U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

H2@Scale Overview

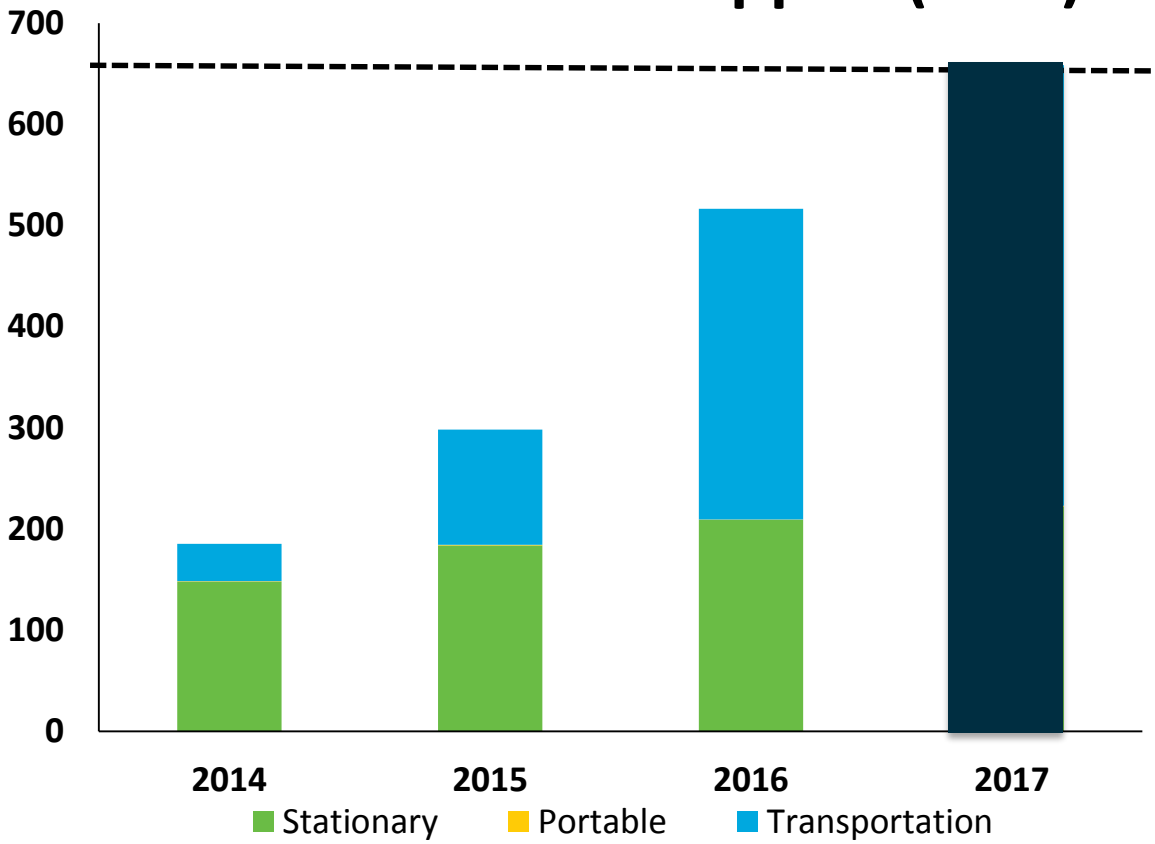
Dr. Sunita Satyapal, Director - Fuel Cell Technologies Office

H2@Scale R&D Consortium Kickoff Meeting

Chicago, IL – August 1, 2018

1. Progress

Upward trend with global fuel cell shipments



650 MW
fuel cell power
shipped worldwide

70,000
fuel cell units
shipped worldwide

Approximately
$2 Billion
fuel cell revenue

Source: DOE and E4Tech

Electrolyzers: Over 100MW/year estimated global sales

*Courtesy of NOW, E4tech and partners: A collaborative effort to assess electrolyzer market potential

An exciting time for the transportation sector

Honda Clarity

Nearly **5,000** | **sold or leased** in the United States

As of Dec 2017


Hyundai Tucson Fuel Cell SUV

Commercial **fuel cell electric cars are here**


Toyota Mirai

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

Interest in material handling equipment applications

More than **20,000 forklifts**

Over **12 million refuelings**

Long-Range, Heavy Duty Applications Emerging

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

Fuel cell buses in CA surpass 19M passengers

Industry demonstrates first heavy duty fuel cell truck in CA

New Applications Emerging- Examples

China

Eight Fuel Cell Trams

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

Germany

Trains to operate in Germany in 2018

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

Stationary Power Applications Expanding

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

Photo Credit: Fukuoka Pref.

Multiple H_2 and Fuel Cell Applications in the U.S.

U.S. Snapshot

>240MW
Backup Power

>20,000
Forklifts

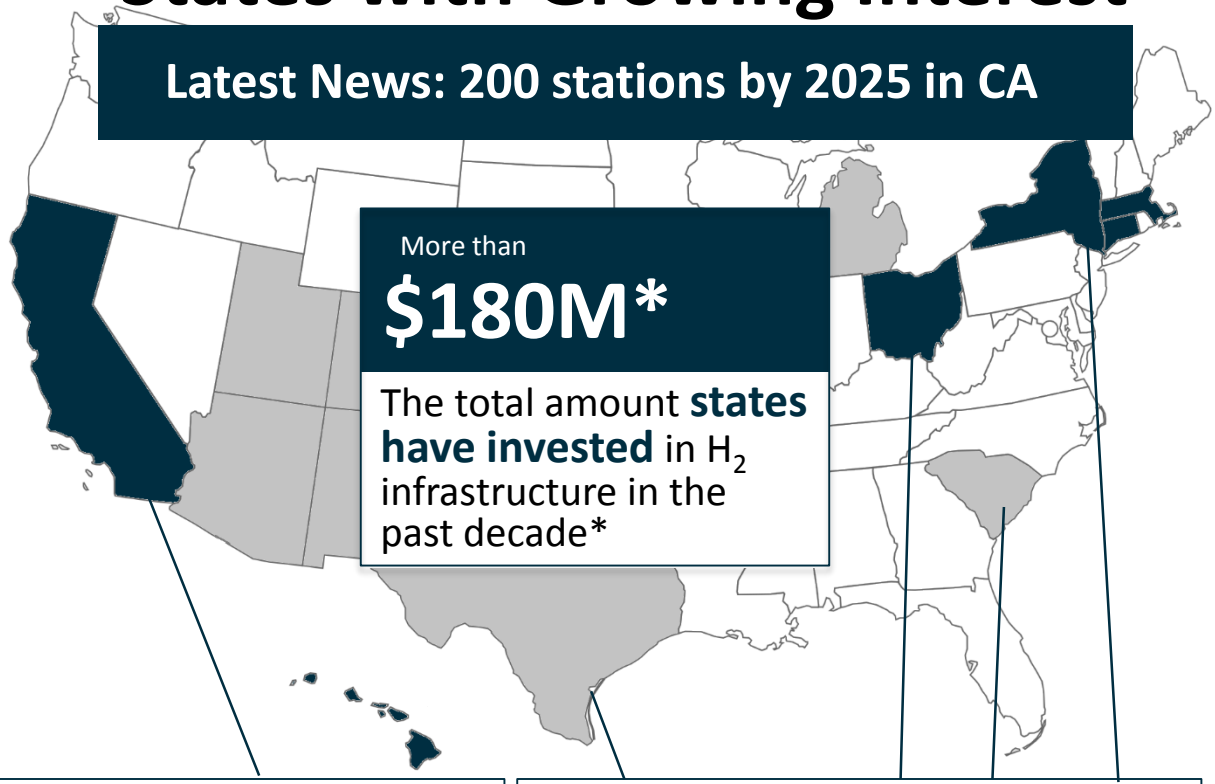
>30
Fuel Cell Buses

35
H_2 retail stations

Nearly
5,000
fuel cell cars

States with Growing Interest

Latest News: 200 stations by 2025 in CA



More than
$180M*
The total amount **states have invested** in H_2 infrastructure in the past decade*

CA
- 200 stations planned
- Over 30 public stations open
- $150M invested
- $235M announced in 2018

HI, OH, SC, NY, CT, MA, CO, UT, TX, MI, and others with interest
- Over $27M invested
- 12-25 stations planned in the NE

*Excludes recent announcement from CA to invest $235M in electric vehicles

2. H_2@Scale concept

Vision

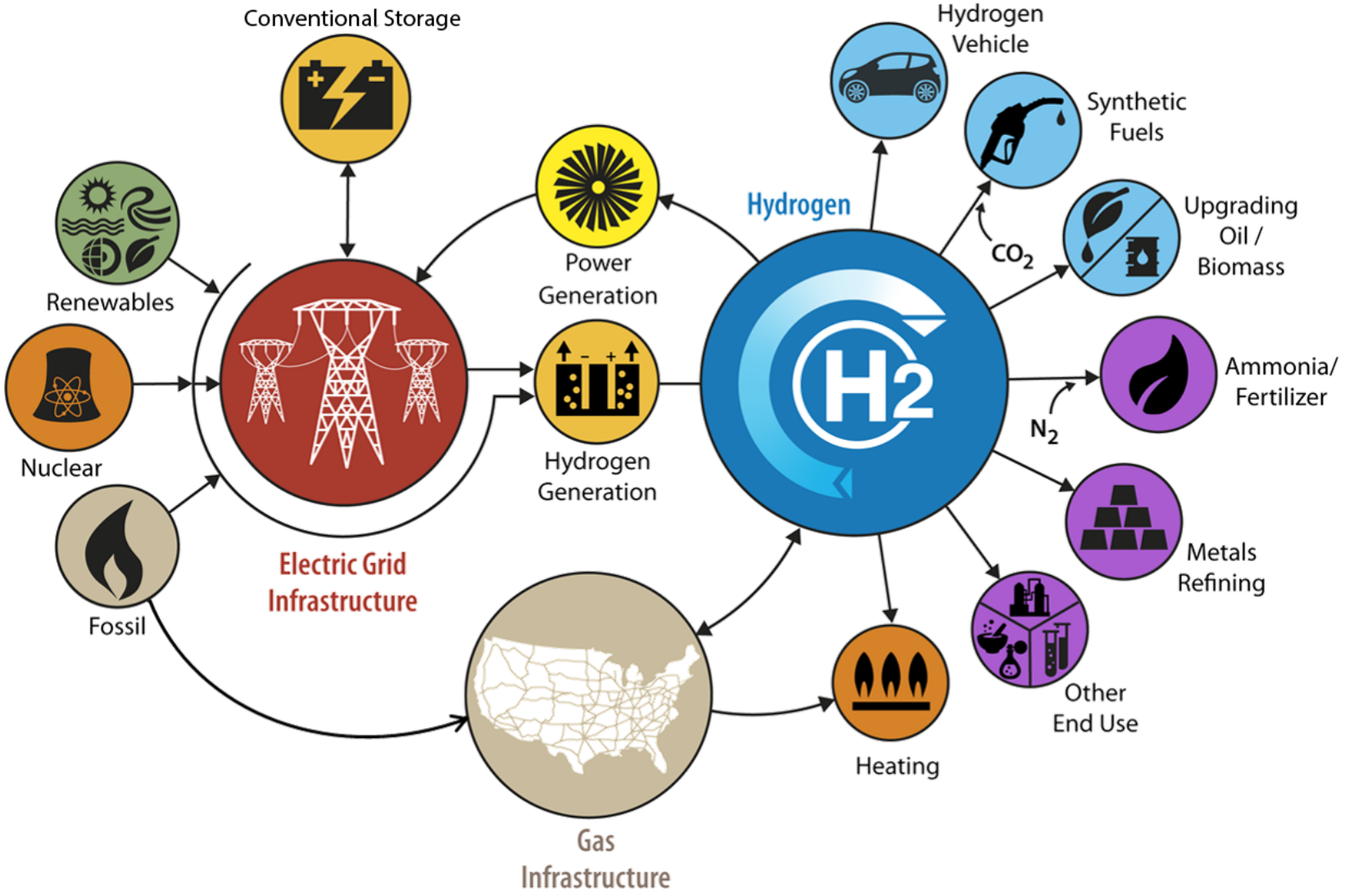
H2@Scale: Enable affordable, reliable, clean and secure energy across sectors

Versatility

Volume

Value Proposition

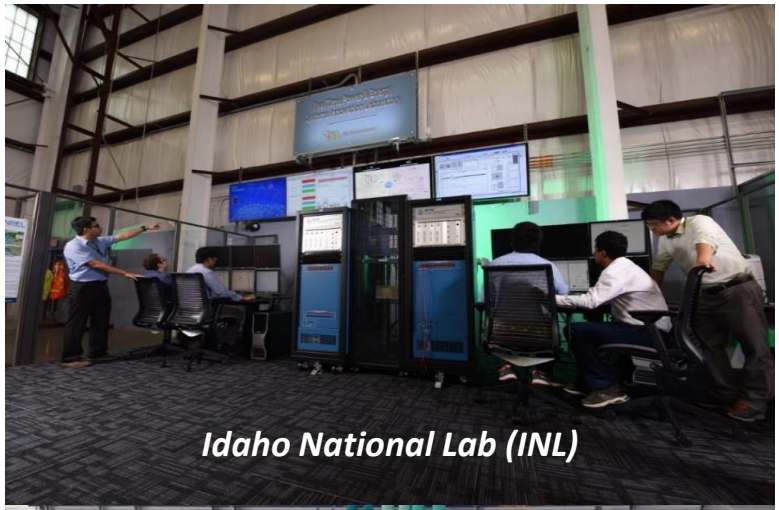
H_2@scale: Enabling affordable, reliable, clean, and secure energy across sectors

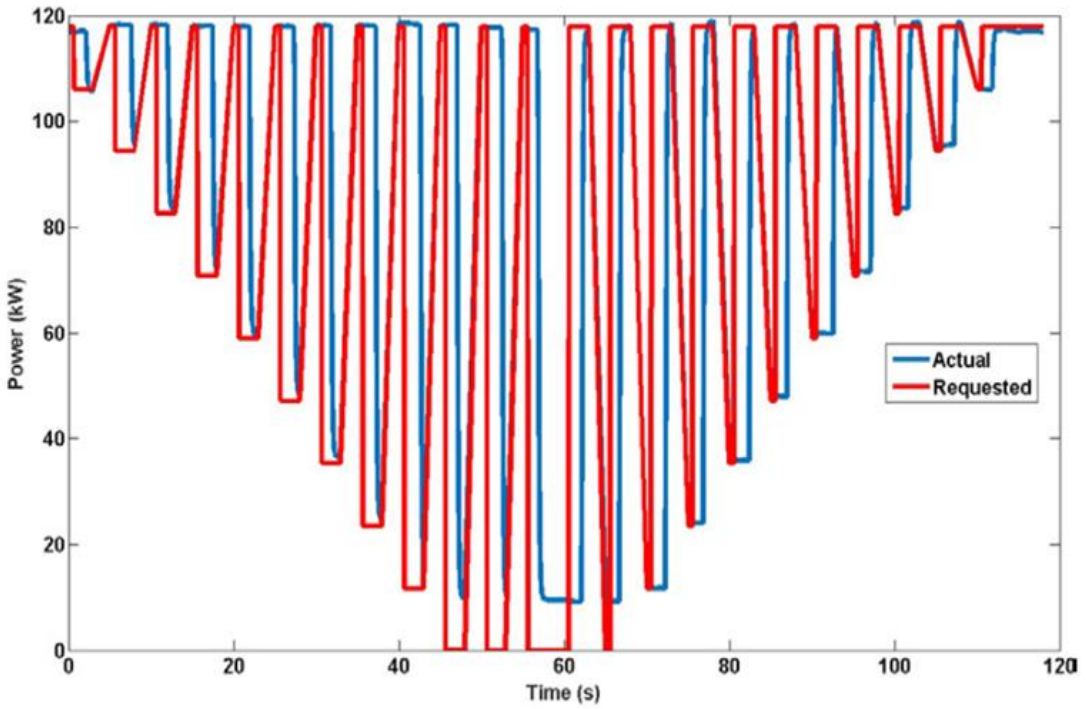


More information at: www.energy.gov/eere/fuelcells/h2-scale

Lab testing electrolyzers' value for ancillary services

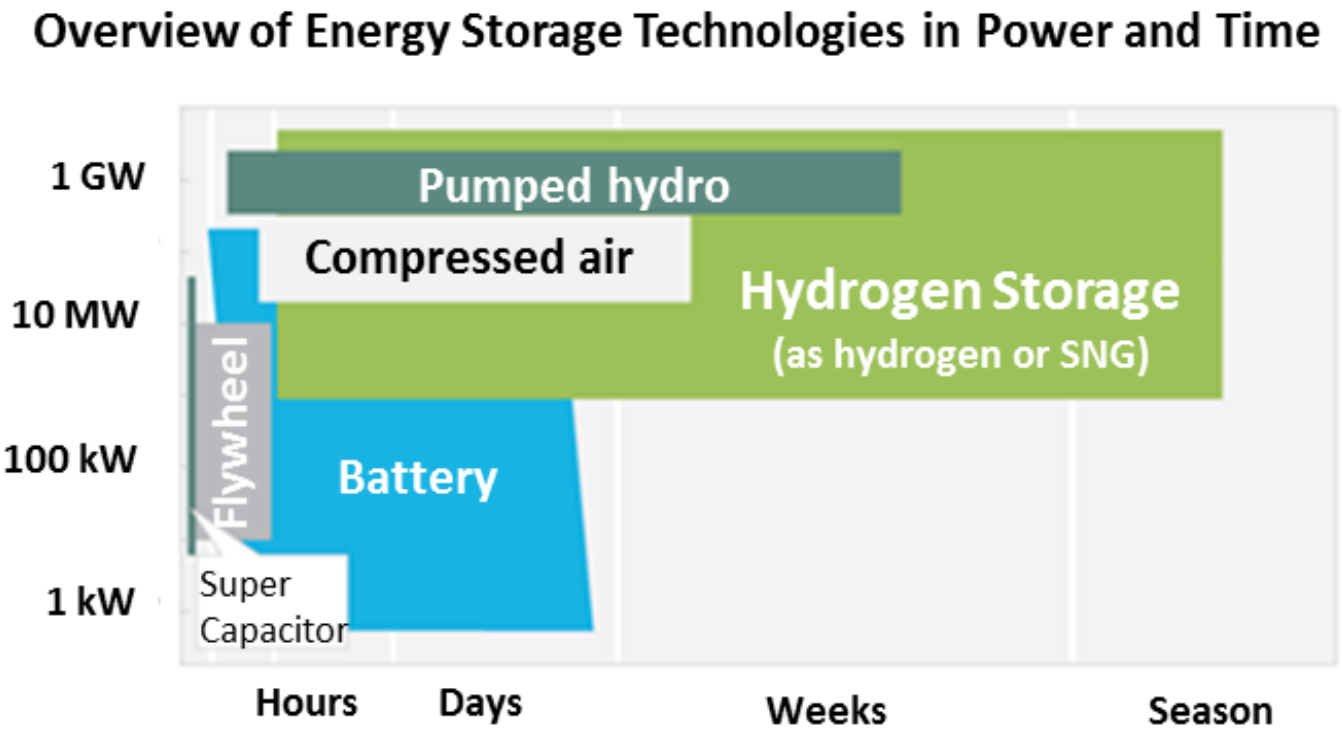
First Ever Validation of Frequency Regulation with Electrolyzers





Lab testing shows dynamic response within seconds and potential for grid services

Hydrogen Energy Storage is Scalable



One hydrogen cavern could provide **~ 100 GWh energy storage**

Image: Hydrogen Council

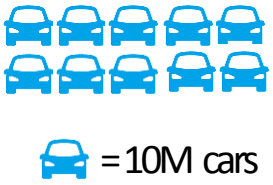
Hydrogen can be used to monetize surplus electricity from the grid, or remote, off-grid energy feedstock (e.g. solar, wind) for days to months.

Scale: Simple Example

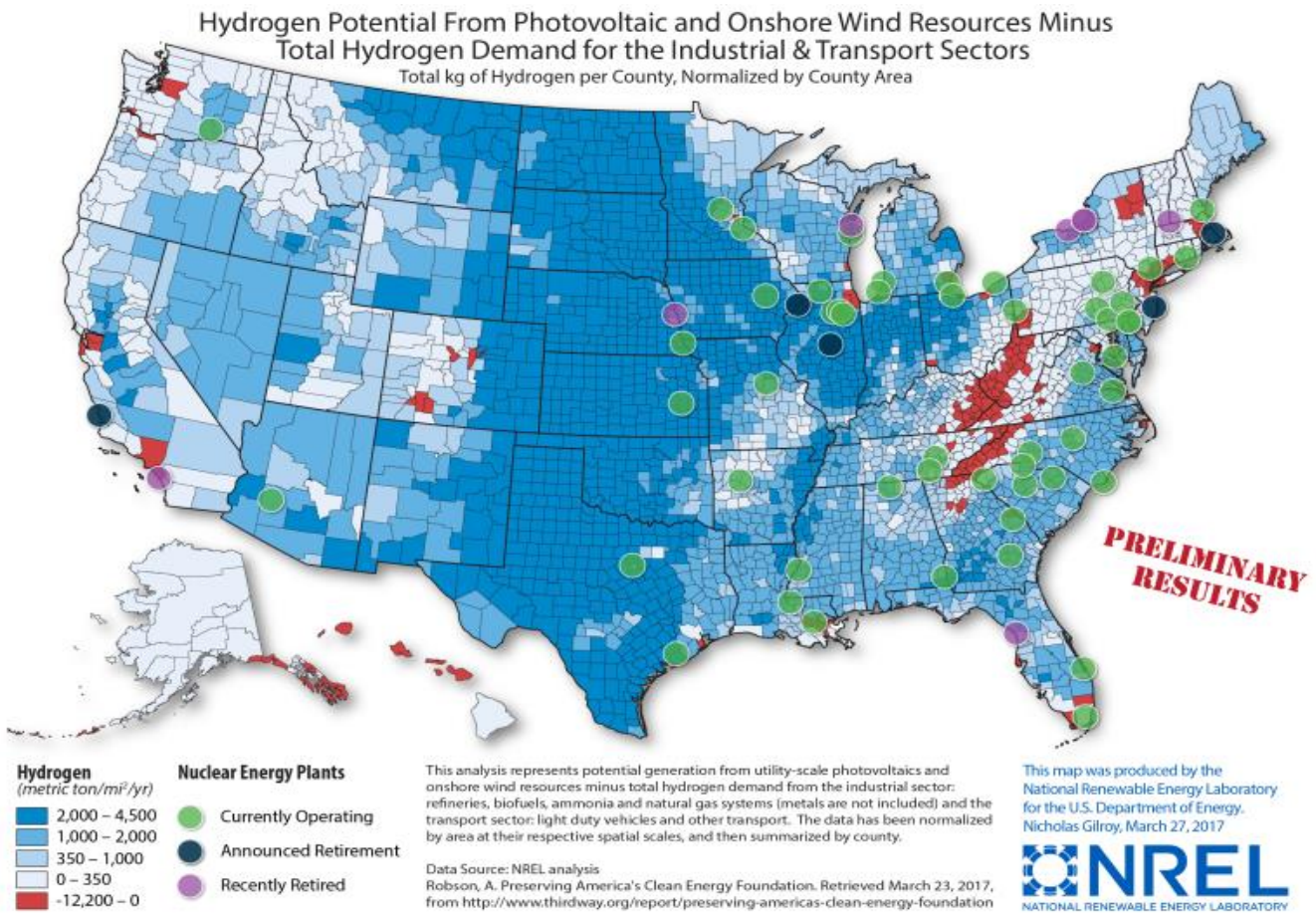
How much hydrogen for 1 car?

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

How much hydrogen for many cars?

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

H2@Scale: Nationwide Resource Assessment



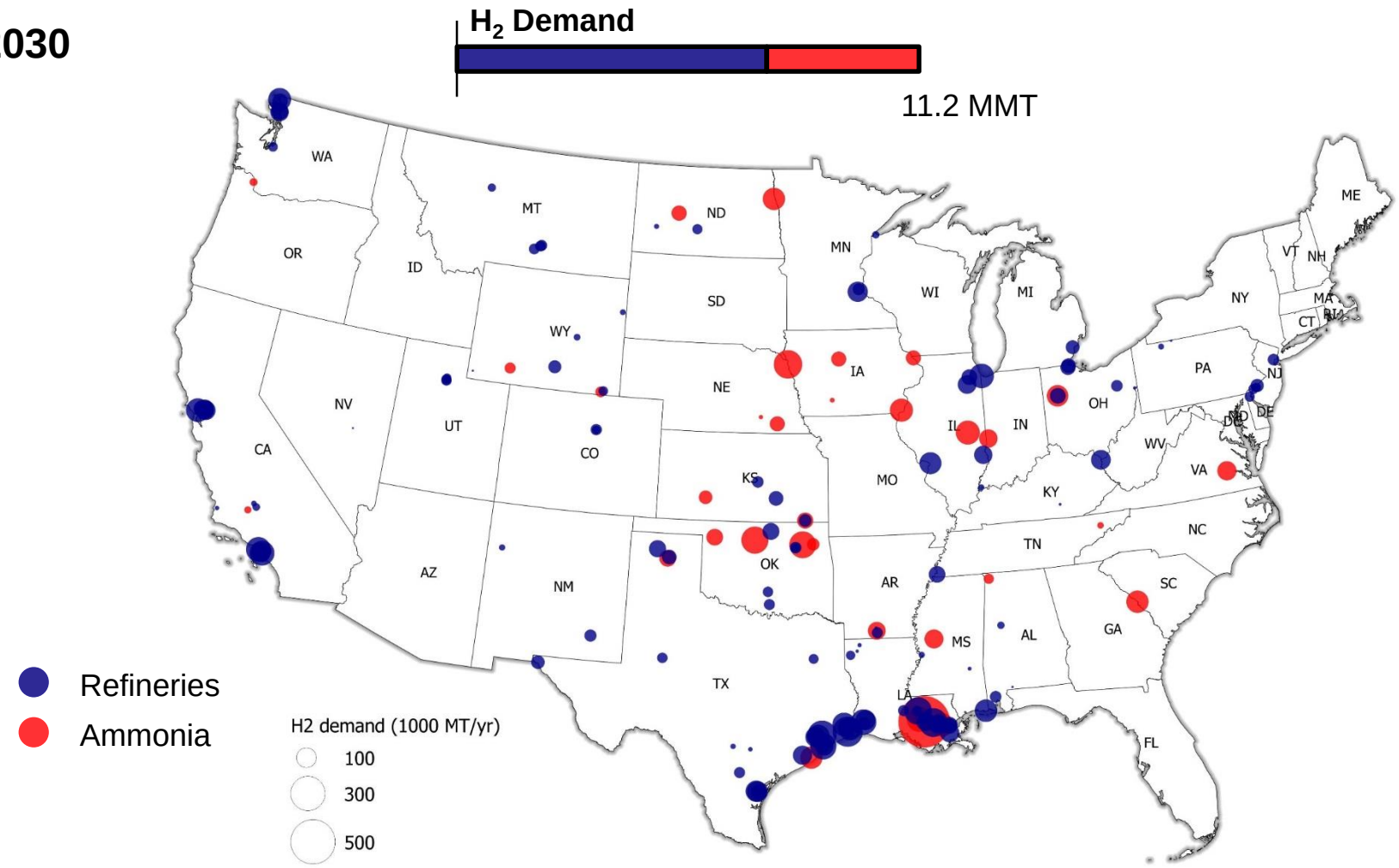
Labs assess resource availability. Most regions have sufficient resources.

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

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

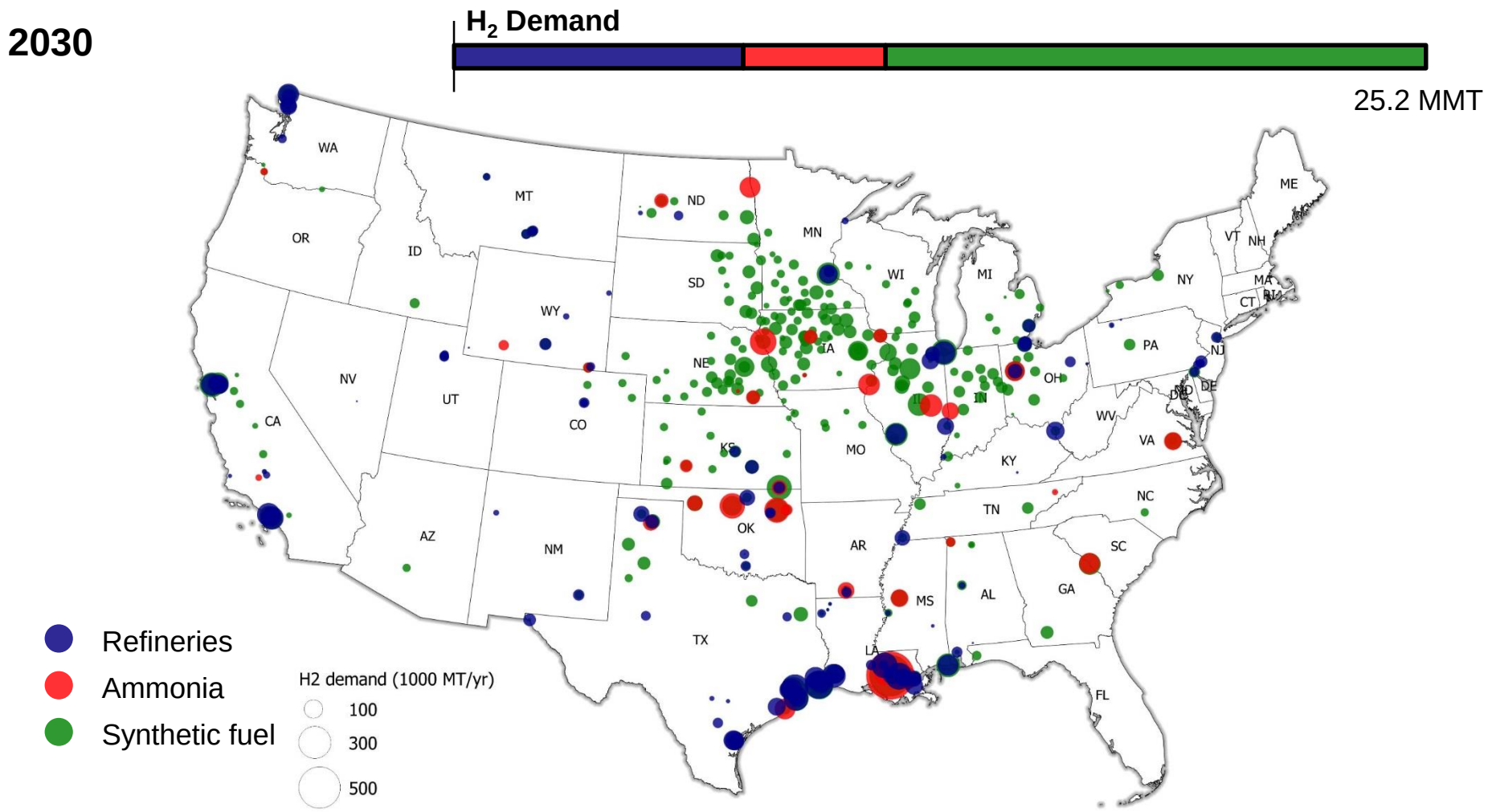
Ammonia & Refineries - Potential H_2 Demand

2030



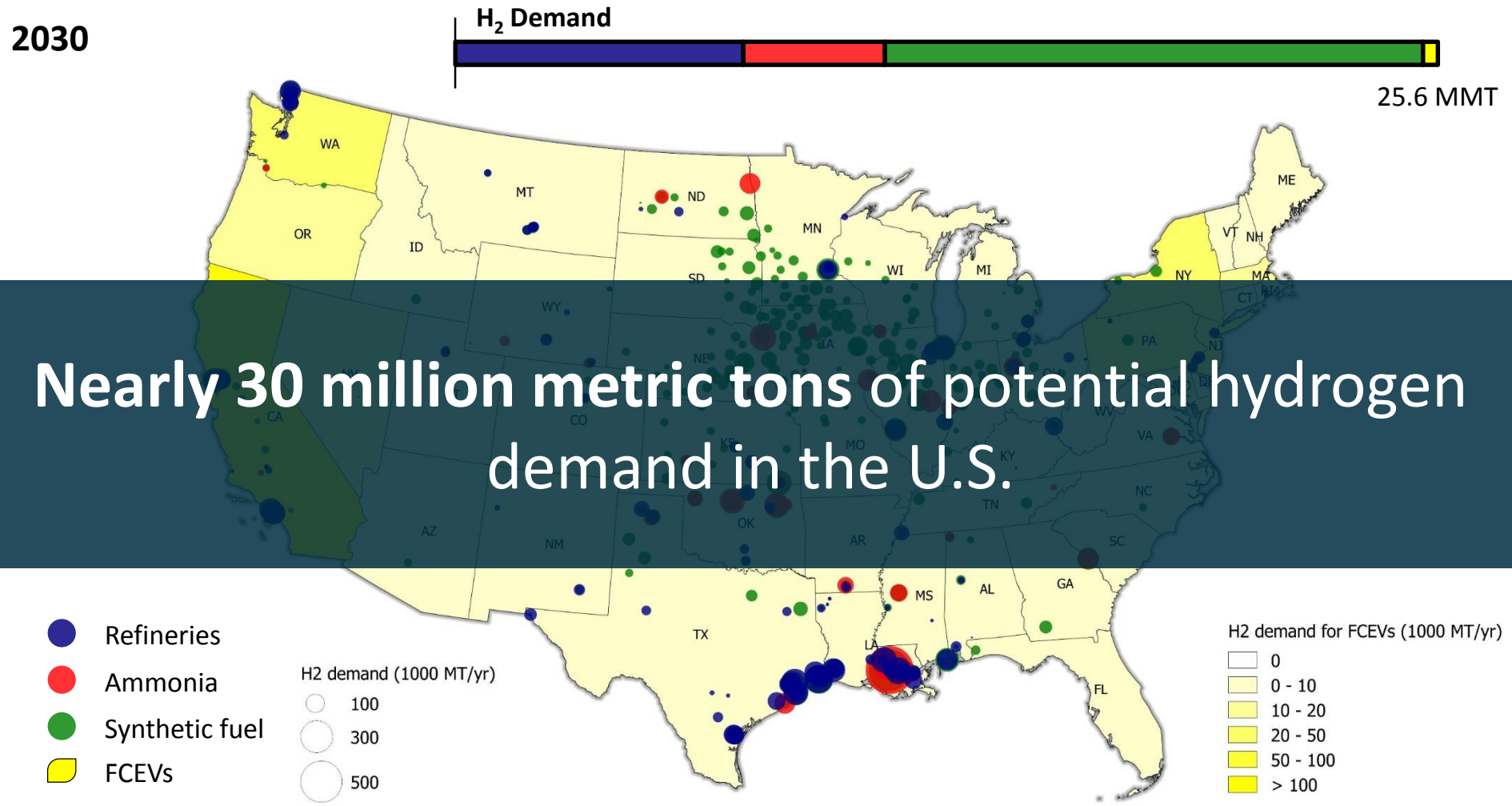
Source: Elgowainy, et al, ANL

Plus demand from synthetic fuel production…



Source: Elgowainy, et al, ANL

Plus demand from FCEVs…



Nearly 30 million metric tons of potential hydrogen demand in the U.S.

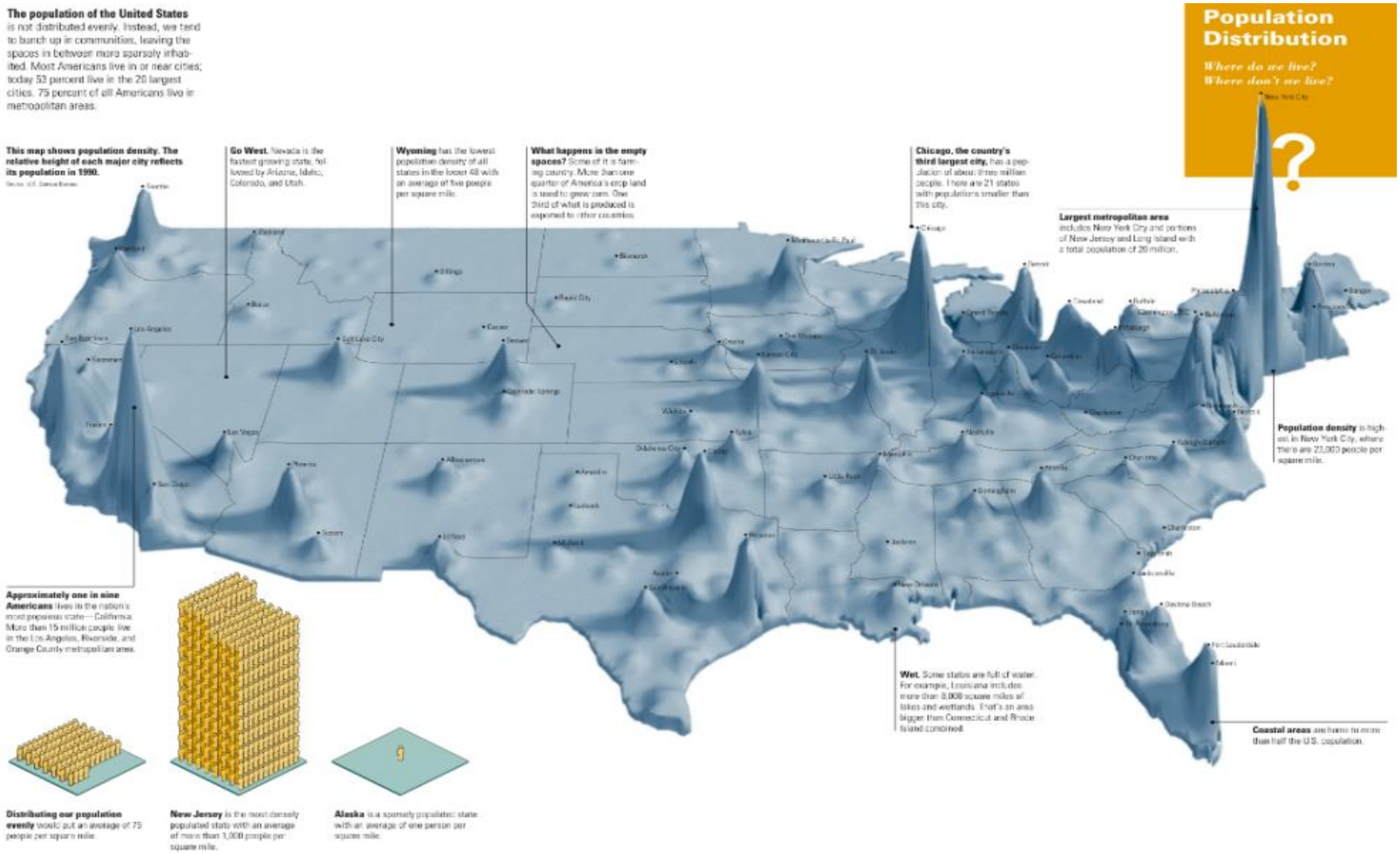
Source: Elgowainy, et al, ANL

H_2@Scale: Enabling renewable energy transport?

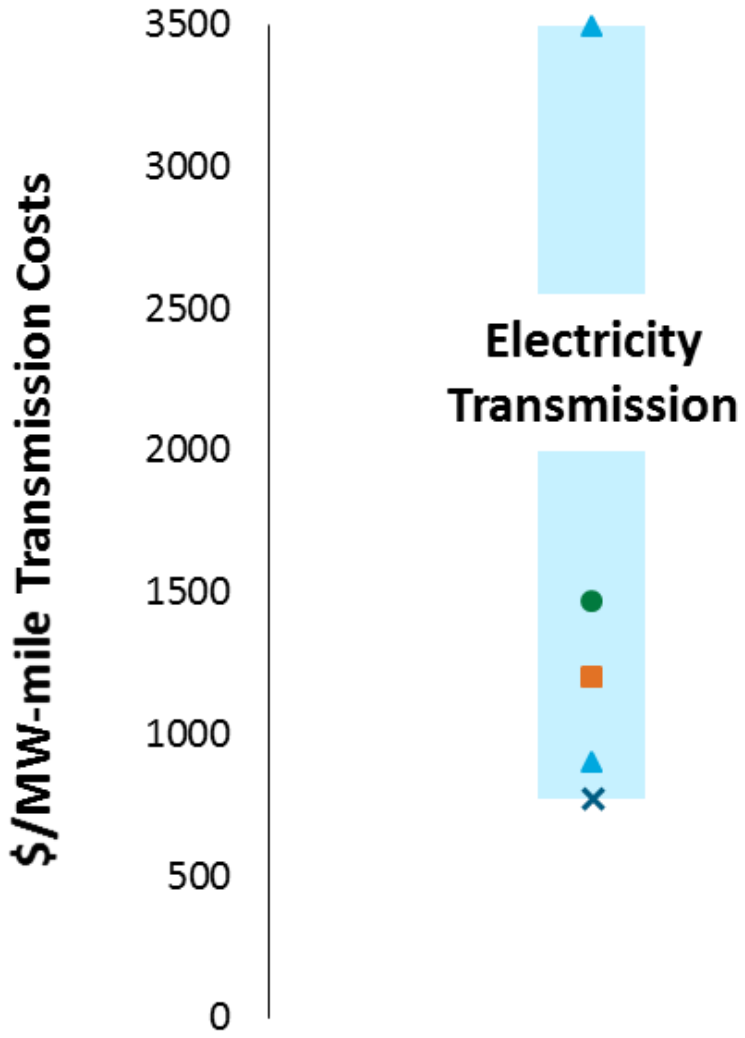
Where we find abundant solar and wind energy

H_2@Scale: Enabling renewable energy transport?

Where energy is consumed



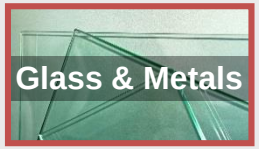
Analysis underway to guide future plans



Cost of long distance electricity transmission is high

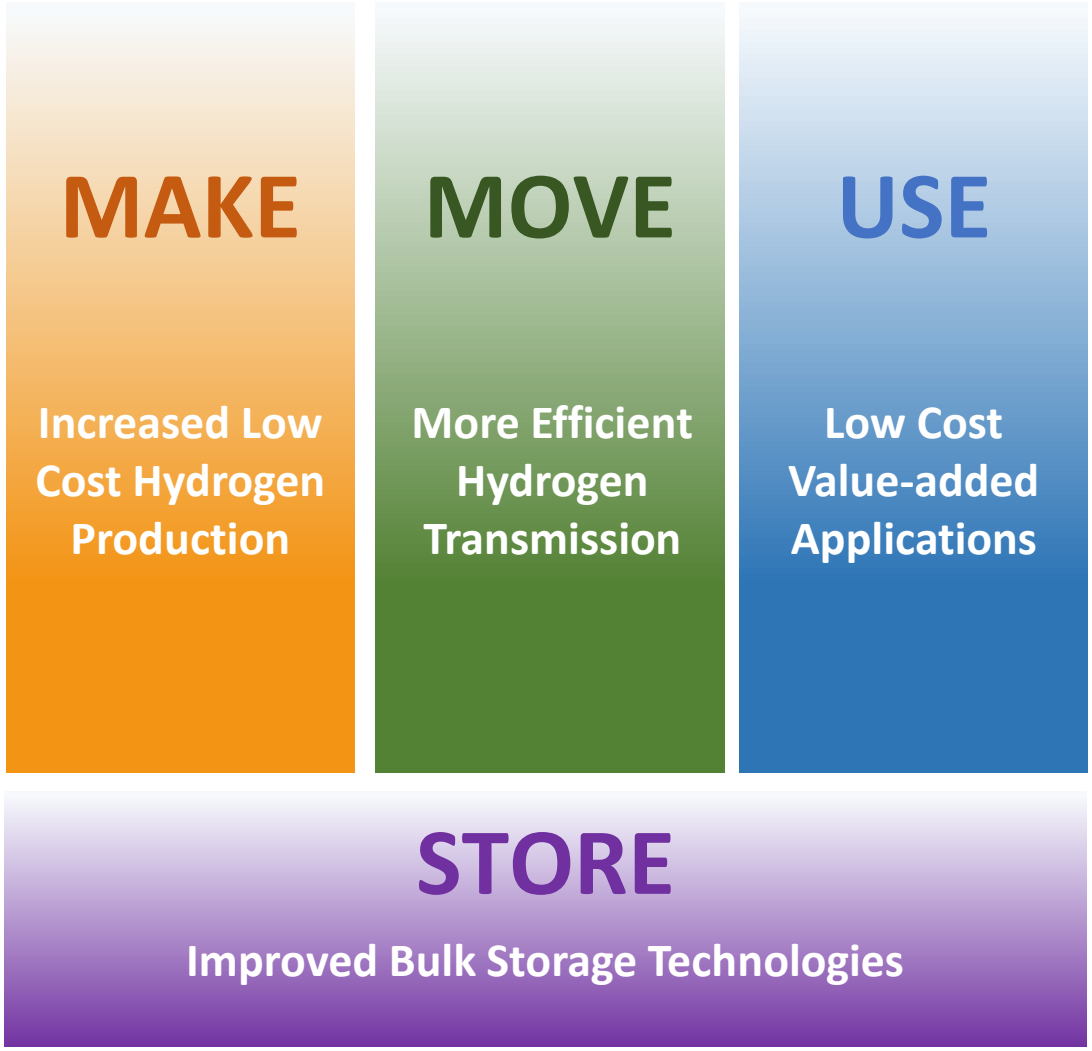
Can H_2 or H_2 carriers be an option?

Hydrogen for different scales and applications

Industry	Key Applications	Supply Systems	Volume
 Small Scale	■ Laboratories ■ Fuel Cell Applications	■ Small on-site ■ Cylinders ■ Tube trailers ■ Liquid H_2	Low < 0.1 mmscfd
 Electronics	■ Thin-film solar ■ Semi-Conductors ■ Materials Processing	■ Tube trailer ■ Liquid H_2 ■ Small On-Site Plant	
 Glass & Metals	■ Float glass mfg ■ Steel Anealing	■ Liquid H_2 ■ On-Site Plant	Medium 0.1- 5 mmscfd
 Chemicals	■ Chemicals ■ Food ■ Biofuels	■ Liquid H2 ■ On-Site Plant ■ Pipeline	
 Refining, Ammonia	■ Hydro-processing ■ De-sulfurization ■ Haber-Bosch	■ Pipeline ■ On-Site Plant	High 60-200+ mmscfd

Early stage R&D needs include cost reduction for materials, compressors, storage, transportation, etc.

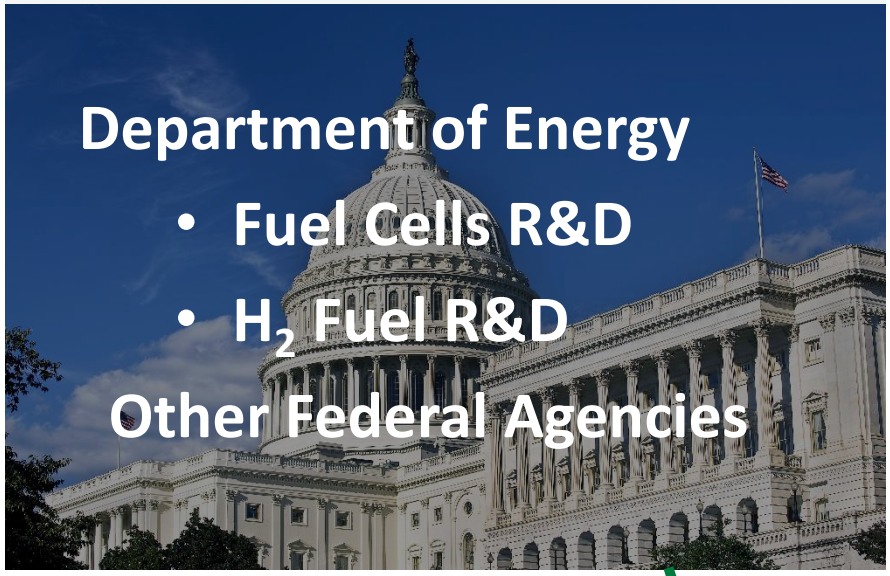
Key focus areas to realize the H_2@scale vision



3. Collaboration

Strategy: Partnerships to enable H_2@Scale

Early- Stage R&D



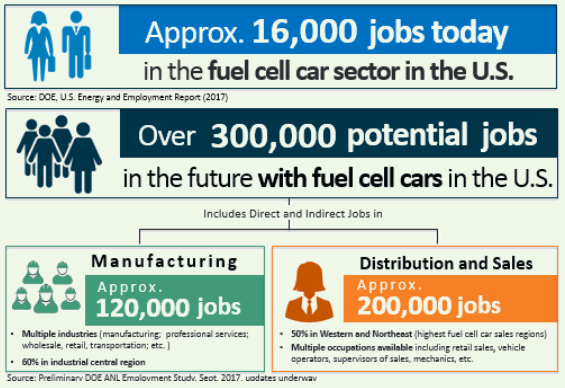
Demonstration, Deployment & Commercialization

H2@Scale U.S. Department of Energy

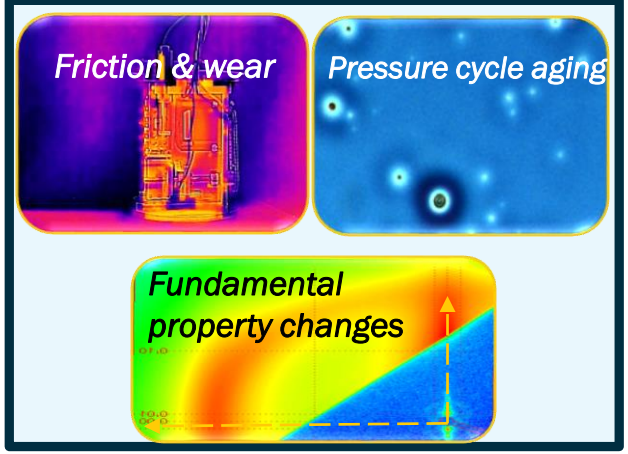
H_2@Scale Consortium

H_2@Scale R&D Lab Capabilities– Examples

Techno economic Modeling and Analysis



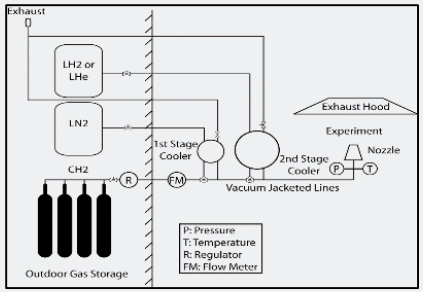
Hydrogen Materials R&D



Grid simulation and Testing R&D

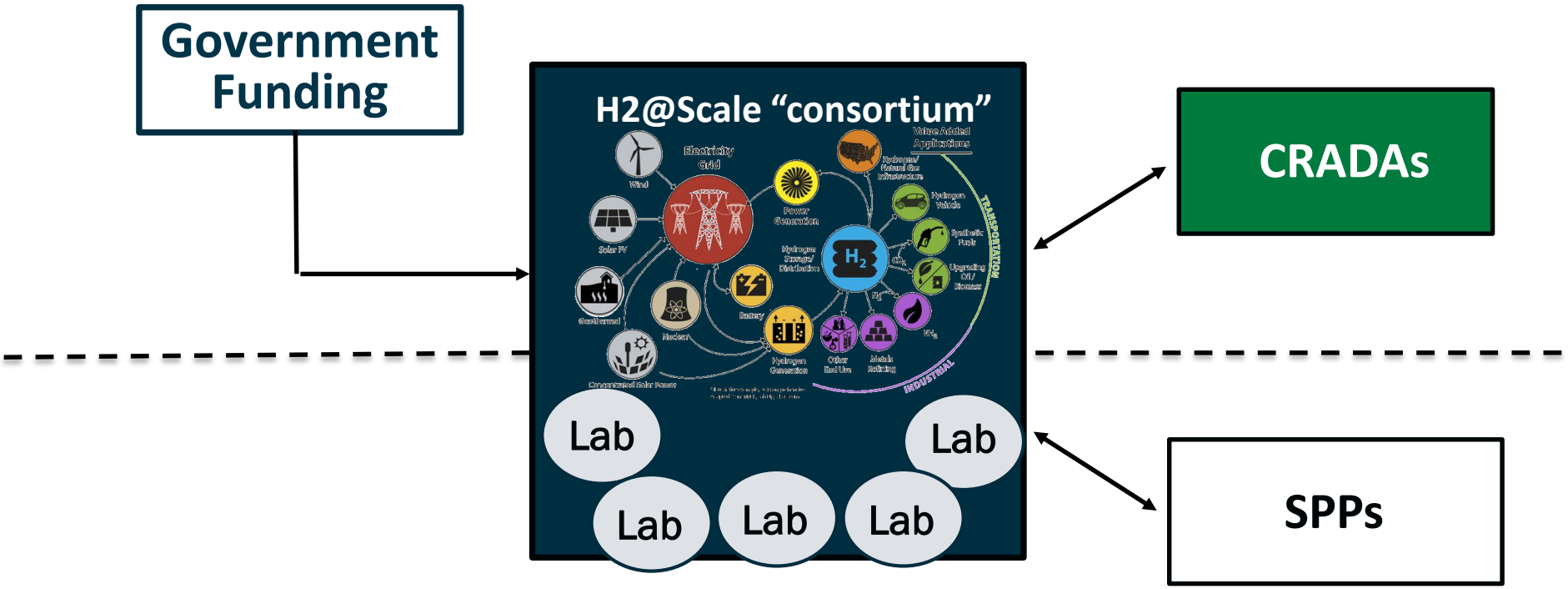
Safety and Infrastructure R&D

HyRAM
HYDROGEN RISK ASSESSMENT MODELS



H_2@Scale – Lab CRADAs

- **Leverages Lab capabilities and expertise to address challenges- materials R&D, analysis, safety R&D, etc.**
- **Round 1 in 2017.**

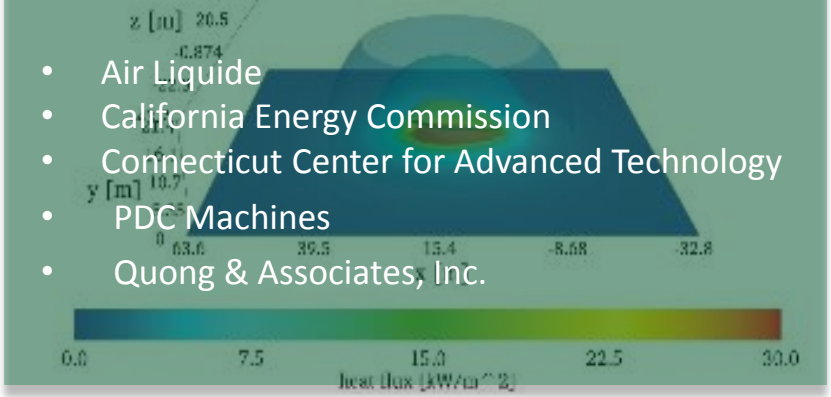


CRADA = Cooperative Research and Development Agreement
SPP- Strategic Partnership Project ('Work for Others')

H_2@Scale 2017 CRADA call selections

HYDROGEN QUANTITATIVE PERFORMANCE ANALYSIS AND OPERATION R&D

- Air Liquide
- California Energy Commission
- Connecticut Center for Advanced Technology
- PDC Machines
- Quong & Associates, Inc.

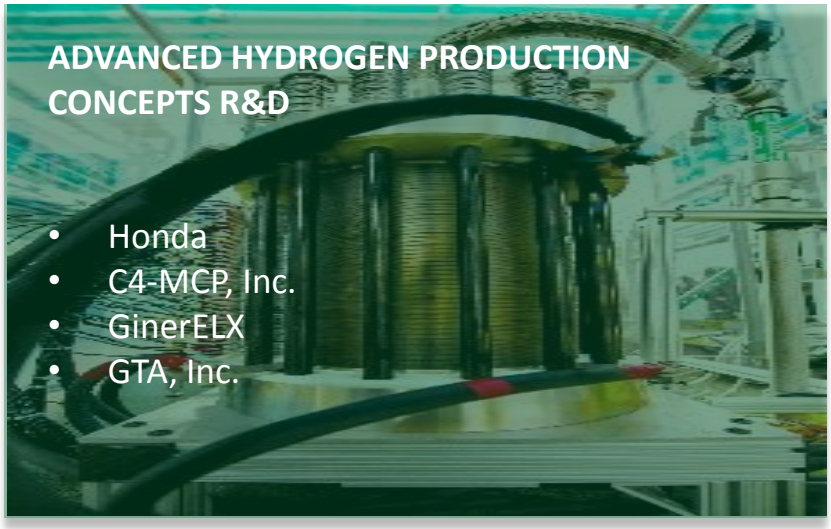


HYDROGEN DISTRIBUTION COMPONENT DEVELOPMENT R&D

- California Go-Biz Office
- Frontier Energy
- HyET
- Honda
- NanoSonic
- RIX
- Tatsuno

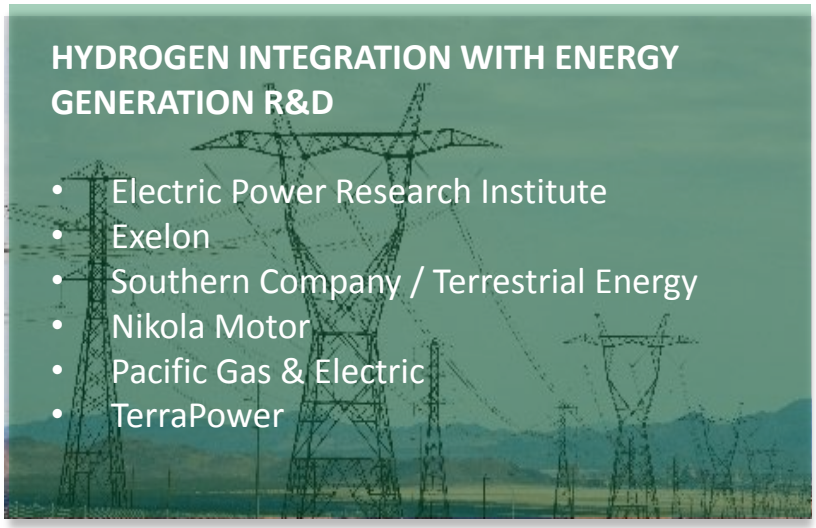
ADVANCED HYDROGEN PRODUCTION CONCEPTS R&D

- Honda
- C4-MCP, Inc.
- GinerELX
- GTA, Inc.



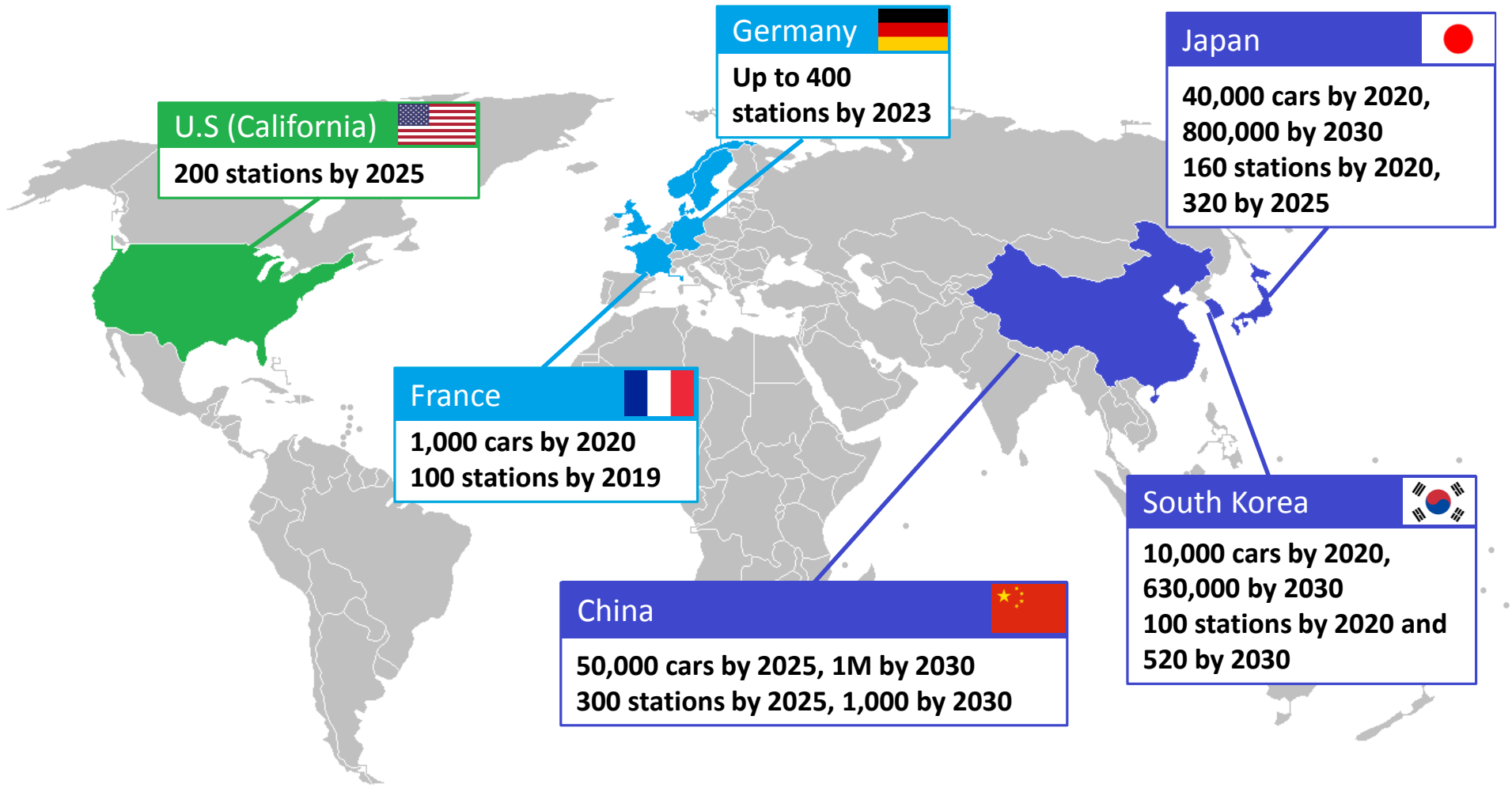
HYDROGEN INTEGRATION WITH ENERGY GENERATION R&D

- Electric Power Research Institute
- Exelon
- Southern Company / Terrestrial Energy
- Nikola Motor
- Pacific Gas & Electric
- TerraPower



Argonne NATIONAL LABORATORY · INL Idaho National Laboratory · BERKELEY LAB · NREL NATIONAL RENEWABLE ENERGY LABORATORY · Pacific Northwest NATIONAL LABORATORY · Sandia National Laboratories · SRNL SAVANNAH RIVER NATIONAL LABORATORY OPERATED BY SAVANNAH RIVER NUCLEAR SOLUTIONS

Global Hydrogen Infrastructure Activity Underway



IPHE: International Partnership for H_2 and Fuel Cells in the Economy

- **Share** information on H_2 and fuel cells, lessons learned, best practices
- **Increase** international **collaboration to accelerate progress**

U.S. elected as Chair

May 2018


Australia


Austria


Brazil


Canada


China


European Commission


France


Germany


Iceland


India


Italy


Japan


Republic of Korea


Norway


Russian Federation


South Africa


United Kingdom


United States

Launched 2003 and includes 18 countries and the European Commission

Two Requests for Information to Enable H2@scale

Opportunities to multi-sector use of hydrogen

Just announced!

Reducing barriers to hydrogen infrastructure

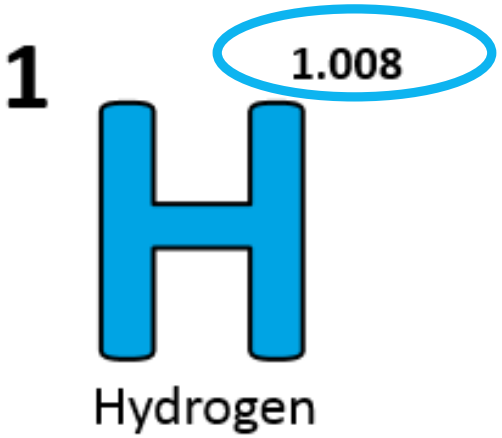
Closes Aug. 10

Opportunities for outreach and to increase awareness

Celebrate National Hydrogen & Fuel Cell Day

October 8 or 10/8

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



Information and Training Resources to Increase Awareness

H2tools.org

INCREASE YOUR H2IQ

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

Learn more at: energy.gov/eere/fuelcells

Thank You

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