

Innovation and Emerging Technology Perspectives in Hydrogen and Fuel cells at the U.S. Department of Energy

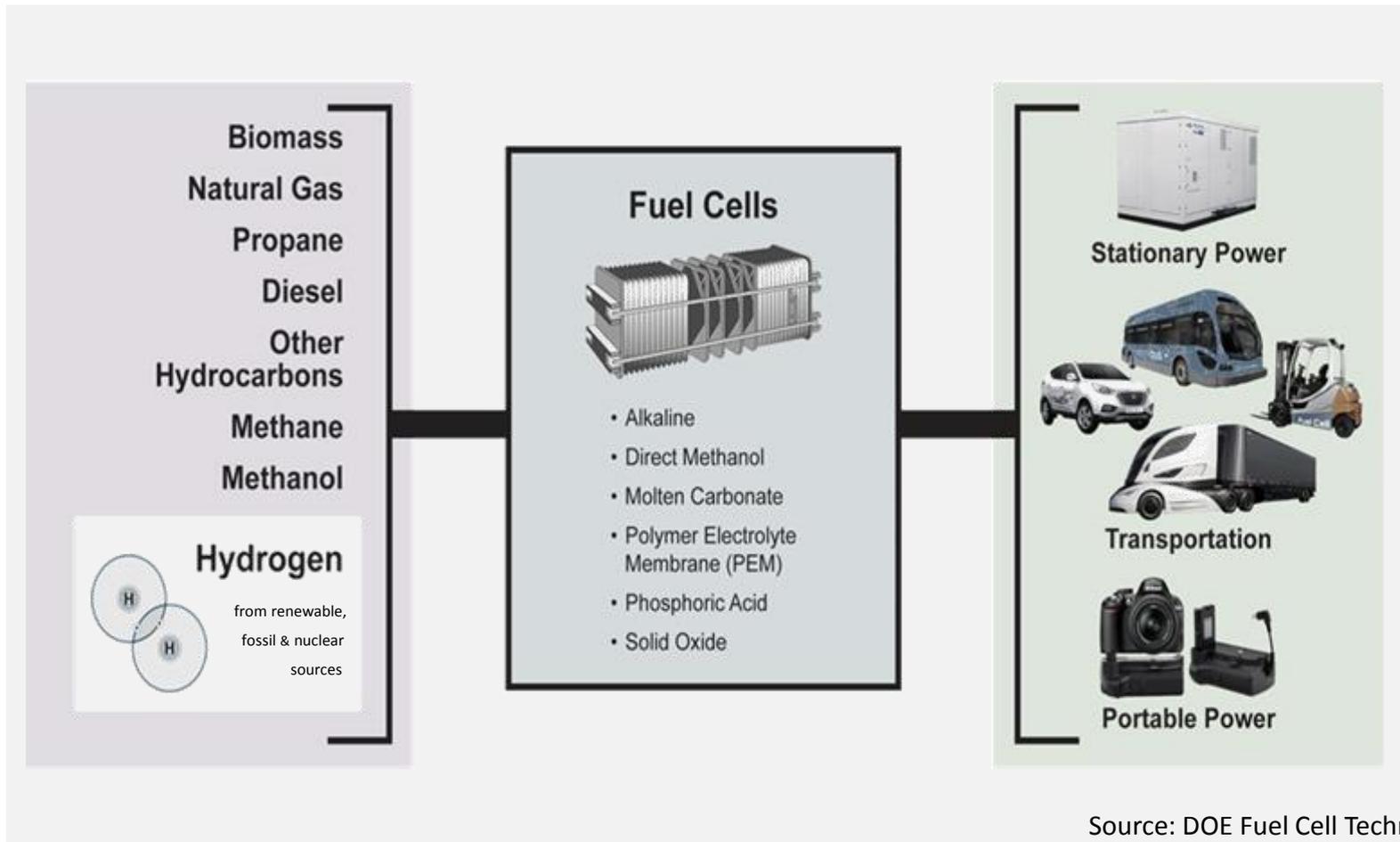
Dr. Sunita Satyapal, Director - Fuel Cell Technologies Office

CleanTech Innovation Showcase 2018

Seattle, WA – June 25, 2018



The Versatility of Fuel Cell Technologies



Source: DOE Fuel Cell Technologies Office

**Domestic
Energy Sources**

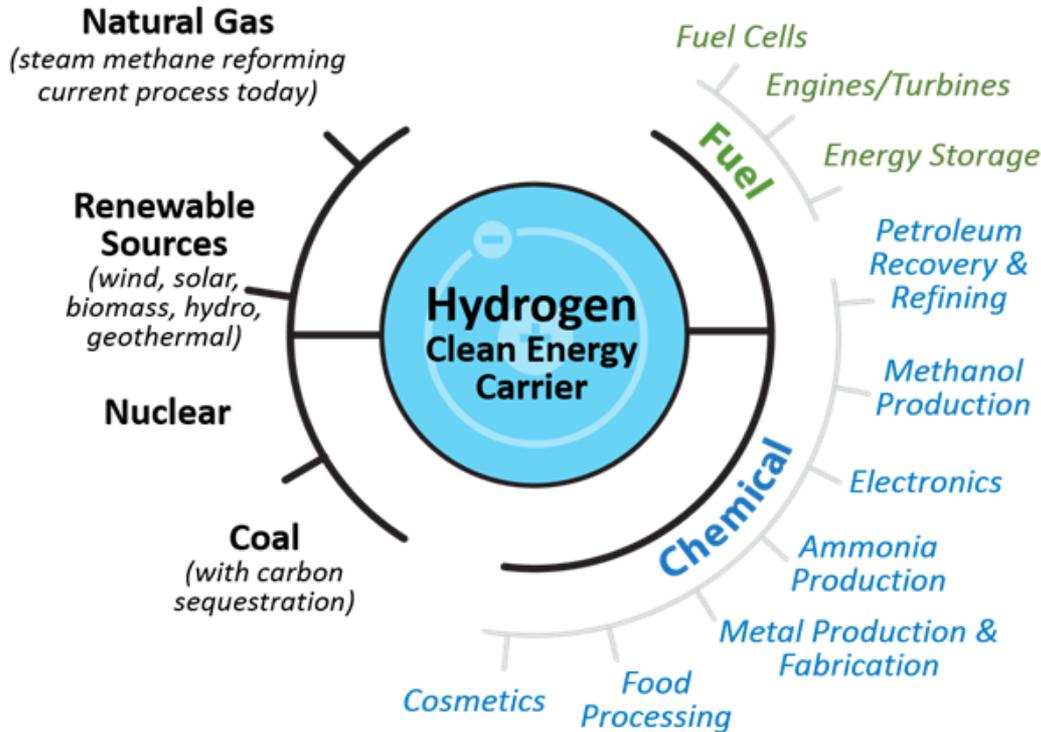
**Clean, Efficient
Energy Conversion**

**Multiple, Diverse
and Versatile Uses**

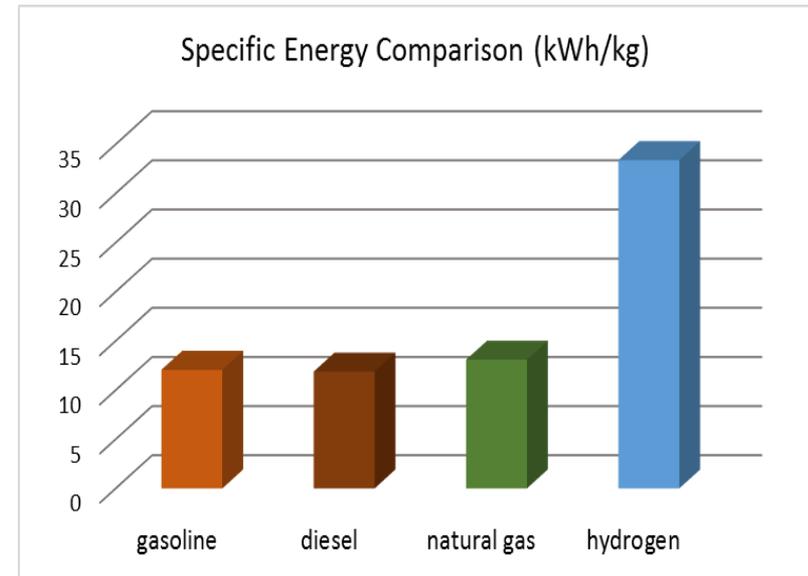
Hydrogen is Part of an All of the Above Portfolio

H₂ can be produced from diverse domestic sources

Many applications rely on or could benefit from H₂



Very High Specific Energy



About *three times* more energy by mass than gasoline. But worse in terms of volume.

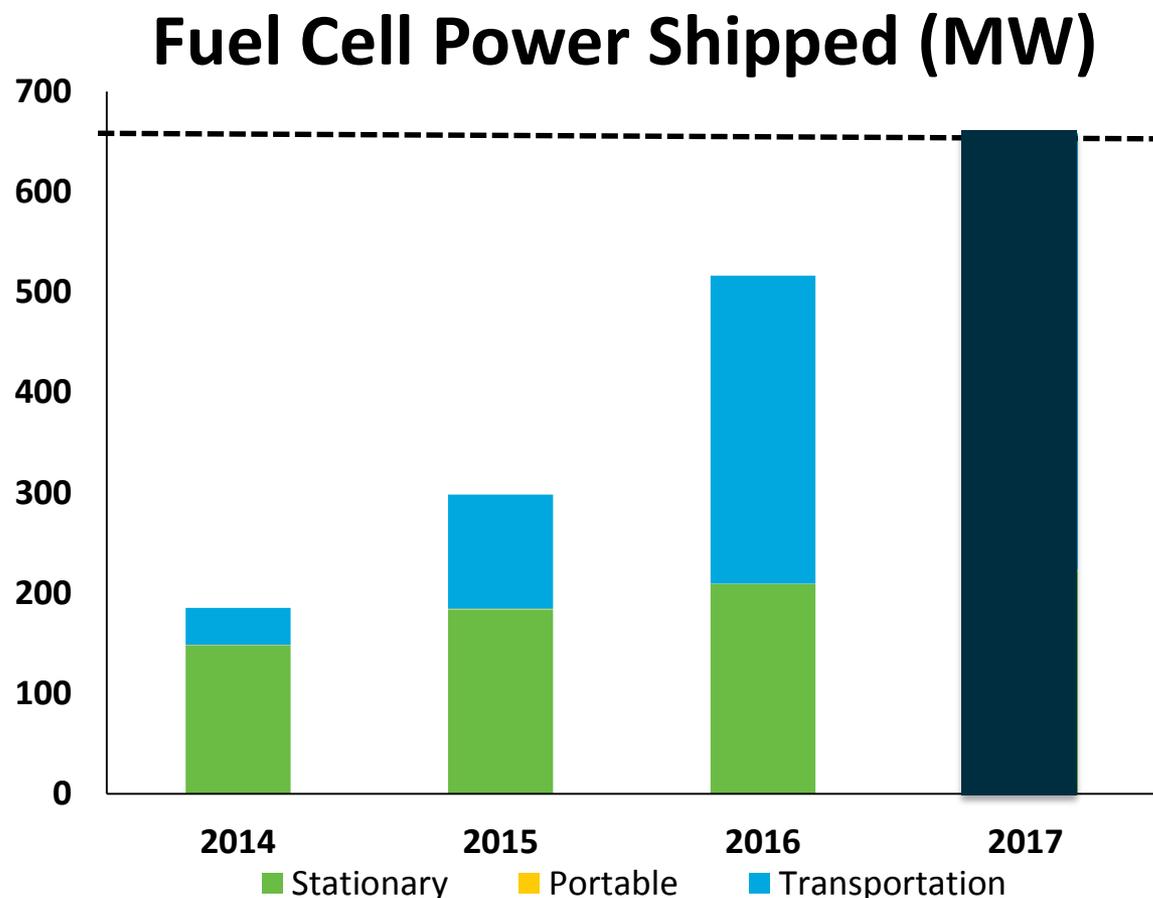
Clean, sustainable, versatile, and efficient energy carrier

4 Key Messages

A photograph of two white hydrogen fuel cell vehicles (FCVs) parked at a hydrogen refueling station. The vehicles are decorated with blue and white graphics and the text "POWERED BY HYDROGEN FUEL". The station is a tall, white and blue structure with "HYDROGEN" written on top. The background shows a clear blue sky and a fence.

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



Hyundai Tucson Fuel Cell SUV

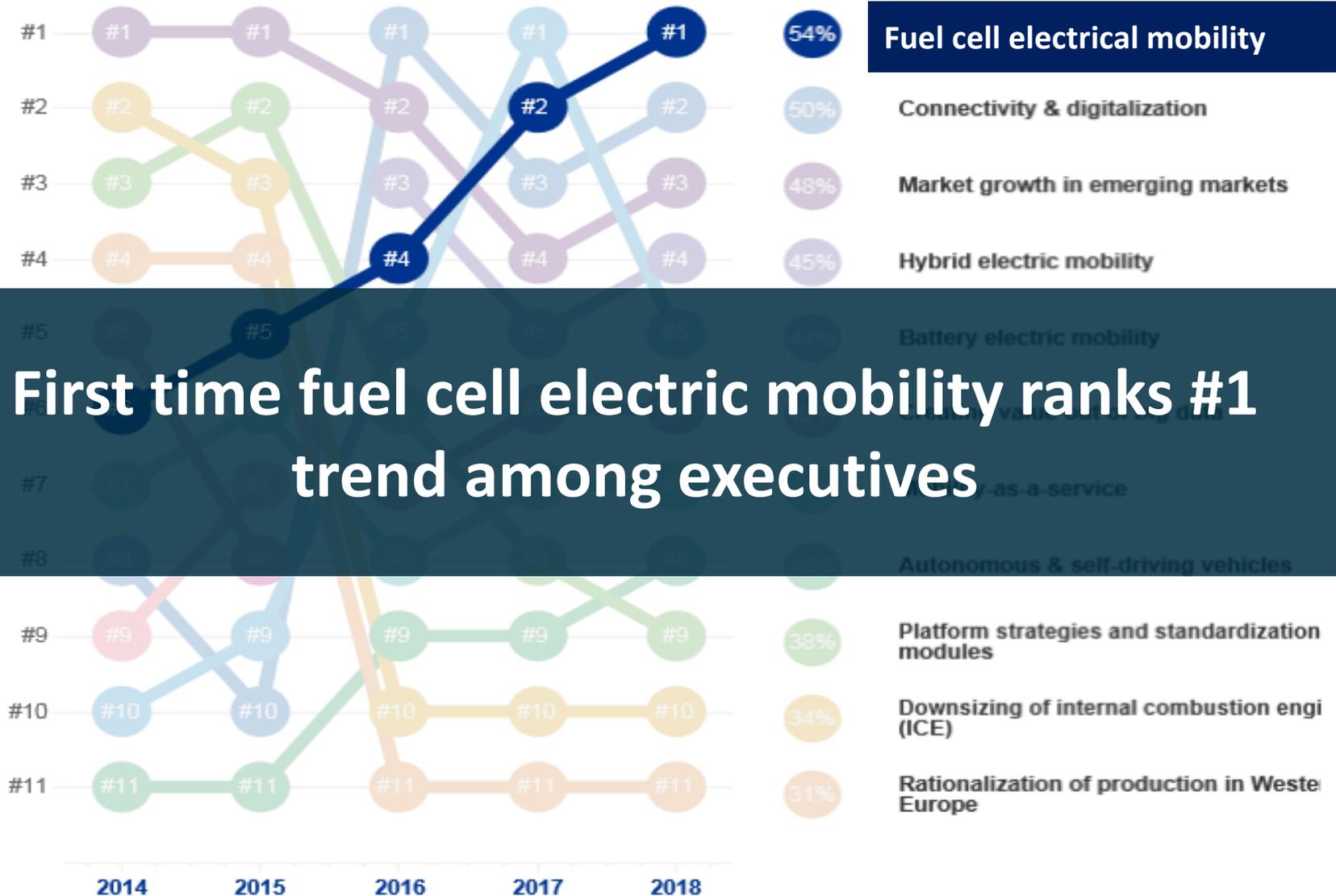
Commercial fuel cell electric cars are here



Toyota Mirai

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

Automotive Executives Survey Results



First time fuel cell electric mobility ranks #1 trend among executives

Source: KPMG Global Automotive Executive Survey 2018

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 Applications Expanding

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

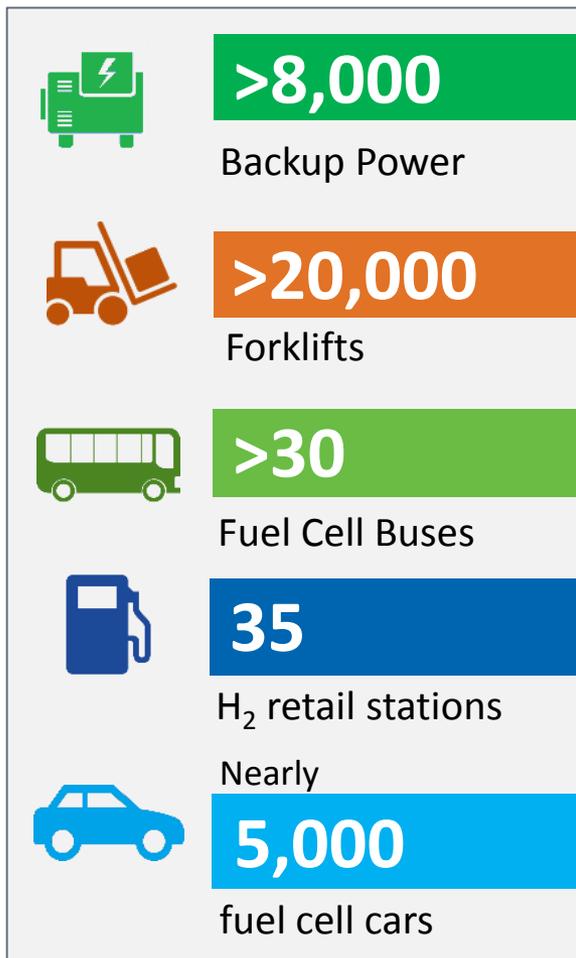


Over 240 MW of fuel cell stationary power installed across more than 40 US states

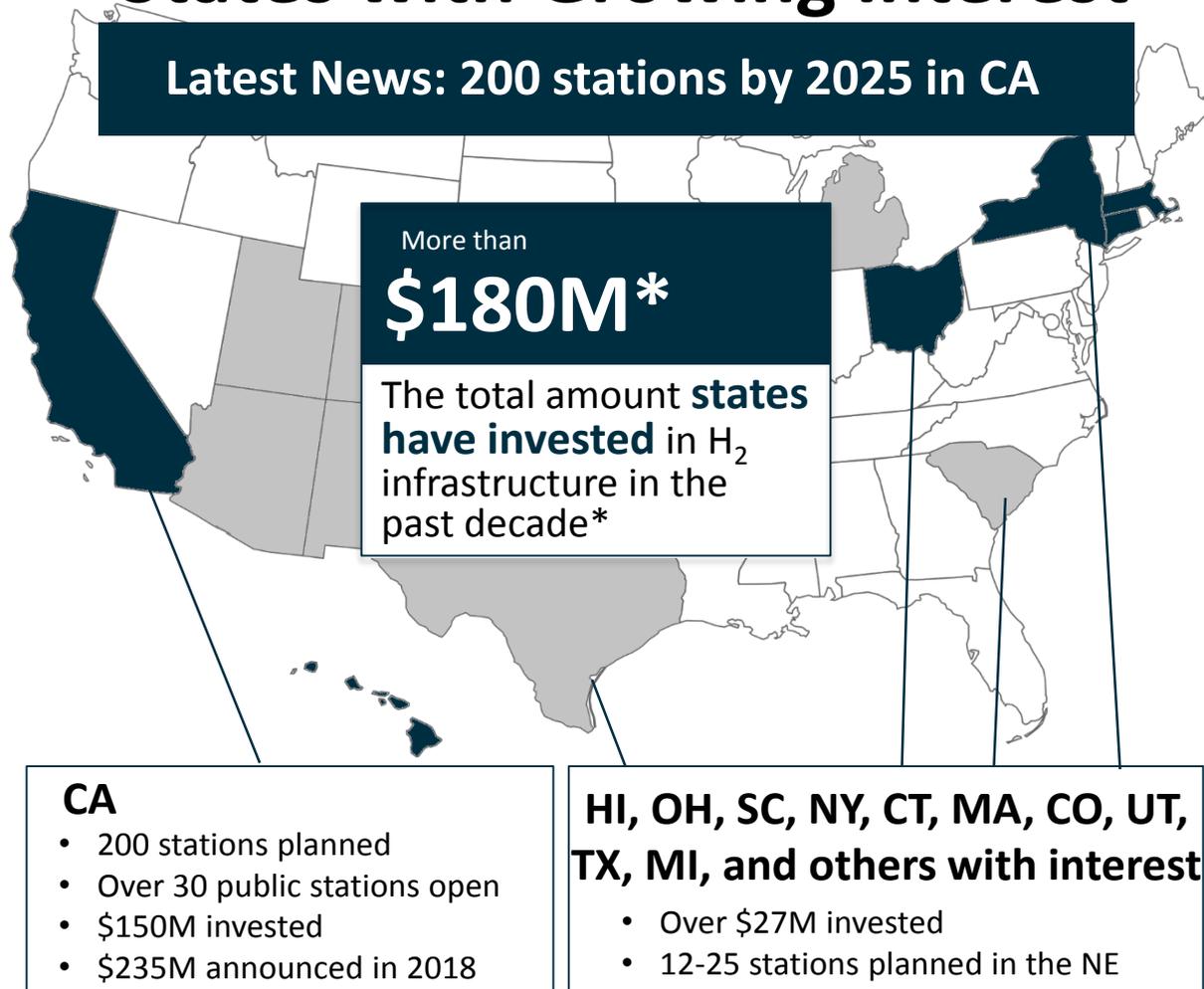


Multiple H₂ and Fuel Cell Applications in the U.S.

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 (FCVs) parked at a hydrogen refueling station. The vehicles are decorated with blue and white graphics and the text "POWERED BY HYDROGEN FUEL". The refueling station is a tall, white and blue structure with a "HYDROGEN" sign at the top. The background shows a clear blue sky and a chain-link fence.

2. 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

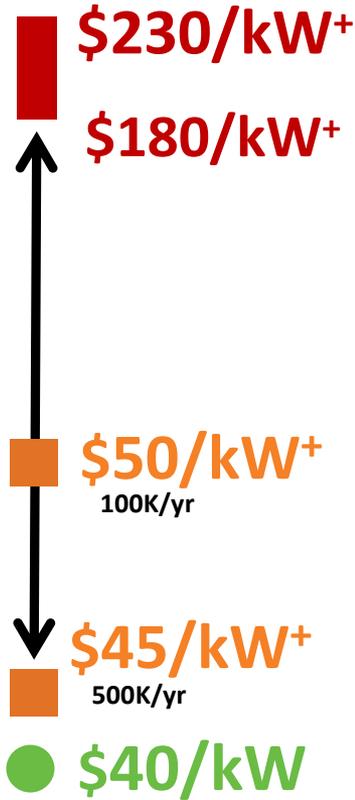
Three or four splendid second-hand cars for sale cheap.



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)



● 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.
Data through 2017

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




U.S. Department of Energy
www.hydrogenprize.org

simple.fuel.™

Email: connect@ivysinc.com

More info: www.teamsimplefuel.com

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

Remaining challenges being addressed

Cost and durability
Infrastructure cost,
availability, reliability

3. H₂@Scale concept

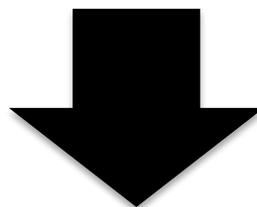


H2@Scale: Enable affordable, reliable, clean and secure energy across sectors

Scale: Simple Example

How much hydrogen for 1 car?

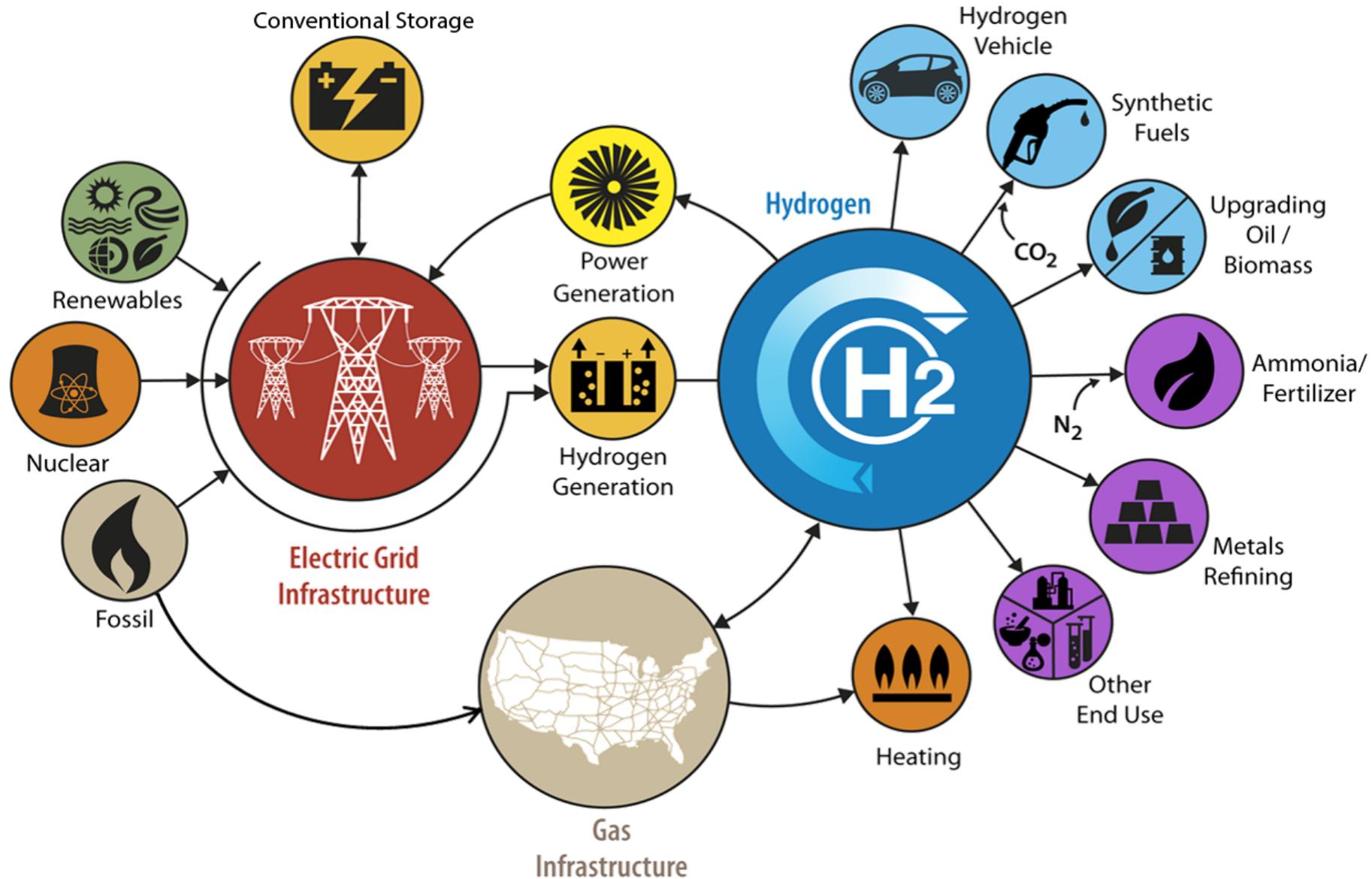
$$\frac{12,000 \text{ miles per year}}{60 \text{ miles per kilogram}} = 200 \text{ kg per year} \text{ or } 0.2 \text{ tonnes per year}$$



How much hydrogen for many cars?

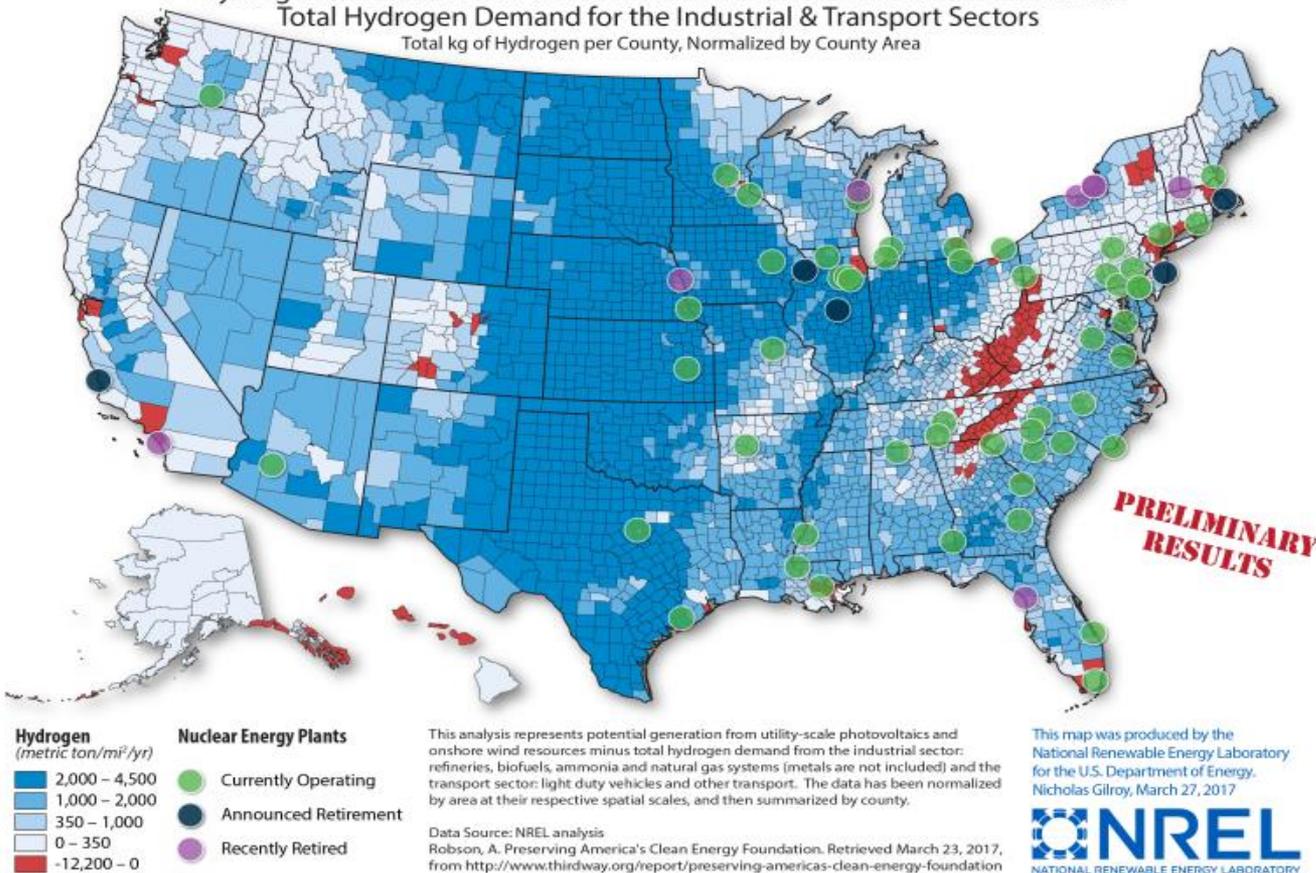
100 M cars   = 10M cars	20M tons H ₂ per year 20 B kg H ₂ per year
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H₂@Scale Energy System



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



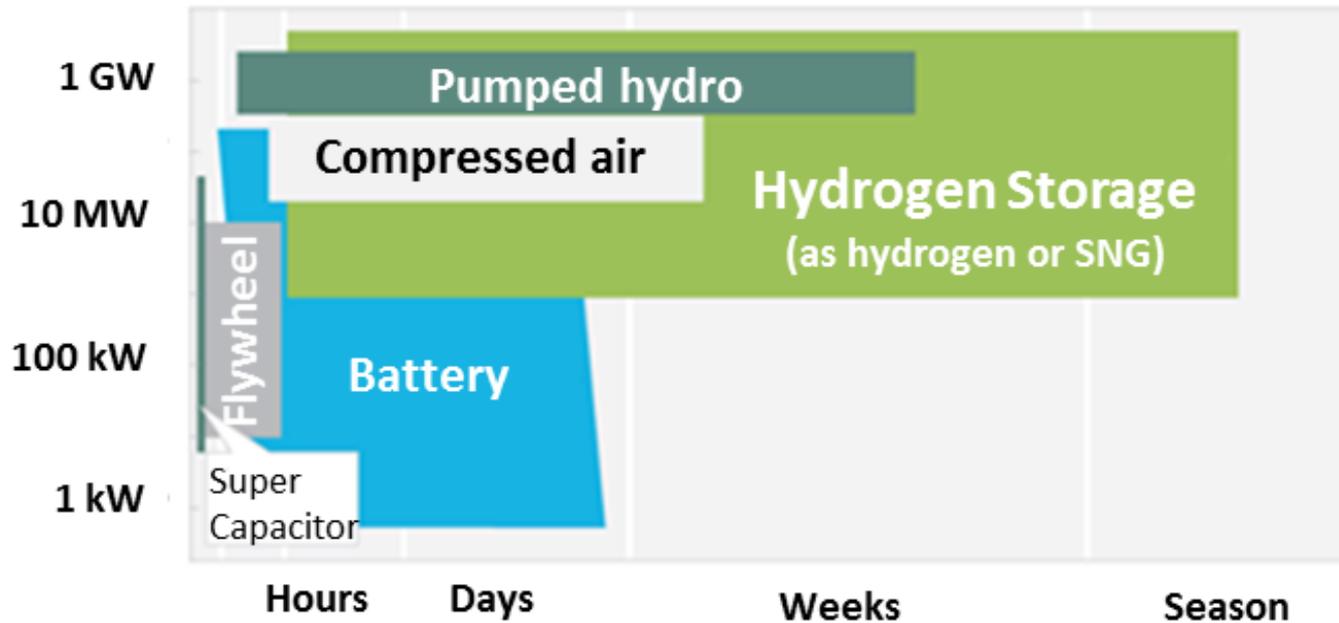
Labs assess resource availability. Most regions have sufficient resources.

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

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

Hydrogen Energy Storage is Scalable

Overview of Energy Storage Technologies in Power and Time



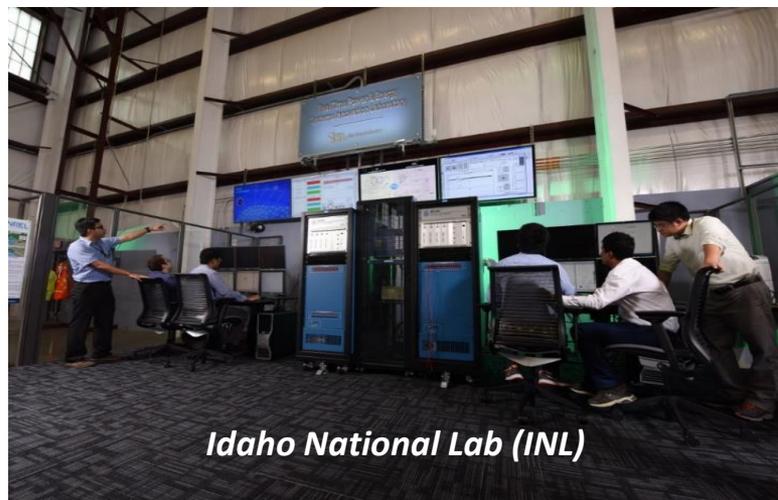
One hydrogen cavern could provide ~ 100 GWh energy storage

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.

Lab testing electrolyzers' value for ancillary services

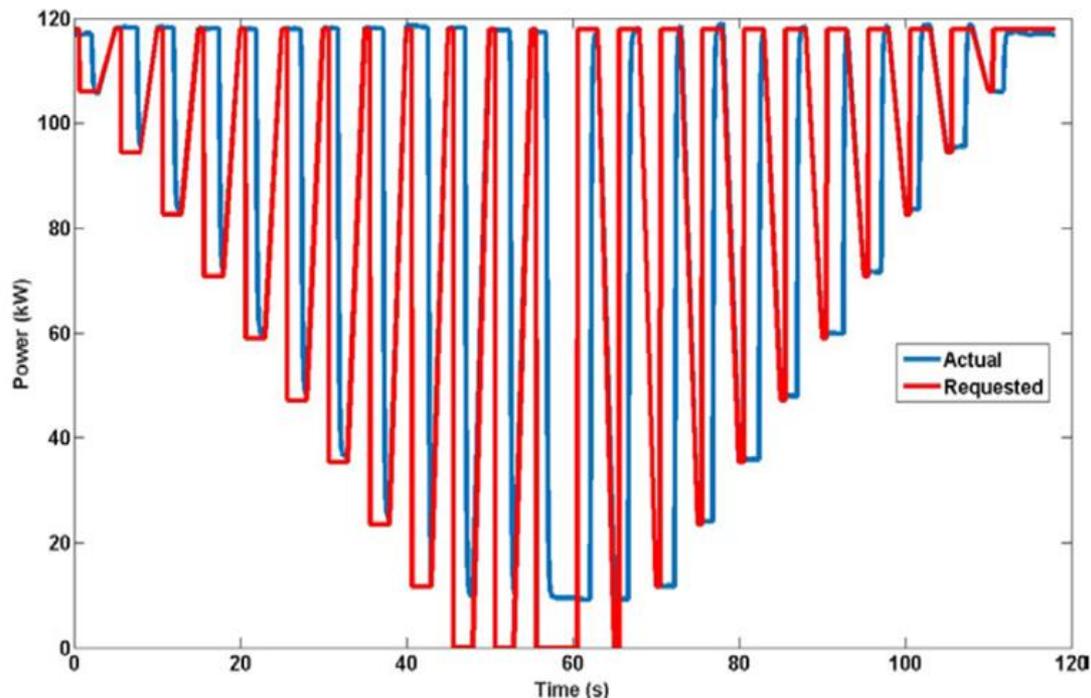
First Ever Validation of Frequency Regulation with Electrolyzers



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



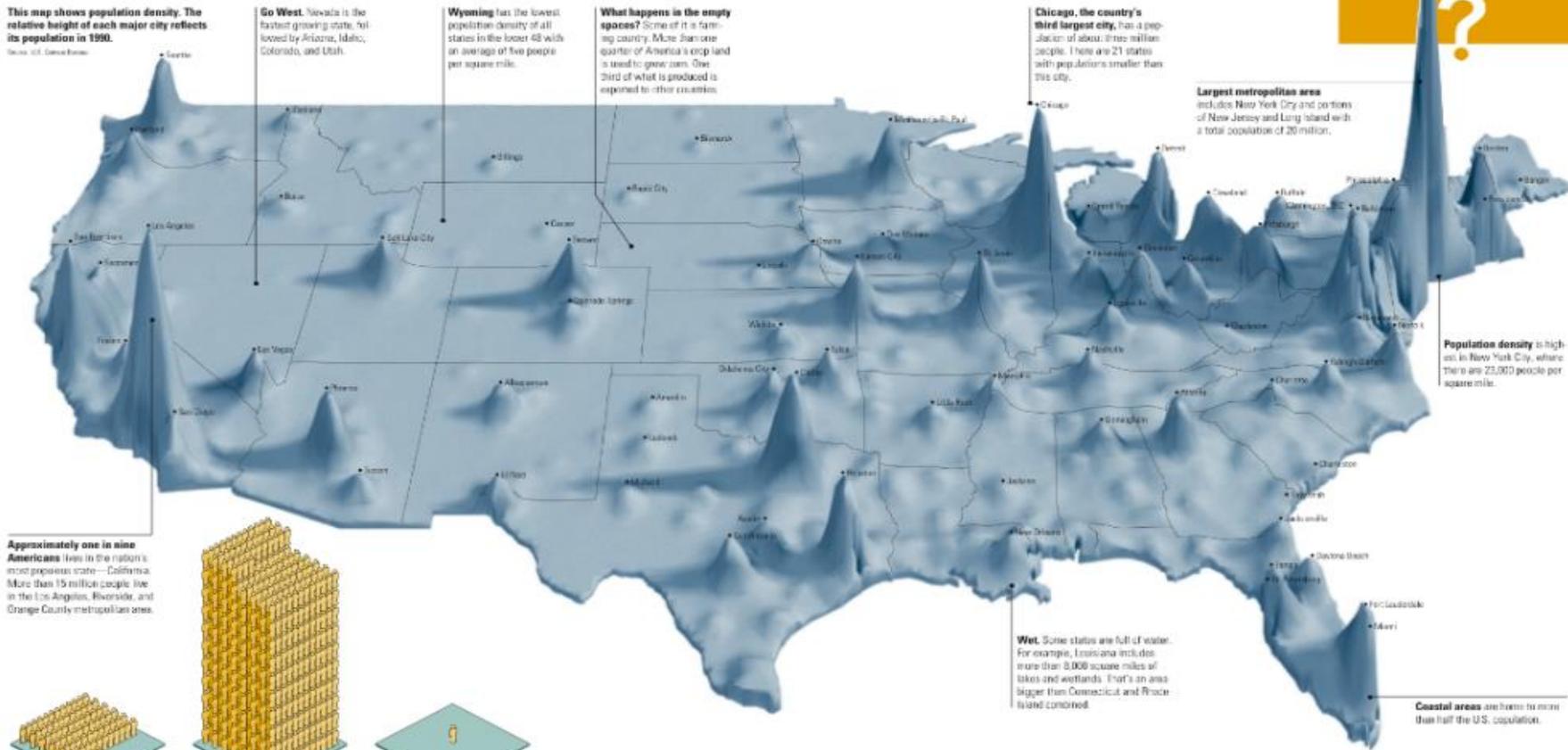
...and deliver it or co-locate distributed generation with demand for certain applications

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.

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.

Approximately one in nine Americans lives 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.

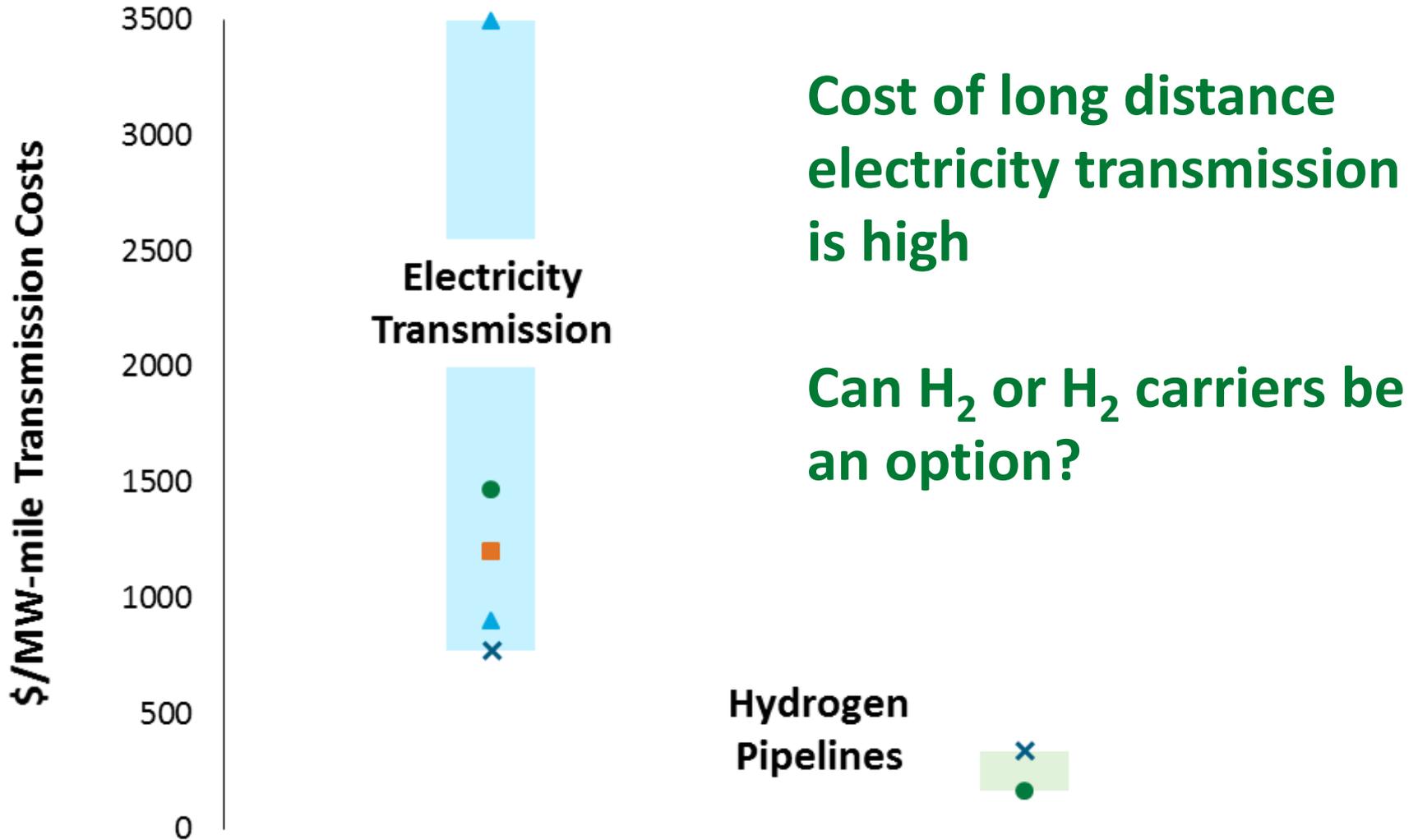


New Jersey is the most densely populated state with an average of more than 1,000 people per square mile.

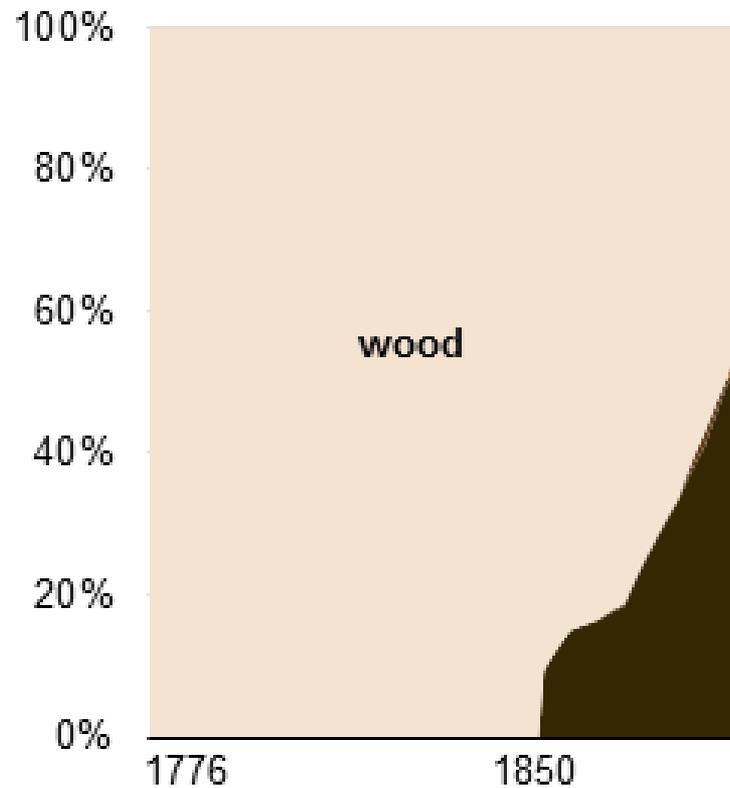


Alaska is a sparsely populated state with an average of one person per square mile.

Analysis underway to guide future plans

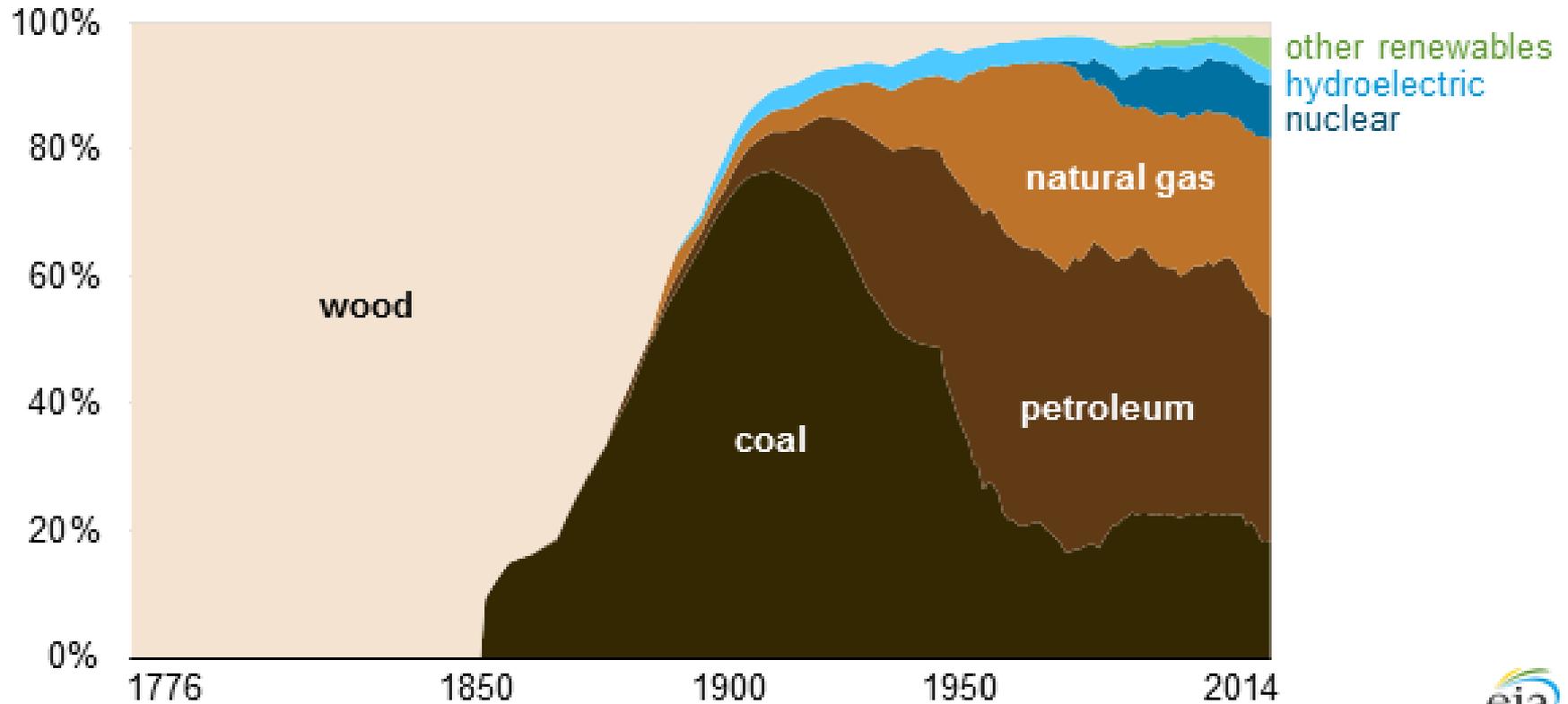


History of energy consumption in the U.S.

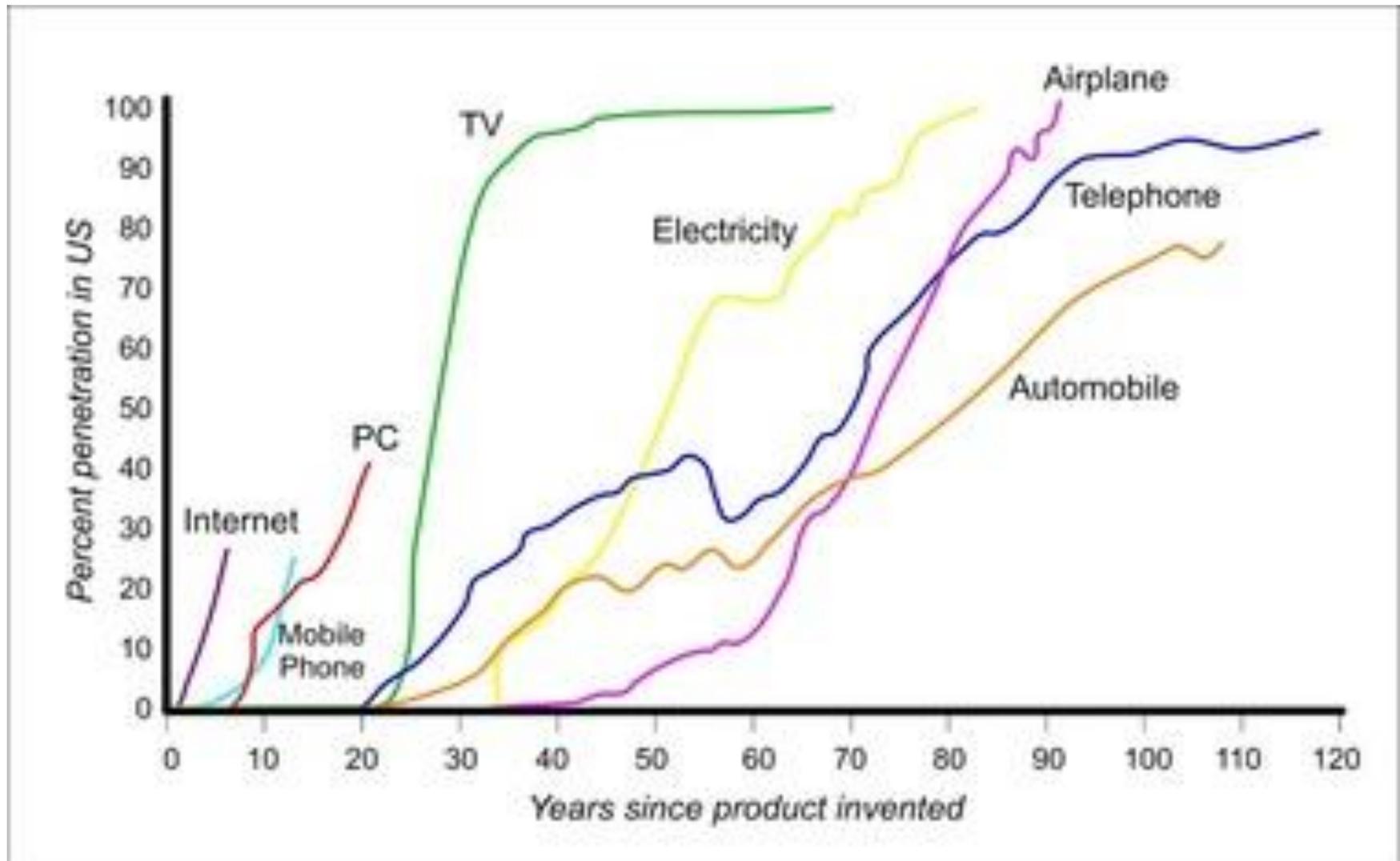


History of energy consumption in the U.S.

Share of energy consumption in the United States (1776-2014)



Technology Adoption Curves

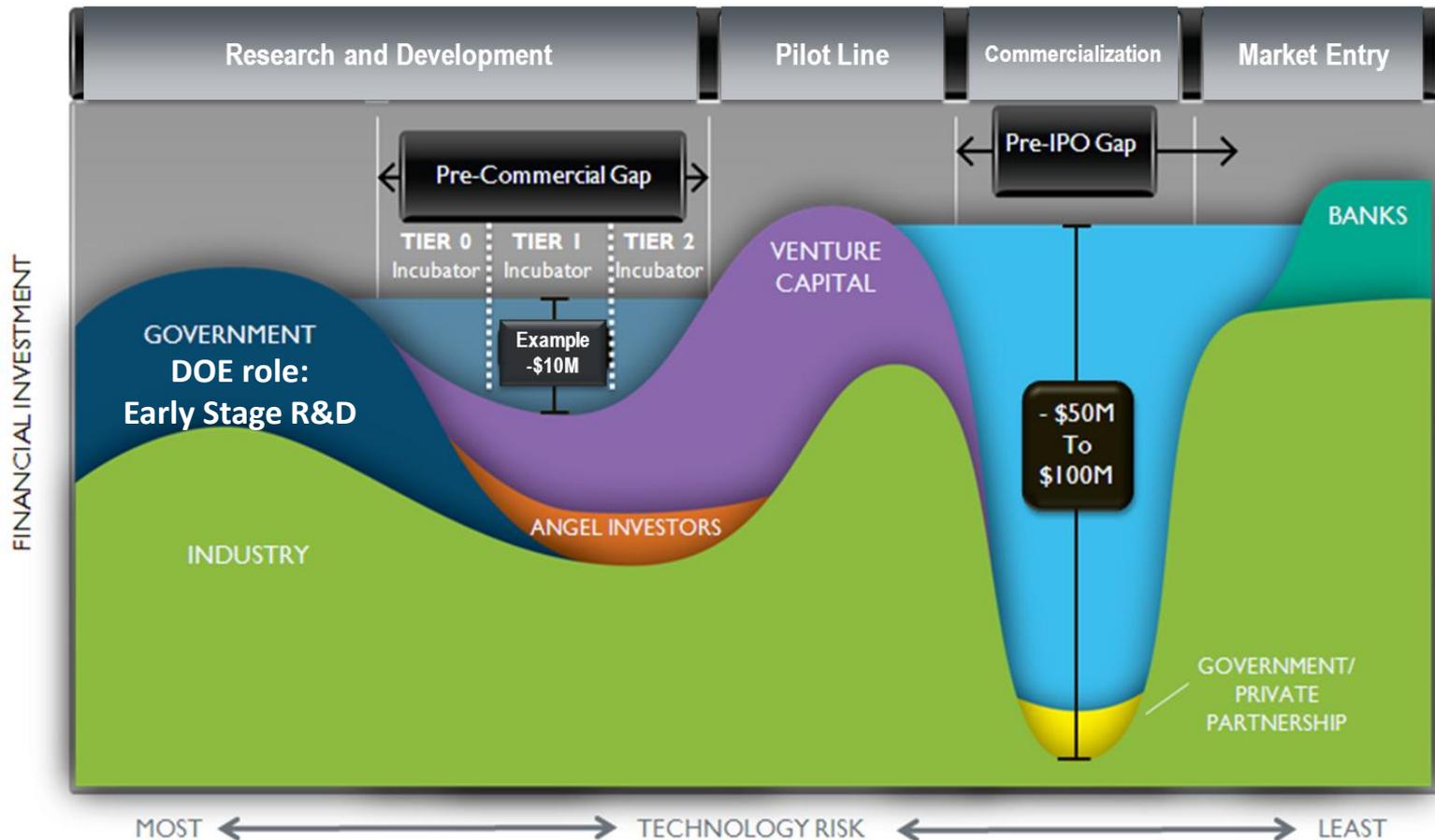




4. Collaboration

Government vs. Private Sector Roles

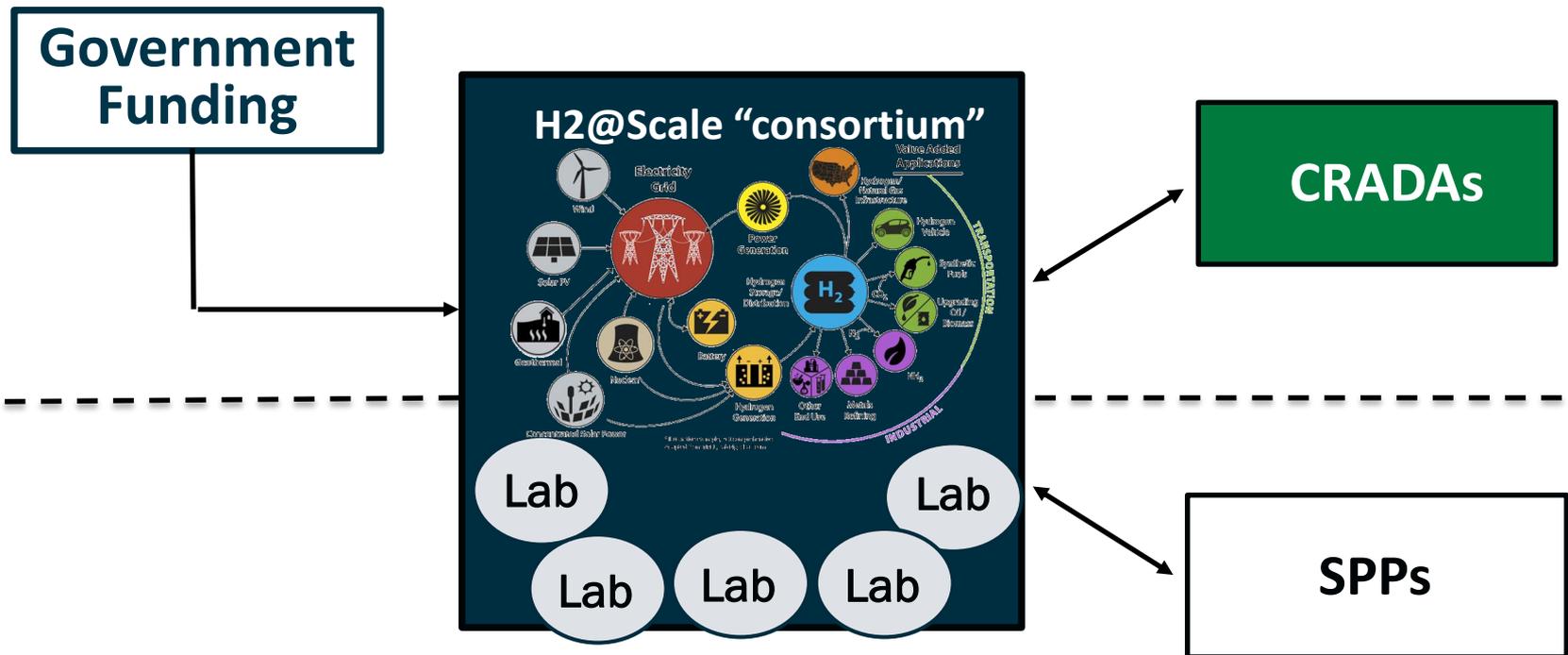
Example— illustrative timeline for innovation & commercialization



Adapted from SunShot Incubator briefing. Pictorial example, not representative of all industry start ups

H₂@Scale – Lab CRADAs

- Leverages Lab capabilities and expertise to address challenges- materials R&D, analysis, safety R&D, etc.
- Round 1 in 2017. Over 20 new projects.



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

Example: Innovation Driving Impact

Innovation



730 H₂ and fuel cell
patents
enabled by DOE funds

Approx.
35% of H₂ and fuel
cell patents
come from National Labs

Market Impact



More than
30 Technologies
commercialized by
private industry

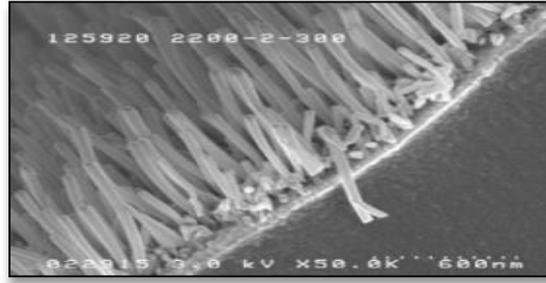
and over
75 with potential
to be commercial in
the next 3-5 years

can be traced back to DOE R&D

Innovation to Market Technologies - Examples



Hydrogen Detection Tape – Element One



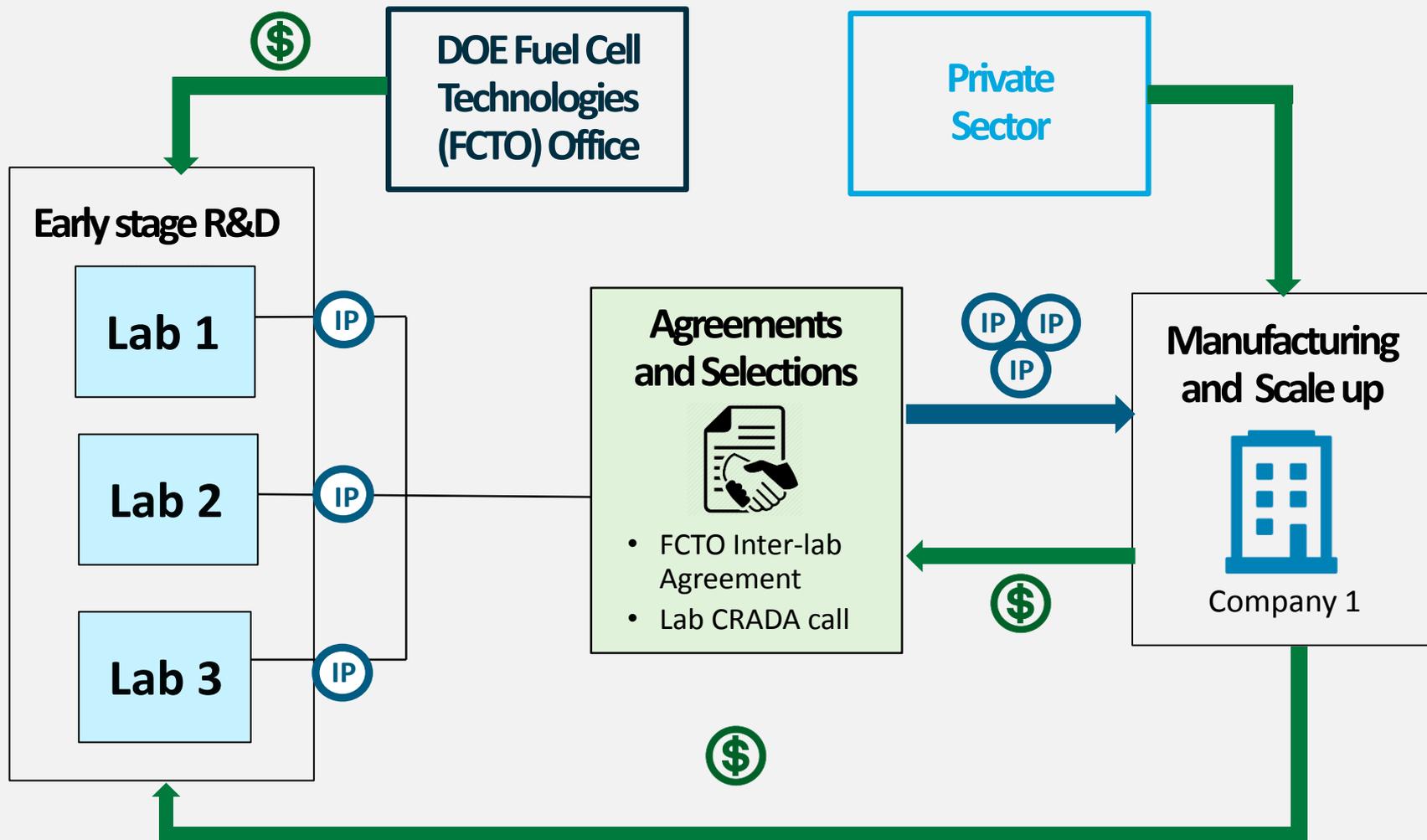
Catalyst and Supports for PEM Fuel Cells – 3M



Hydrogen Tube Trailers – Hexagon Lincoln

Innovations Provided to Industry & Investors

L'Innovator= "Lab Innovator" FCTO Pilot



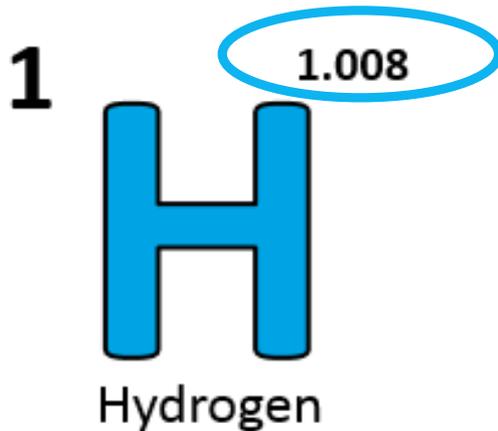
Opportunities for outreach and to increase awareness

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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H₂ and fuel cells potential to reduce petroleum use

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



Fuel Cell Electric



Battery Electric



Extended-Range
Electric

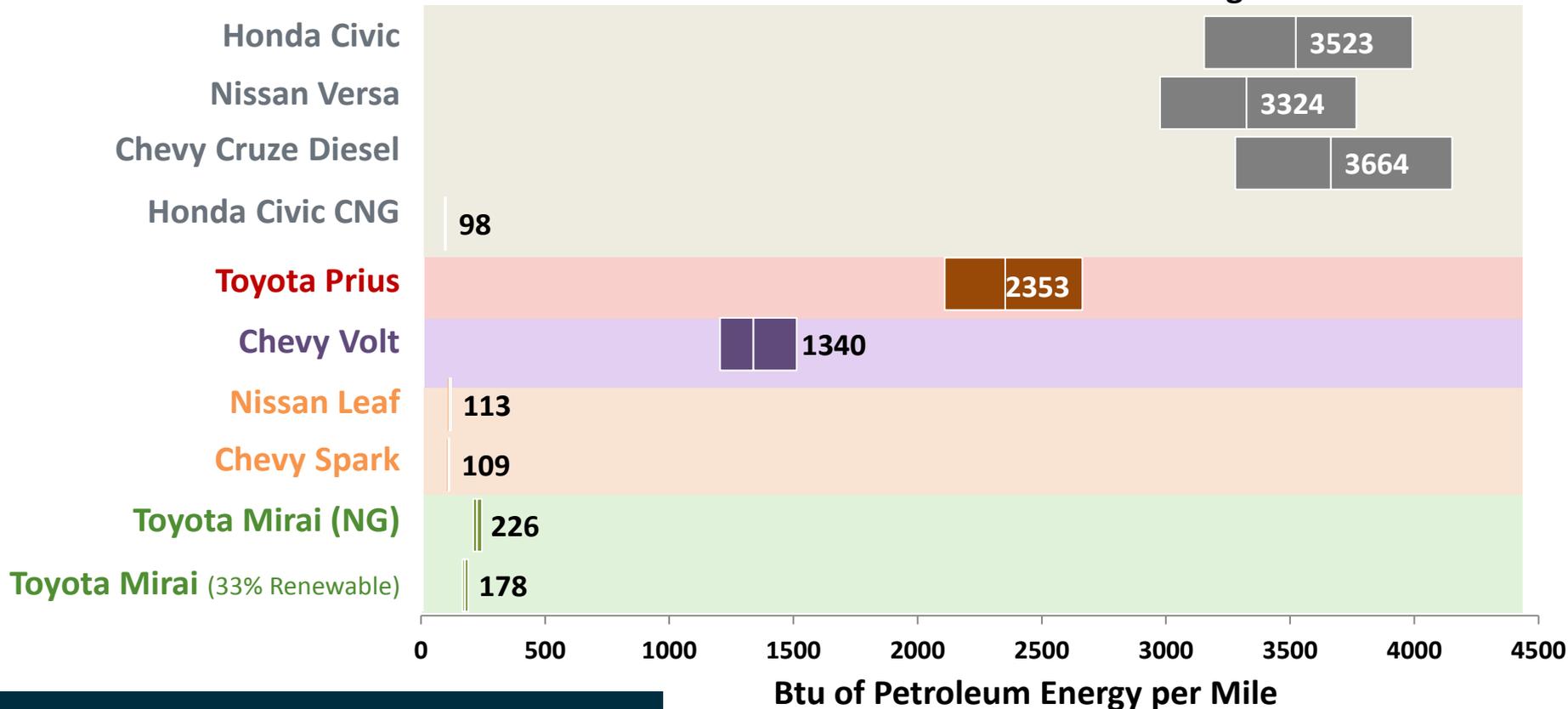


Hybrid Electric



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)

And lifecycle emissions

Low, Medium & High Emissions/Mile for 2015 Technology



Fuel Cell Electric



Battery Electric



Extended-Range
Electric

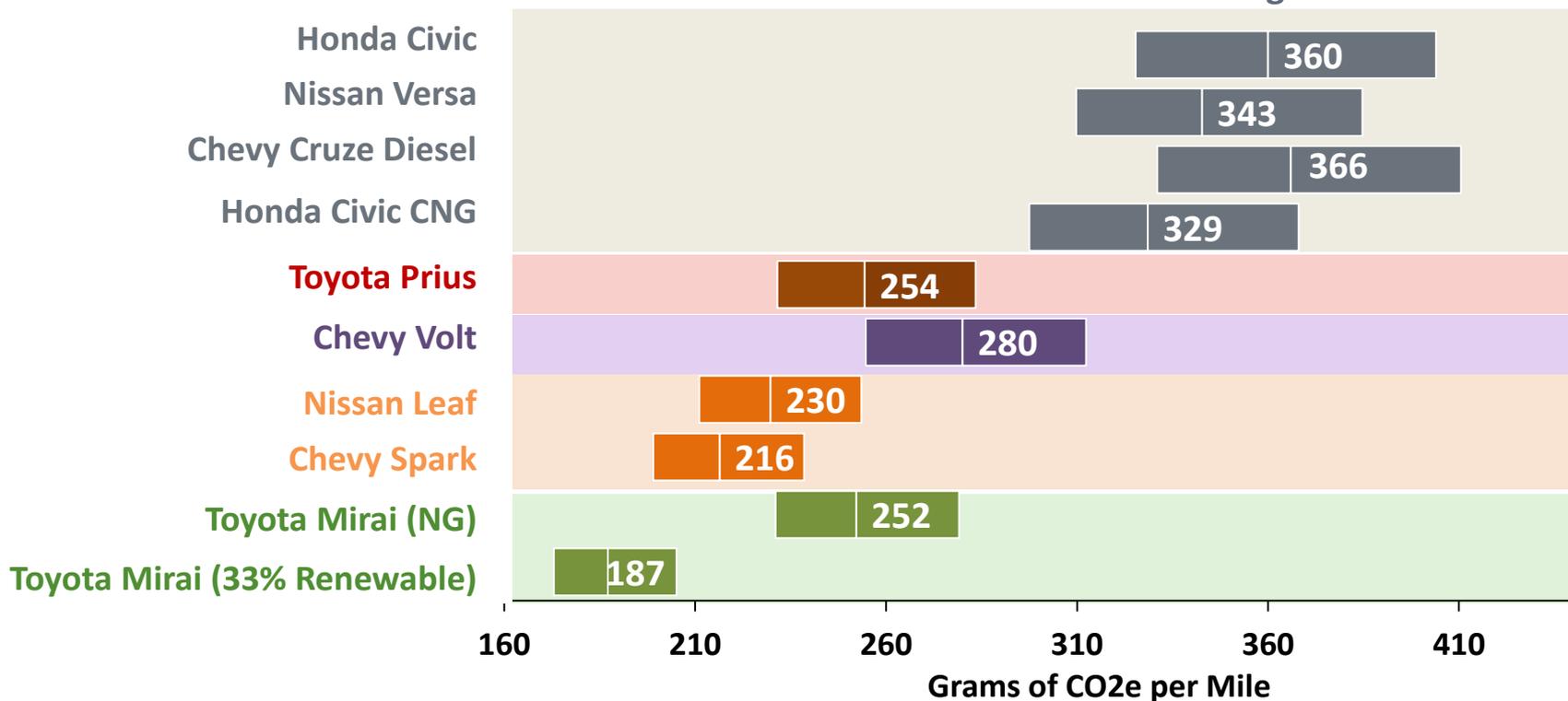


Hybrid Electric



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)