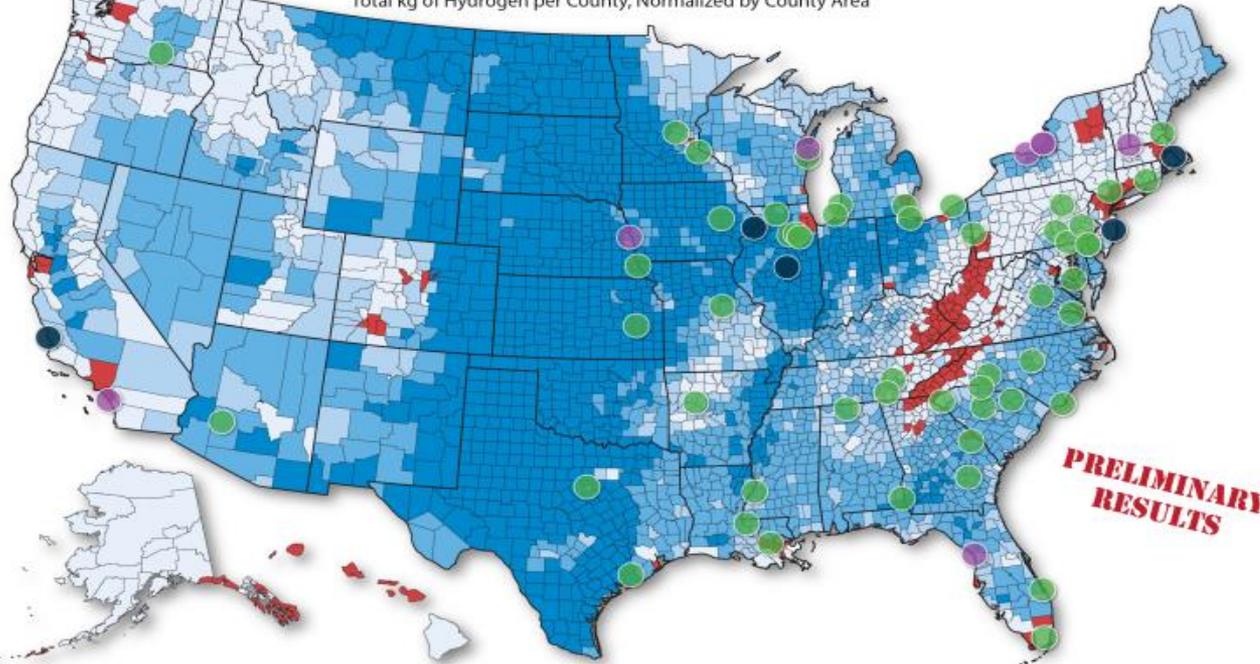
Over 20 companies

representing
**Over \$1.3T in revenues
and 2.06M jobs**

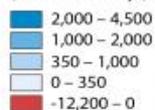
More information: hydrogeneurope.eu

H2@Scale: Nationwide Resource Assessment

Hydrogen Potential From Photovoltaic and Onshore Wind Resources Minus Total Hydrogen Demand for the Industrial & Transport Sectors
Total kg of Hydrogen per County, Normalized by County Area



Hydrogen
(metric ton/m²/yr)



Nuclear Energy Plants



This analysis represents potential generation from utility-scale photovoltaics and onshore wind resources minus total hydrogen demand from the industrial sector: refineries, biofuels, ammonia and natural gas systems (metals are not included) and the transport sector: light duty vehicles and other transport. The data has been normalized by area at their respective spatial scales, and then summarized by county.

Data Source: NREL analysis
Robson, A. Preserving America's Clean Energy Foundation. Retrieved March 23, 2017, from <http://www.thirdway.org/report/preserving-americas-clean-energy-foundation>

This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy.
Nicholas Gilroy, March 27, 2017



Labs assess resource availability. Most regions have sufficient resources.

Red: Only regions where projected industrial & transportation demand exceeds supply.

Lab PIs: Mark Ruth, Bryan Pivovar, Richard Boardman, et al

A long freight train with colorful containers (orange, yellow, blue, green) on tracks, viewed from a low angle. The train is moving away from the viewer into the distance. The sky is blue with some clouds.

Opportunities: Rail

Hydrogen and Fuel Cells in Rail Sector

- **Examples- RD&D projects over the years:**

- **Asia:** Japan, Taiwan, China, Dubai
- **Europe:** Spain, Germany
- **Africa:** South Africa
- **North America:** U.S. and Canada

See: International Hydrail Conferences

- **Three segments: Application dependent**

- **Long distance freight and inter-city** (over 3MW systems)
- **Intra-city and regional rail systems** (light and commuter rail)
- **Short distance industrial** (mining, railyard shunters)

Demonstrations – Examples

China



Several Fuel Cell Trams Planned

Capacity: 285 passengers
Maximum speed: 70 km/hr.

Germany

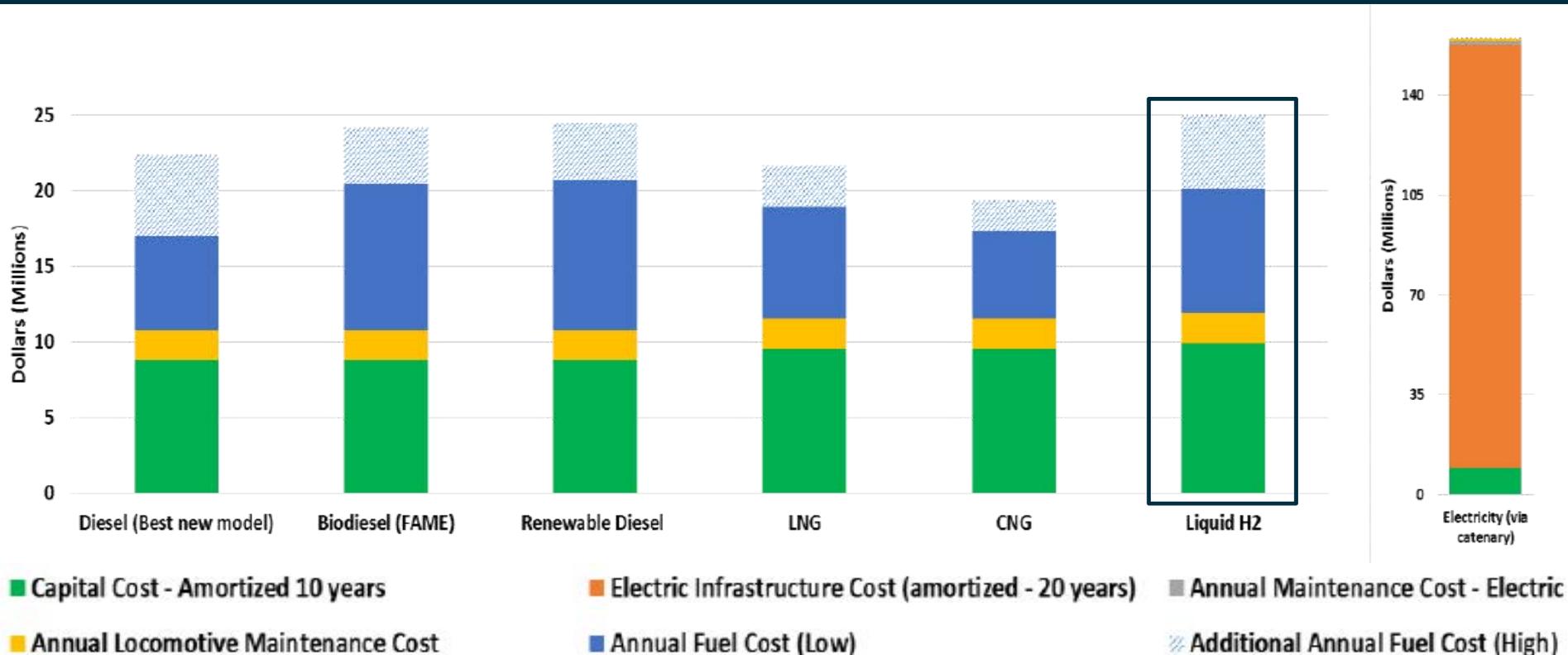


Trains to operation in early 2018

Capacity: 300 passengers
Maximum speed: 140 km/hr.

Annual Costs – Passenger Rail – UC Davis Study

Hydrogen fuel technology cost is slightly higher than the diesel, LNG, and biodiesel, but much less than catenary electric technology

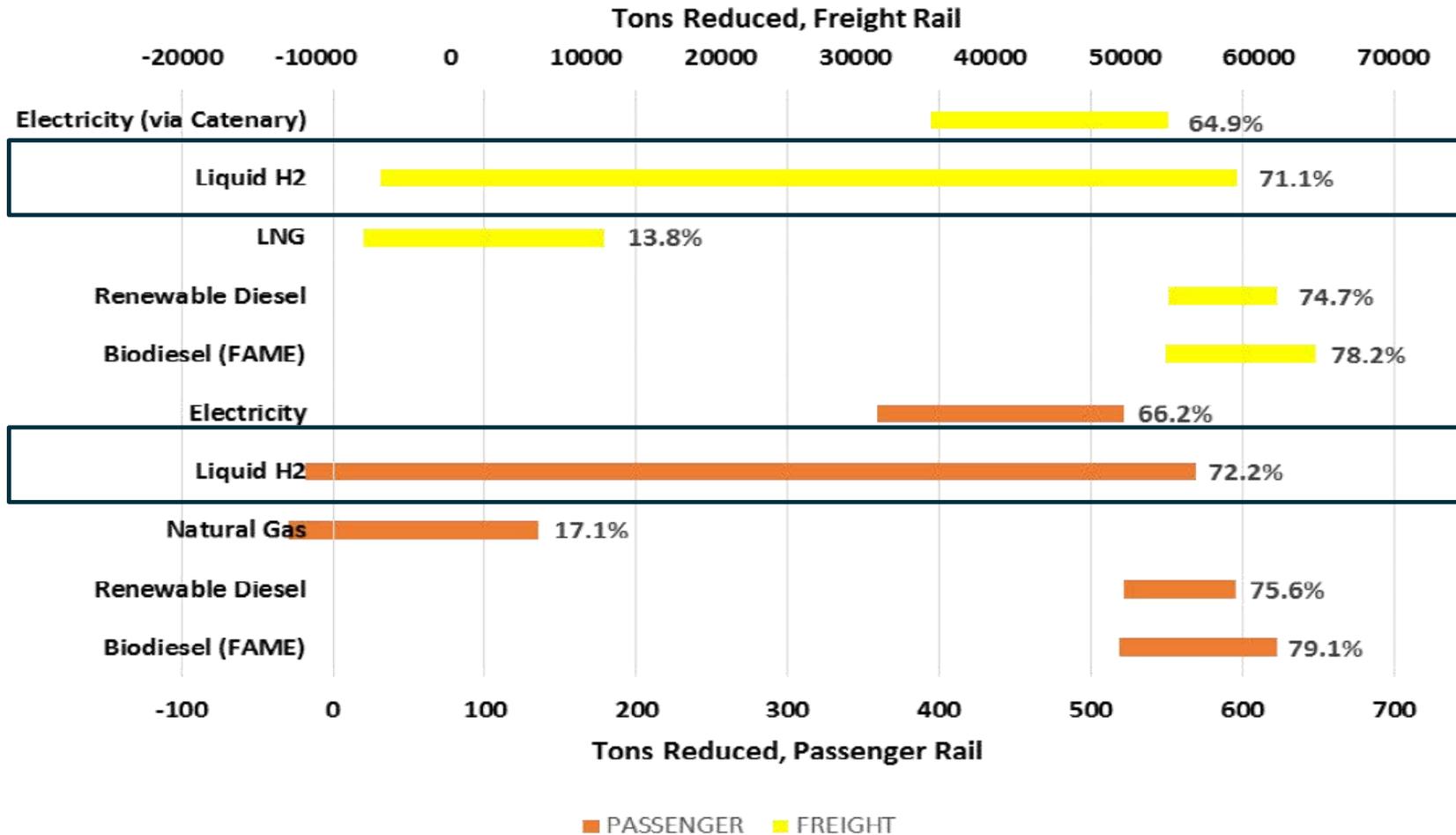


Assumptions:
Liquid Hydrogen Cost: \$5.16-\$9.03/gallon
Vehicle Cost: \$8.05-\$9.95 million/locomotive + Tender car

Source: Isaac, Raphael et al. UC Davis (2016)

Emissions Reduced - Passenger and Freight Rail

Potential: 70% reduction with hydrogen via electrolysis with CA grid mix



Source: Isaac, Raphael et al. UC Davis (2016)

The background of the slide features a silhouette of three people climbing a mountain. One person is at the base on the left, another is in the middle, and a third is near the top on the right, holding a flag on a tall pole. The sky is a mix of blue and orange, suggesting a sunset or sunrise. The title text is overlaid in the center.

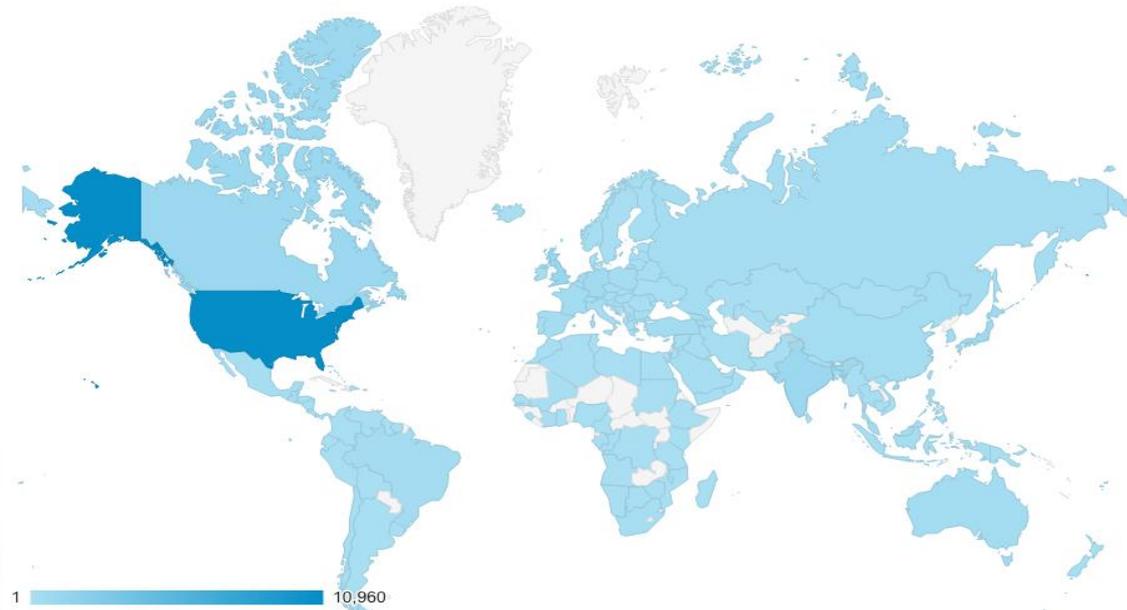
Collaboration and Resources

DOE Resources: H₂ Safety Information Sharing

H₂Tools.org : A one stop resource for hydrogen safety



h2tools.org



- Site visit tracking shows a **global reach: 50% of visits are international!**
- Over **31,000 site visits** in the first year alone
- Training resource **translated into Japanese**

Collaboration Opportunities: Data Sharing

Data Validation of Real World Applications through the NREL's NFCTEC

- Data products provide insights on technology improvements, issues and gaps



NFCTEC: The National Fuel Cell Technology Evaluation Center

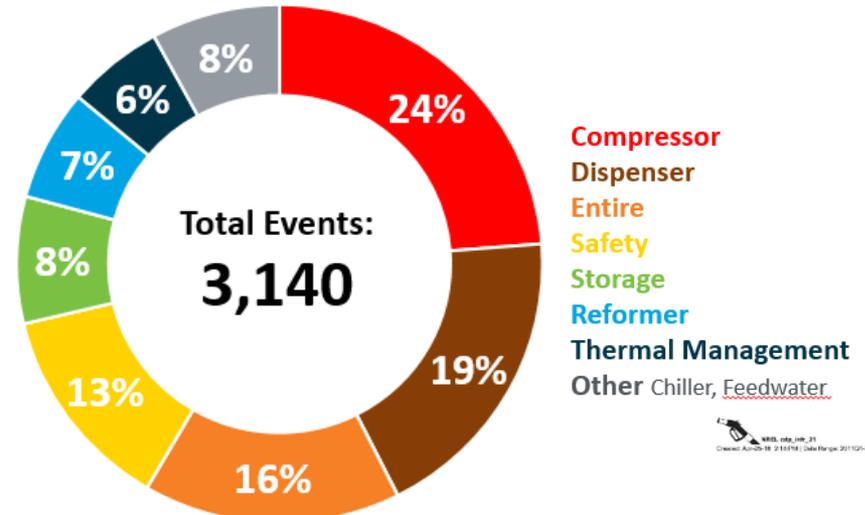
To Participate

techval@nrel.gov

Models “Toolbox” Online

- Financial, technical and economic models covering H₂ infrastructure, jobs, and more.
- Visit: energy.gov/eere/fuelcells/hydrogen-analysis-toolbox

Example: Sources of H₂ Infrastructure Maintenance



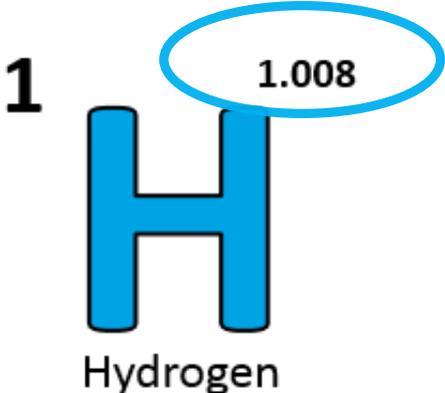
Most maintenance related to **compressors** and **dispensers**

Collaboration Tools: Increasing Awareness

Celebrate Hydrogen & Fuel Cell Day October 8 or 10/8

(Held on its very own atomic- weight-day)

Share Information using ready-to-use H₂ and fuel cell training resources



INCREASE YOUR
H₂IQ



h2tools.org

Learn more:
energy.gov/eere/fuelcells

Download slide deck for free at at:
energy.gov/eere/fuelcells/downloads/increase-your-h2iq-training-resource



FUEL CELL

Powered by
Hydrogen Fuel Cells

Thank You

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energy.gov/eere/fuelcells