

U.S. Department of Energy Hydrogen and Fuel Cell Technology Perspectives

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22nd World Hydrogen Energy Conference

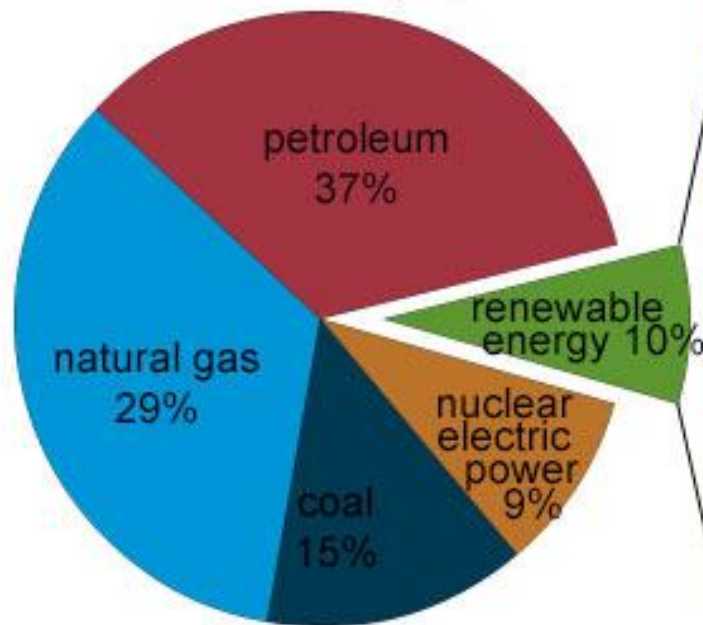
Rio de Janeiro, Brazil – June 20, 2018



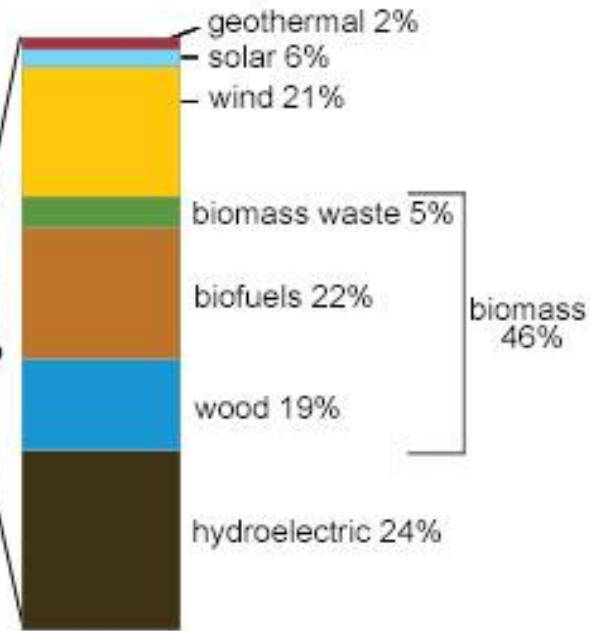
U.S. energy mix covers wide of energy sources

U.S. energy consumption by energy source, 2016

Total = 97.4 quadrillion
British thermal units (Btu)



Total = 10.2 quadrillion Btu



Note: Sum of components may not equal 100% because of independent rounding.

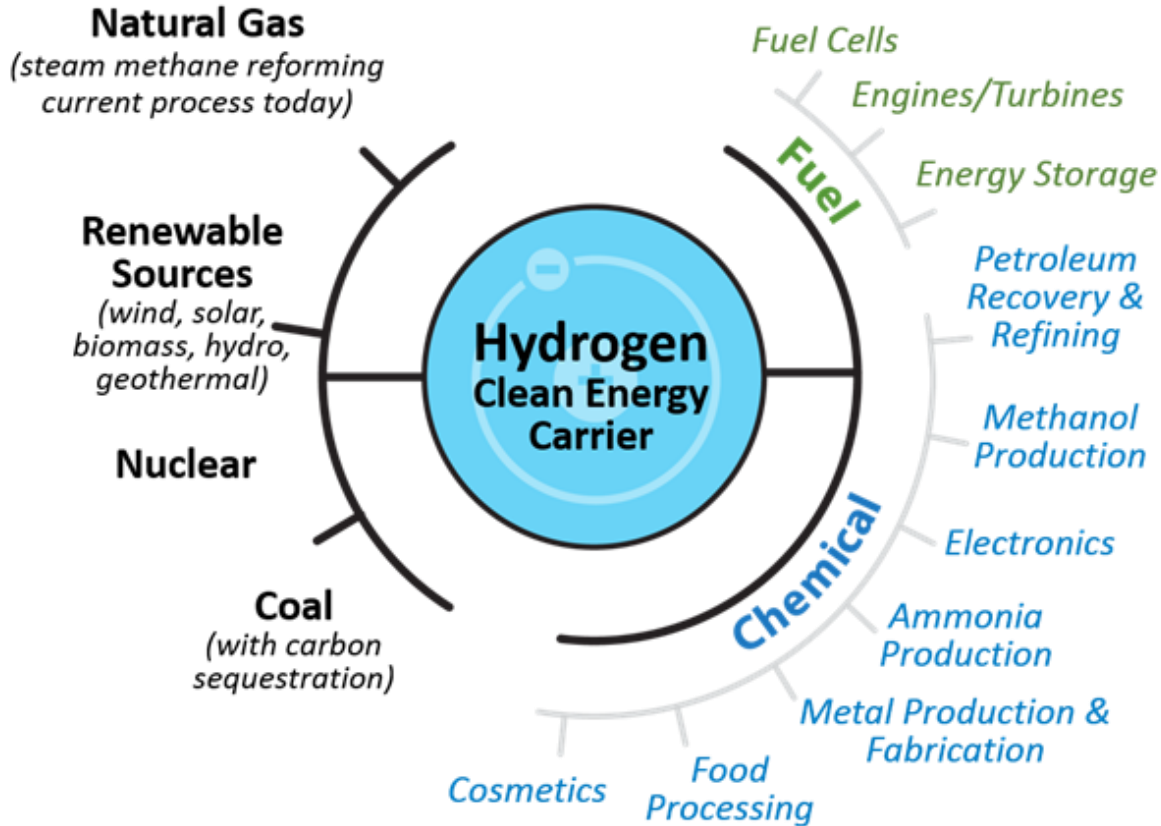
Source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 1.3 and 10.1, April 2017, preliminary data



Hydrogen is one part of an 'all of the above' portfolio

H₂ can be produced from diverse domestic sources

Many applications rely on or could benefit from H₂



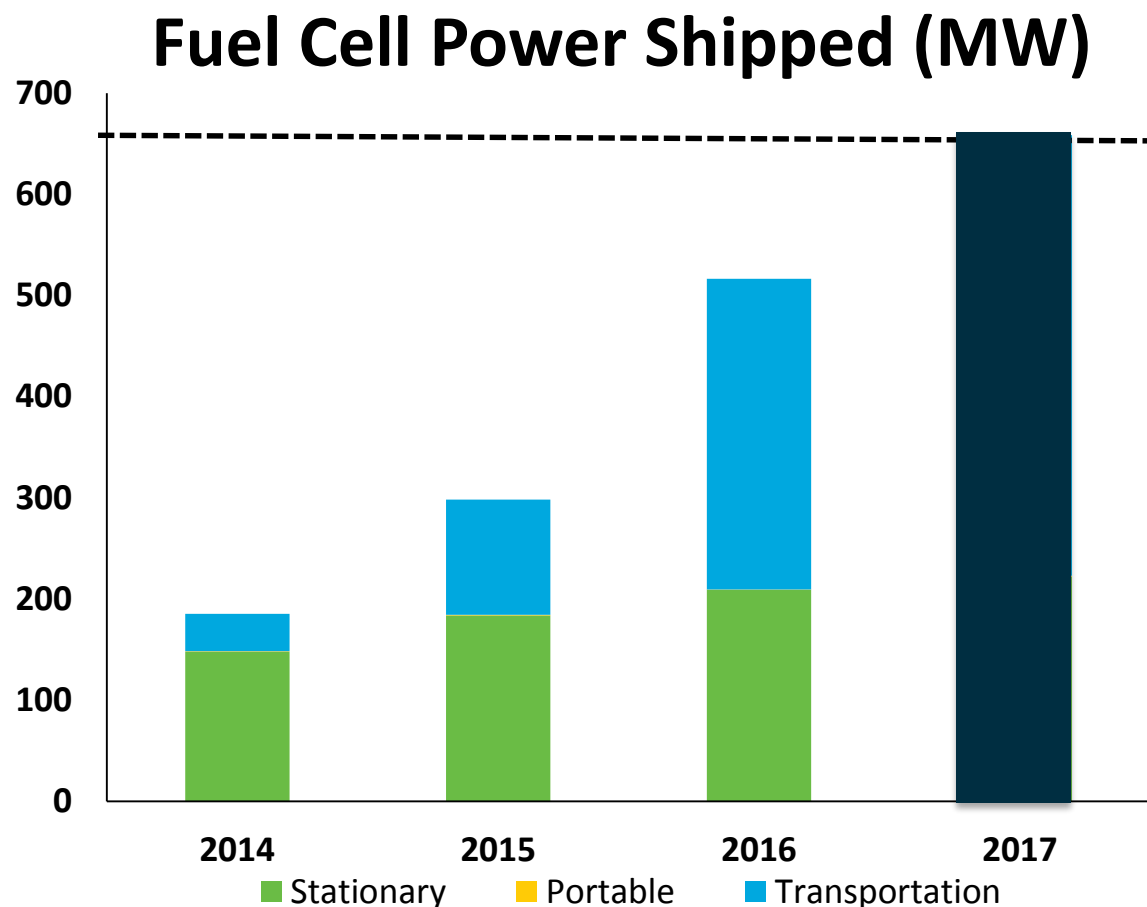
Clean , sustainable, versatile, and efficient energy carrier

4 Key Messages

A photograph of two white hydrogen fuel cell vehicles (FCVs) parked at a hydrogen refueling station. The vehicles have blue and white graphics with the words "HYDROGEN FUEL" visible on their sides. A hydrogen refueling station with a blue and white dispenser is positioned between the two cars. The background shows a clear blue sky and some greenery. The text "1. Progress on multiple fronts, increased industry activity and global interest" is overlaid in white on the image.

1. Progress on multiple fronts, increased industry activity and global interest

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



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

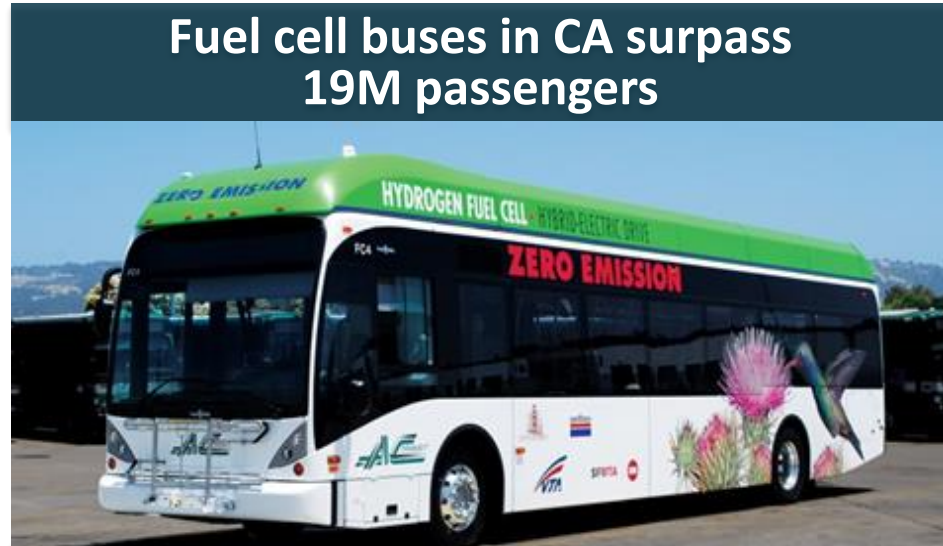
More than 20,000 forklifts

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



Stationary Power for Multiple Applications

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

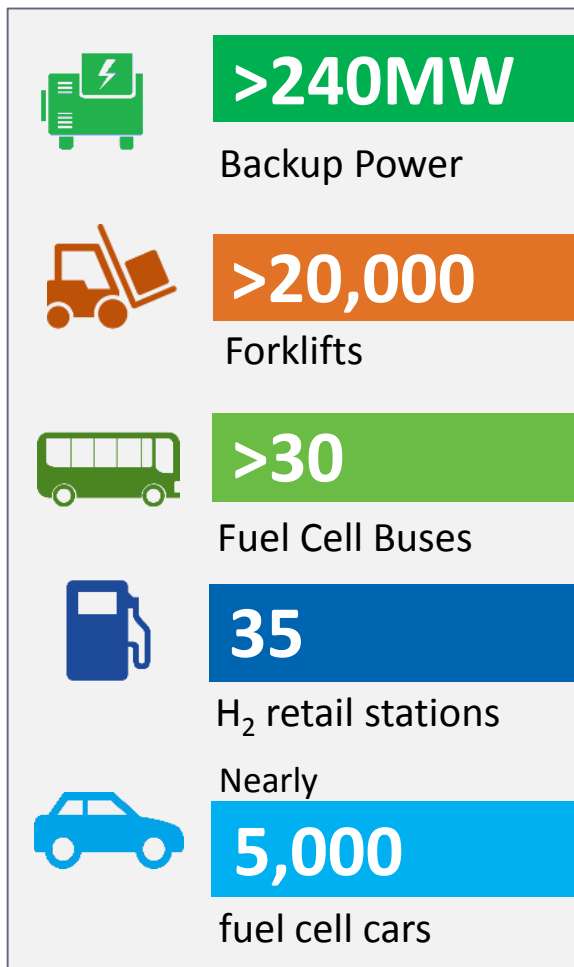


Over 240 MW of fuel cell stationary power installed across more than 40 US states

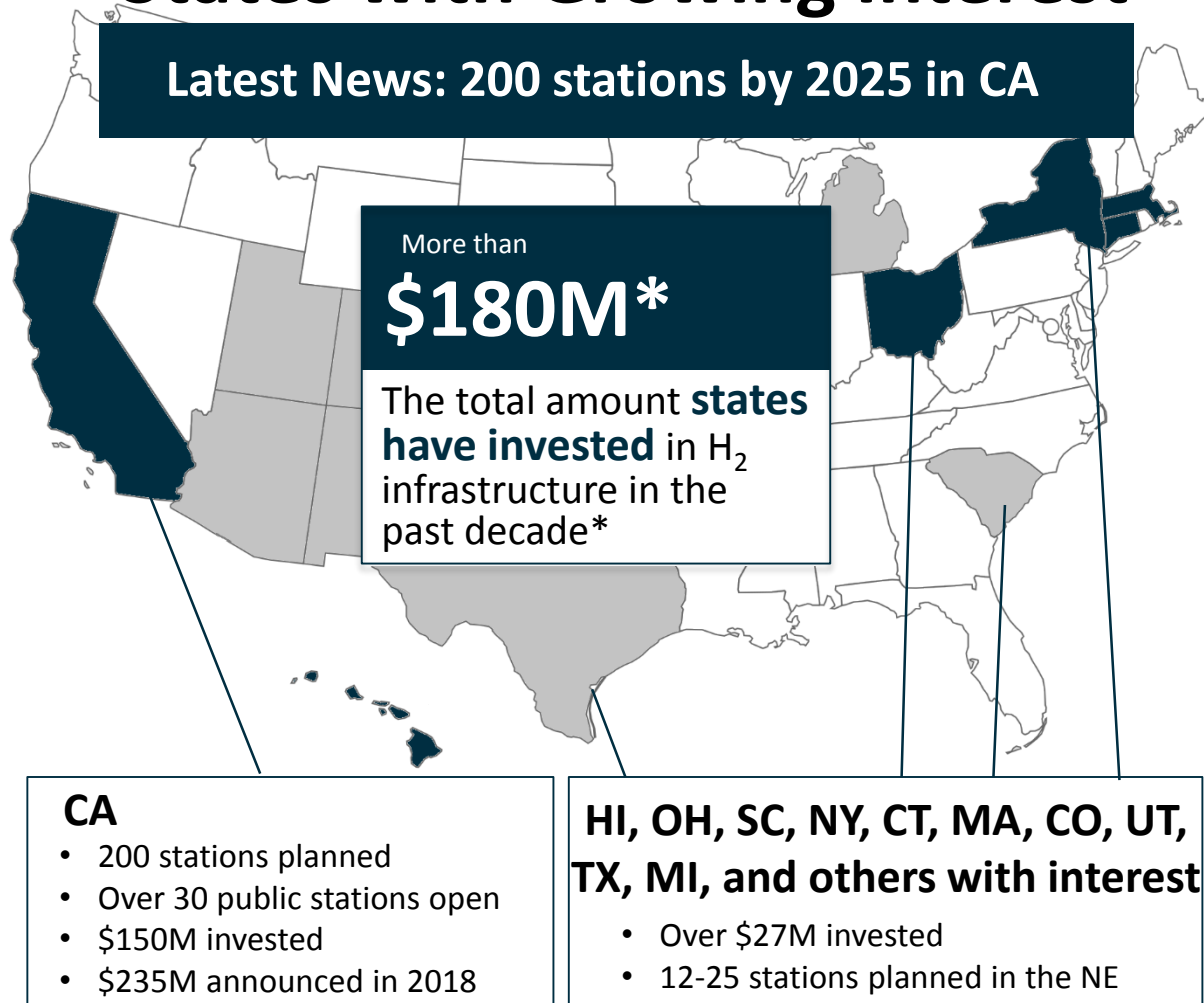


Multiple H₂ and Fuel Cell Applications in the U.S.

U.S. Snapshot



States with Growing Interest



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

A photograph of two white hydrogen fuel cell vehicles parked at a hydrogen refueling station. The vehicles have blue and white graphics that say "POWERED BY HYDROGEN FUEL". The station is a blue and white structure with "HYDROGEN" written on top. The background shows a clear blue sky and some greenery.

2. Technical and institutional challenges remain and need to be addressed

U.S. Dept. Of Energy H₂ and Fuel Cells R&D Focus

Early R&D Focus

Applied research, development and innovation in hydrogen and fuel cell technologies leading to:

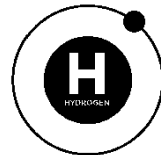
- Energy security
- Energy resiliency
- Strong domestic economy

Early R&D Areas



Fuel Cells

- PGM- free catalysts
- Durable MEAs
- Electrode performance



Hydrogen Fuel

- Production Pathways
- Advanced materials for storage



Infrastructure R&D

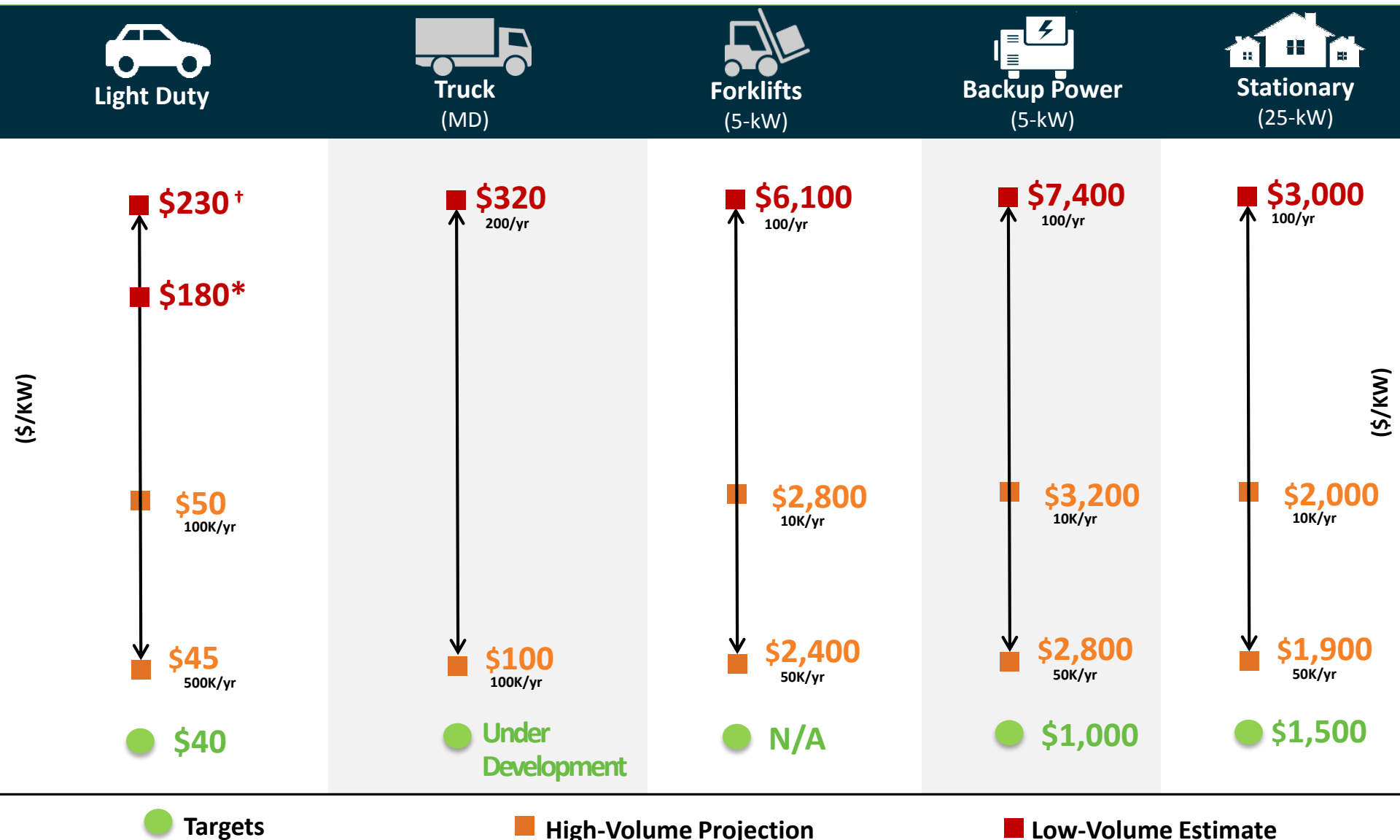
- Safety
- Manufacturing
- Delivery components
- Others

PGM = Platinum group metals
MEA = Membrane Electrode Assembly

Enabling



Technology targets in various applications guide R&D

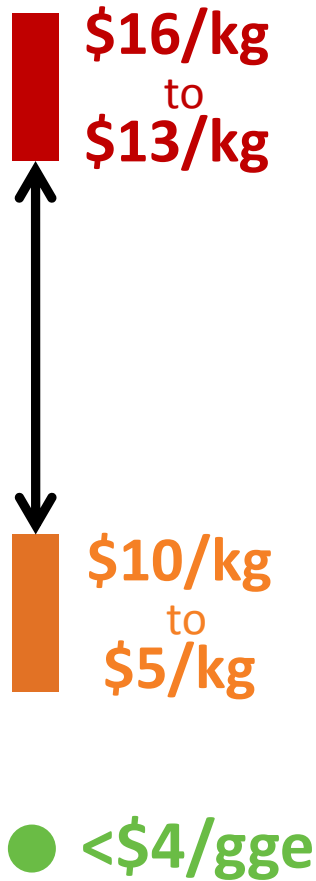


†Based on commercially available FCEVs †Based on state of the art technology

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

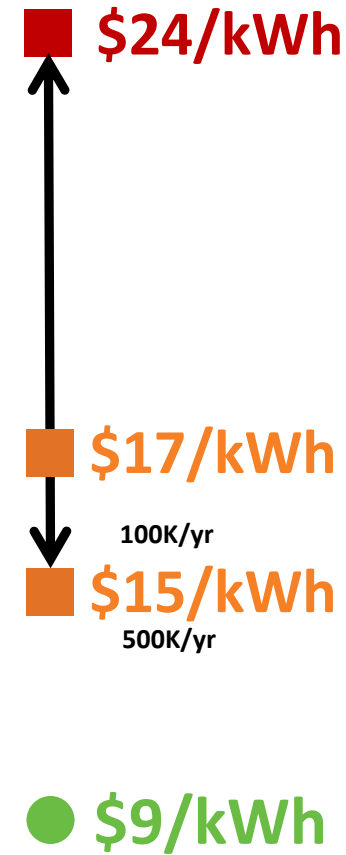
More R&D needed to meet affordability targets

Production, Delivery & Dispensing



On-board Storage

(700-bar compressed system)



● DOE Targets

■ High-Volume Projection

■ Low-Volume Estimate

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

The Hydrogen Infrastructure Challenge

- **Cost**
- **Reliability**
- **Availability**

Gasoline History: Many diverse options

Cans, barrels, home models, mobile refuelers



Source: M. Melaina 2008.



Source: Vieyra, 1979



Source: Milkues, 1978

Complementing Retail Stations: H₂Refuel H-Prize



DOE awards \$1M H-Prize to Simple Fuel for winner small-scale H₂ fueling design




www.hydrogenprize.org

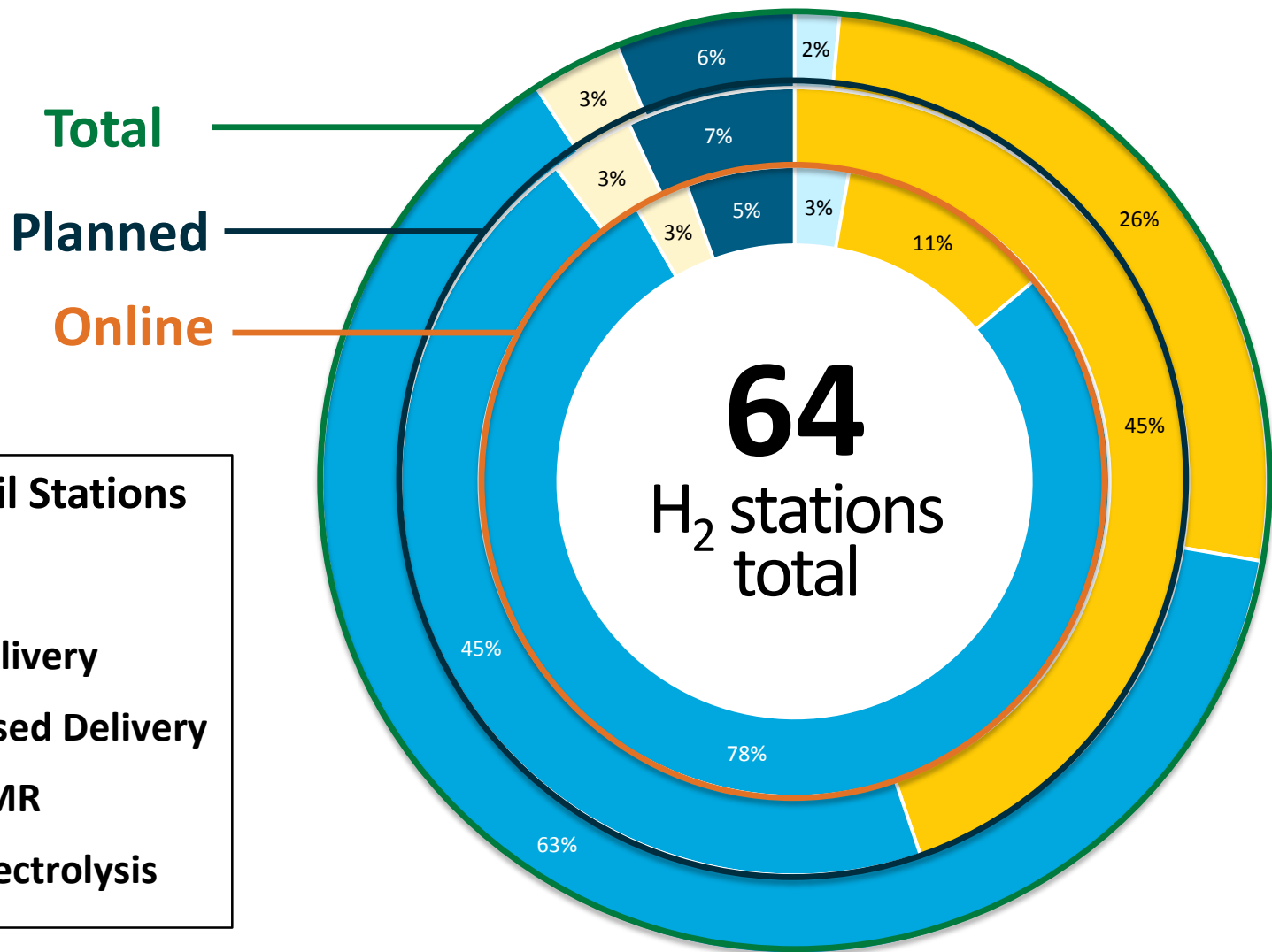
simple.fuel.™

Email: connect@ivysinc.com

More info: www.teamsimplefuel.com

Ivys Energy Solutions (MA)
McPhy Energy (MA)
PDC Machines (PA)

More liquid stations planned in the U.S.



Based on data from NREL

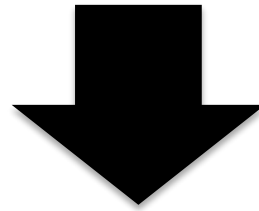


3. H₂@Scale concept: value, volume and versatility



Scale: Simple Example

How much hydrogen for 1 car?

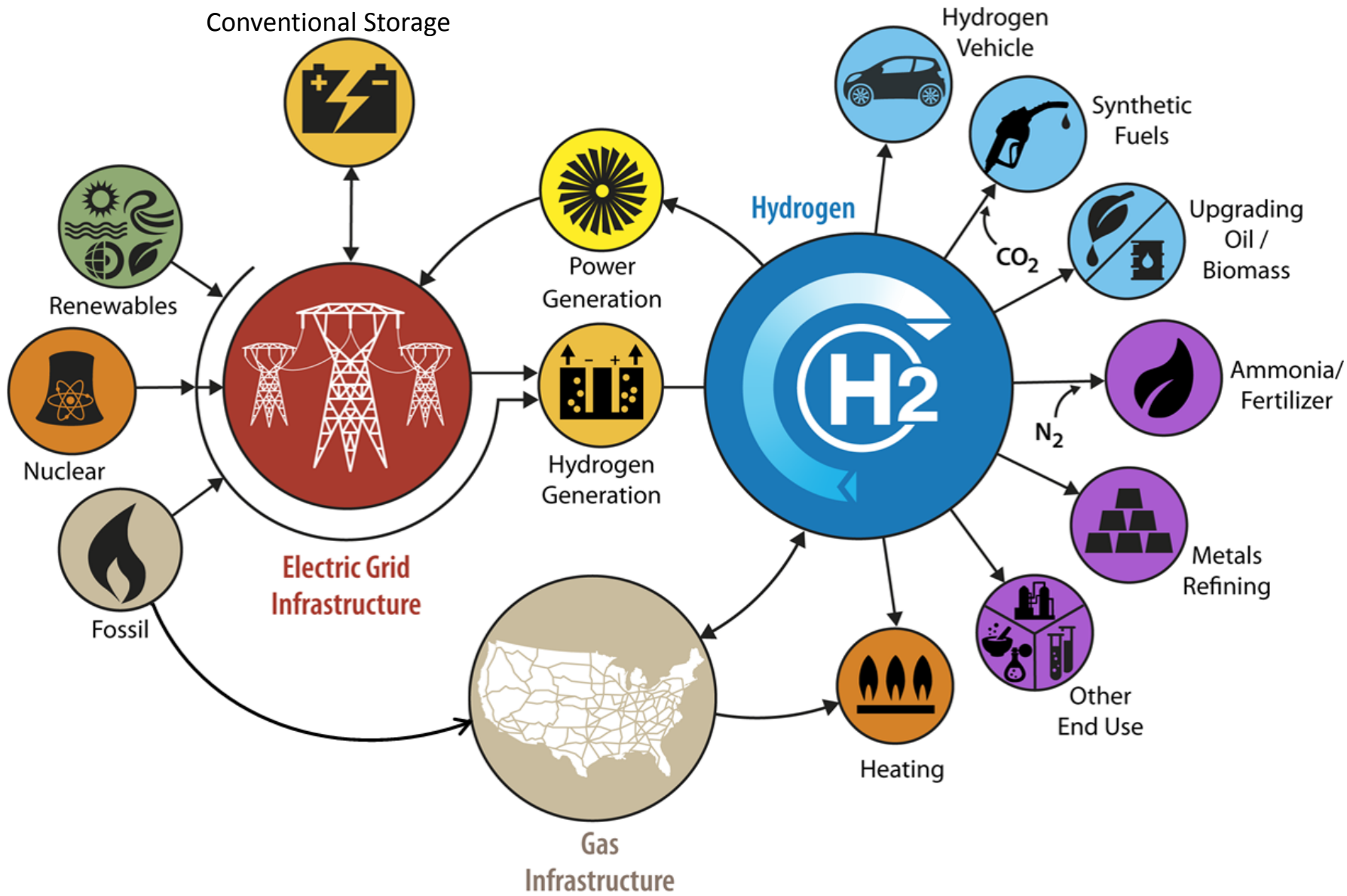
$$\frac{12,000 \text{ miles per year}}{60 \text{ miles per kilogram}} = 200 \text{ kg per year} \text{ or } 0.2 \text{ tonnes per year}$$



How much hydrogen for many cars?

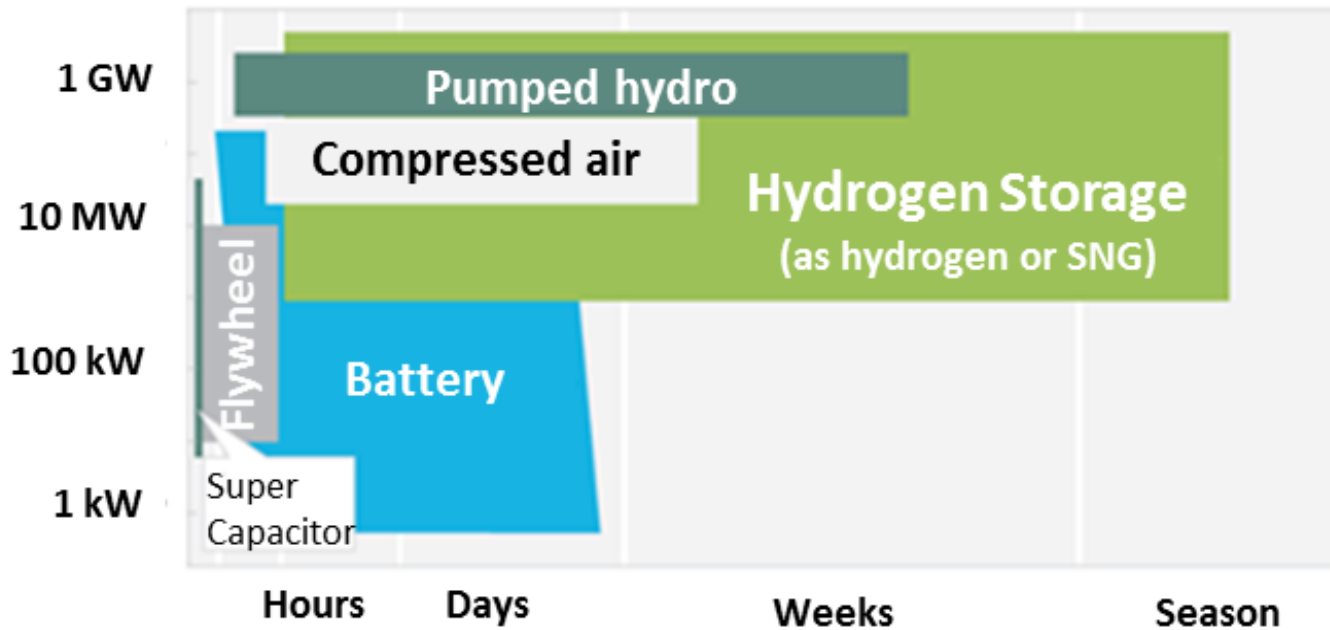
100 M cars   = 10M cars	20M tons H ₂ per year 20 B kg H ₂ per year
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H₂@Scale Energy System



Hydrogen Energy Storage is Scalable

Overview of Energy Storage Technologies in Power and Time

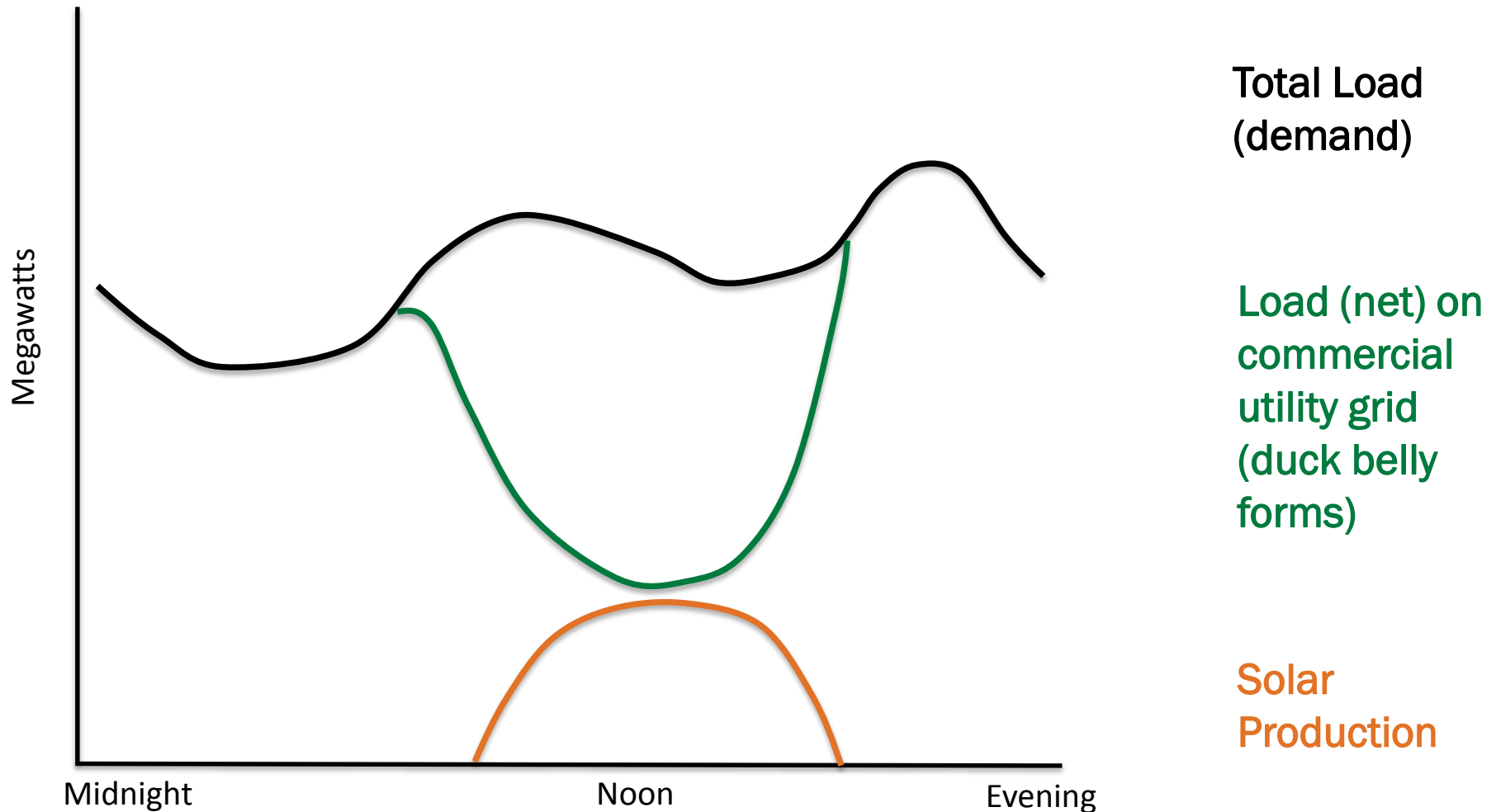


One hydrogen cavern could provide ~ 100 GWh energy storage

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.

The Duck Curve 101 - Example

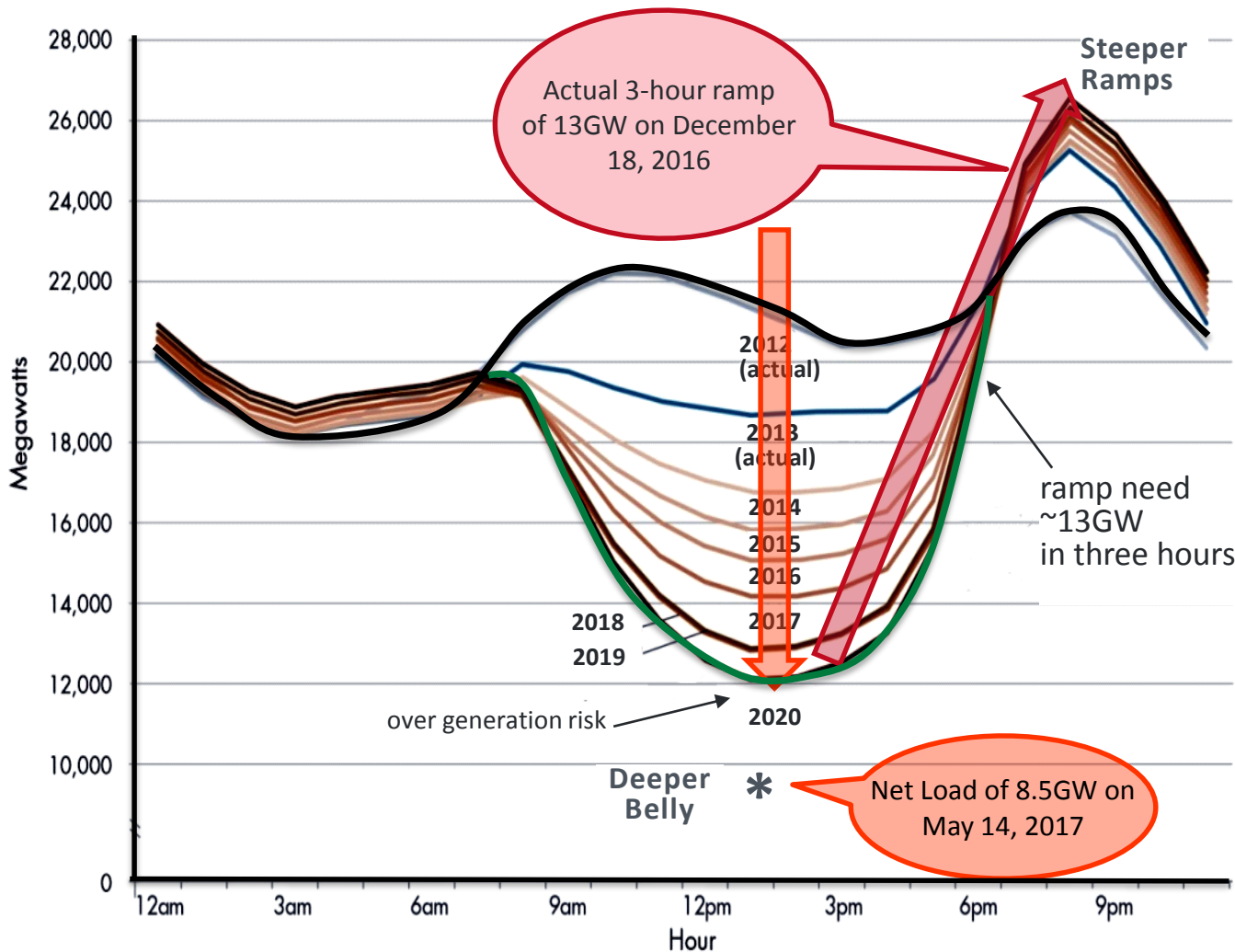


The Duck's belly is getting bigger

Two Concerns:

- **Low Net Load:** flexibility to reduce baseload generation resources is limited
- **High Ramp Rates in Evening:** flexibility of other generation to ramp up is limited

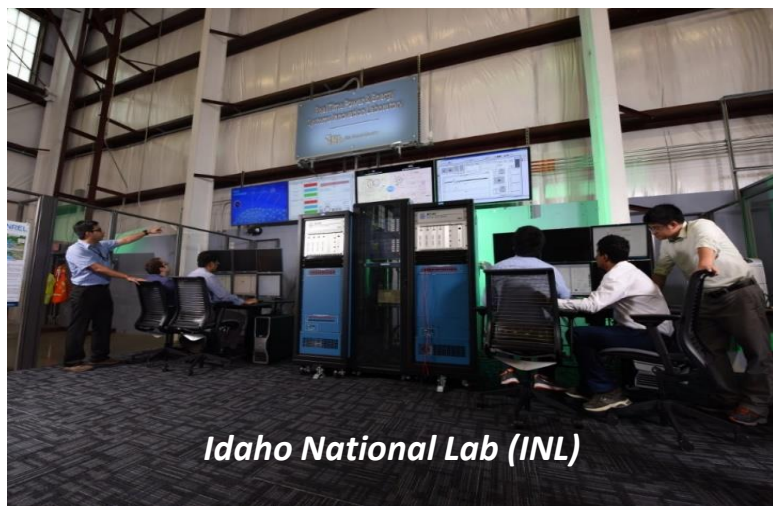
Can be addressed by



Source U.S. DOE Solar Energy Technologies Office

Lab testing electrolyzers' value for ancillary services

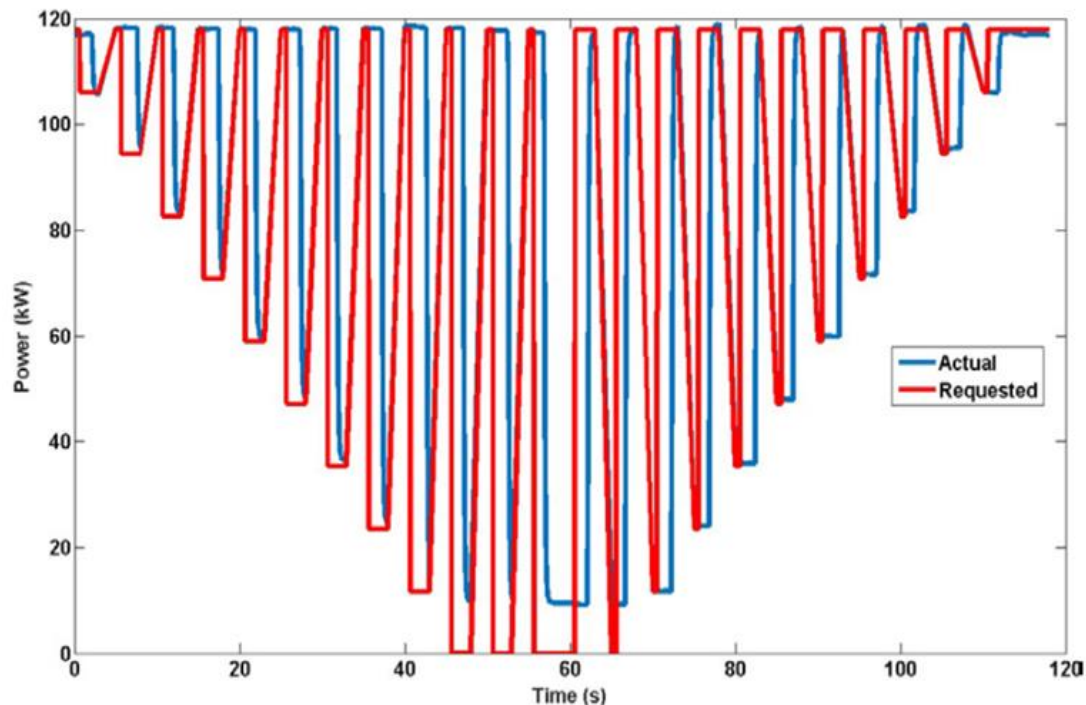
First Ever Validation of Frequency Regulation with Electrolyzers



Idaho National Lab (INL)



National Renewable Energy Lab (NREL)



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

H₂@Scale: Enabling renewable energy transport?

Where we find abundant solar and wind energy



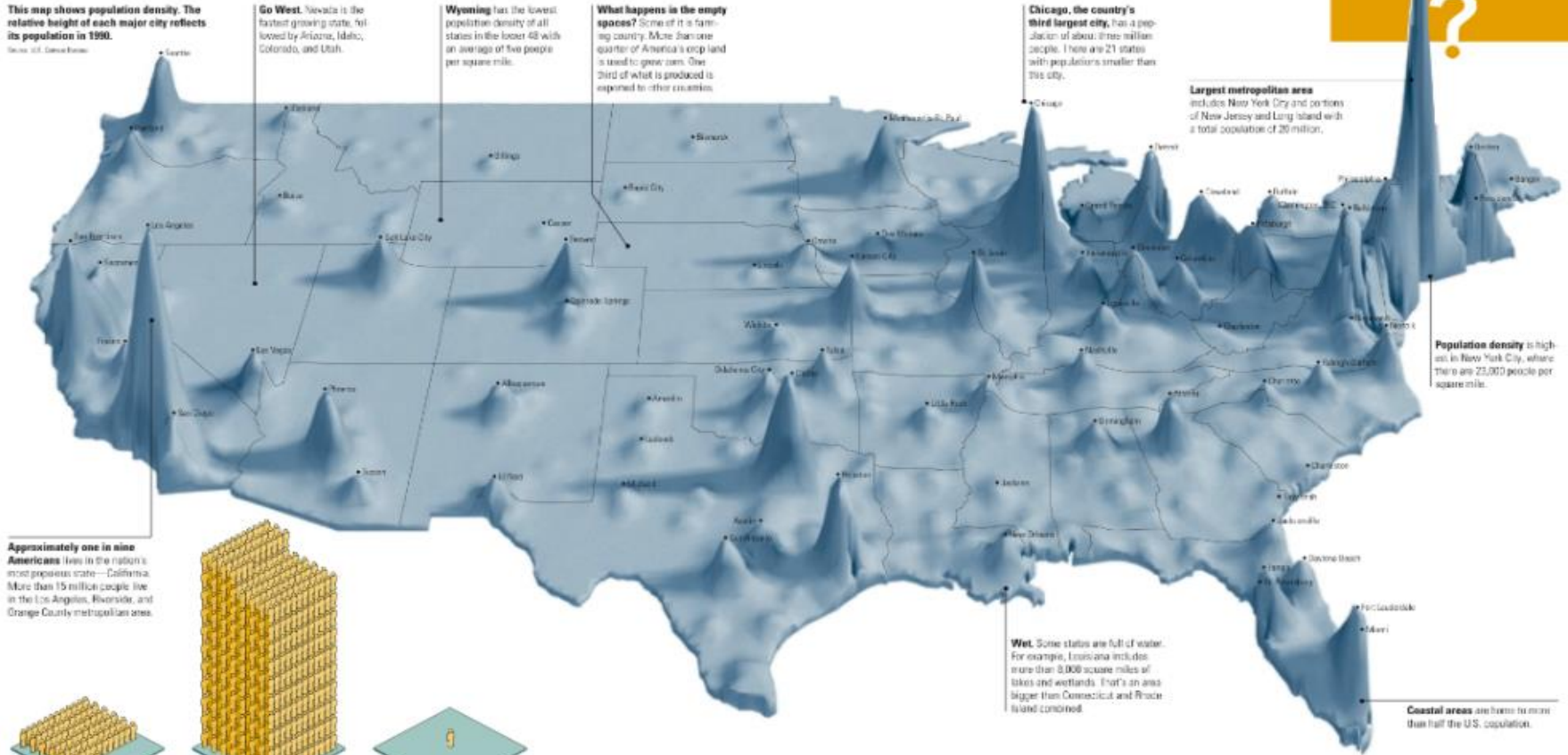
...and deliver it or co-locate distributed generation with demand for certain applications

The population of the United States is not distributed evenly. Instead, we tend to bunch up in communities, leaving the spaces in between more sparsely inhabited. Most Americans live in or near cities; today 53 percent live in the 20 largest cities, 75 percent of all Americans live in metropolitan areas.

Where energy is consumed

This map shows population density. The relative height of each major city reflects its population in 1990.

Source: U.S. Census Bureau



Go West. Nevada is the fastest growing state, followed by Arizona, Idaho, Colorado, and Utah.

Wyoming has the lowest population density of all states in the lower 48 with an average of two people per square mile.

What happens in the empty spaces? Some of it is farming country. More than one quarter of America's crop land is used to grow corn. One third of what is produced is exported to other countries.

Chicago, the country's third largest city, has a population of about three million people. There are 21 states with populations smaller than this city.

Largest metropolitan area includes New York City and portions of New Jersey and Long Island with a total population of 20 million.

Population Distribution

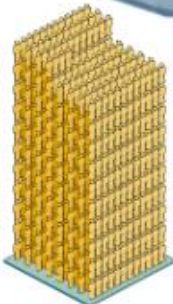
*Where do we live?
Where don't we live?*

Population density is highest in New York City, where there are 23,000 people per square mile.

Approximately one in nine Americans live in the nation's most populous state—California. More than 15 million people live in the Los Angeles, Riverside, and Orange County metropolitan areas.



Distributing our population evenly would put an average of 75 people per square mile.



New Jersey is the most densely populated state with an average of more than 1,000 people per square mile.

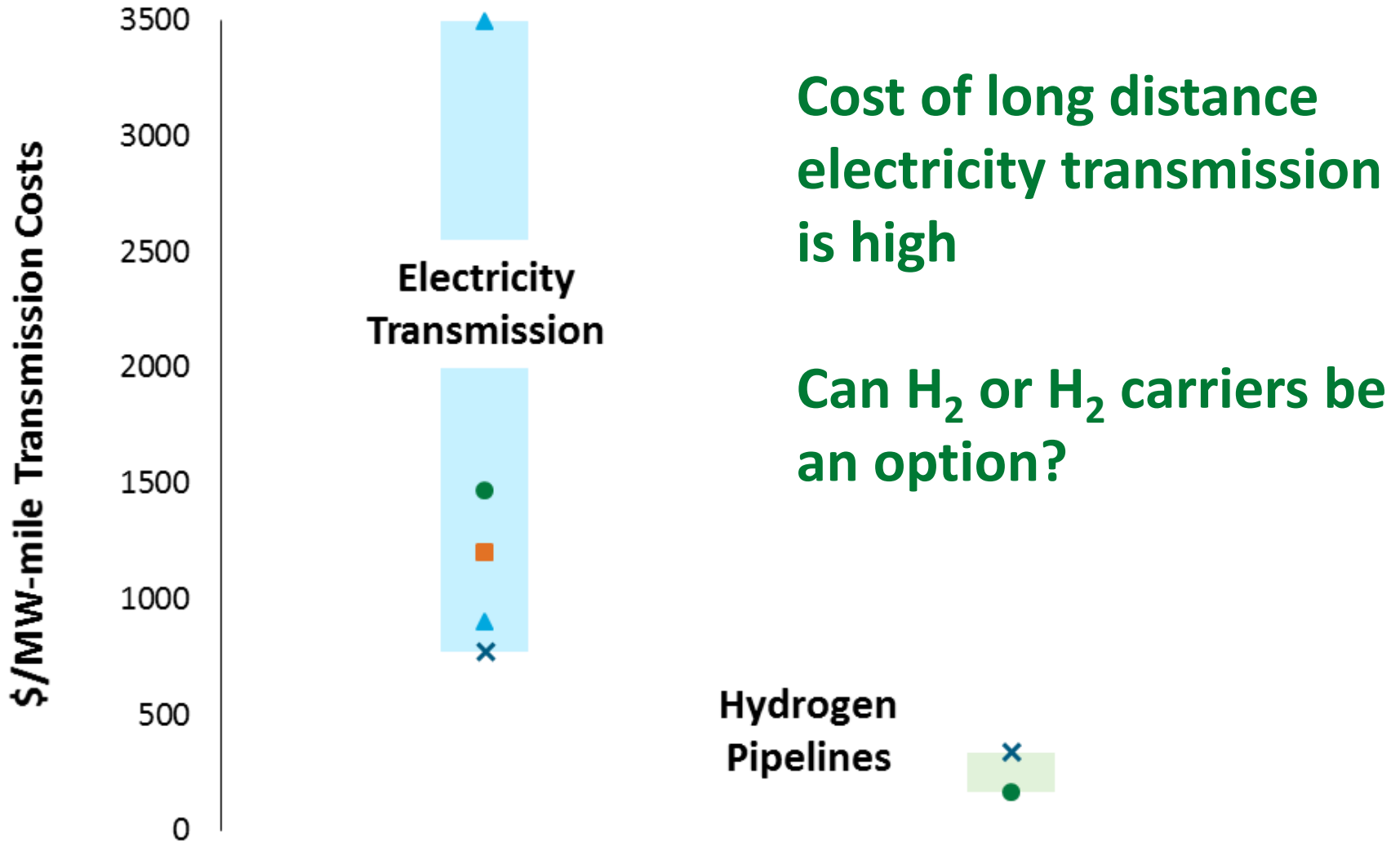


Alaska is a sparsely populated state with an average of one person per square mile.

Wet. Some states are full of water. For example, Louisiana includes more than 8,000 square miles of lakes and wetlands. That's an area bigger than Connecticut and Rhode Island combined.

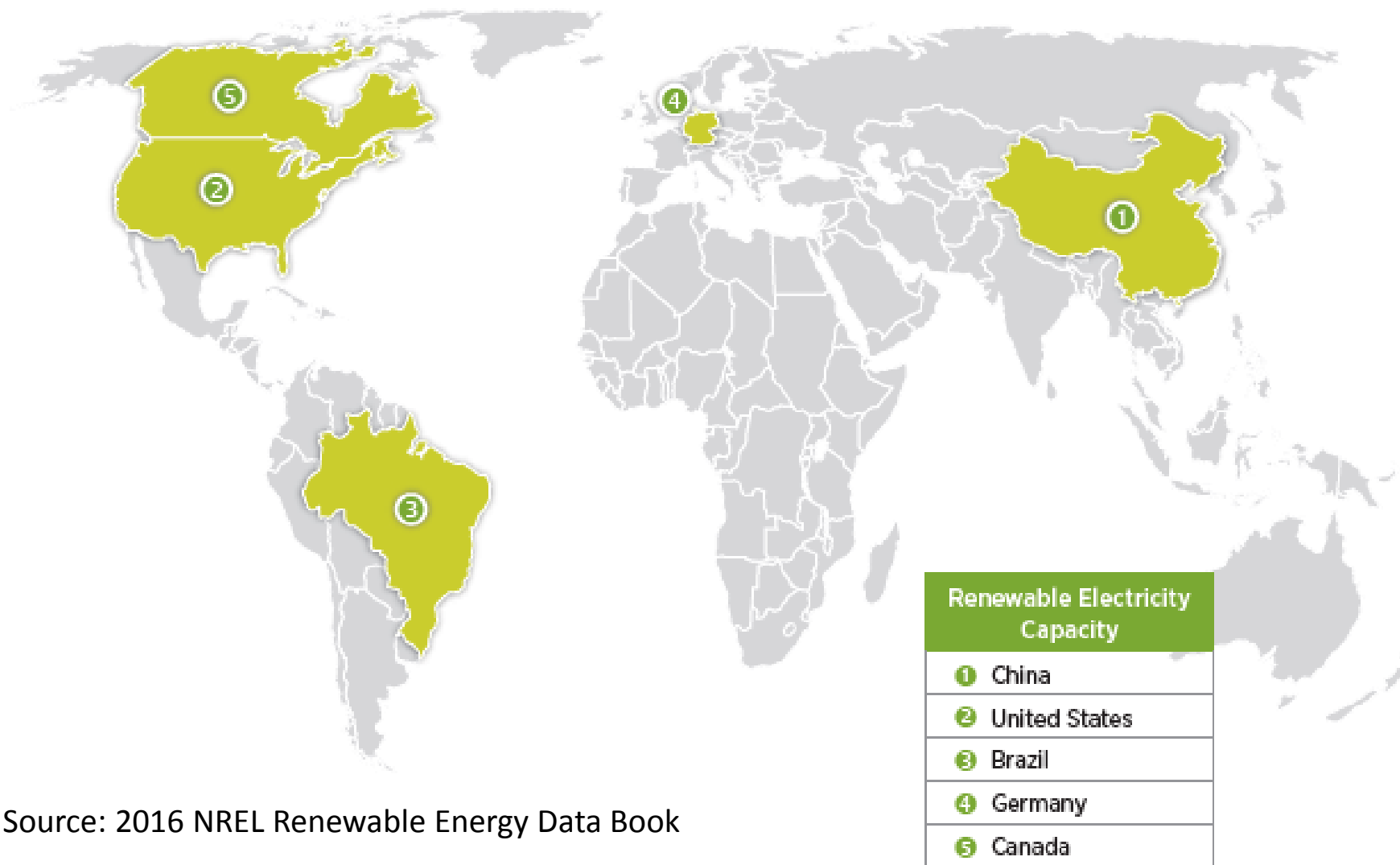
Coastal areas are home to more than half the U.S. population.

Analysis underway to guide future plans



H₂@scale can enable increased renewable penetration

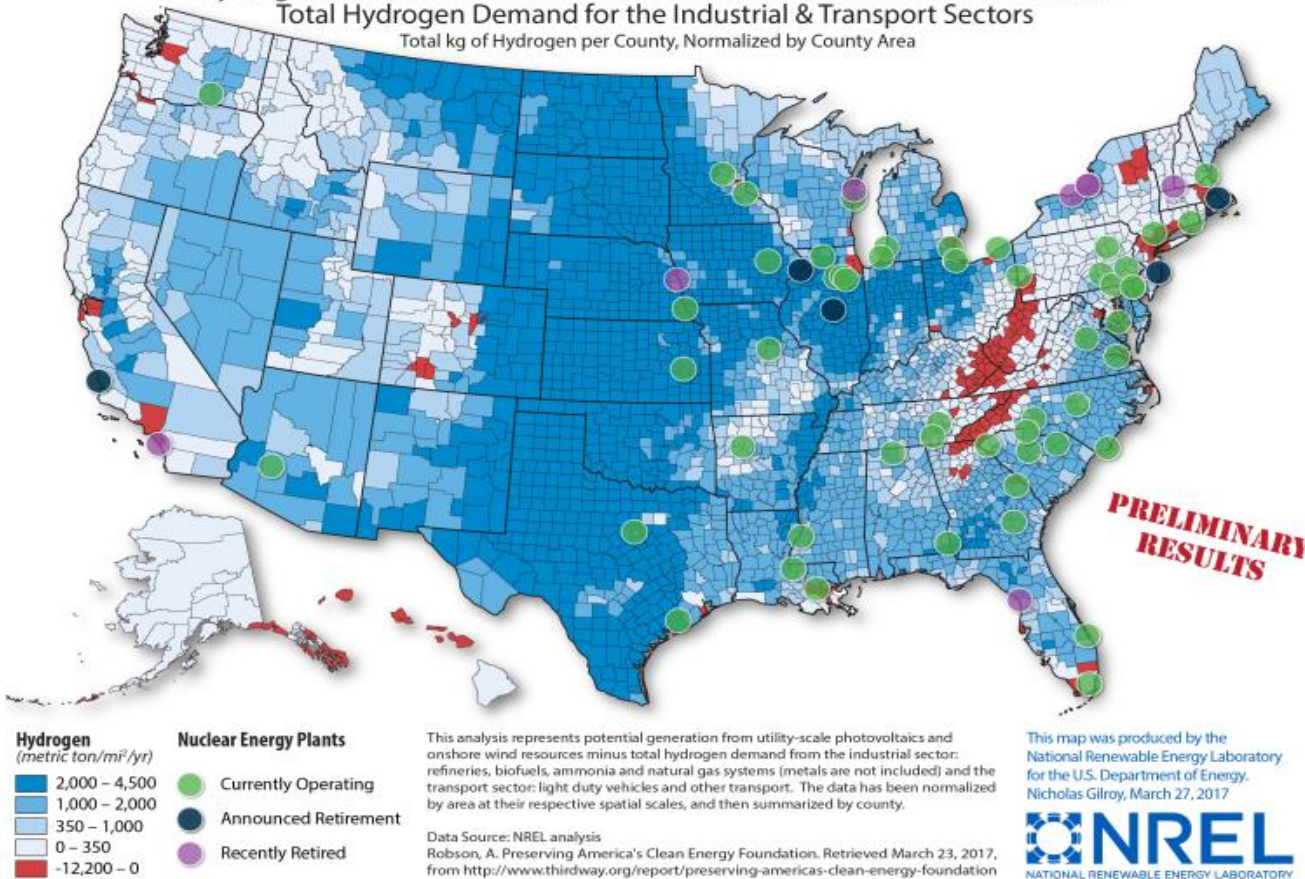
Top Countries for Renewable Electricity Installed



Source: 2016 NREL Renewable Energy Data Book

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



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



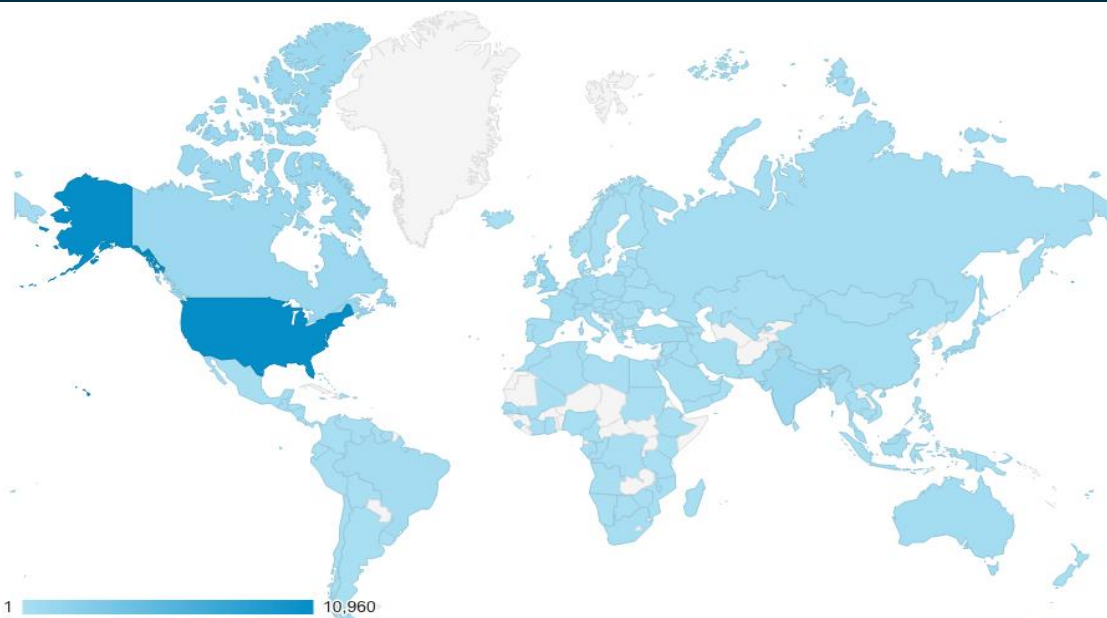
**4. Continued collaboration
and information
sharing are key moving
forward**

H₂ Safety Information Sharing Resources Available

H₂Tools.org : A one stop resource for hydrogen safety



h2tools.org



- Site visit tracking shows a **global reach: 50% of visits have been international after launch**
- Over **250,000 site visits**
- Training resource **translated into Japanese. Interest in other languages.**

IPHE: International Partnership for H₂ and Fuel Cells in the Economy

- **Share** information on H₂ 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

Examples of Brazil and U.S. Collaboration on Energy



- **Fossil energy, energy efficiency, nuclear energy and other technical exchanges** (U.S.-Brazil Strategic Energy Dialogue or SED)
- **Natural gas energy storage** (DOE Fossil Energy Office, Energy Information Administration and Brazil's Energy Planning Authority)
- **Buildings energy efficiency** (DOE Lawrence Berkley National Laboratory and Brazil's Federal University of Santa Catarina)

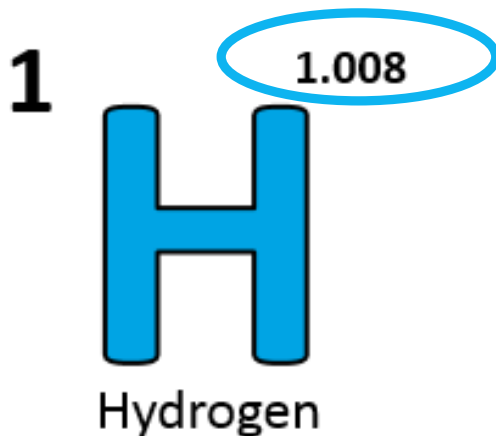
Opportunities for outreach and to increase awareness

Celebrate Hydrogen & Fuel Cell Day

October 8 or 10/8

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

Information and Training Resources to Increase Awareness



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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energy.gov/eere/fuelcells