U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Hydrogen and Fuel Cells Perspective and Opportunities

Sunita Satyapal – Director, Fuel Cell Technologies Office

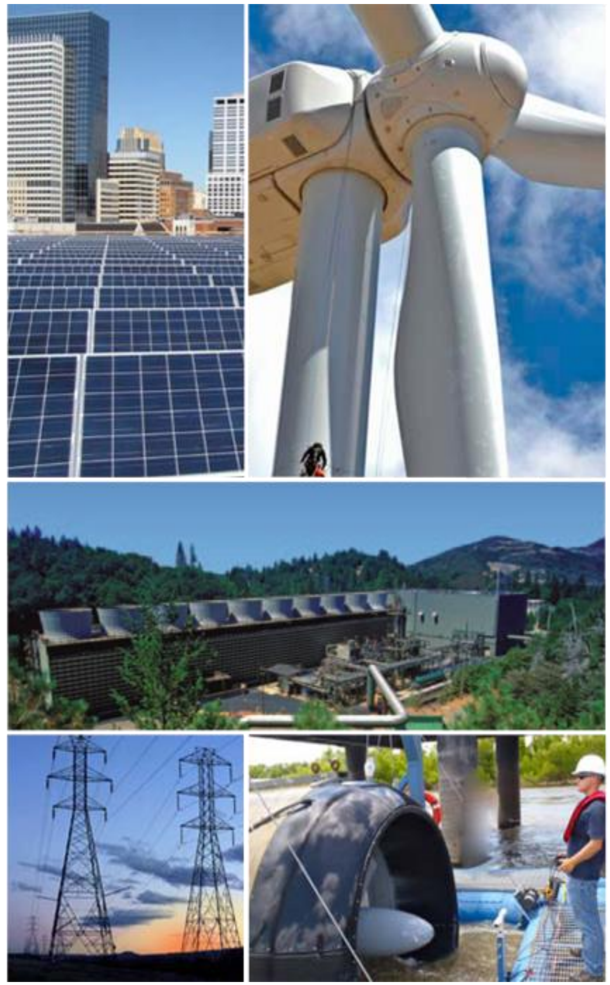
American Nuclear Society Meeting – Nuclear Hybrid Systems Panel

Washington, D.C. – Oct. 30, 2017

Office of Energy Efficiency & Renewable Energy (EERE)

Sustainable TRANSPORTATION

Renewable ELECTRICITY GENERATION



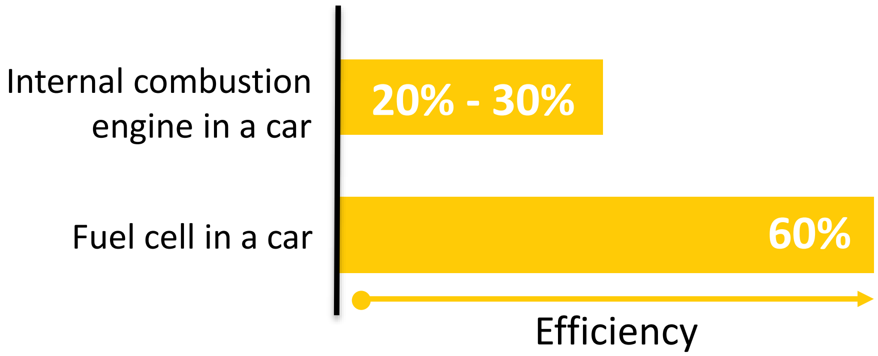
Energy Saving HOMES, BUILDINGS, & MANUFACTURING

Overview

- H_2 and Fuel Cell Intro
- Technology Status
- Key Focus Areas and Opportunities

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

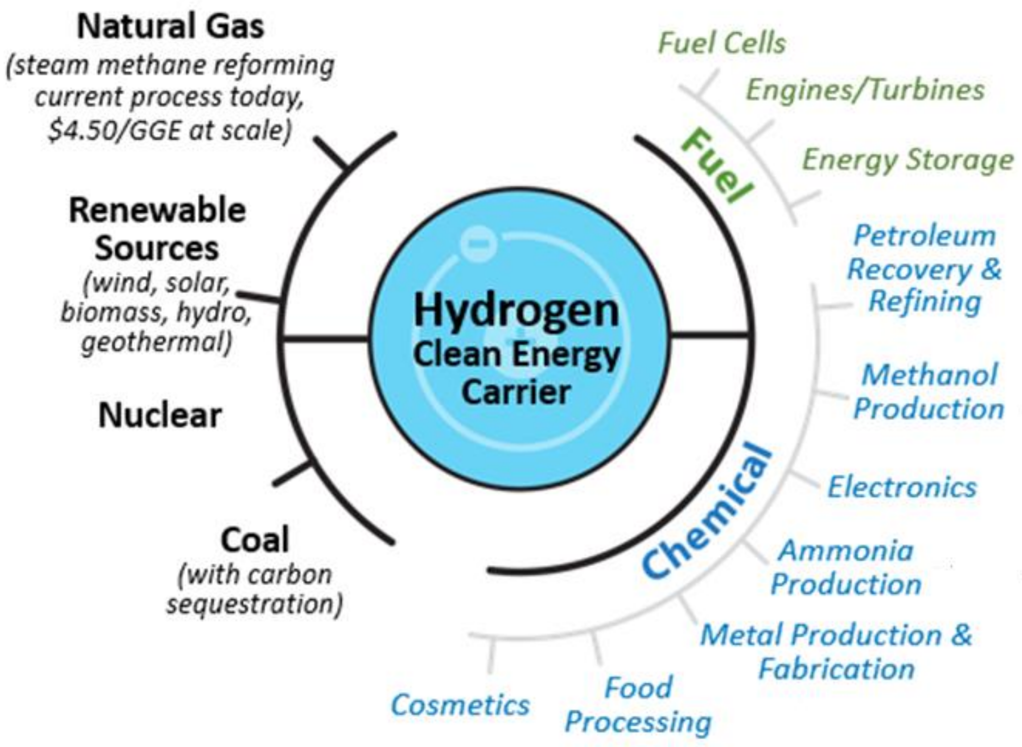
Transportation

Stationary

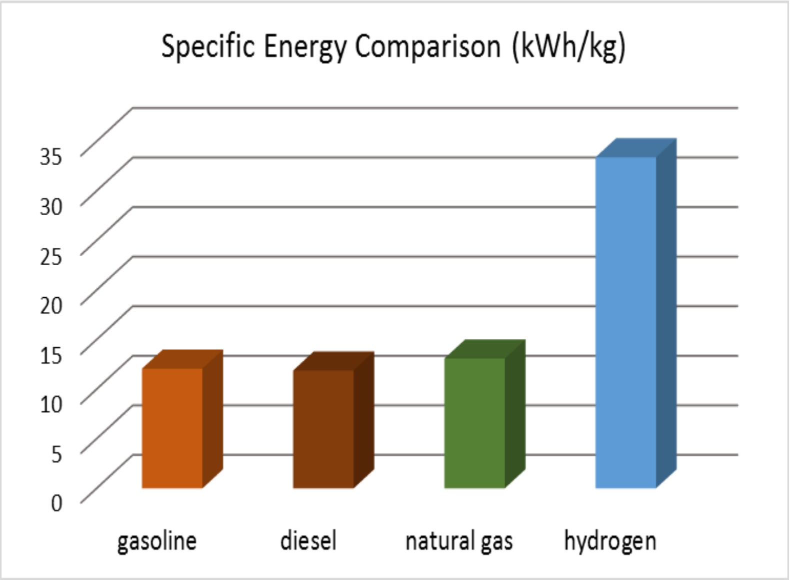
Hydrogen as an Energy Carrier

Multiple 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 gasoline. But worse in terms of volume.

Clean , sustainable, versatile, and efficient energy carrier

The Beginning of the DOE Fuel Cell Program…

1970s | **A group from labs, government and industry met at Los Alamos to set the foundation for DOE fuel cell programs**

Lab researchers taught scientists around the world how to fabricate fuel cell electrodes. Group from GM relocated to Los Alamos.

Forty years later, for the first time in history….

Hyundai Tucson Fuel Cell SUV

Toyota Mirai

Honda Clarity

Commercial
fuel cell electric cars are here!

Power, performance, petroleum-free, pollution-free

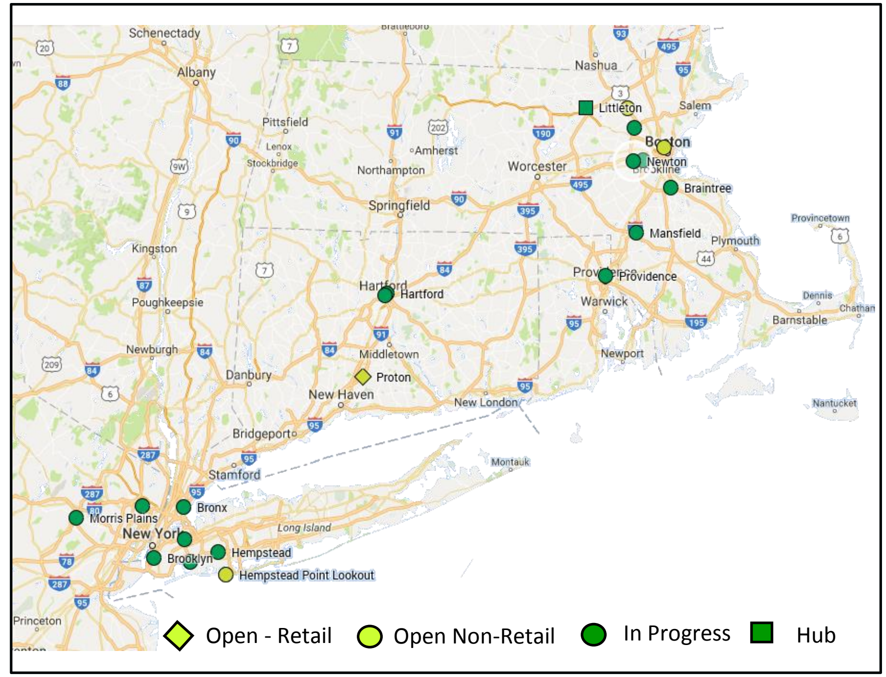
- **Refuels in minutes**
- **More than 360 mi driving range**
- **Over 60 mpgge**

Hydrogen refueling stations: strong State support

California

Over 30 open retail

Funding for 100



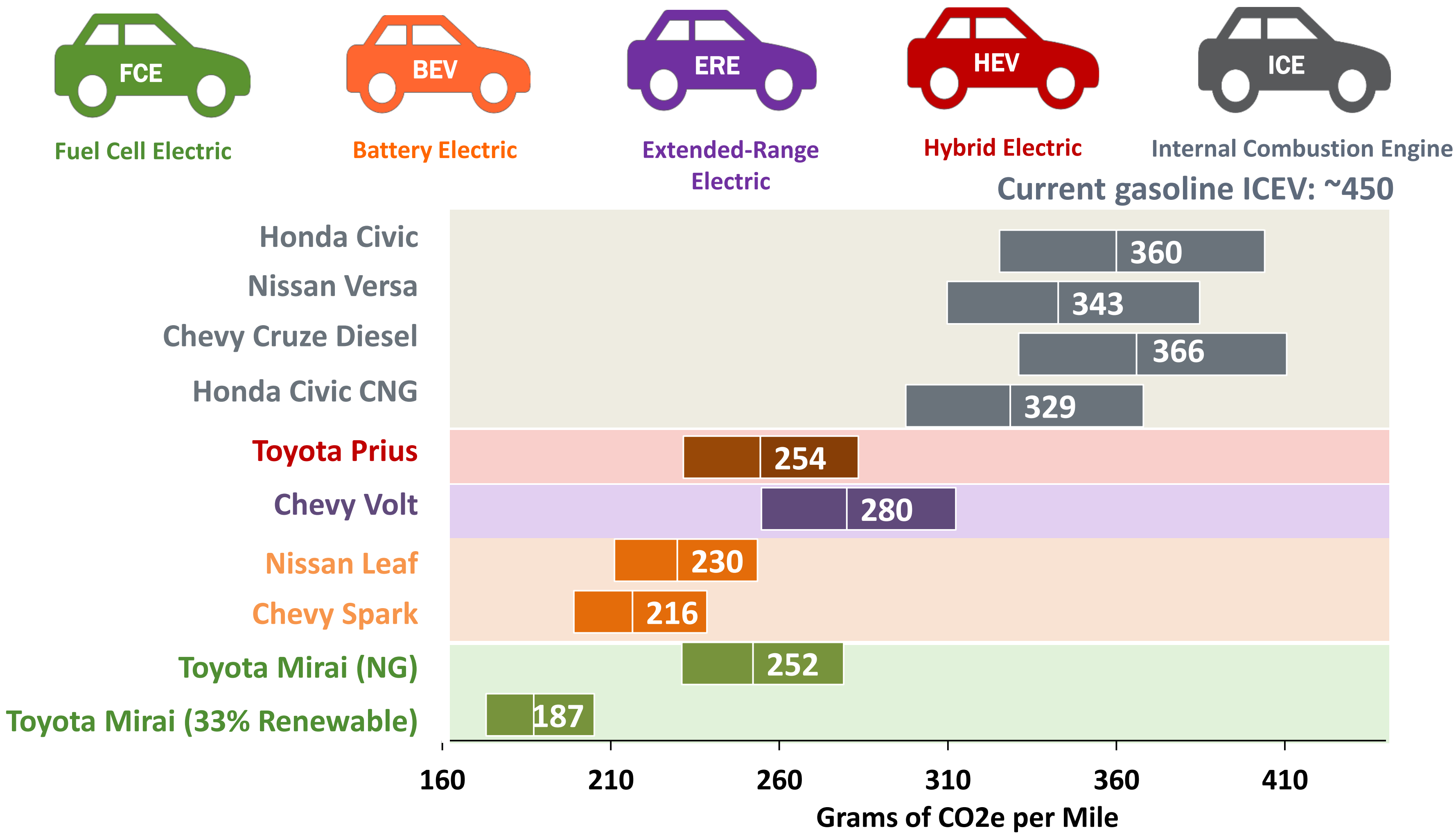
Northeast

Approx. 12 to 25 stations planned

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

Life-cycle Emissions- Today's Cars

Low, Medium & High Emissions/Mile for 2015 Technology

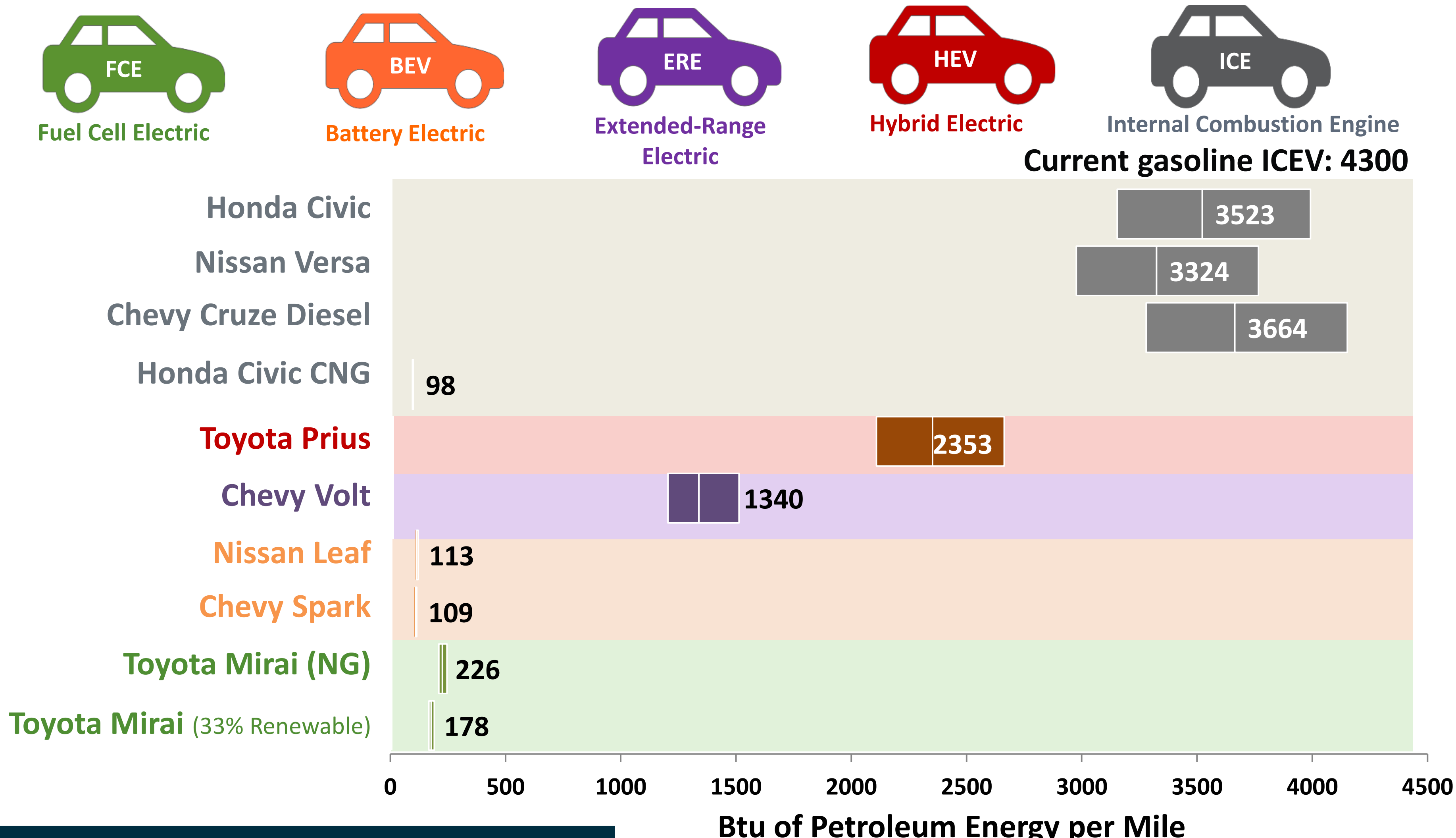


Joint VTO-FCTO Analysis Example

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

Life-Cycle Petroleum Use- Today's Cars

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



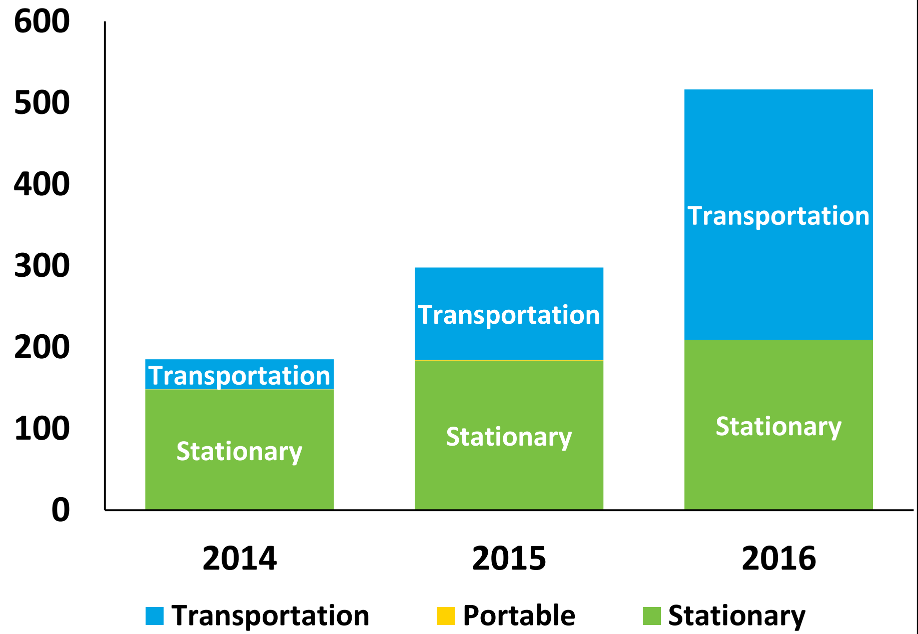
Joint VTO-FCTO Analysis Example

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

2016 Global Shipments – Trends

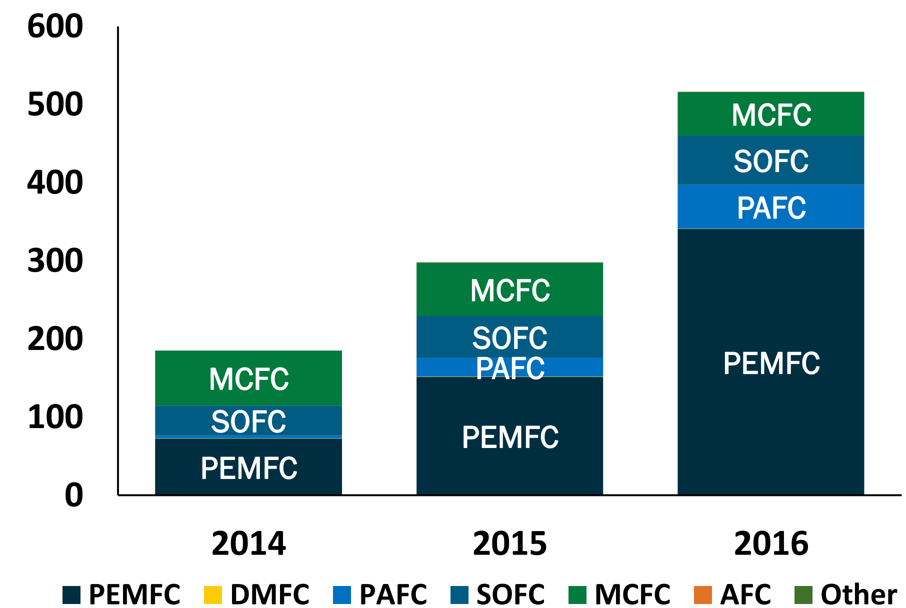
Total power (in MW) shipped by application

Growth in Transportation



Total power (in MW) shipped by fuel cell chemistry

Growth in PEMFC



500 MW
fuel cell power
shipped worldwide

62,000
fuel cell units
shipped worldwide

Approximately
$1.6 Billion
fuel cell revenue

Source: DOE Fuel Cell Technologies Market Report. Available at: https://energy.gov/eere/fuelcells/market-analysis-reports

Heavy Duty Vehicle Applications Emerging

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

ZH2: U.S. Army and GM collaboration First of its kind

Stationary Power Applications Emerging – Examples

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

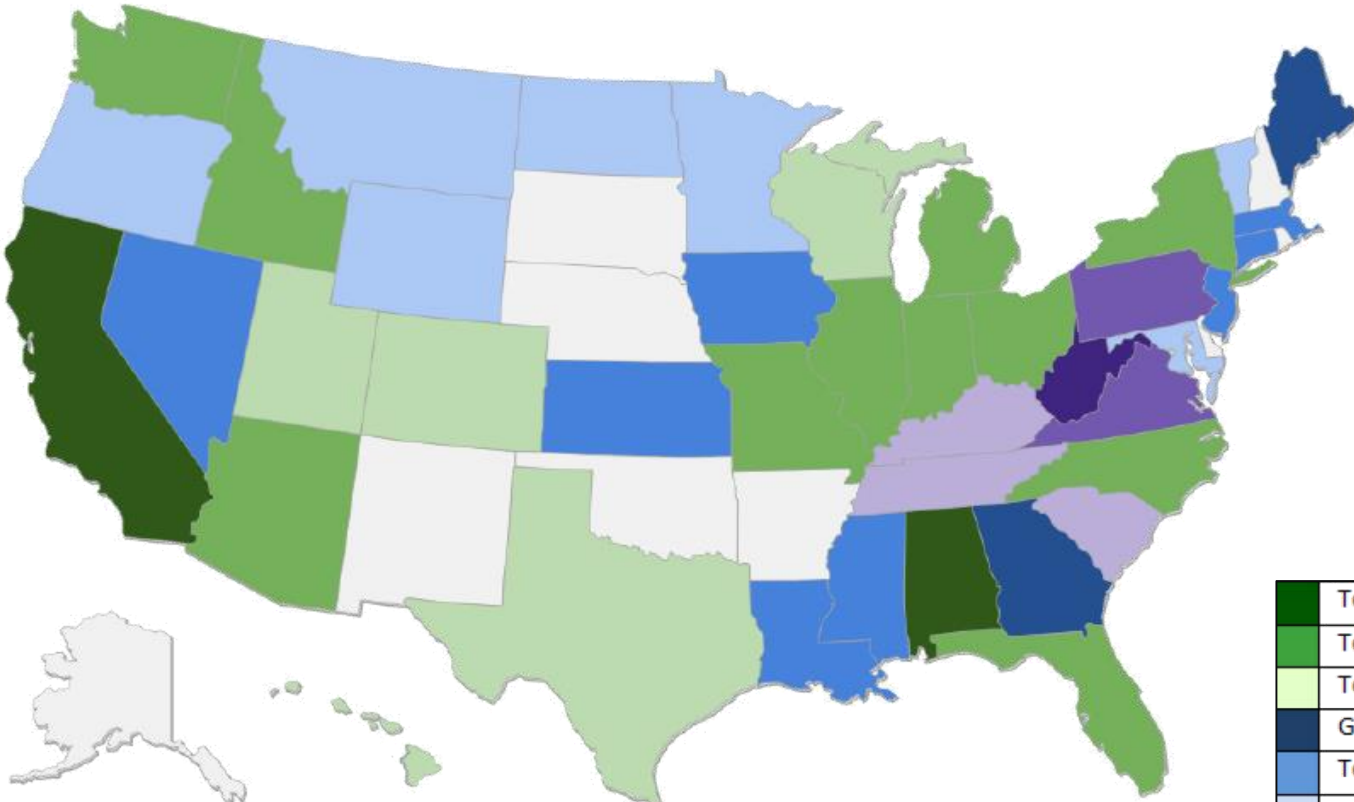
Fuel cells used to power new World Trade Center in NYC

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

Fuel cells operating all over the U.S.

Fuel cells used for backup power in more than 40 states



Over 235MW

in stationary fuel cell power installed

- Telecom, Government, Railroad, Utility sites
- Telecom, Government, Railroad sites
- Telecom and Government sites
- Government, Railroad, Utility sites
- Telecom sites
- Government sites
- Railroad sites
- Utility sites
- Government and Railroad sites
- Telecom and Railroad sites

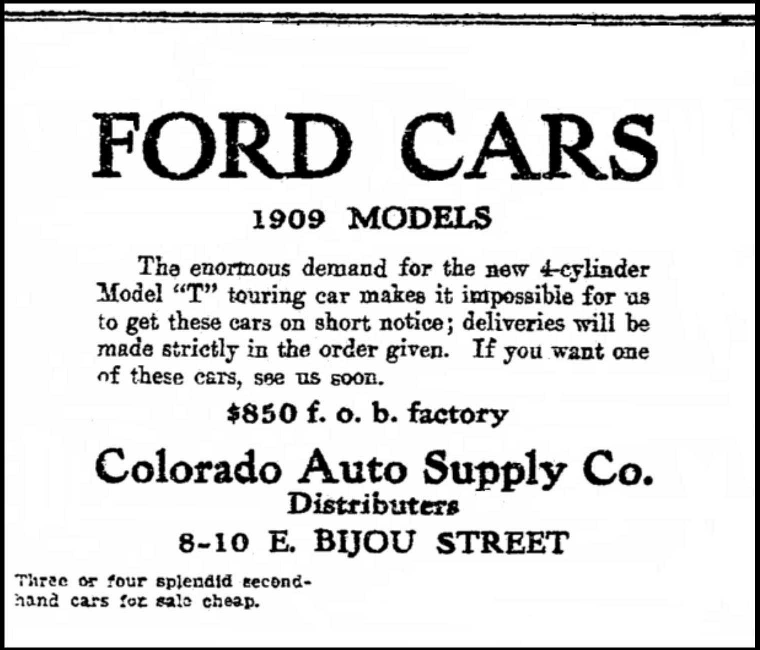
Over 8,000 backup power units

deployed or on order

Source: DOE State of the States: Fuel Cells in 2016 Report

What can we learn from history?

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



FORD CARS

1909 MODELS

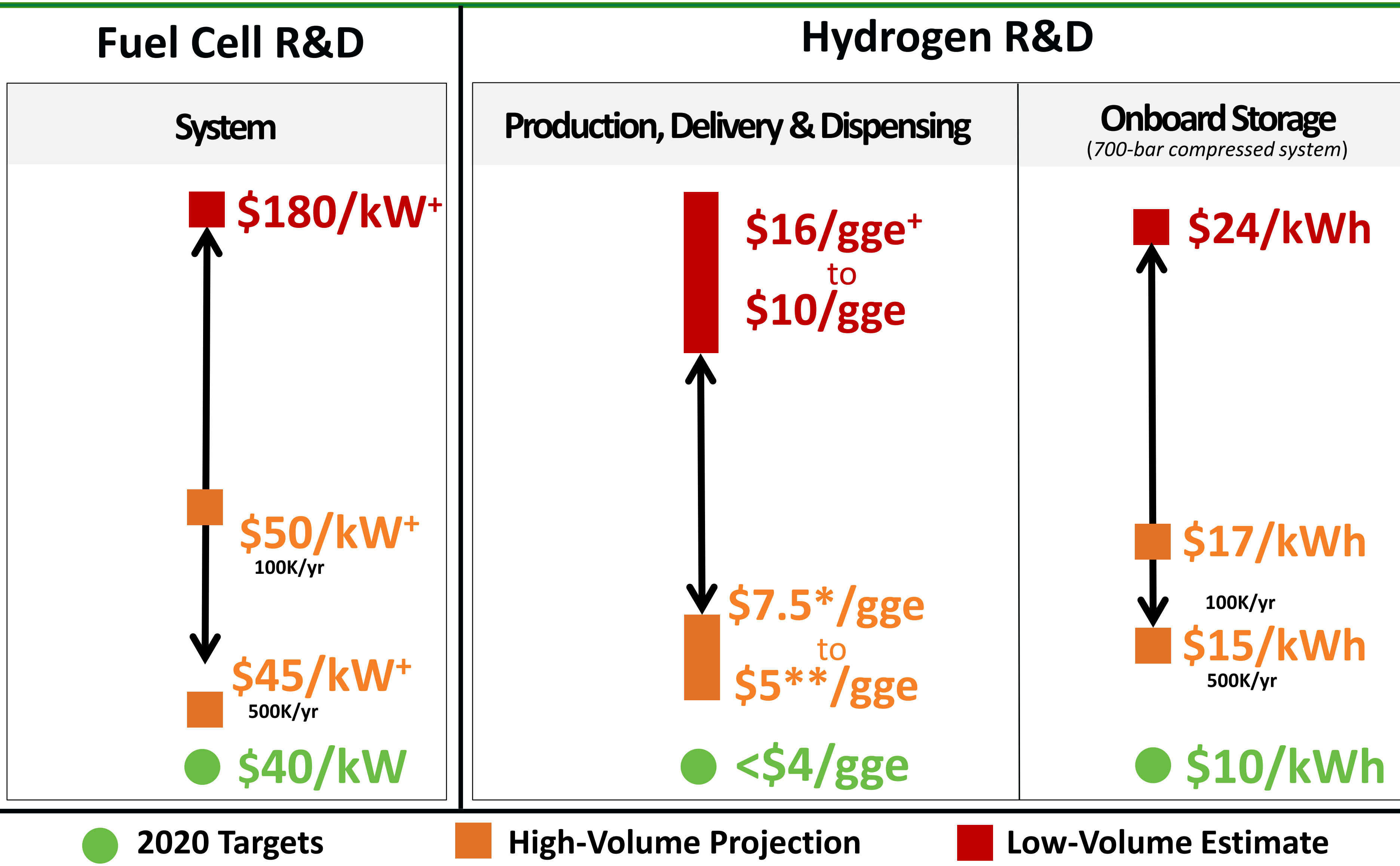
The enormous demand for the new 4-cylinder Model "T" touring car makes it impossible for us to get these cars on short notice; deliveries will be made strictly in the order given. If you want one of these cars, see us soon.

$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

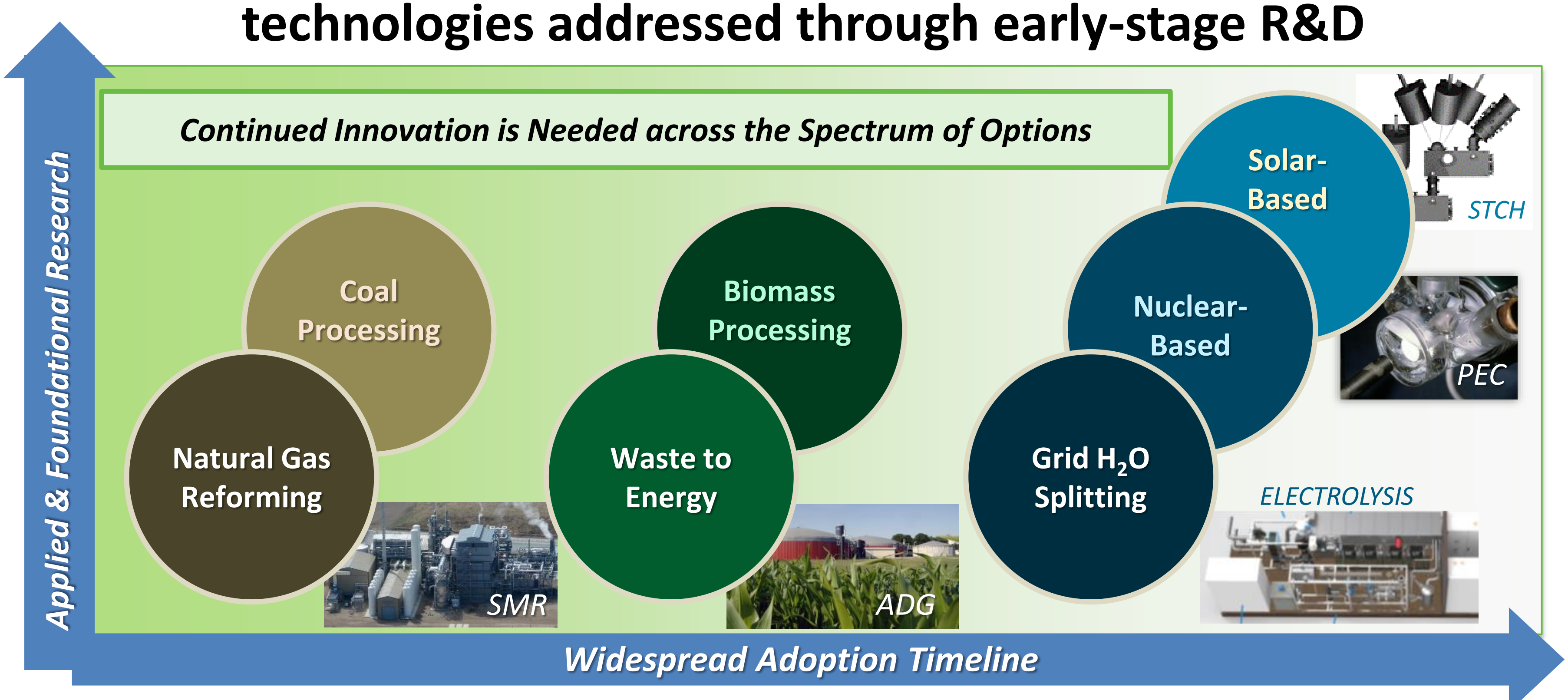


*Based on Electrolysis **Based on NG SMR + Preliminary, updates underway
Onboard storage cost status from DOE Program Record 15013

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

H_2 Production from Diverse Domestic Resources

Broad portfolio of near- to longer-term H_2 production technologies addressed through early-stage R&D



FOSSIL RESOURCES

- Low-cost, large scale H_2 production with CCUS options
- New options offer scalability and byproduct benefits (e.g. CHHP)

WASTE/BIOMASS

- Options included biogas reforming & fermentation of waste streams
- Byproduct benefits include clean water, electricity & chemicals

WATER SPLITTING

- Grid electrolysis is proven process being improved with innovation
- Emerging nuclear/solar options offer long-term sustainable H_2

H_2 Production R&D

Pathway using domestic natural gas can be competitive today

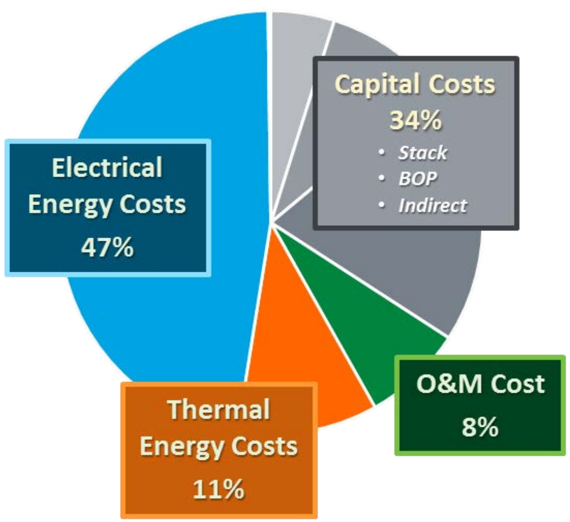
Portfolio Covers*:

- Fossil Resources
- Waste and Biomass
- Water-splitting

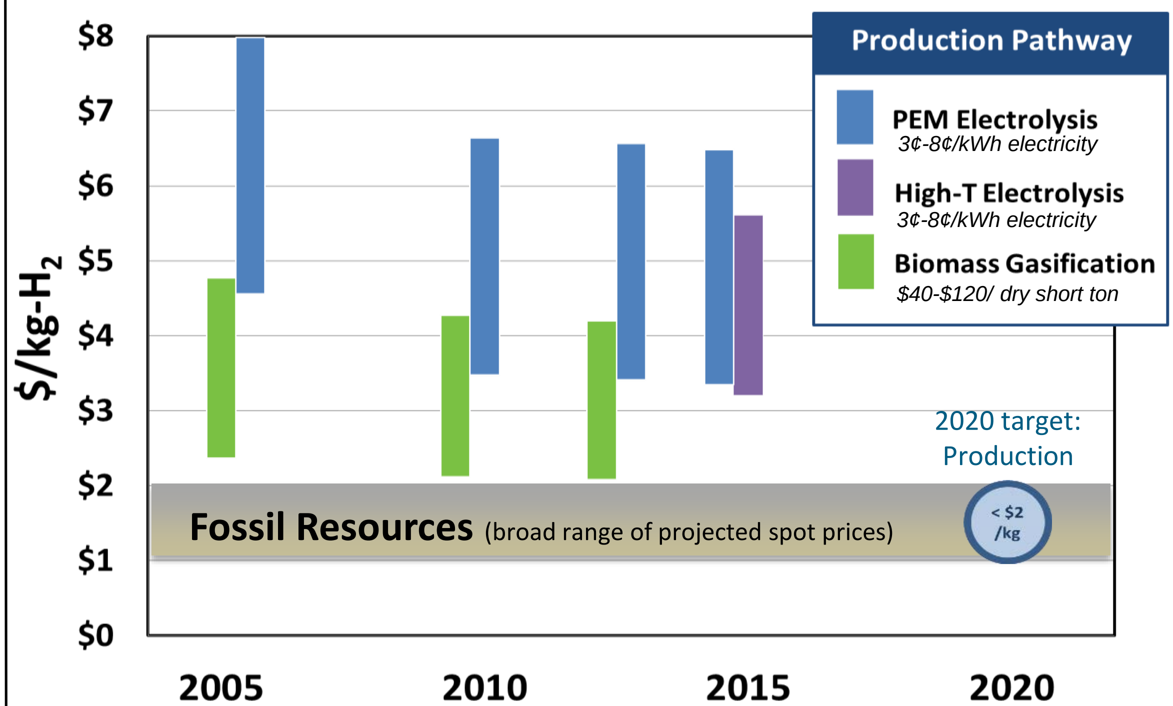
*examples

Cost by Component

High-T Electrolysis Example



Projected Production Cost* by Pathway

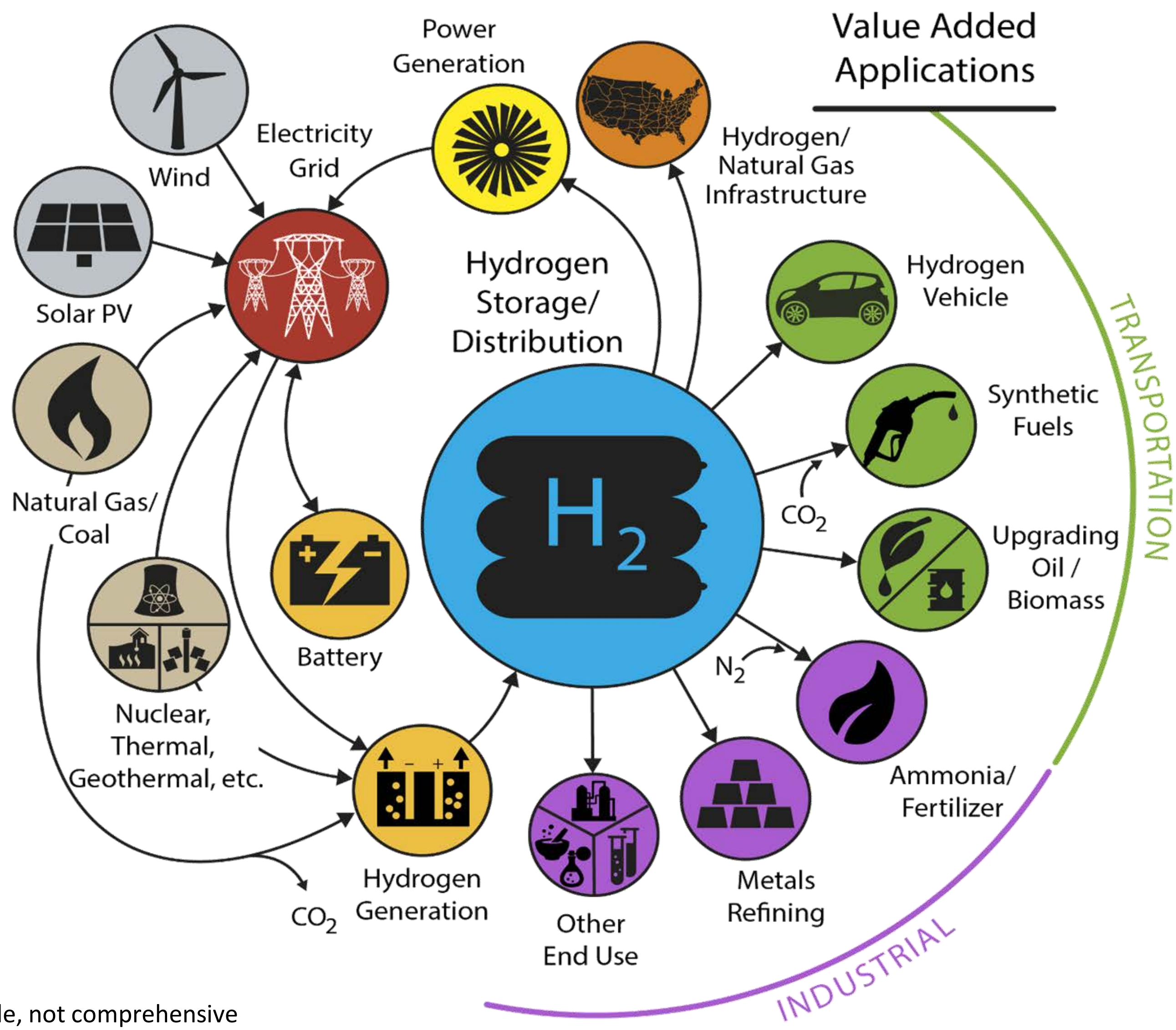


*Ranges with sensitivities to feedstock price variations

Consortium leveraging National Lab capabilities

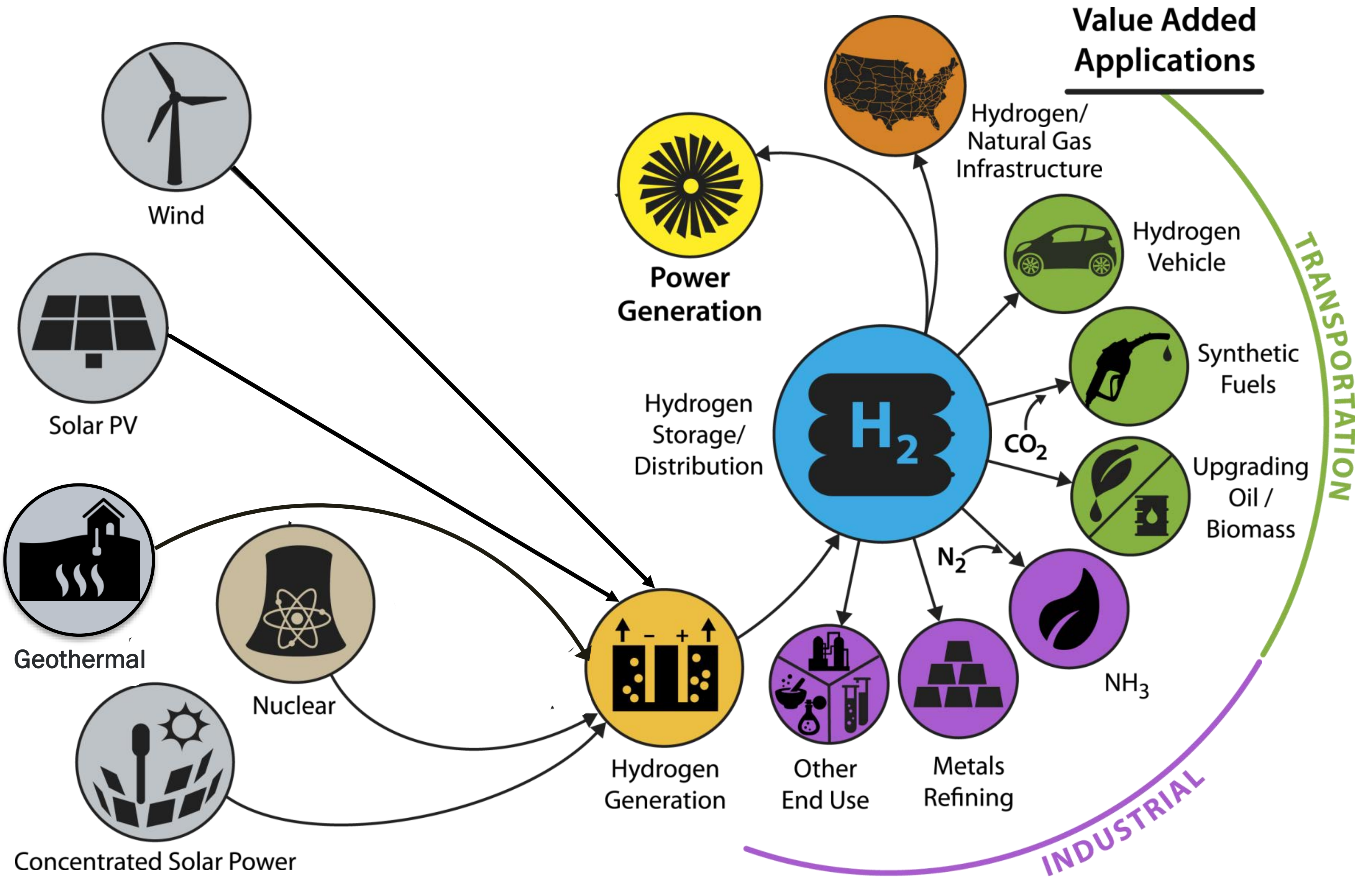
HydroGEN Advanced Water Splitting Materials

H_2 at Scale Energy System



*Illustrative example, not comprehensive
Source: NREL

H_2 at Scale Energy System



How much H_2 is needed?

How much hydrogen for 1 car?

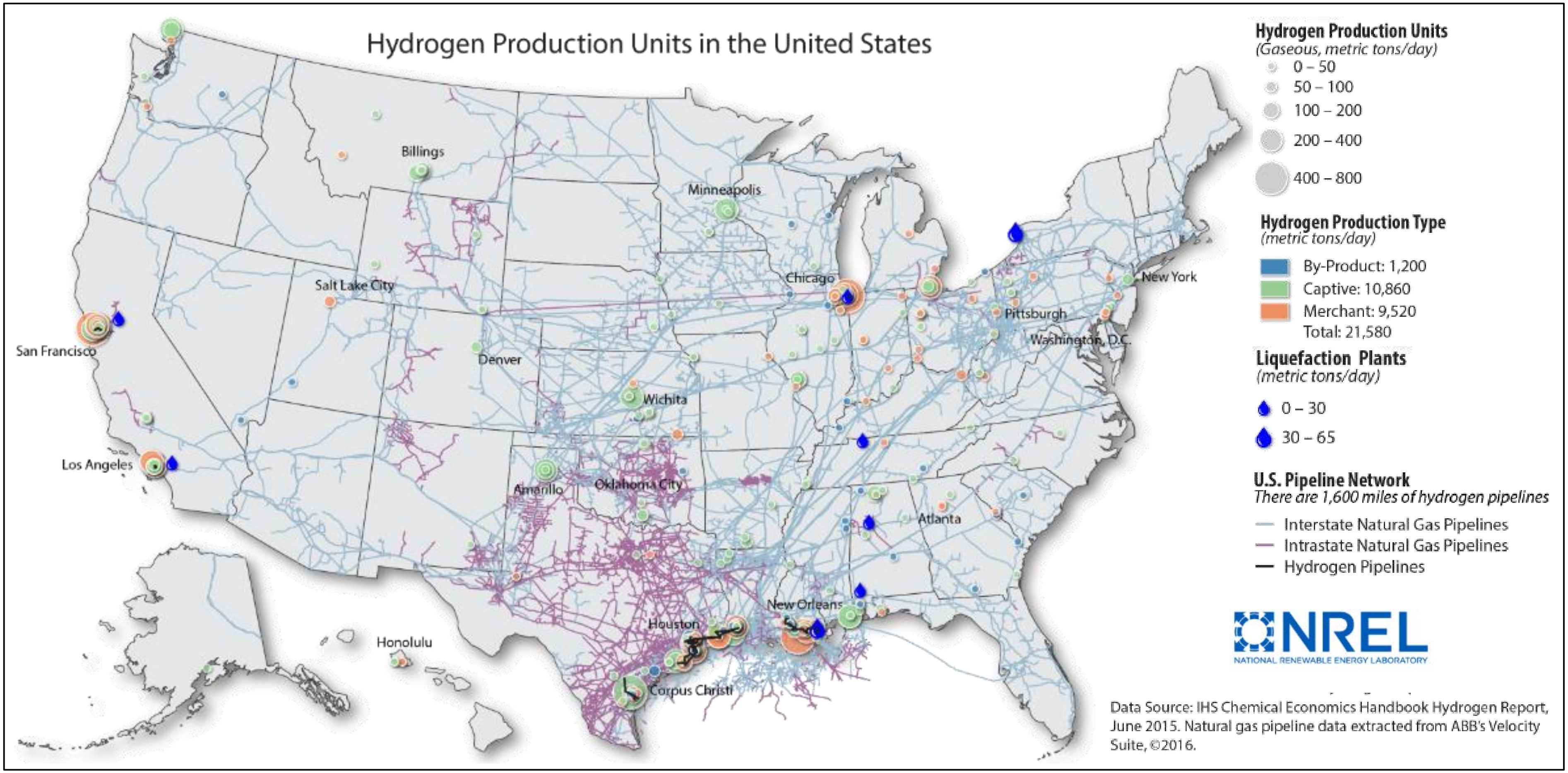
$$\frac{\textbf{12,000 miles} \text{ per year}}{\textbf{60 miles} \text{ per kilogram}} = \textbf{200 kg} \text{ per year} \textbf{ or } \textbf{0.2 tonnes} \text{ per year}$$

How much hydrogen for many cars?

1 M cars	0.2 M tonnes H_2 per year 200 M kg H_2 per year
= 100,000 cars	

100 M cars	20M tons H_2 per year 20 B kg H_2 per year
= 10M cars	

Hydrogen Production Sites in the U.S.

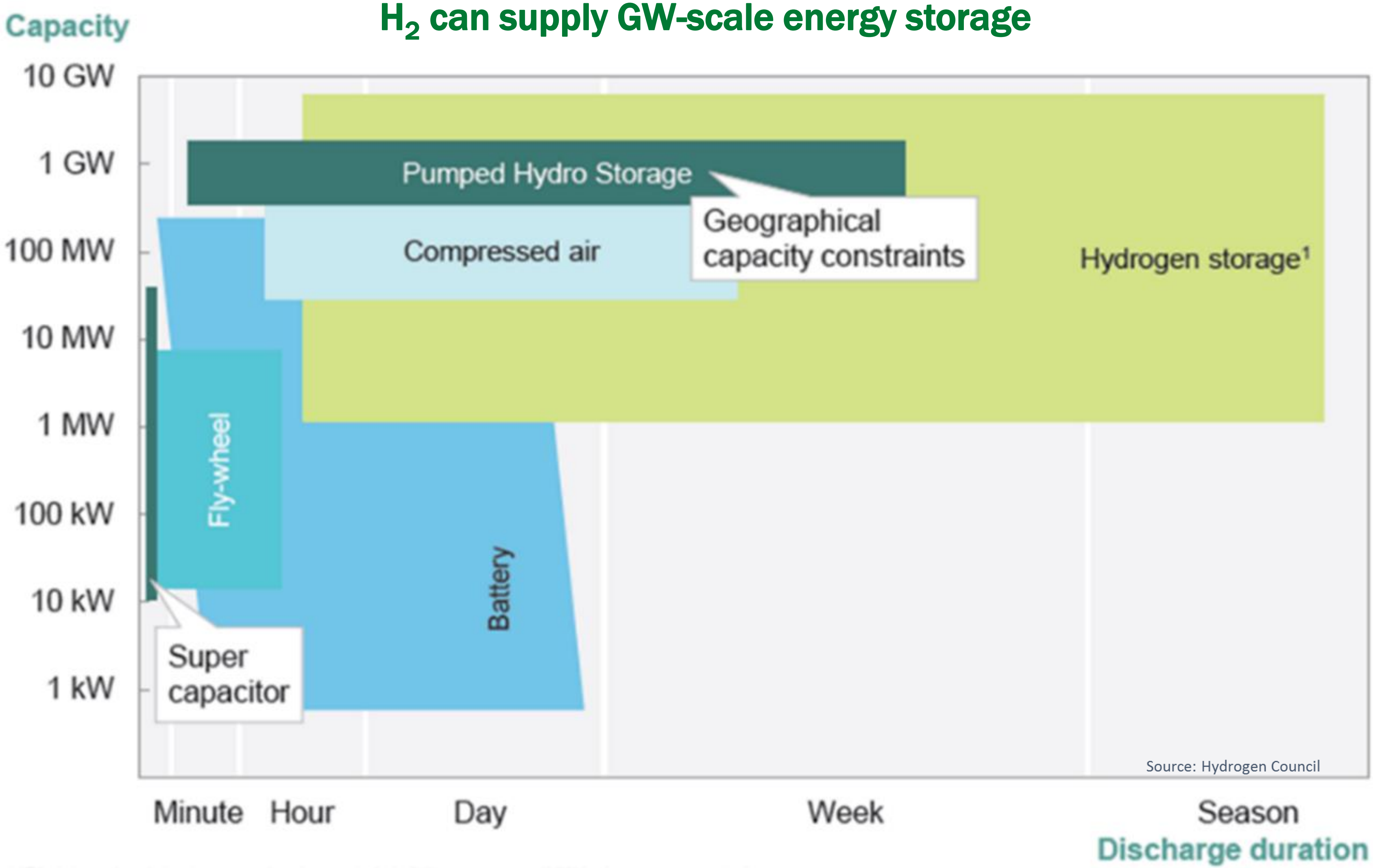


U.S. annual hydrogen production
10 million metric tons

Largest Users in the U.S.			
Petroleum Processing	68%	Fertilizer Production	21%

Example of H_2 and Electrolyzer Benefits

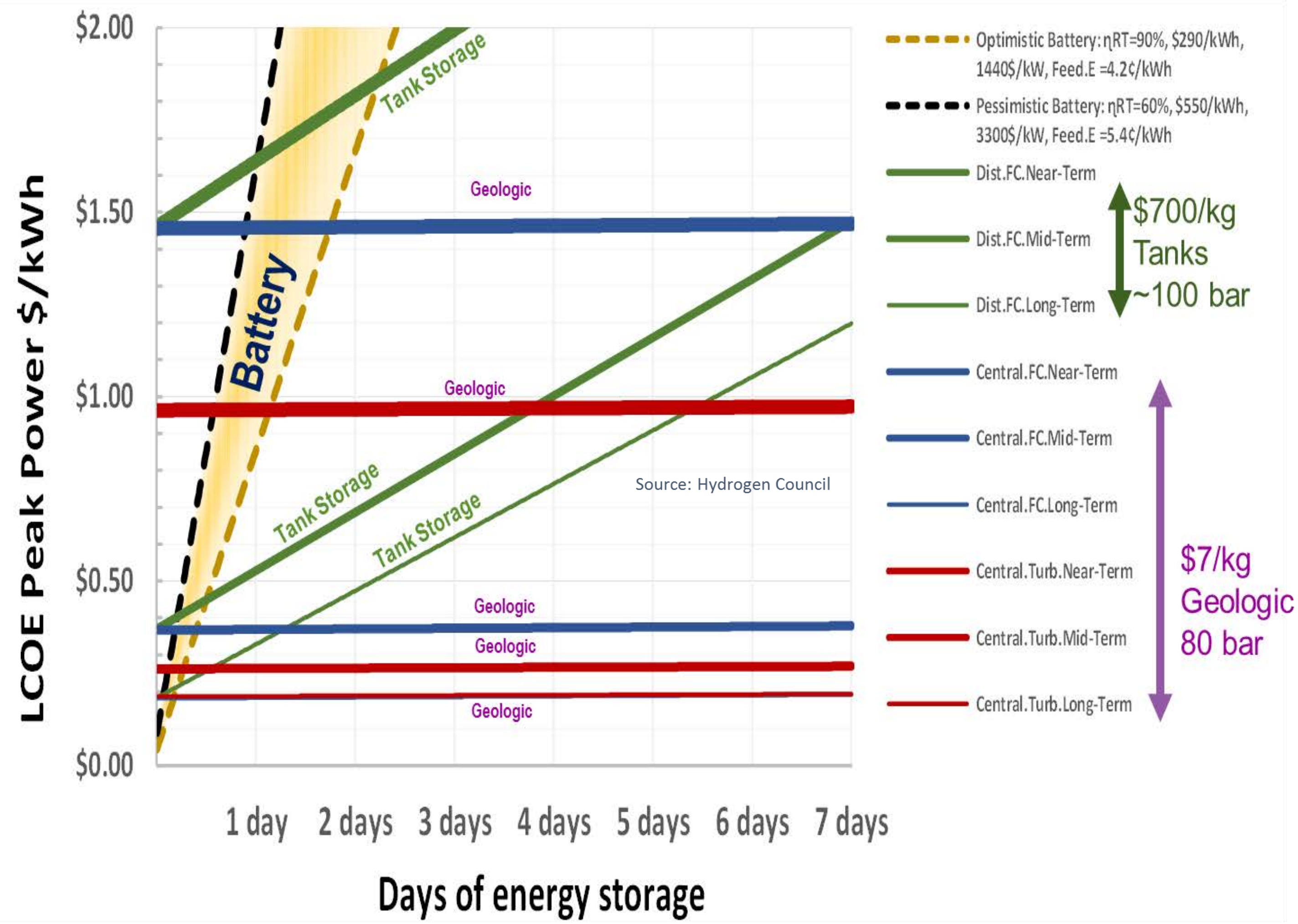
H_2 can supply GW-scale energy storage



Preliminary analysis- to be updated

Example of H_2 and Electrolyzer Benefits

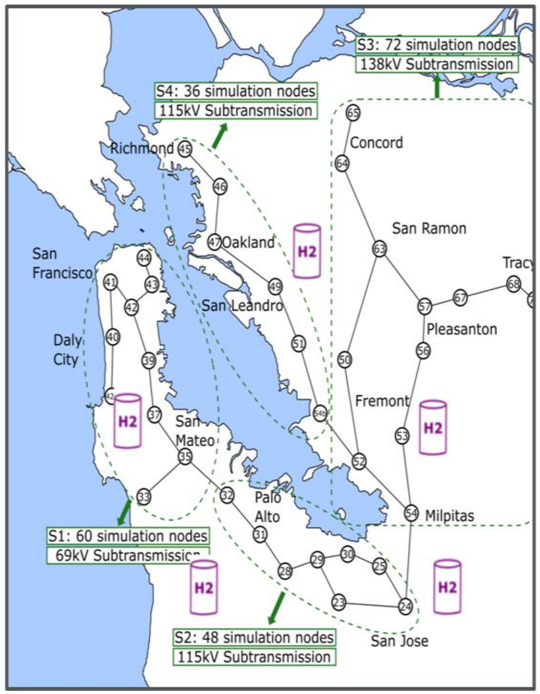
H_2 can be cost effective for long duration storage

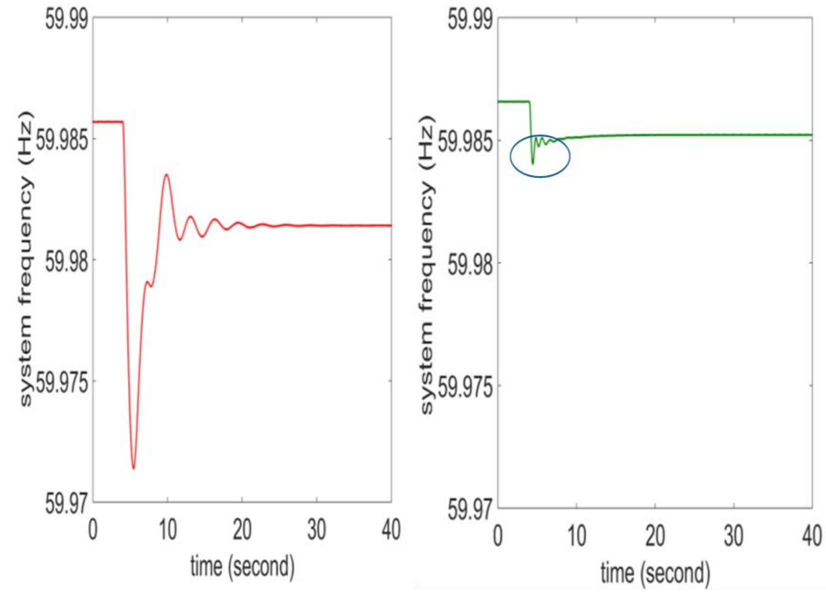


Preliminary analysis- to be updated

Examples of H_2 and Electrolyzer Benefits

First ever validation of real time grid simulation with electrolyzers





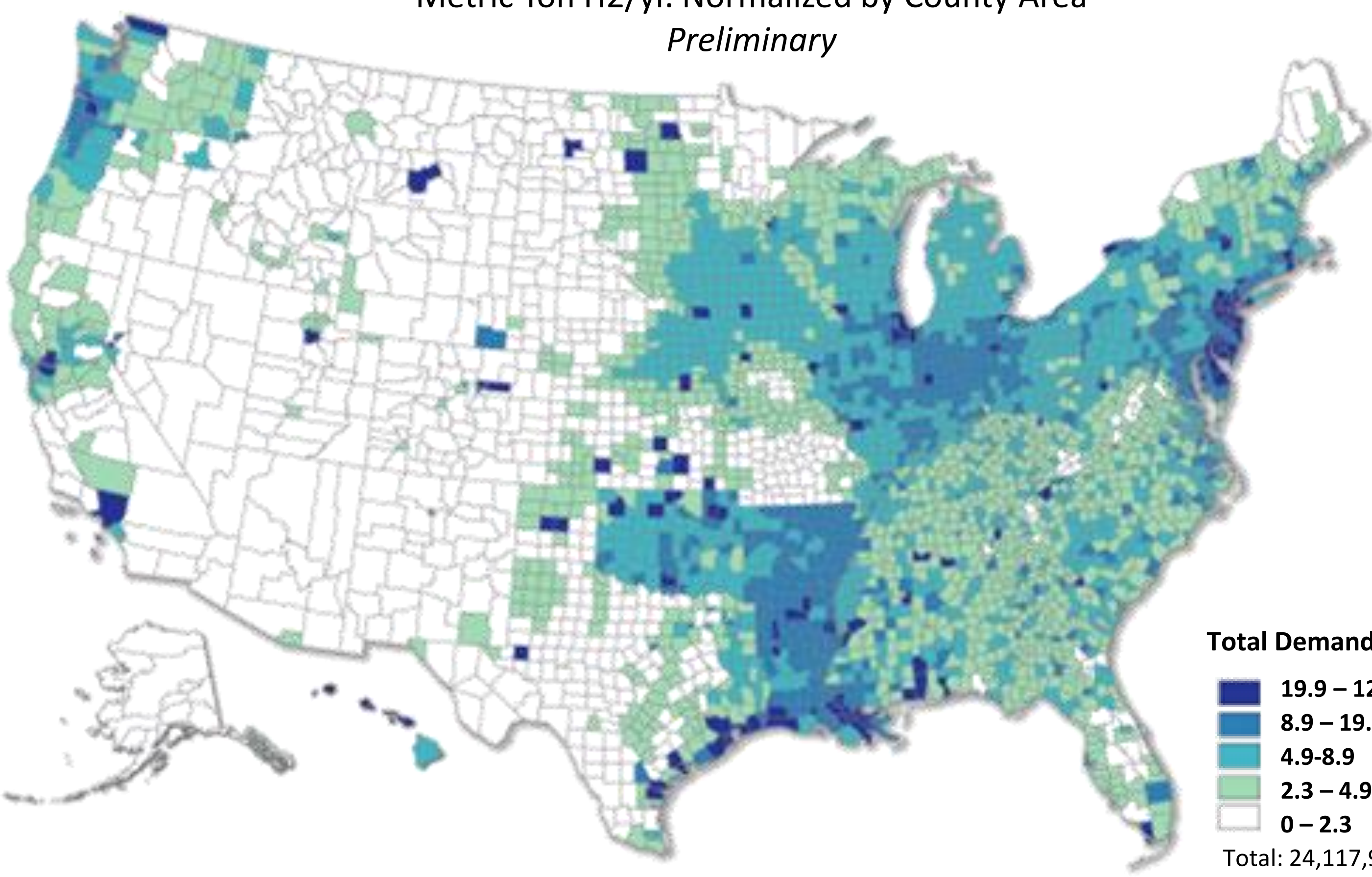
First independent validation of frequency regulation with electrolyzers and sub-second response times (INL, NREL)

Preliminary analysis- to be updated

Market Potential for Hydrogen Demand

60 Million Metric Tons of Hydrogen/ Year

Total Hydrogen Demand for the Industrial Sector
Metric Ton H2/yr. Normalized by County Area
Preliminary

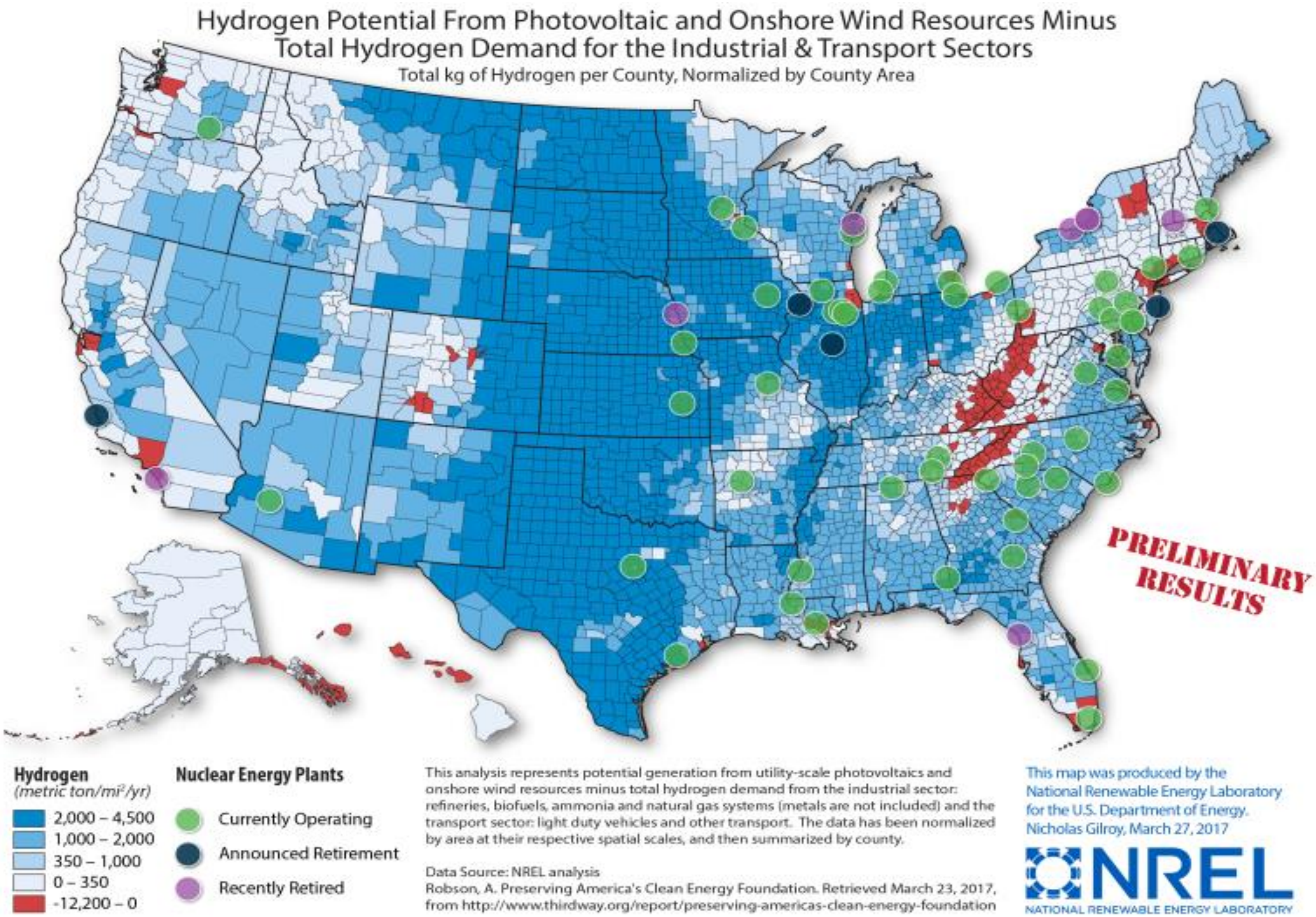


NREL NATIONAL RENEWABLE ENERGY LABORATORY

Multiple Industries:

- **Refinery**
- **Metals**
- **Ammonia**
- **Natural Gas**
- **Biofuels**
- **LDVs**
- **Other transportation**

H2@Scale: Nationwide Resource Assessment



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

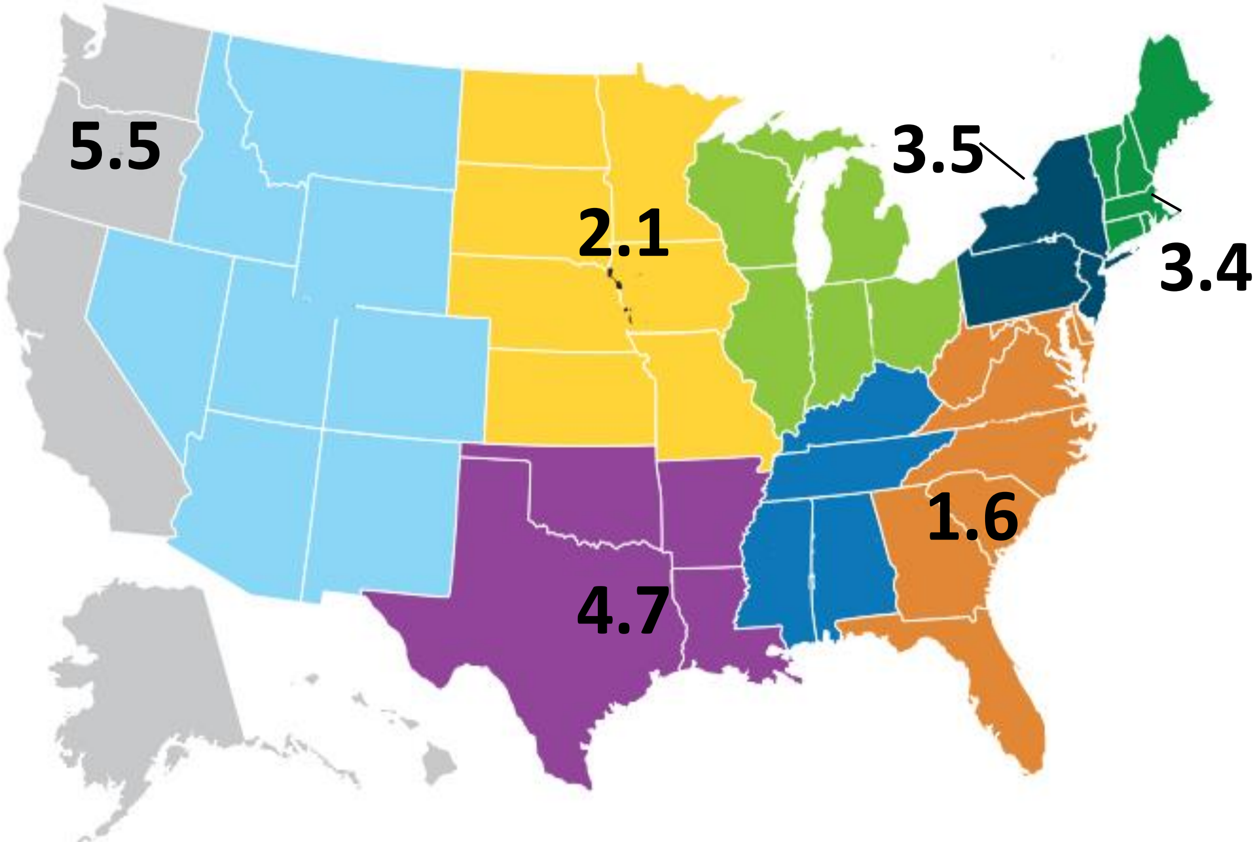
Labs assess resource availability. Most regions have sufficient resources.

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

Market Conditions Pushing Nuclear Power Transition

Over 20 GW in existing nuclear plants retired or at risk of retiring

Nuclear Plants at Risk or Recently Retired in GW[1]



[1] U.S. DOE Quadrennial Energy Review, 01/2017

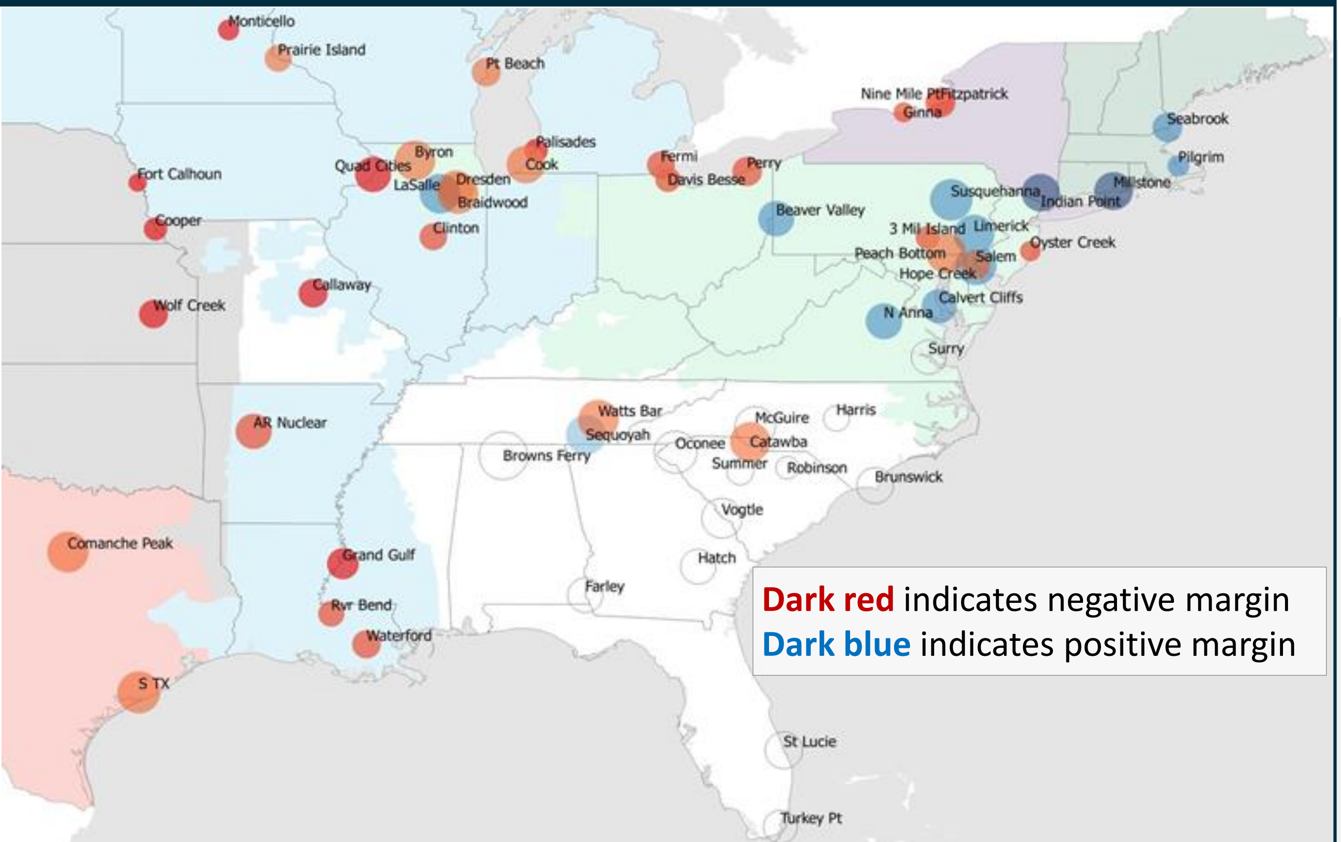
Gen IV Reactors (2030 – 2050) Compatible with High Temp. Electrolysis:

- ✓ High-temperature*
- ✓ Gas- cooled fast
- ✓ Supercritical Water
- ✓ Molten salt

* Outlet temperature: 500-1,000C

Market Conditions Pushing Nuclear Power Transition

7,000 MW Nuclear Plants Announced Retirement since 2016*



Map Source: Bloomberg New Energy Finance Note: For more information of U.S. electric generators, see U.S. Plant Stack: Info on Every Generator Unveiled (web | Terminal)

*DOE Staff Report to the Secretary on Electricity Markets and Reliability
https://energy.gov/sites/prod/files/2017/08/f36/Staff%20Report%20on%20Electricity%20Markets%20and%20Reliability_0.pdf

Gen IV Reactors (2030 – 2050) Compatible with High Temp. Electrolysis:

- ✓ High-temperature*
- ✓ Gas- cooled fast
- ✓ Supercritical Water
- ✓ Molten salt

* Outlet temperature: 500-1,000C

High-Temp. Steam (HTSE) Electrolysis and Nuclear

Benefits

- High electrical efficiency
- Scalable
- Leverages heat sources from nuclear
- Improves economics of nuclear reactors
- Can operate over wide range of loads

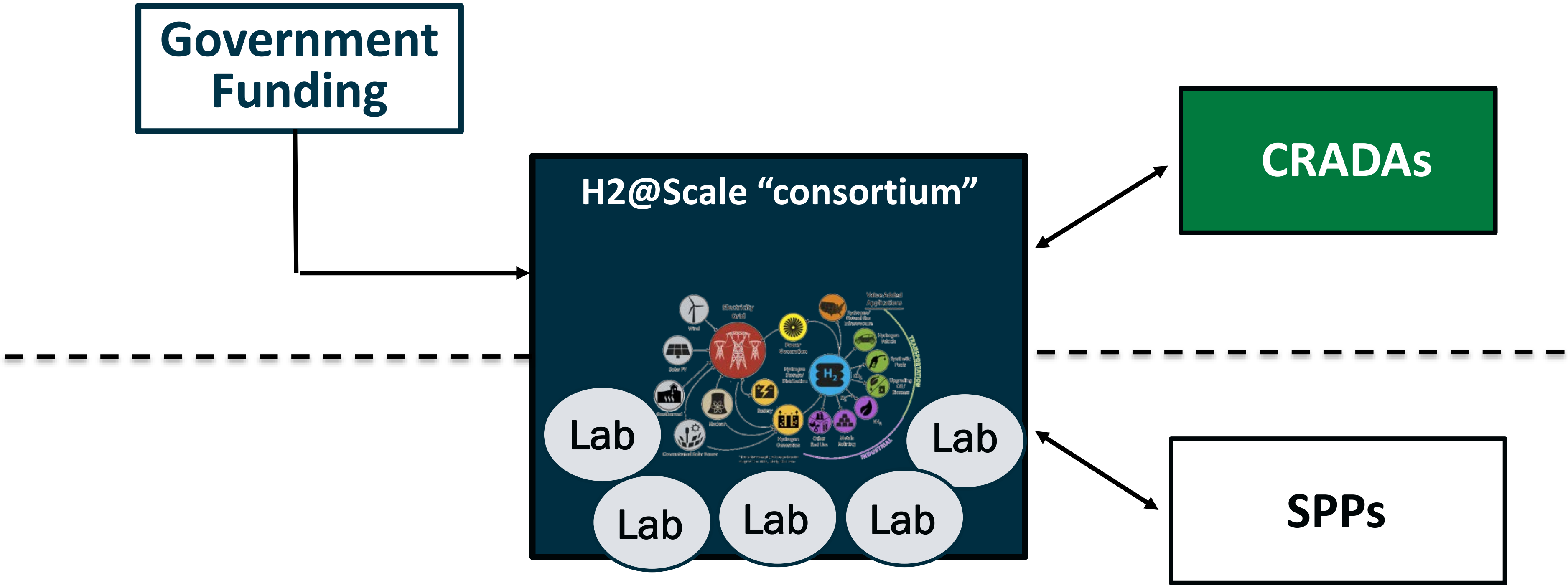
Needs

- Electrolyzer cell/stack durability improvements
- Load following capability dependent on time-frame (minutes vs hours)
- System-level demonstration

Gen IV Reactors produce process heat compatible with high-temp. steam electrolysis (HTSE)

H2@Scale CRADA Call

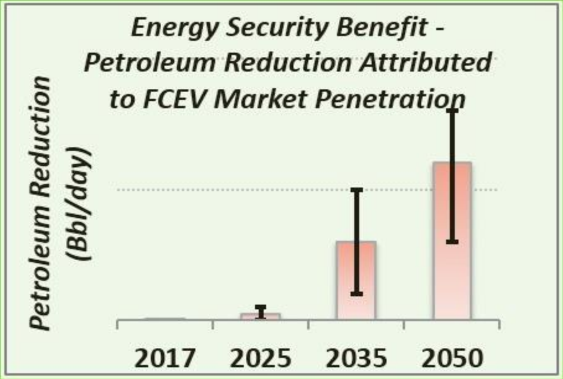
- To leverage **lab capabilities and expertise to address challenges- materials R&D, analysis, safety R&D, etc.**
- **Round 1 closed Sept. 15 – stay tuned for winners and future rounds**



CRADA = Cooperative Research and Development Agreement
SPP- Strategic Partnership Project ('Work for Others')

H2@Scale CRADA Call Addressing R&D Needs relevant to Nuclear – Example

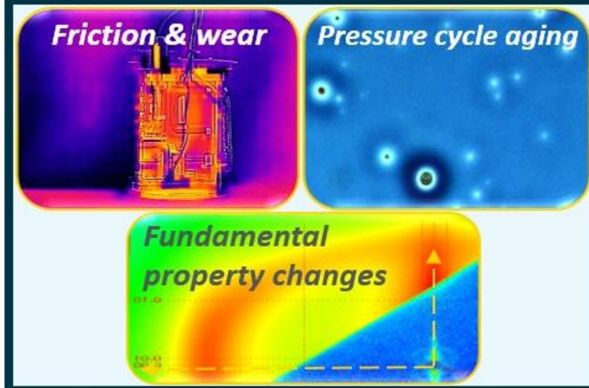
Technoeconomic Modeling and Analysis



Labs

Argonne National Laboratory, NREL (National Renewable Energy Laboratory)

Hydrogen Materials Compatibility R&D



Labs

Oak Ridge National Laboratory, Sandia National Laboratories, SRNL, Pacific Northwest National Laboratory

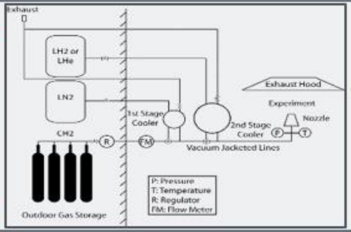
Grid simulation and Testing

Labs

INL Idaho National Laboratory, NREL (National Renewable Energy Laboratory)

Safety R&D

HyRAM
HYDROGEN RISK ASSESSMENT MODELS

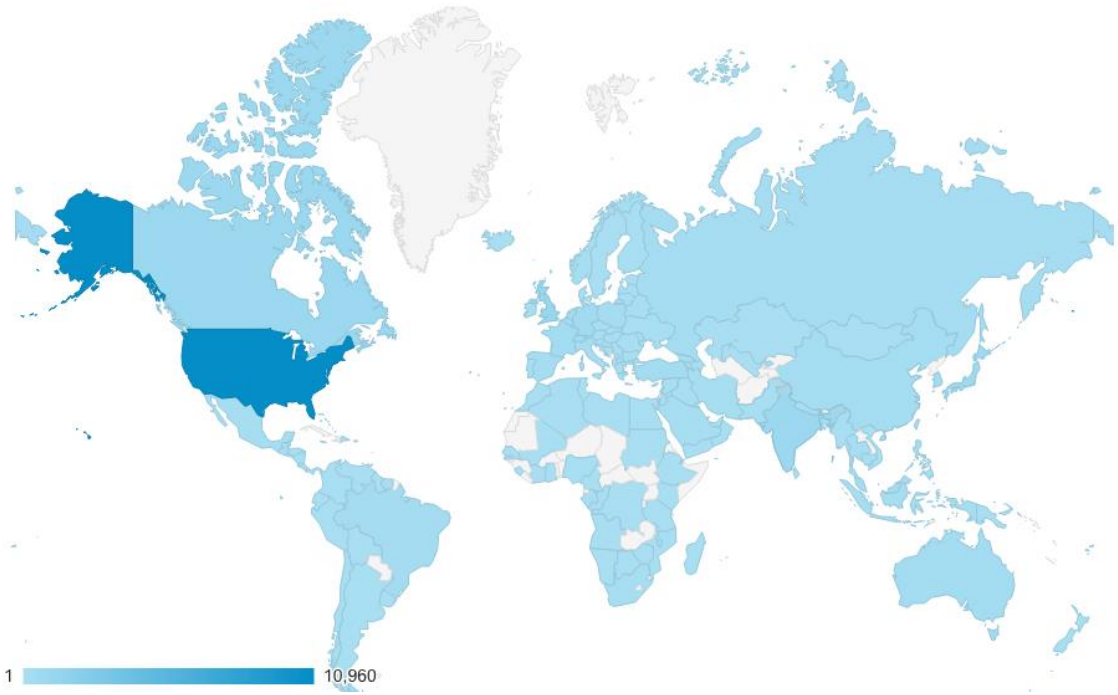


Labs

NREL (National Renewable Energy Laboratory), Sandia National Laboratories, Pacific Northwest National Laboratory

Information sharing and education are critical as we move forward

H_2Tools: One-stop for H_2 safety knowledge



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

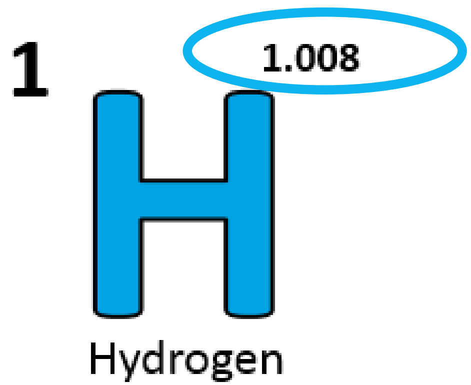
- Site visit tracking shows a **global reach: 50%** of visits are **international!**
- Over **31,000 site visits** in the first year alone
- Training resource **translated into Japanese**

Ways to Spread the Word

Celebrate Hydrogen & Fuel Cell Day

October 8 or 10/8

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



Learn more:

energy.gov/eere/fuelcells

Give an *"Increase your H2IQ"* presentation in your community!

INCREASE YOUR H_2IQ

Download for free at:

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


Powered by
Hydrogen Fuel Cells

Summary

- **Enable early R&D innovation**
  - Hydrogen fuel
  - Fuel cells
  - H2@Scale

- **Leverage activities to maximize impact**
  - Enable infrastructure and cross-sector impacts
  - Partnerships- other agencies, industry, states, etc.
  - Collaboration on safety R&D and information sharing

Thank You

Dr. Sunita Satyapal
Director
Fuel Cell Technologies Office
Sunita.Satyapal@ee.doe.gov

energy.gov/eere/fuelcells