U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Hydrogen and Fuel Cells: Progress and Opportunities

Sunita Satyapal, Director – Fuel Cell Technologies Office

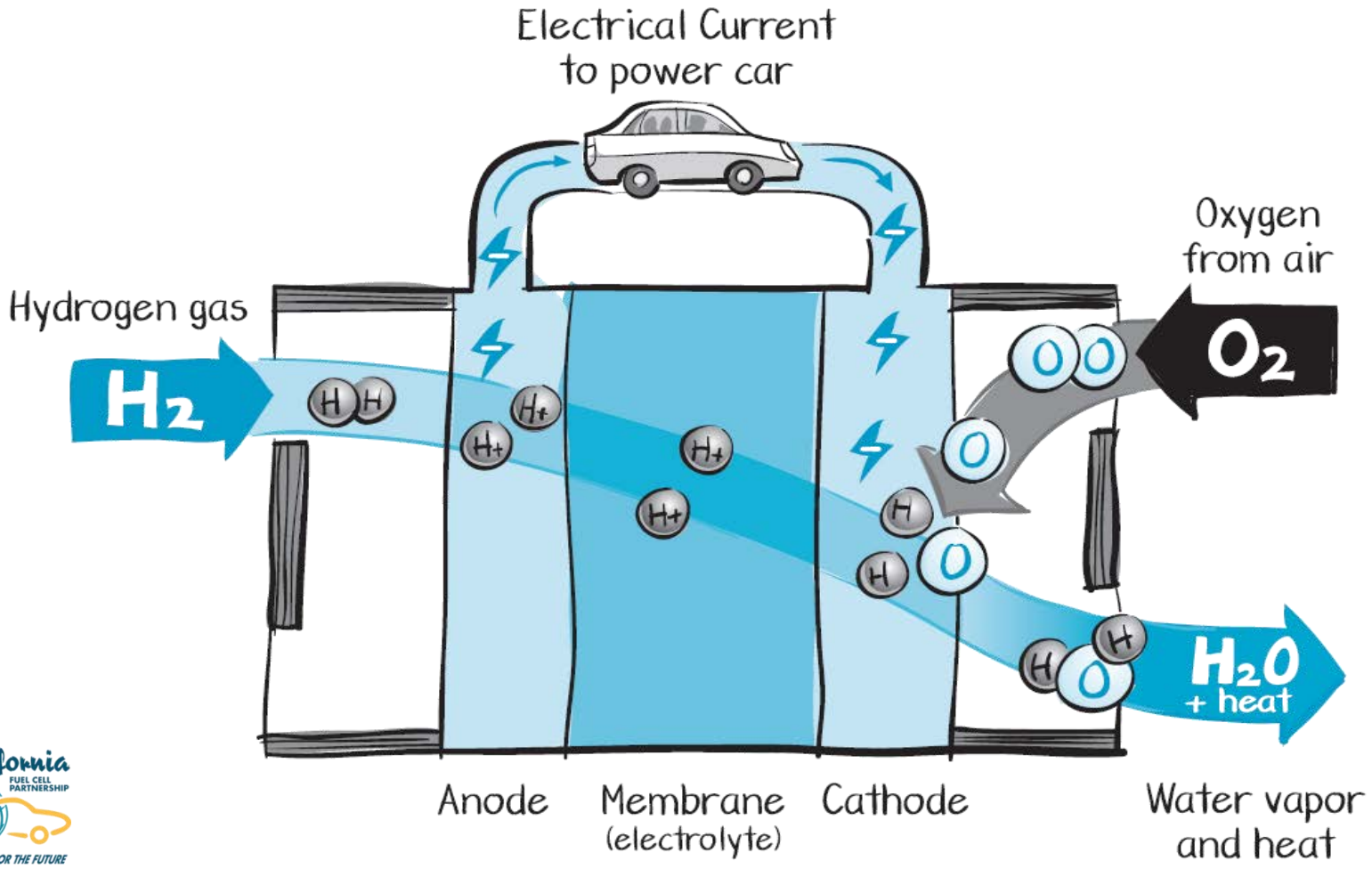
Hydrail Symposium

Ontario, Canada – November 16, 2017

Basics

What is a fuel cell?

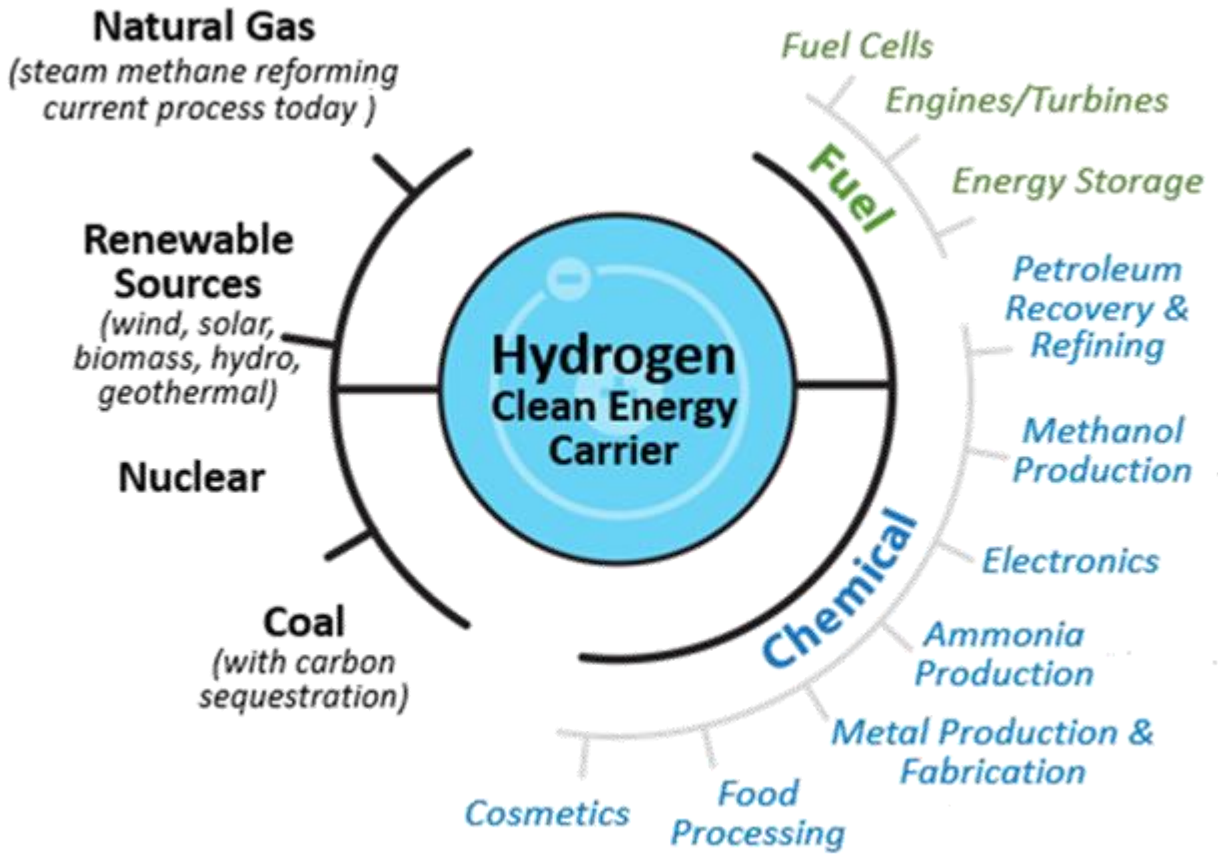
Takes hydrogen in and puts electricity and water vapor out



California FUEL CELL PARTNERSHIP
DRIVING FOR THE FUTURE

What is Hydrogen?

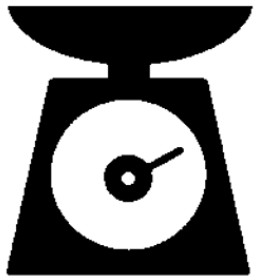
Hydrogen is an energy carrier: Used as fuel or feedstock



Produced from diverse domestic resources and used in many applications

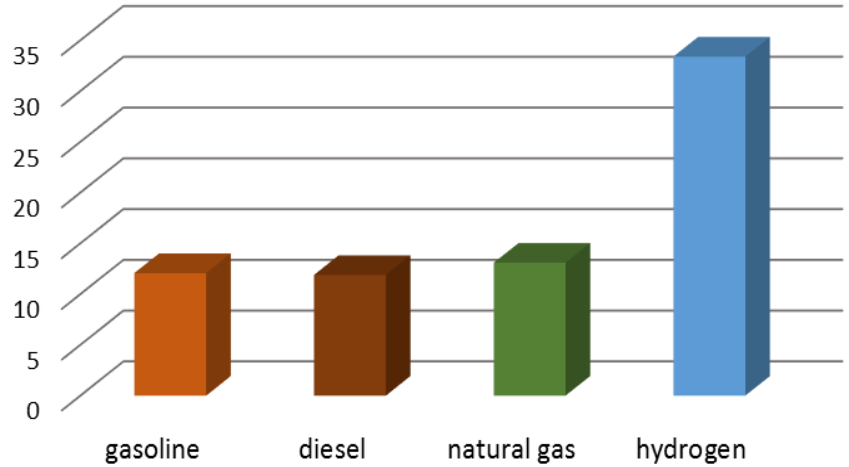
Hydrogen's Energy Content

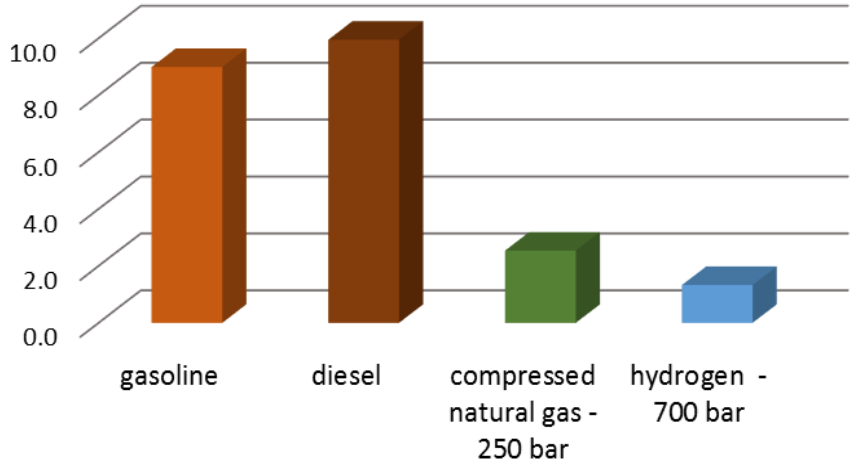
High Energy by Mass, Low Energy by Volume



Approx.
3X more
energy content
by mass
than gasoline

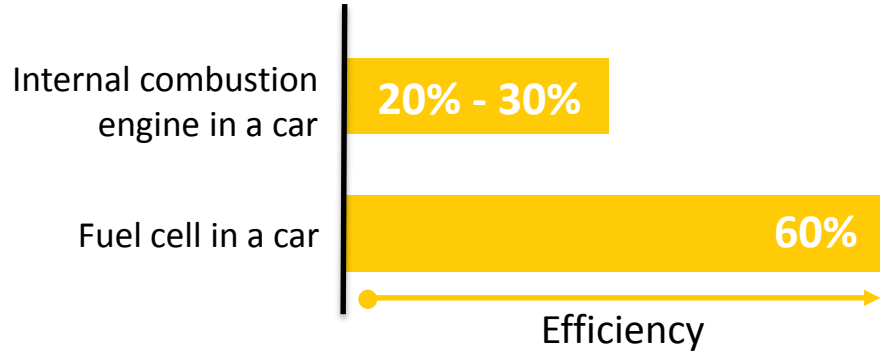
Approx.
4X less
energy content
by volume
than gasoline





Why Hydrogen and Fuel Cells?

Efficient



Uses domestic fuels

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

Convenient

Refuels in minutes

Quiet

No noise in operation

Clean

Zero tailpipe emissions

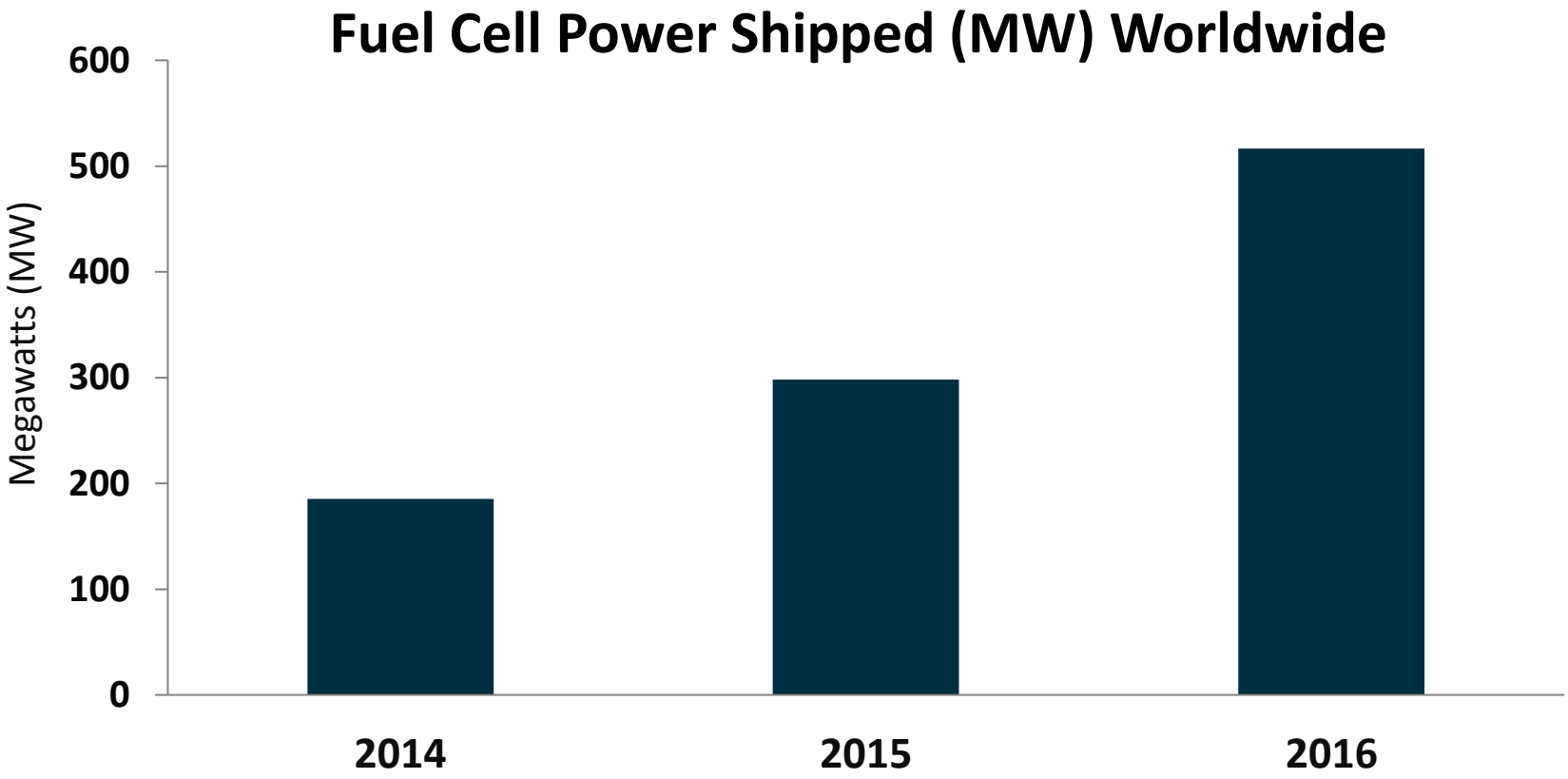
Versatile and easily scalable

Transportation

Stationary


Progress

Consistent Fuel Cell Market Growth Continues



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

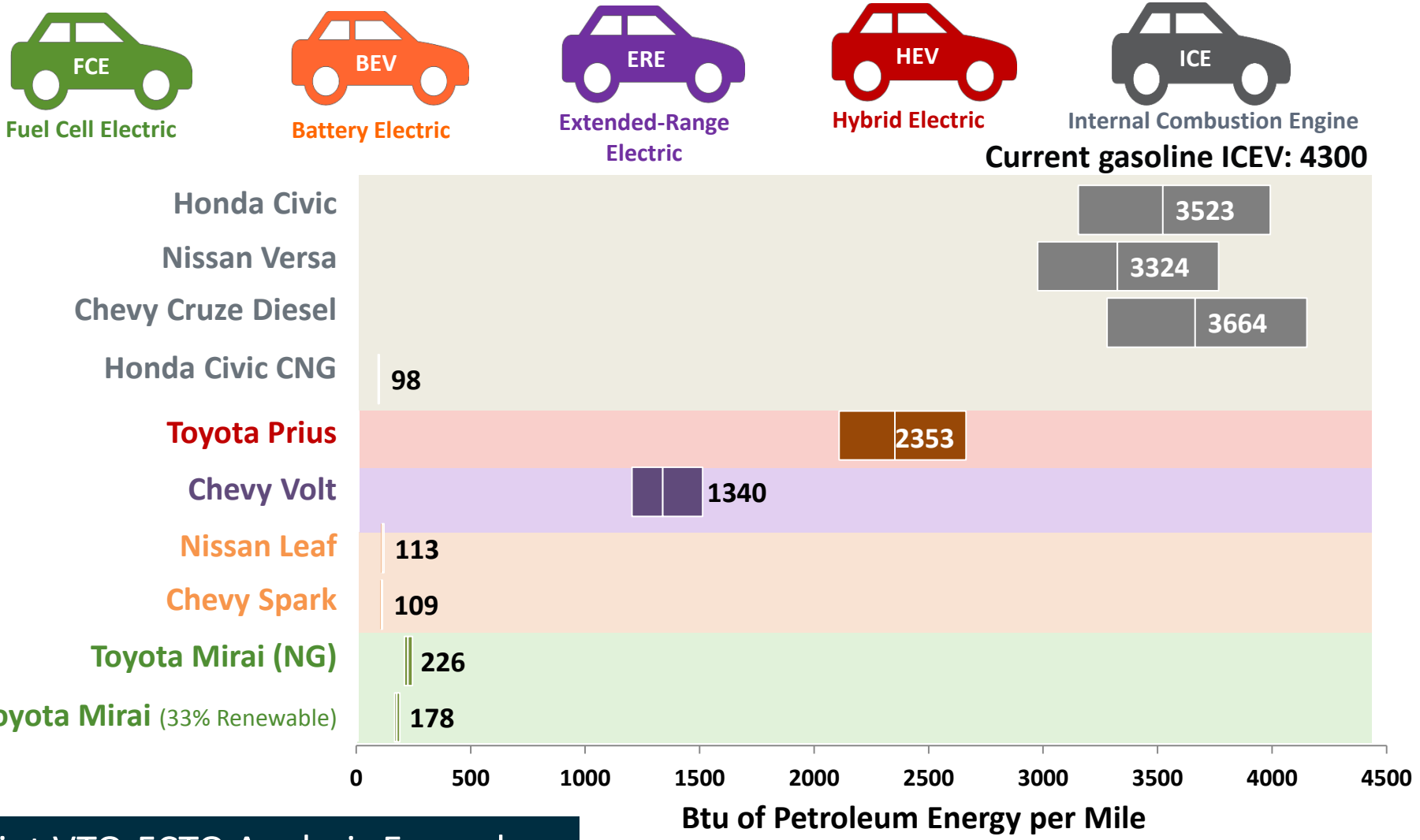
Commercial **fuel cell electric cars are here!**

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

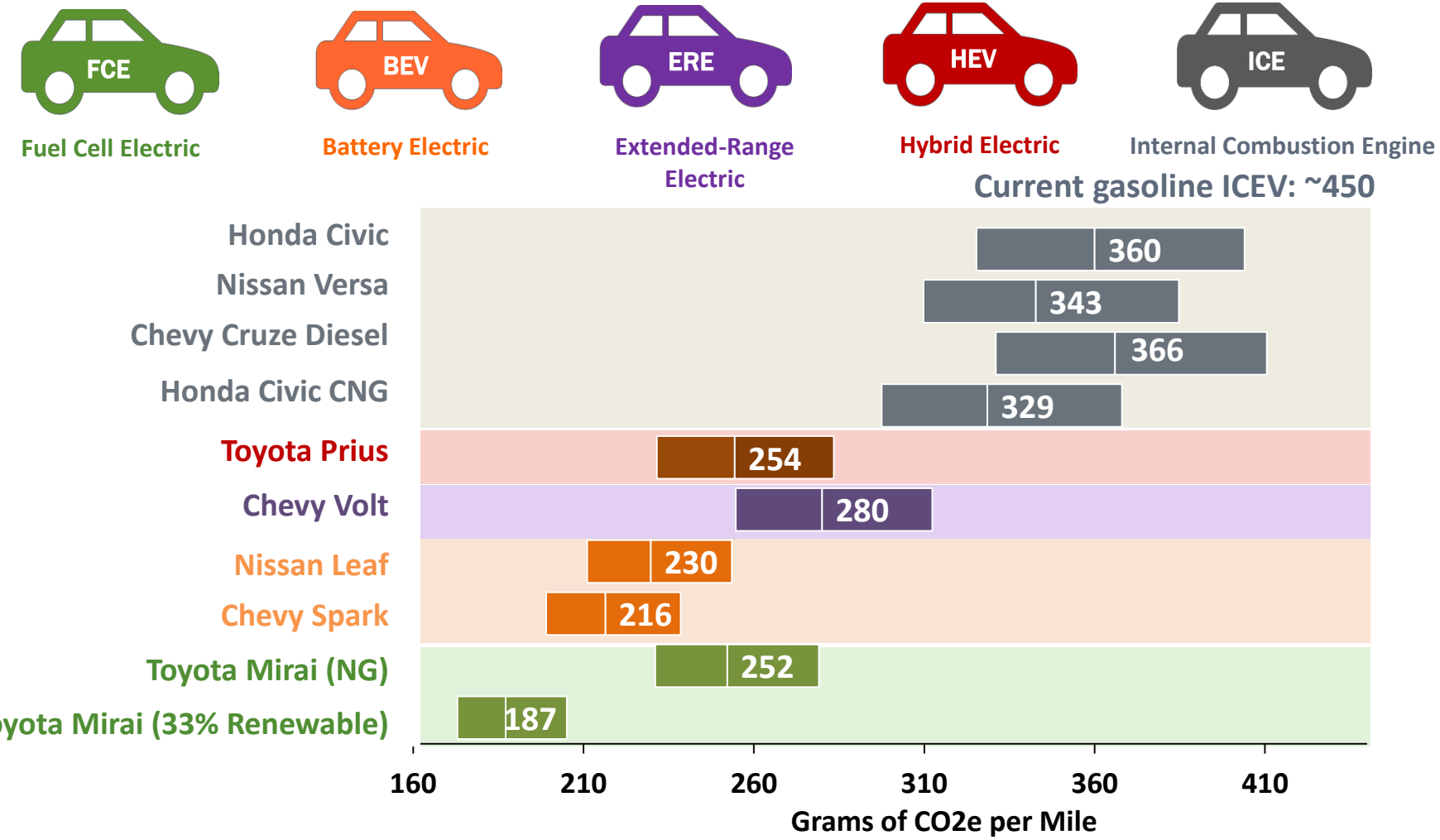


Joint VTO-FCTO Analysis Example

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



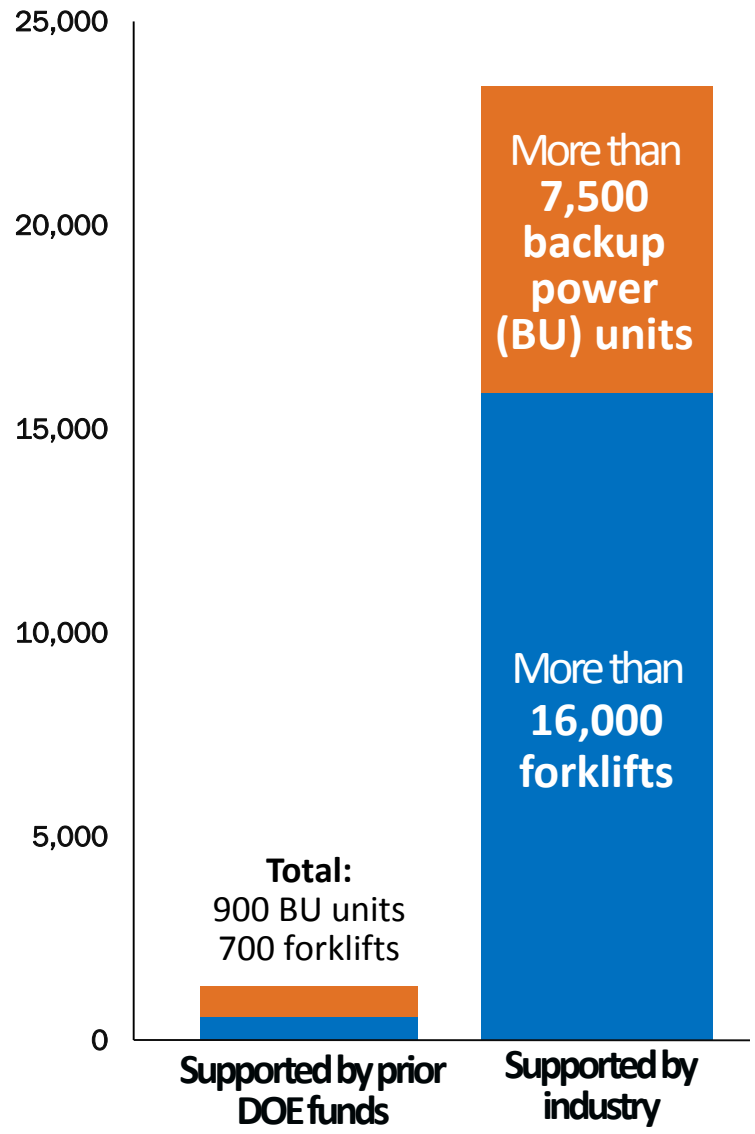
Joint VTO-FCTO Analysis Example

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

Catalyzing Early Markets for Fuel Cells

Credit: BMW Manufacturing


Credit: Fuel Cell Energy



Heavy Duty Vehicle Applications Emerging- Examples

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

Fuel cell buses in CA surpass 17M passengers

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 cells used to power new World Trade Center in NYC

Fuel cell power for maritime ports demonstrated in Honolulu, Hawaii

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

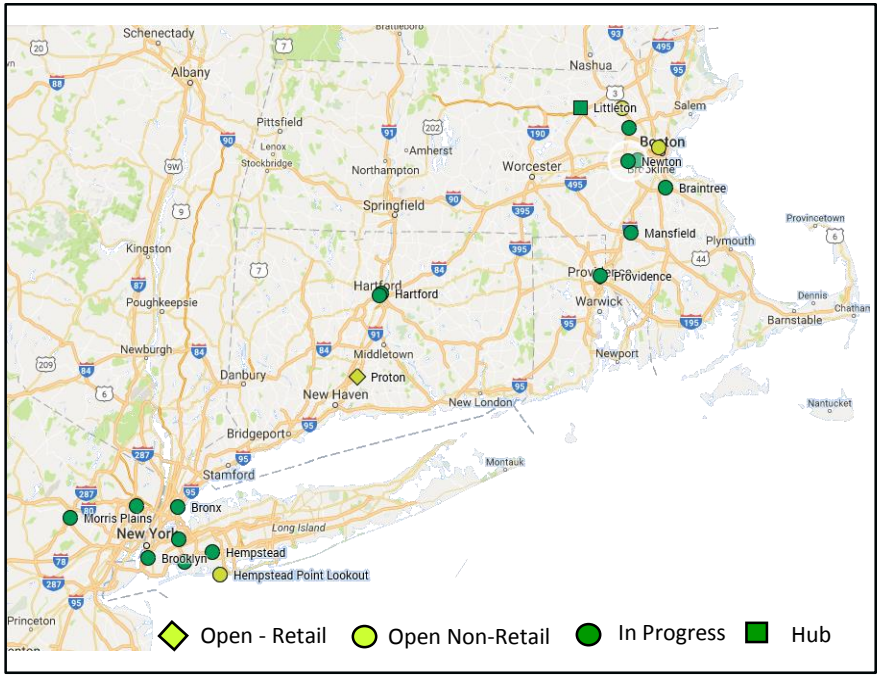
Photo Credit: Fukuoka Pref.

U.S. Hydrogen Refueling Stations

California

Over 30 open retail

Funding for 100



Northeast

Approx. 12 to 25 stations planned

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

Global Expansion of Infrastructure

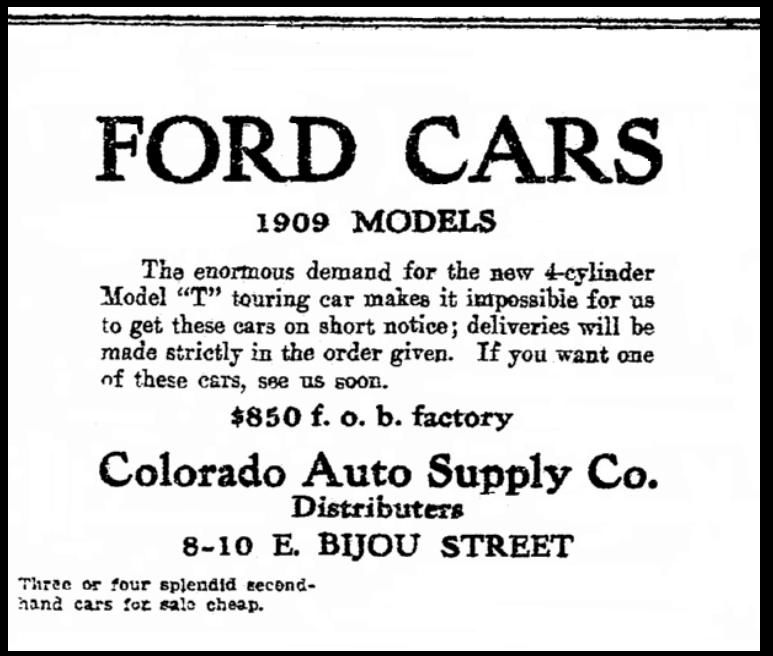
Examples:

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


Challenges

What can we learn from history?

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



FORD CARS

1909 MODELS

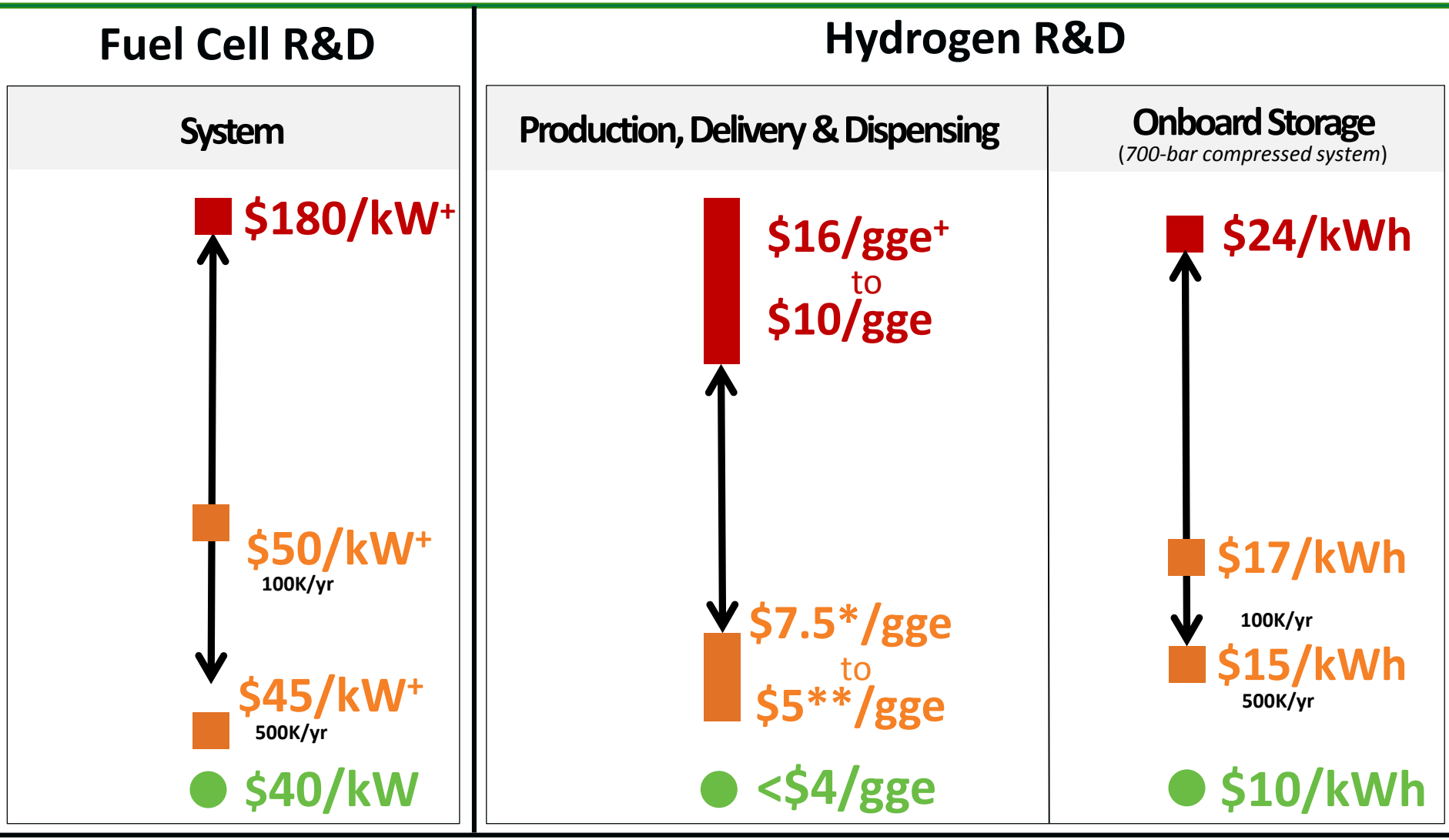
The enormous demand for the new 4-cylinder Model "T" touring car makes it impossible for us to get these cars on short notice; deliveries will be made strictly in the order given. If you want one of these cars, see us soon.

$850 f. o. b. factory

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

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

DOE Cost Status and Targets for R&D



*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

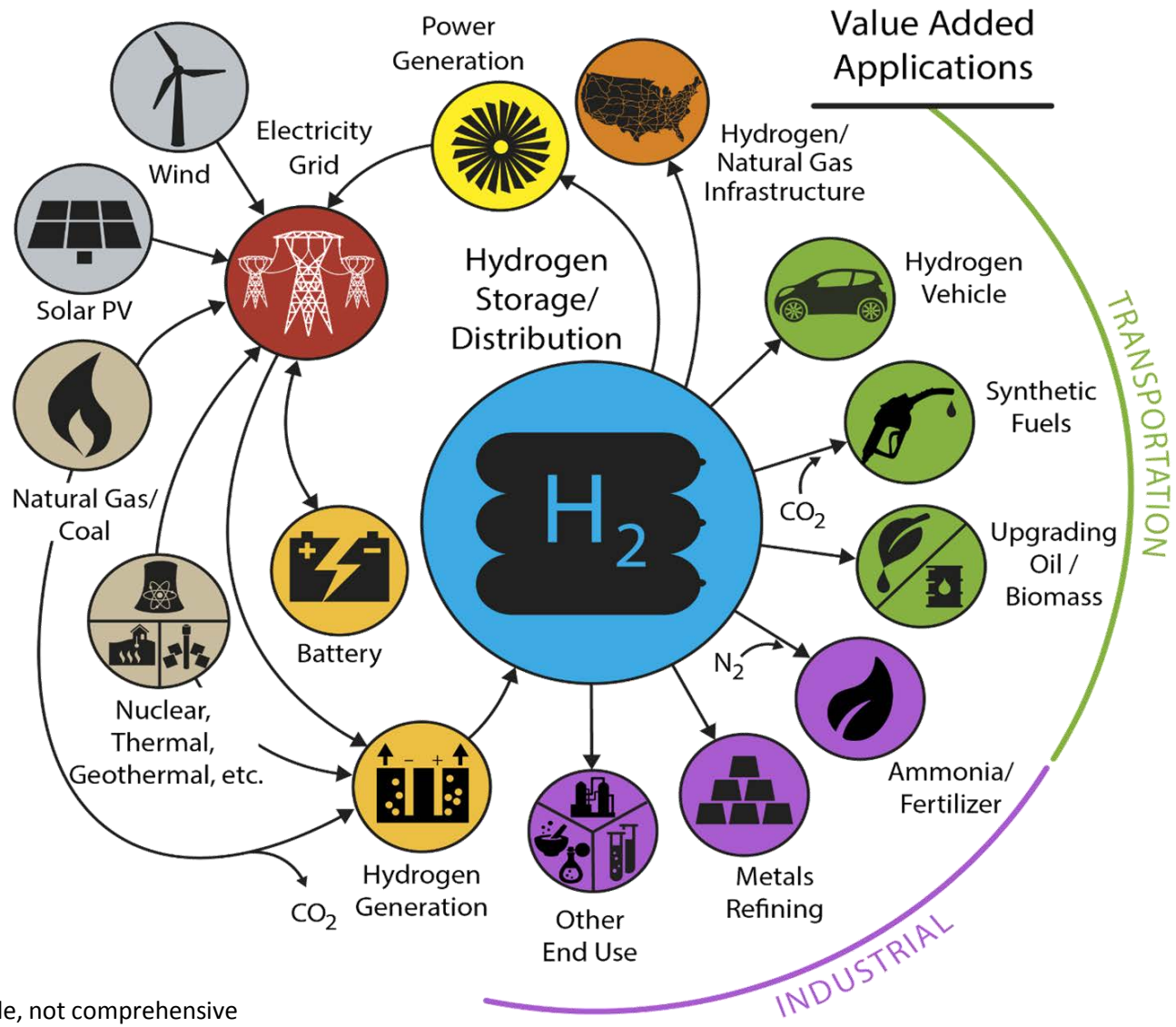
The Hydrogen Infrastructure Challenge

- Cost
- Reliability
- Availability

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

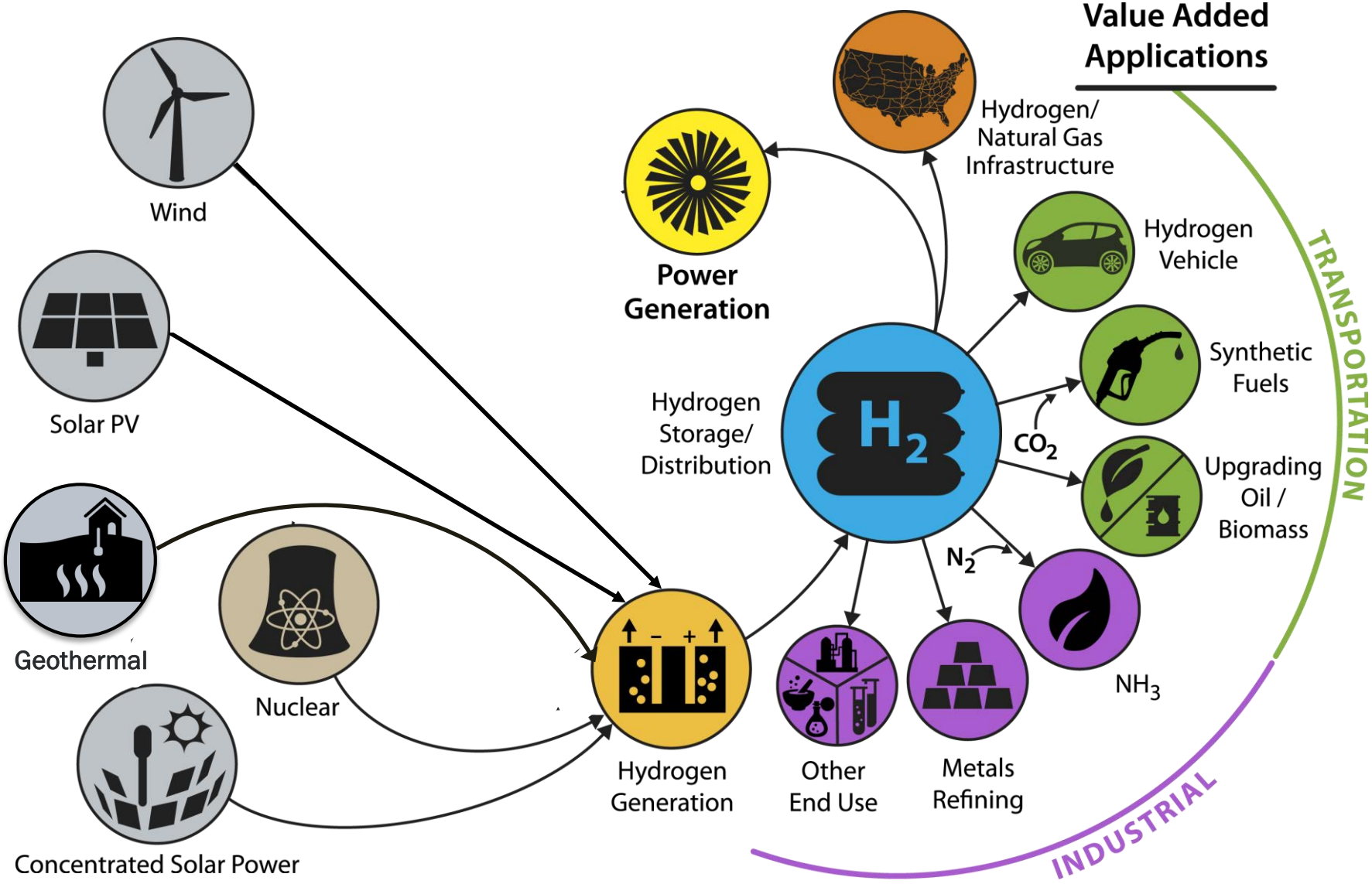

Opportunities

H_2 at Scale Energy System



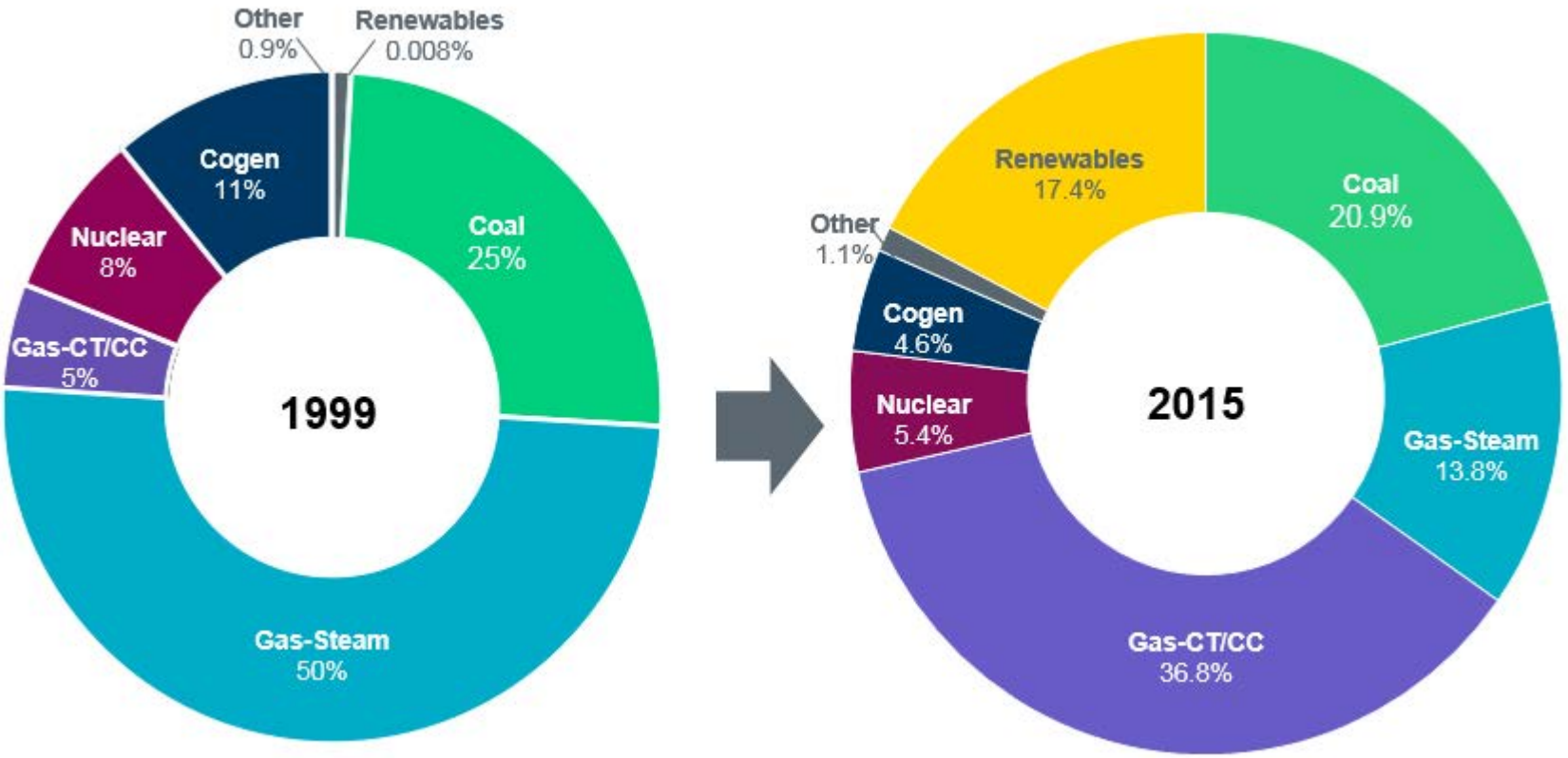
*Illustrative example, not comprehensive
Source: NREL

H_2 at Scale Energy System



Changing Energy Resource Mix for Electricity - Example

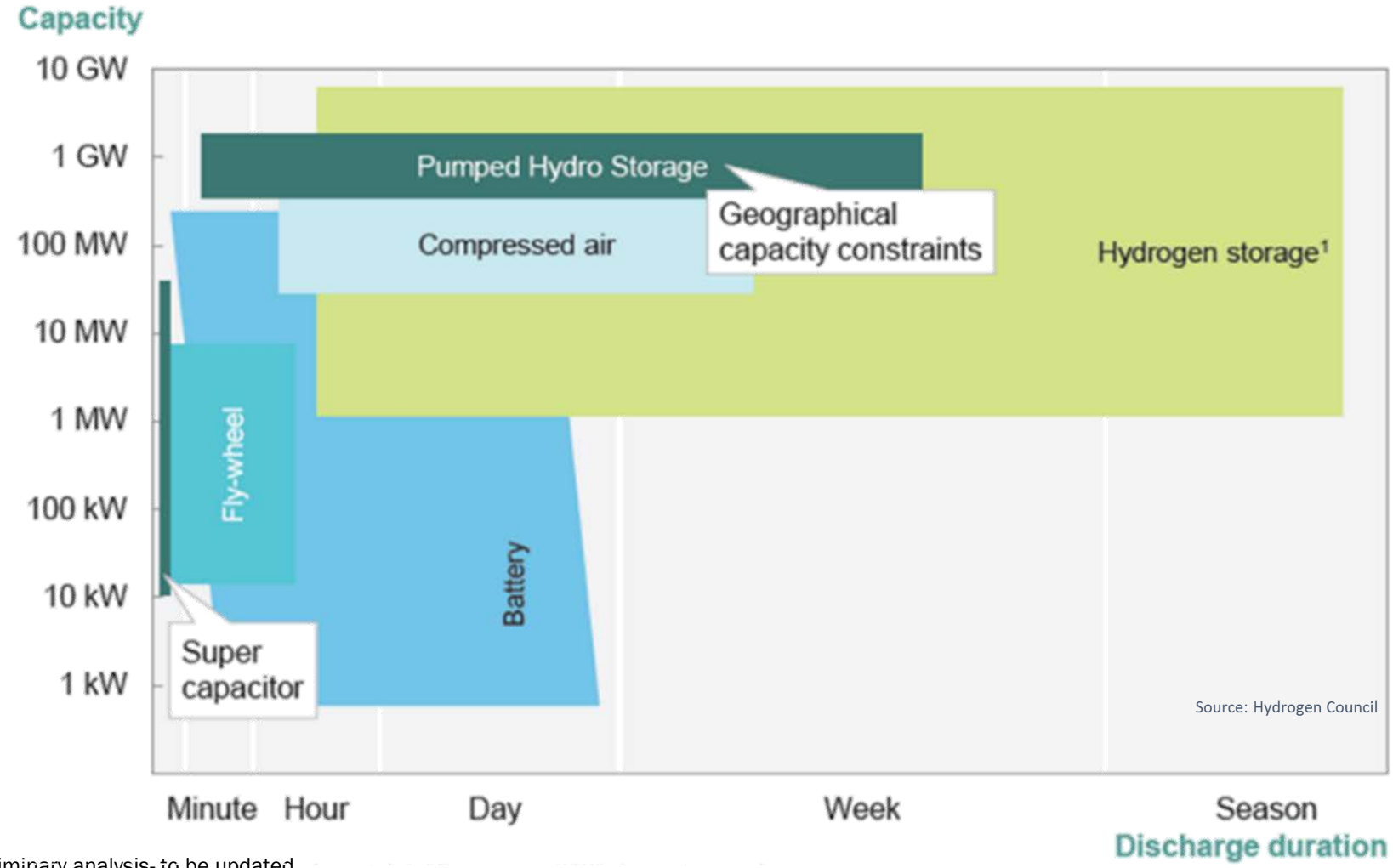
Installed Capacity in Texas



Source: ERCOT

Hydrogen as a medium for storing intermittent energy

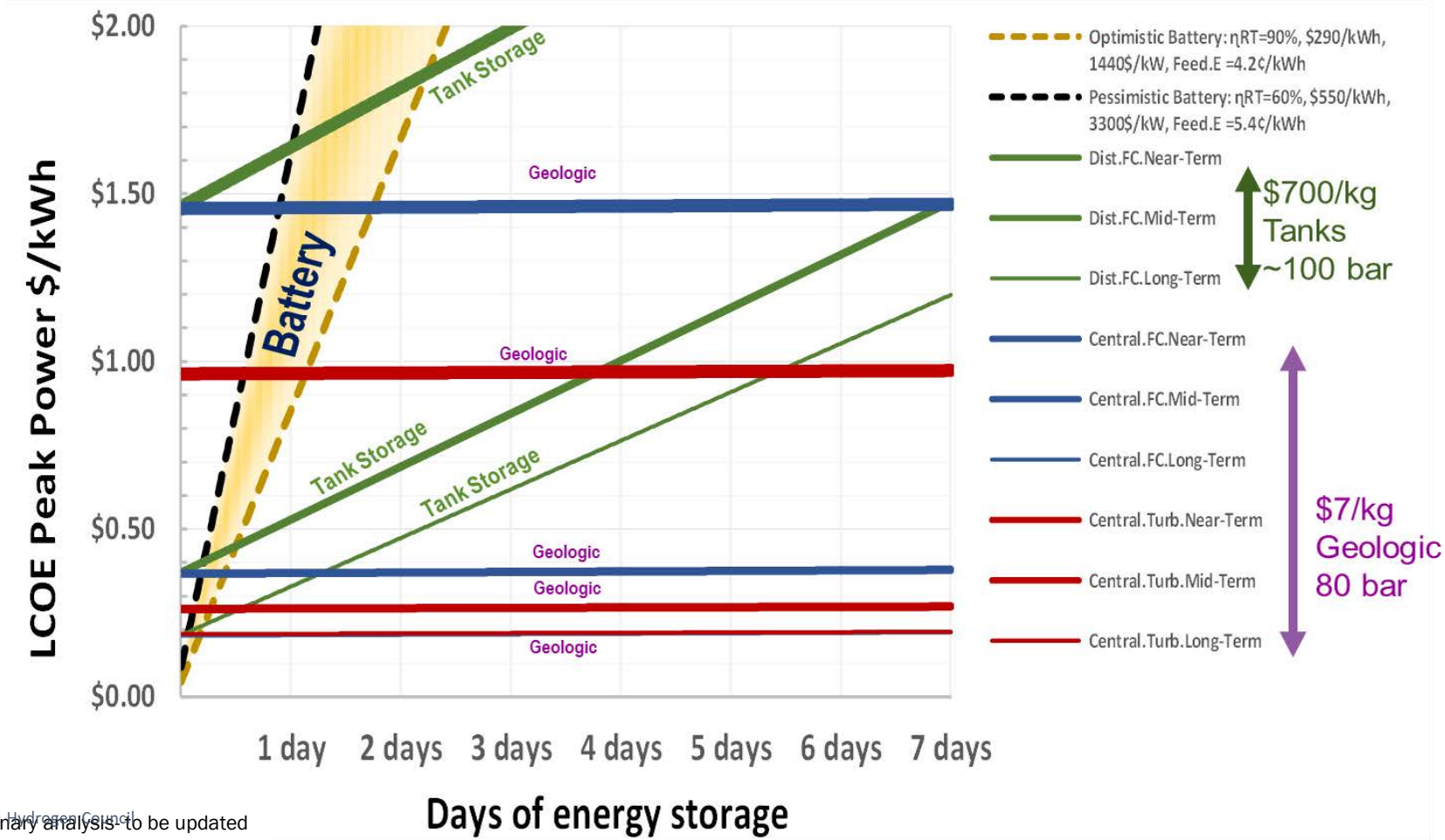
Gigawatt-scale energy storage and long discharge duration



Preliminary analysis- to be updated

Example of H_2 and Electrolyzer Benefits

H_2 can be cost effective for long duration storage



Source: Hydrogen Council

Preliminary analysis - to be updated

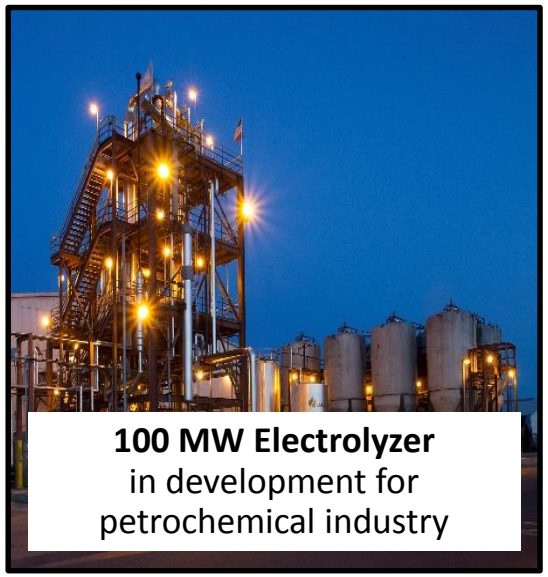
Examples: Large-scale Hydrogen Projects Worldwide

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

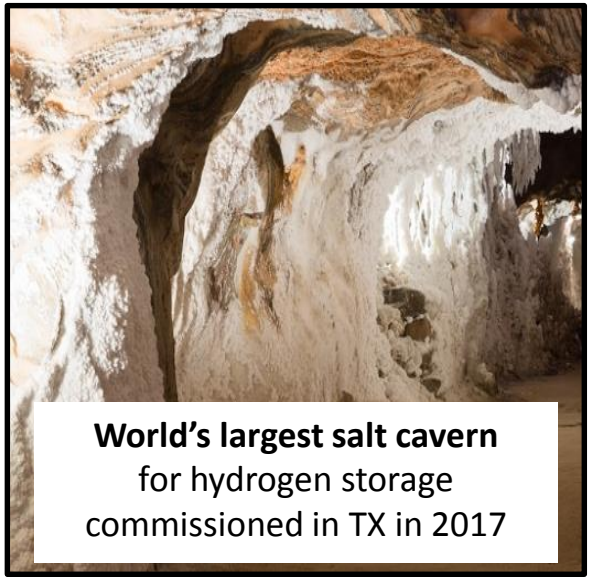
Austria 2017: 6-MW electrolyzer for steel plant

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 H_2

The Hydrogen Council

Investment

Over $10B

towards

hydrogen and fuel cells

Members

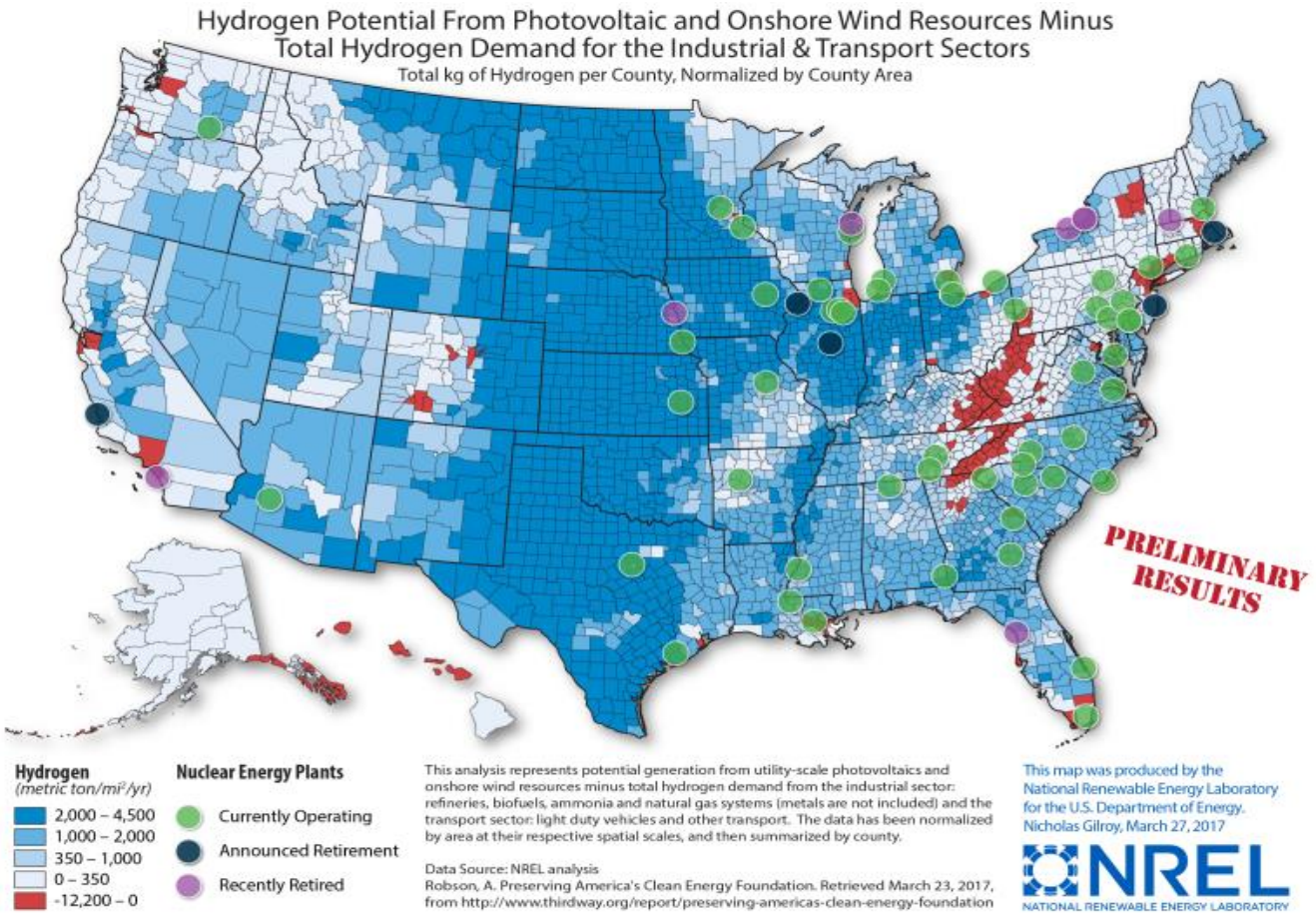
Over 20 companies

representing

Over $1.3T in revenues and 2.06M jobs

More information: hydrogeneurope.eu

H2@Scale: Nationwide Resource Assessment



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

Labs assess resource availability. Most regions have sufficient resources.

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


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.

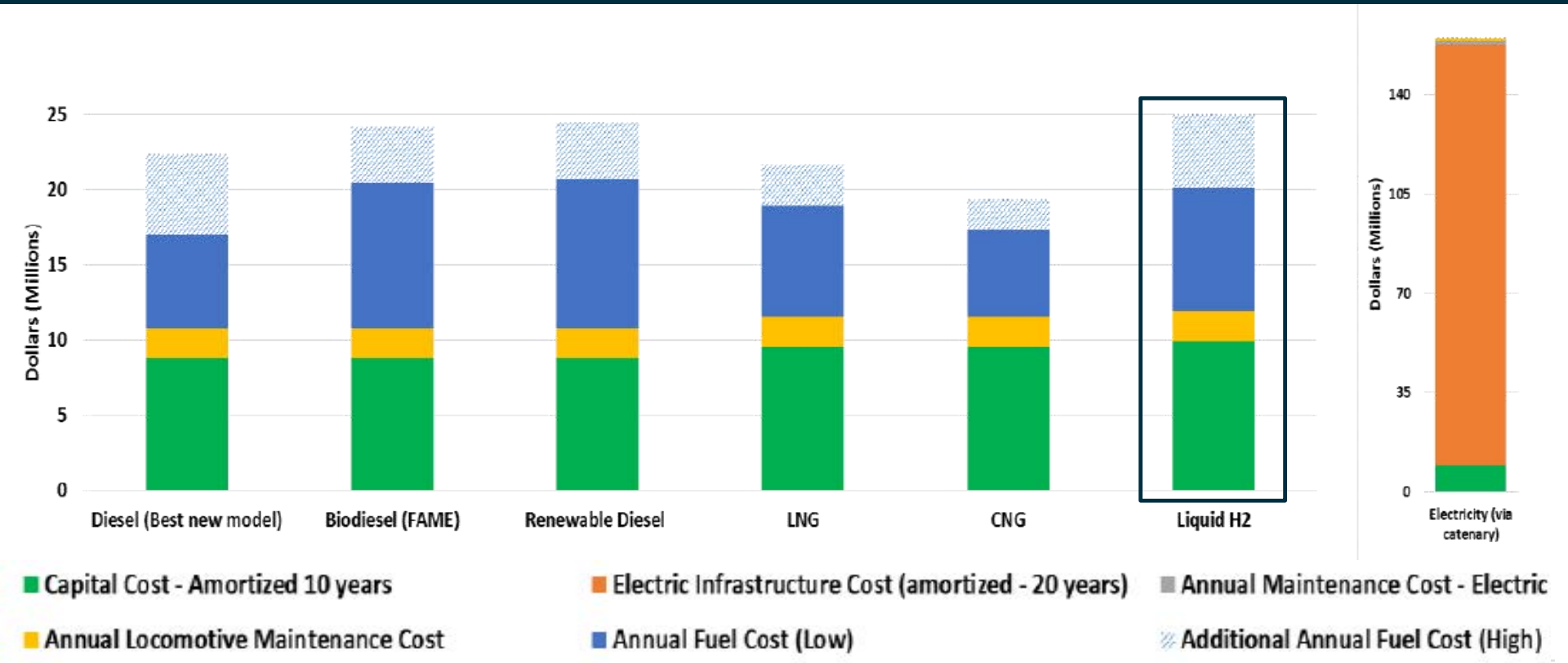
Germany

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

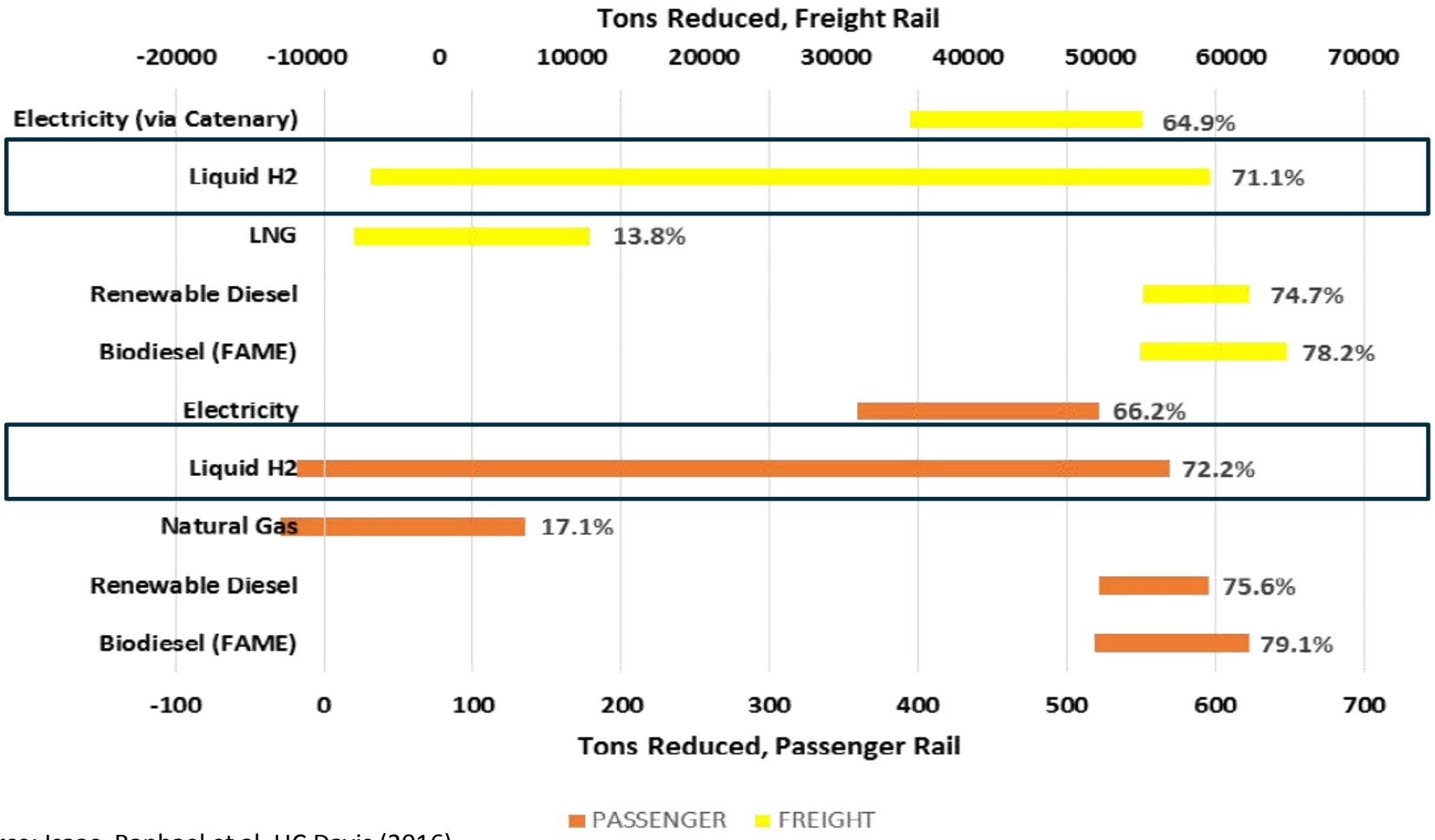


Assumptions:
Liquid Hydrogen Cost: $5.16-$9.03/gallon
Vehicle Cost: $8.05-$9.95 million/locomotive + Tender car

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



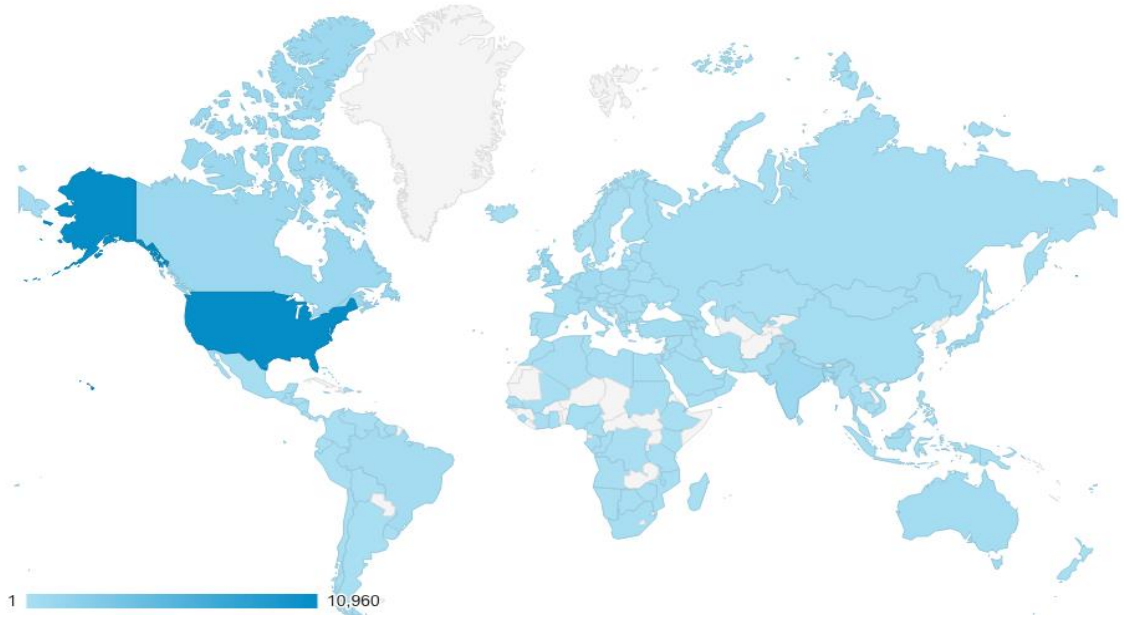
Source: Isaac, Raphael et al. UC Davis (2016)


Collaboration
and Resources

DOE Resources: H_2 Safety Information Sharing

H_2Tools.org : A one stop resource for hydrogen safety

h2tools.org



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

- 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

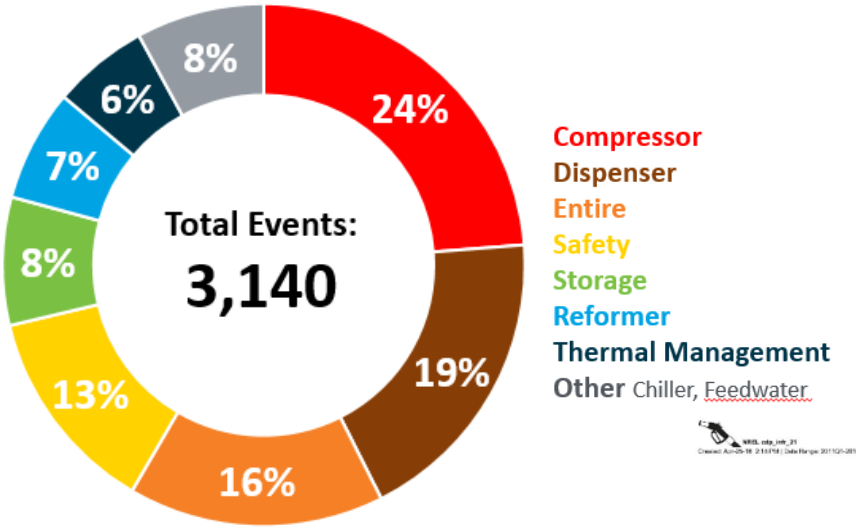
To Participate

techval@nrel.gov

Models "Toolbox" Online

- Financial, technical and economic models covering H_2 infrastructure, jobs, and more.
- Visit: **energy.gov/eere/fuelcells/hydrogen-analysis-toolbox**

Example: Sources of H_2 Infrastructure Maintenance



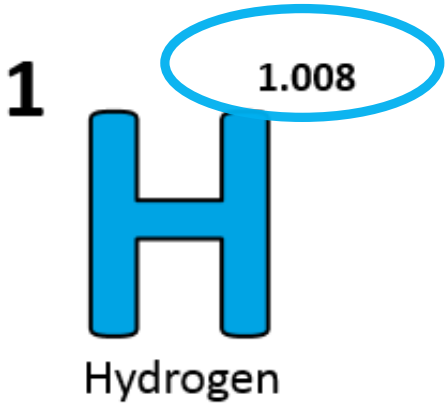
Most maintenance related to compressors and dispensers

Collaboration Tools: Increasing Awareness

Celebrate Hydrogen & Fuel Cell Day

October 8 or 10/8

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



Learn more:

energy.gov/eere/fuelcells

Share Information

using ready-to-use H_2 and fuel cell training resources

h2tools.org

Download slide deck for free at at:

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