U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

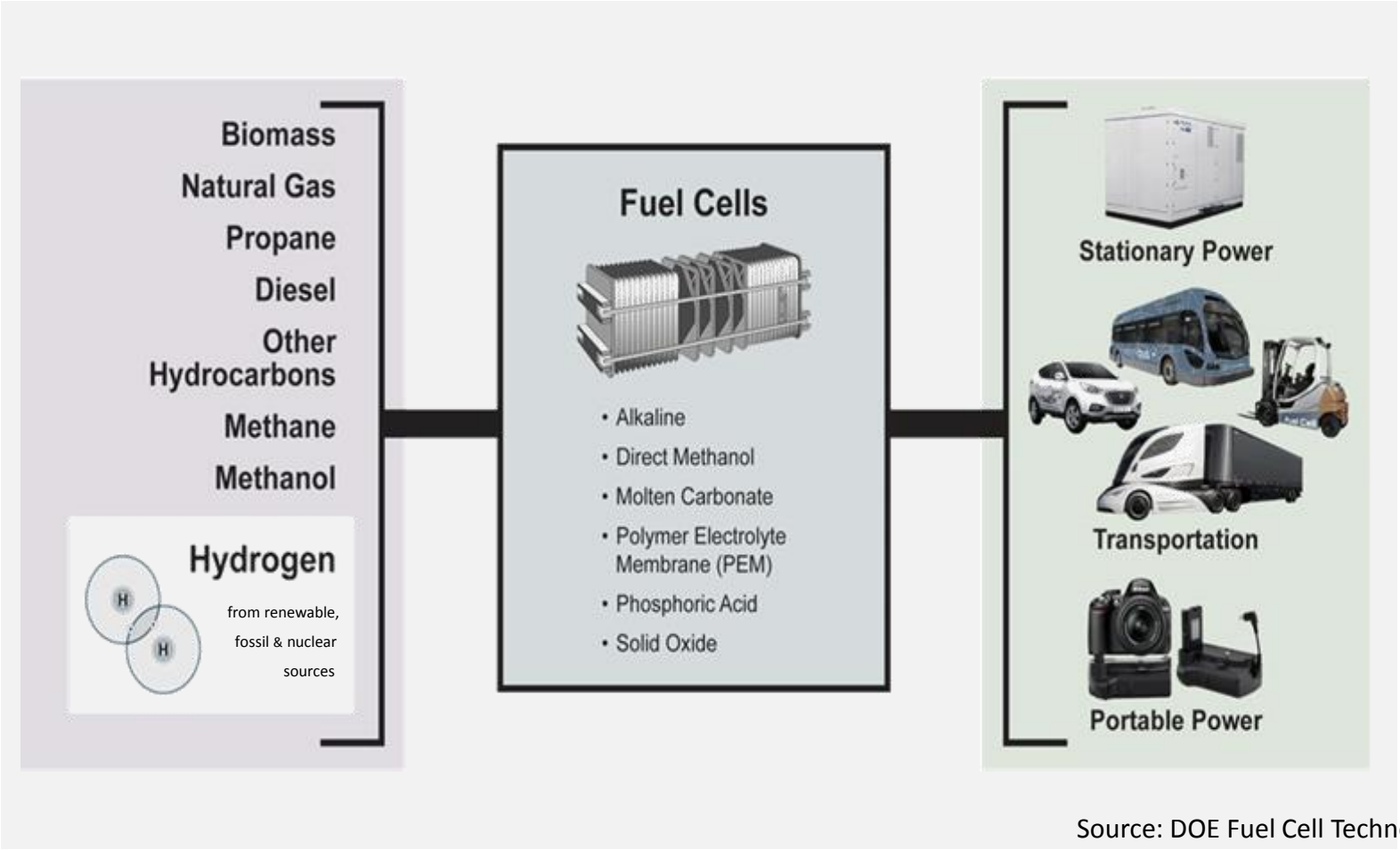
Innovation and Emerging Technology Perspectives in Hydrogen and Fuel cells at the U.S. Department of Energy

Dr. Sunita Satyapal, Director - Fuel Cell Technologies Office

CleanTech Innovation Showcase 2018

Seattle, WA – June 25, 2018

The Versatility of Fuel Cell Technologies



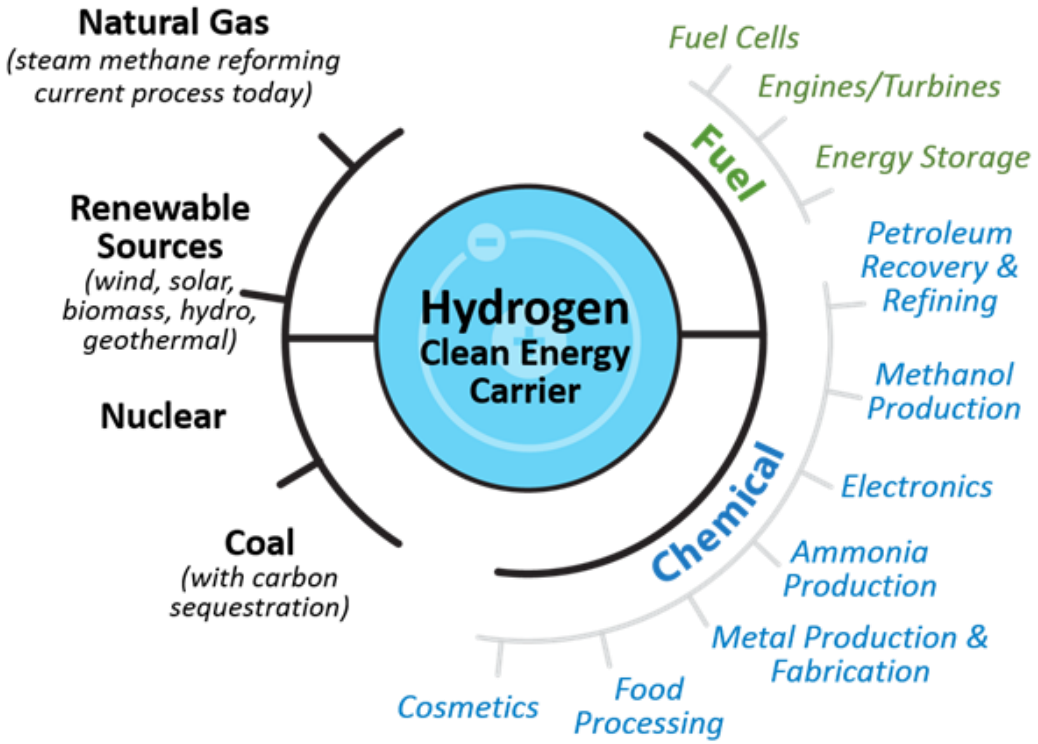
Source: DOE Fuel Cell Technologies Office

Domestic Energy Sources | **Clean, Efficient Energy Conversion** | **Multiple, Diverse and Versatile Uses**

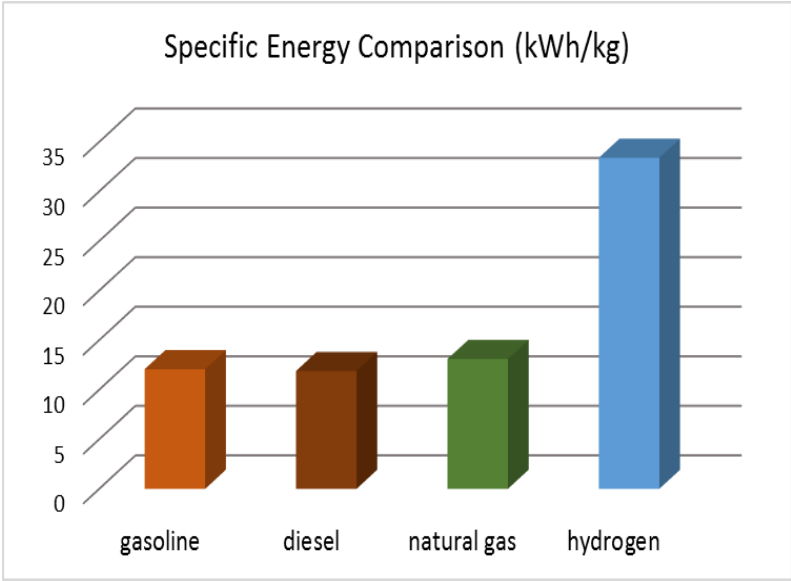
Hydrogen is Part of an All of the Above Portfolio

H_2 can be produced from diverse domestic sources

Many applications rely on or could benefit from H_2



Very High Specific Energy



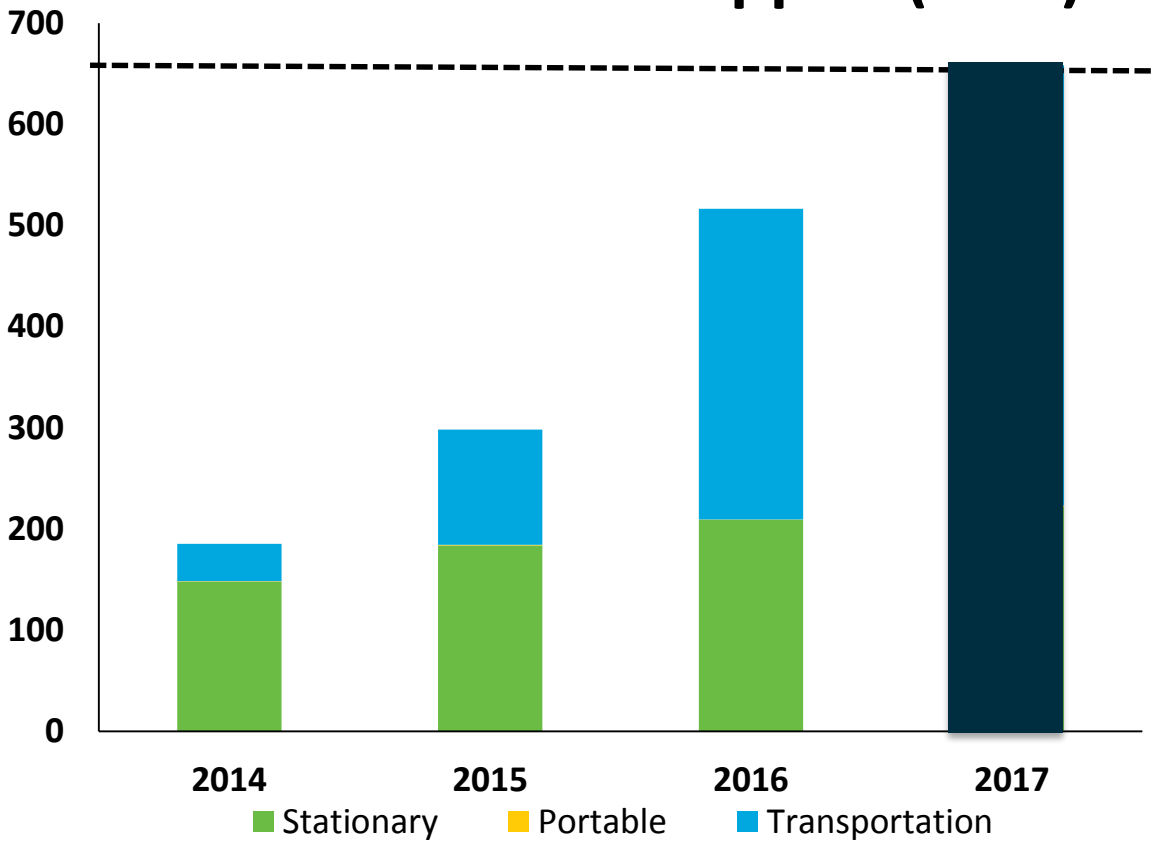
About *three times* more energy by mass than gasoline. But worse in terms of volume.

Clean , sustainable, versatile, and efficient energy carrier

4 Key Messages

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

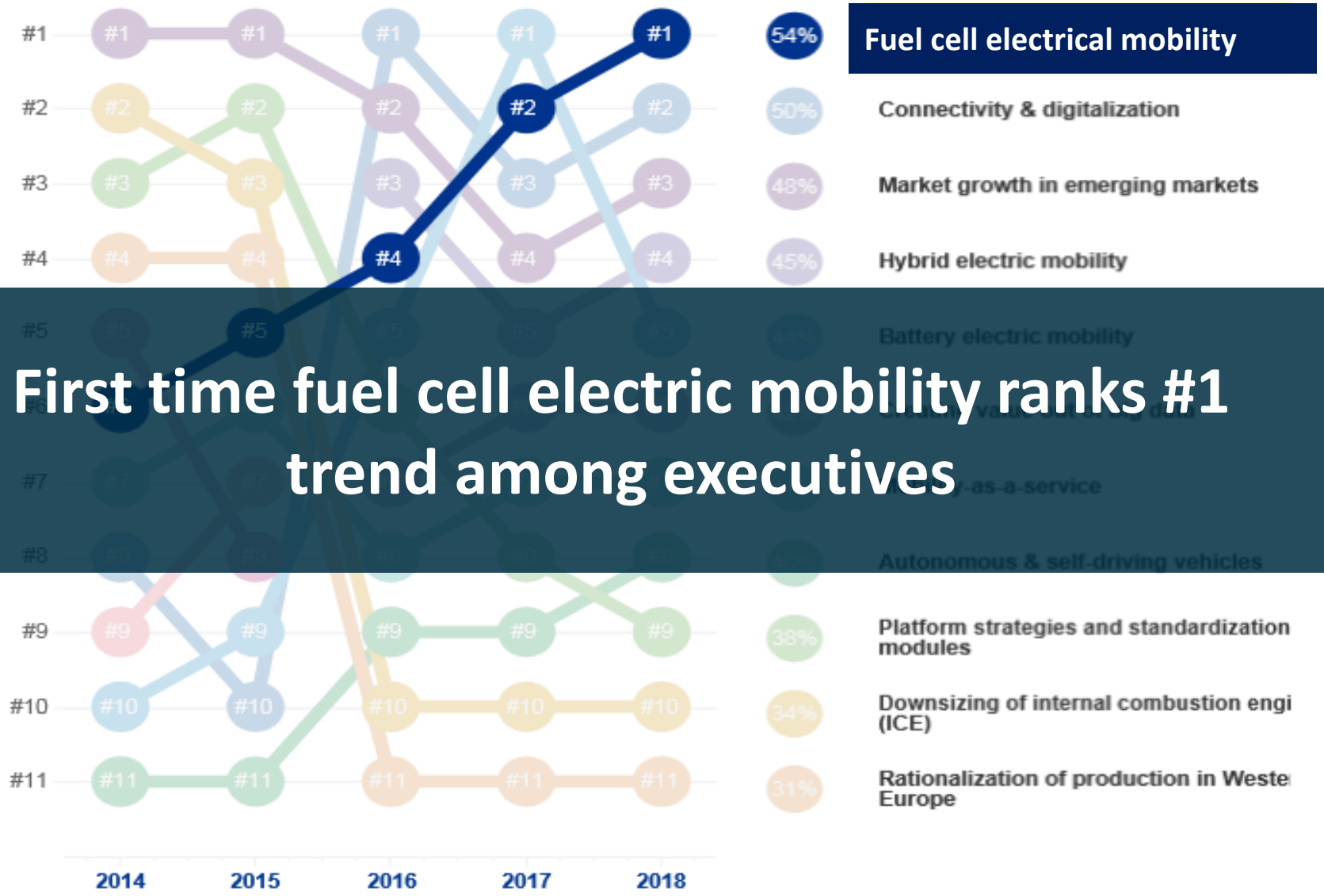

Hyundai Tucson Fuel Cell SUV

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

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 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.

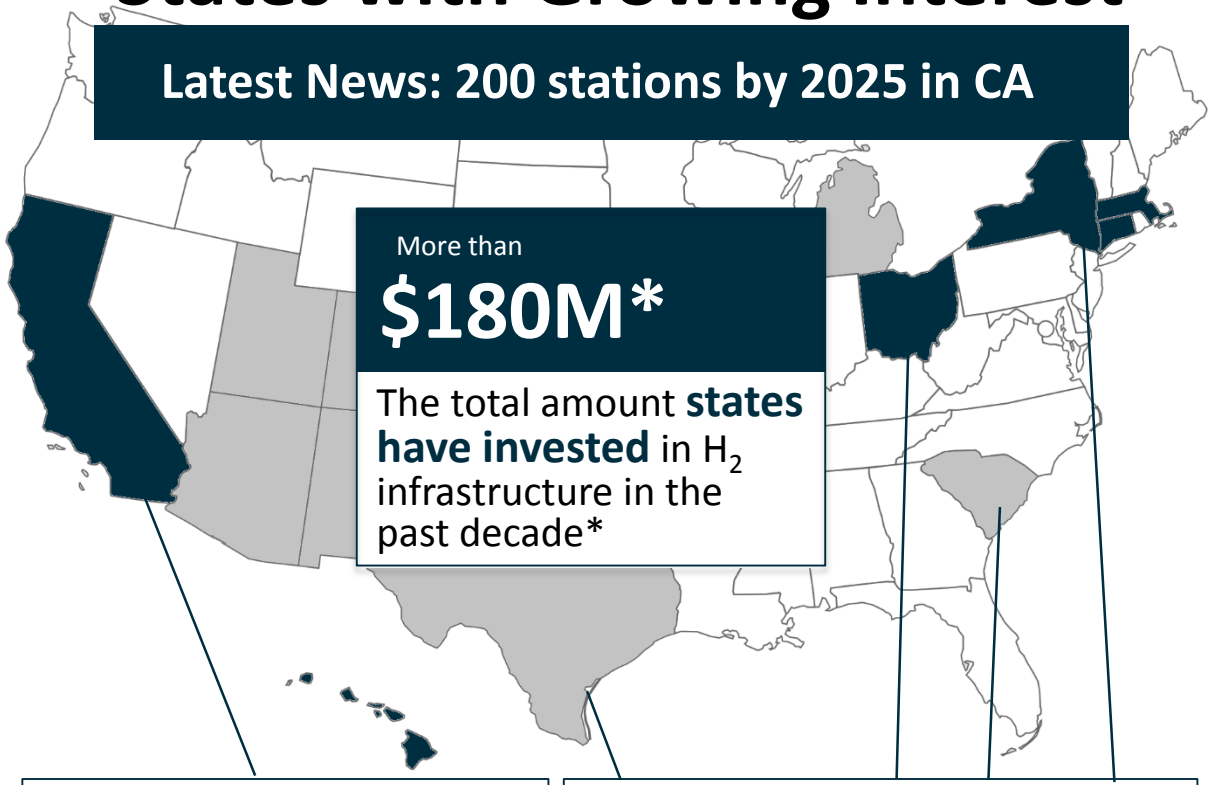
Multiple H_2 and Fuel Cell Applications in the U.S.

U.S. Snapshot

- **>8,000** 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

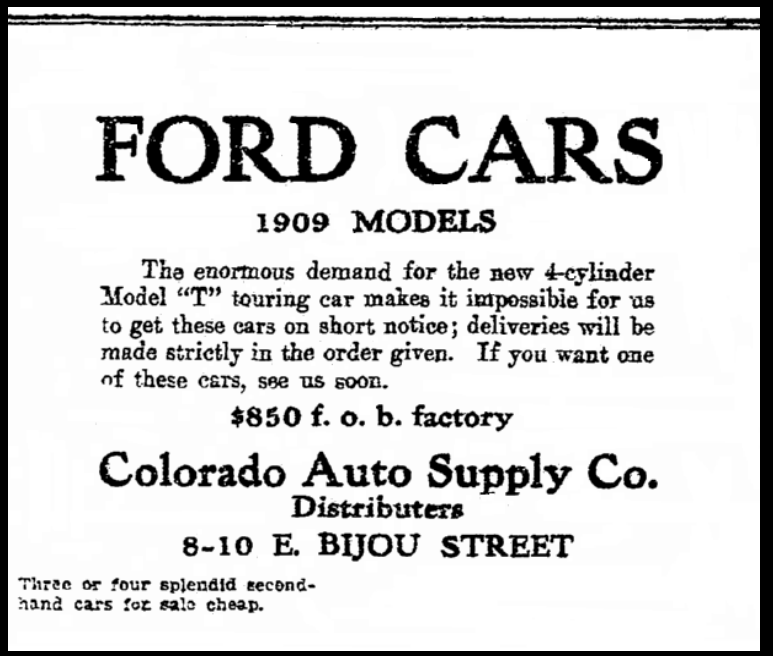
- Over $27M invested
- 12-25 stations planned in the NE

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

2. 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

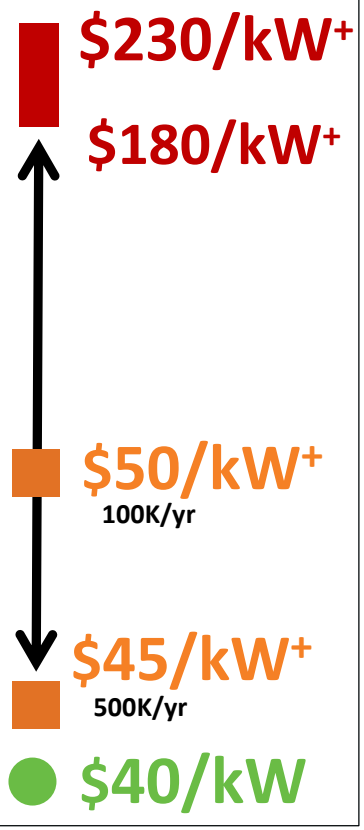
Colorado Auto Supply Co.
Distributers
8-10 E. BIJOU STREET

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

DOE Cost Status and Targets for R&D

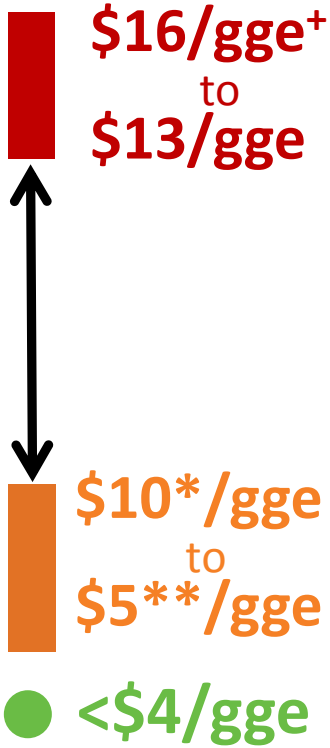
Fuel Cell R&D

System

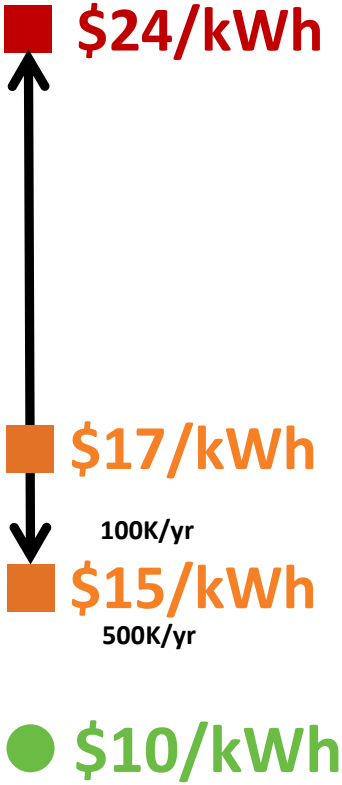


Hydrogen R&D

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

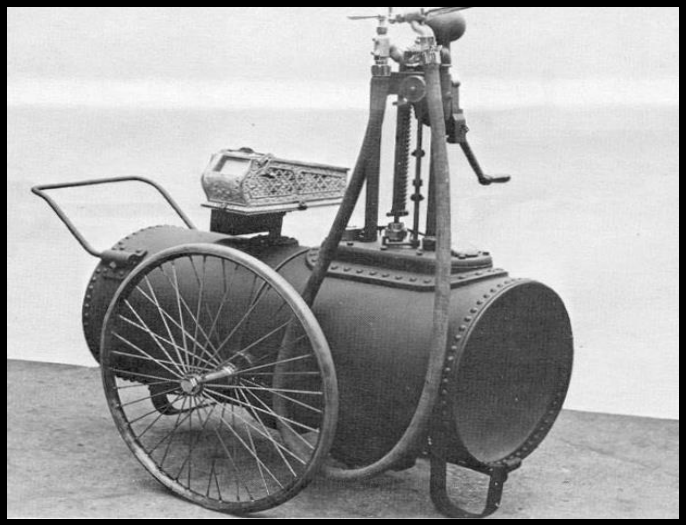
Note: Graphs not drawn to scale and are for illustration purposes only.
Data through 2017

Gasoline History: Many diverse options

Cans, barrels, home models, mobile refuelers

Source: M. Melaina 2008.

Source: Vieyra, 1979



Source: Milkues, 1978

Complementing Retail Stations: H_2Refuel H-Prize

DOE awards $1M H-Prize to Simple Fuel for winner small-scale H_2 fueling design

H2refuel 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. H_2@Scale concept

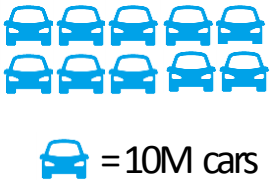

H2@Scale: Enable affordable, reliable, clean and secure energy across sectors

Scale: Simple Example

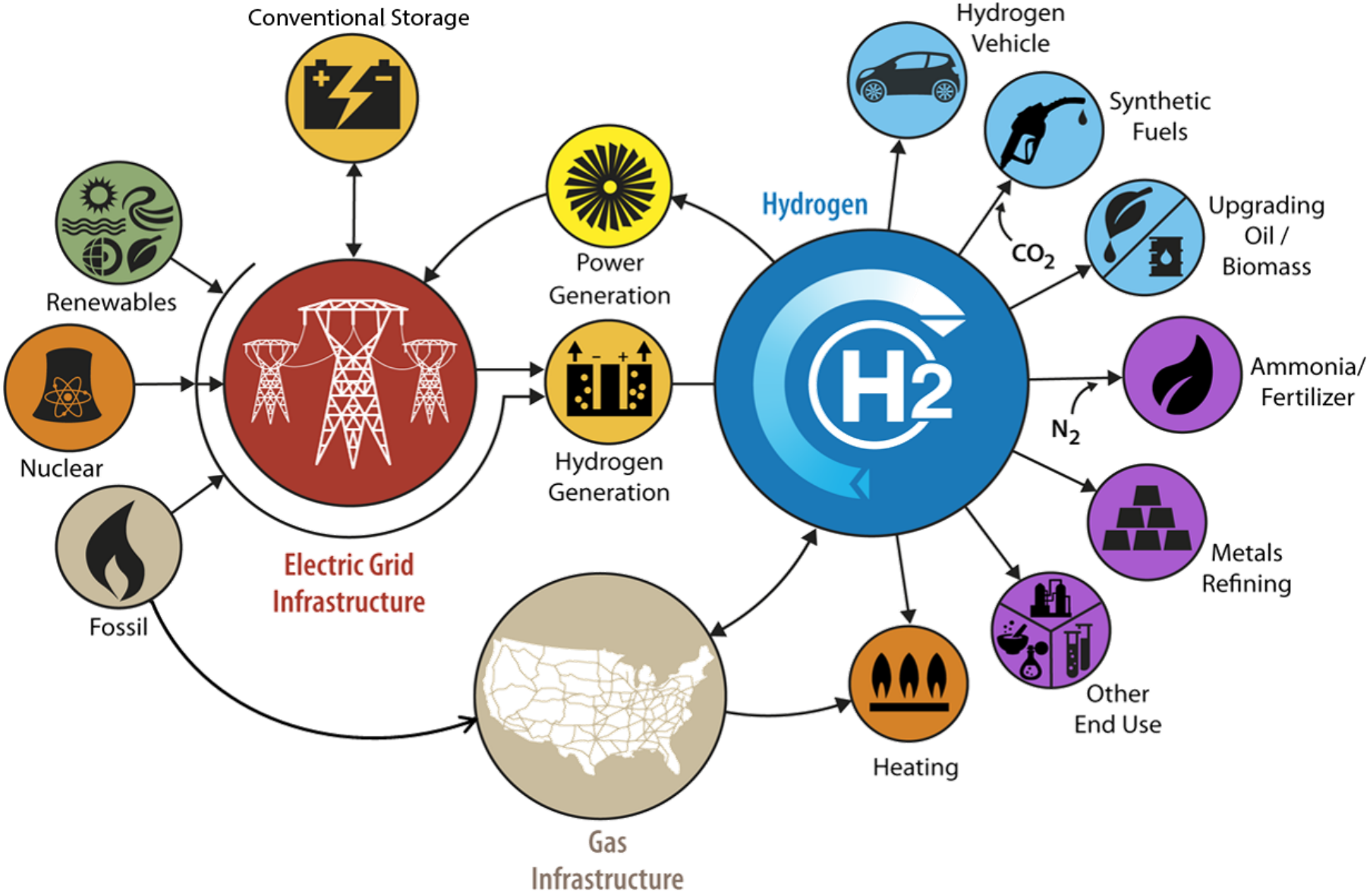
How much hydrogen for 1 car?

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

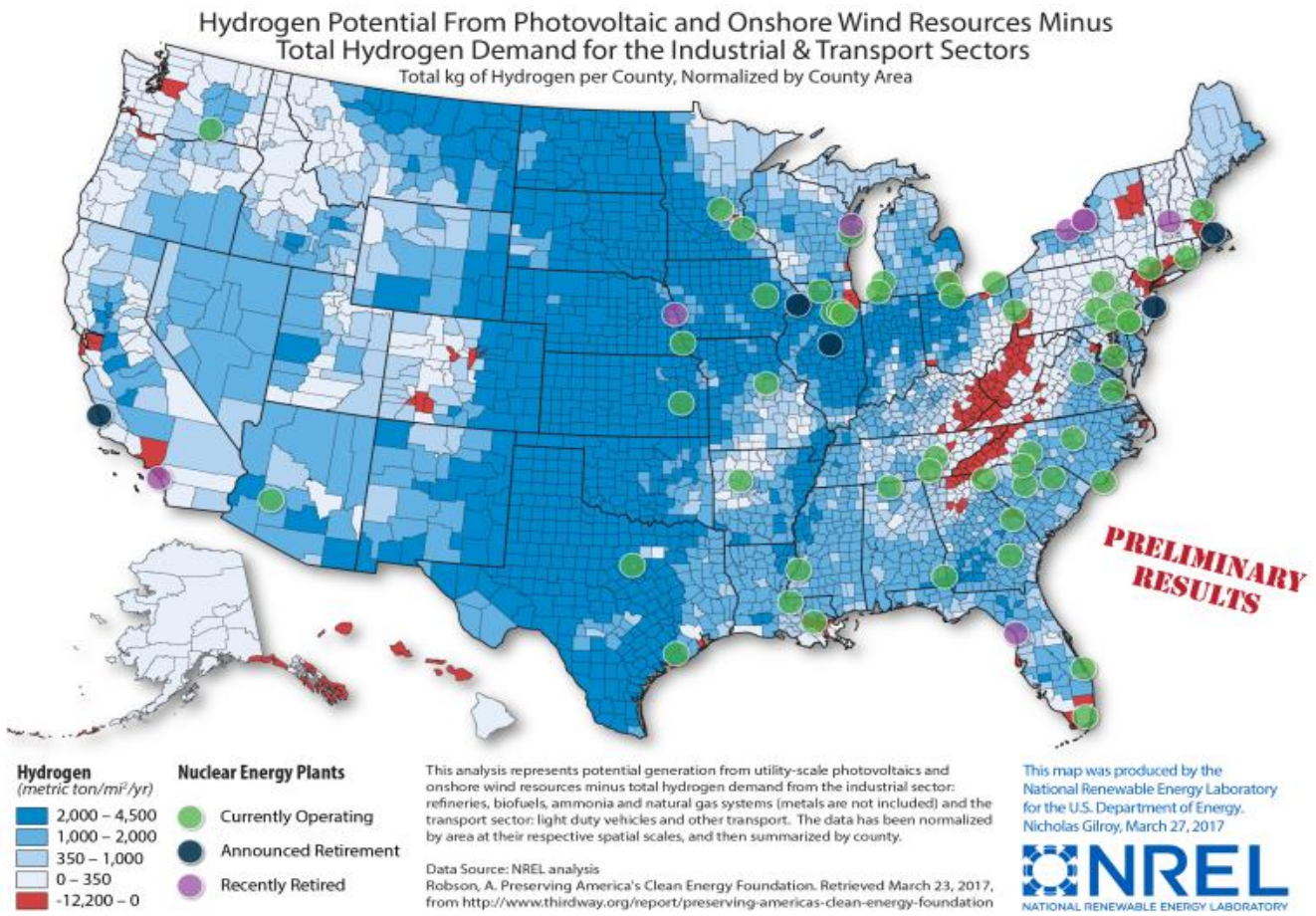
How much hydrogen for many cars?

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

H_2@Scale Energy System



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

Hydrogen Energy Storage is Scalable

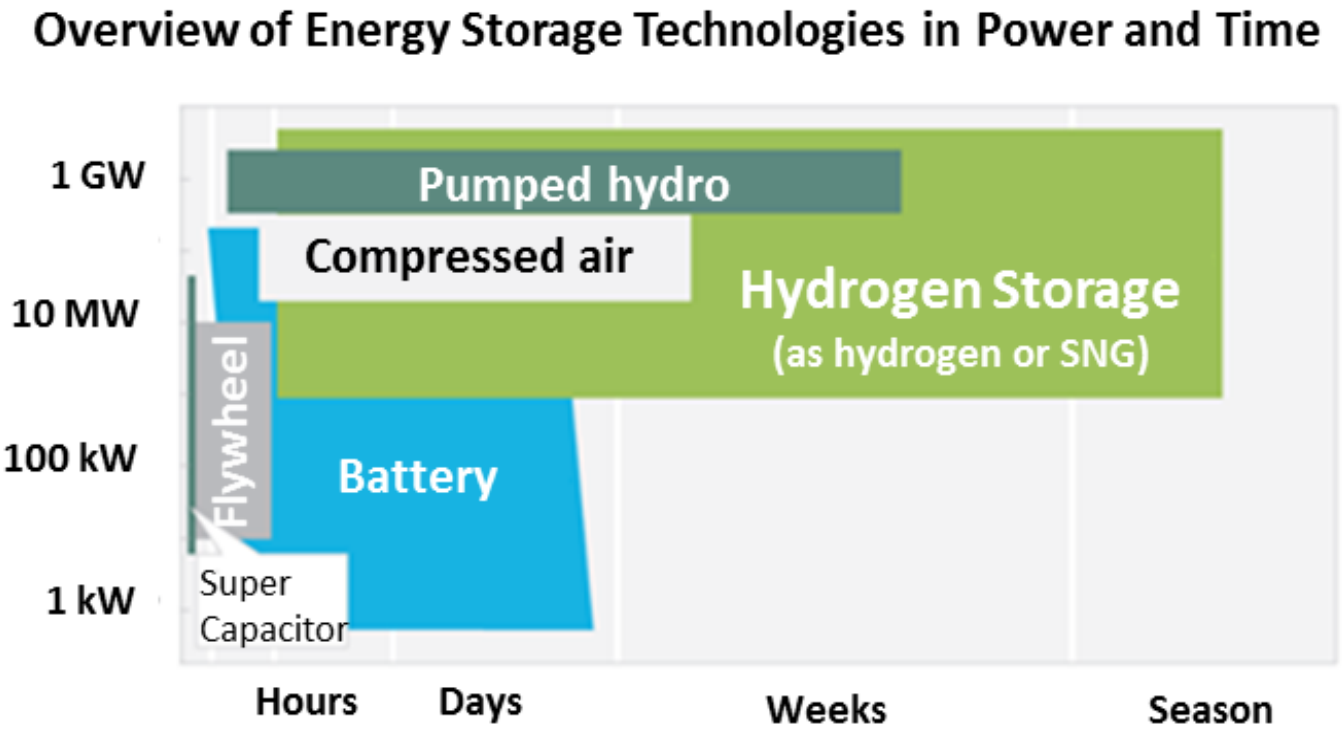


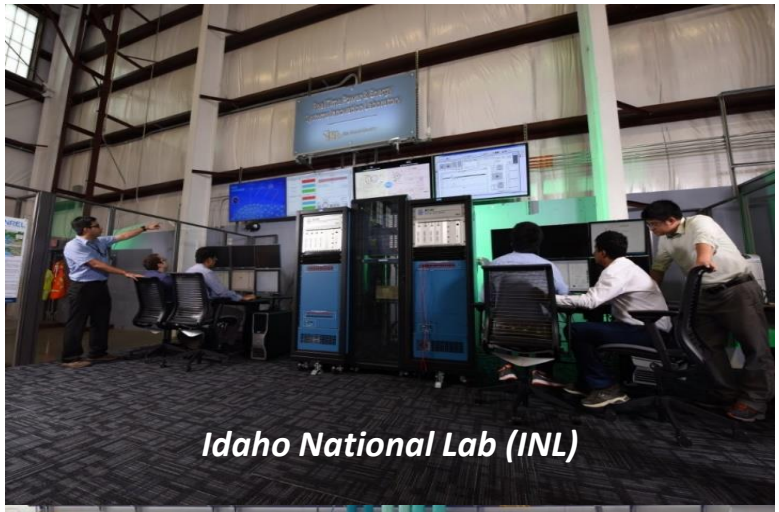
Image: Hydrogen Council

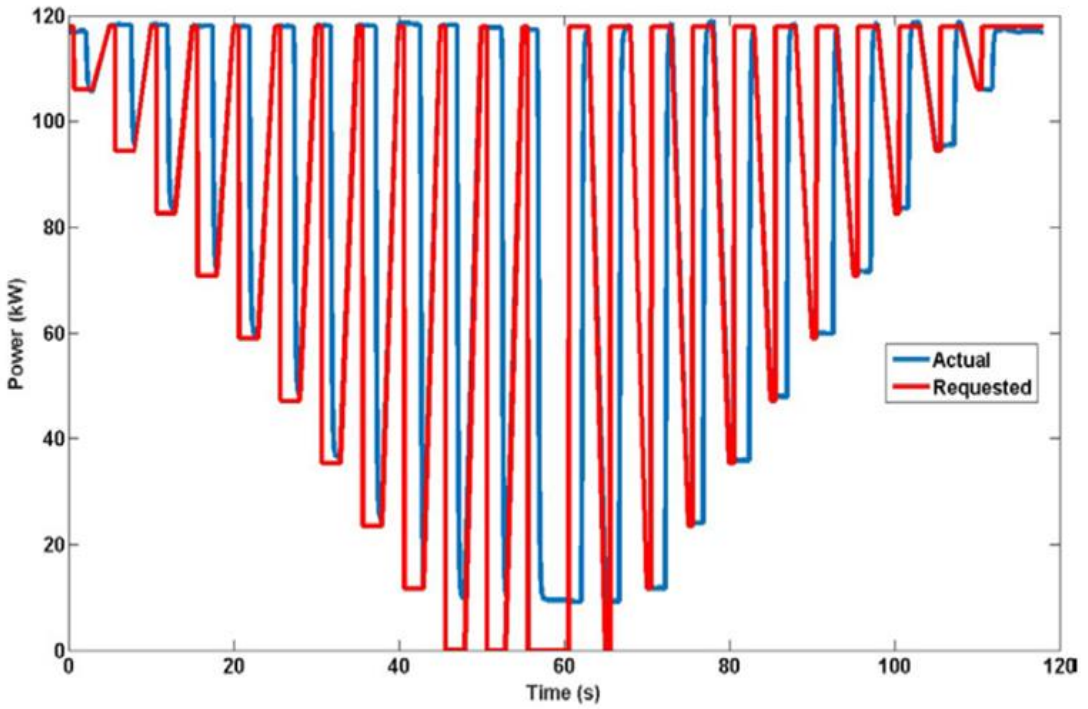
One hydrogen cavern could provide **~ 100 GWh energy storage**

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





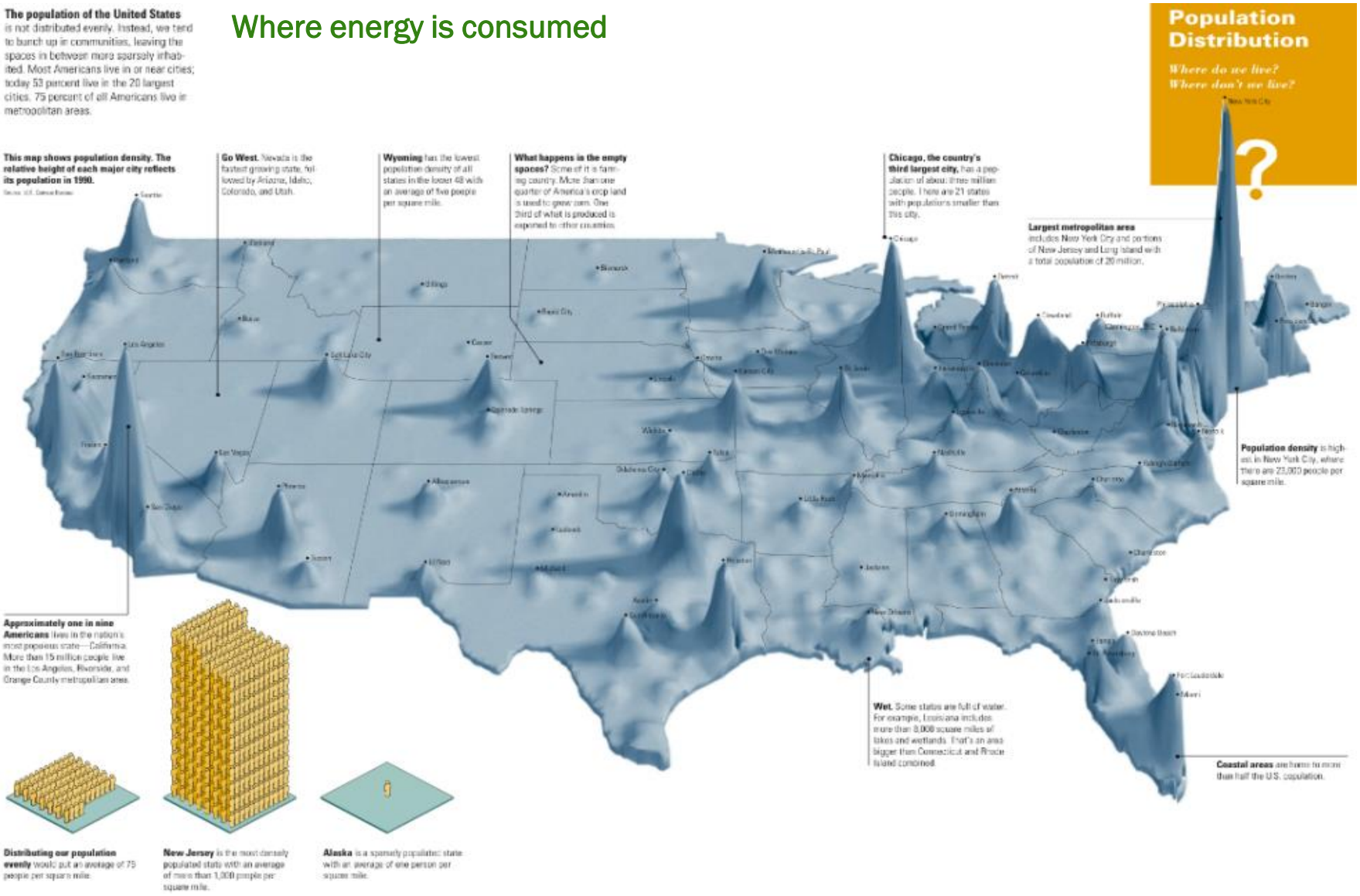
Lab testing shows dynamic response within seconds and potential for grid services

H_2@Scale: Enabling renewable energy transport?

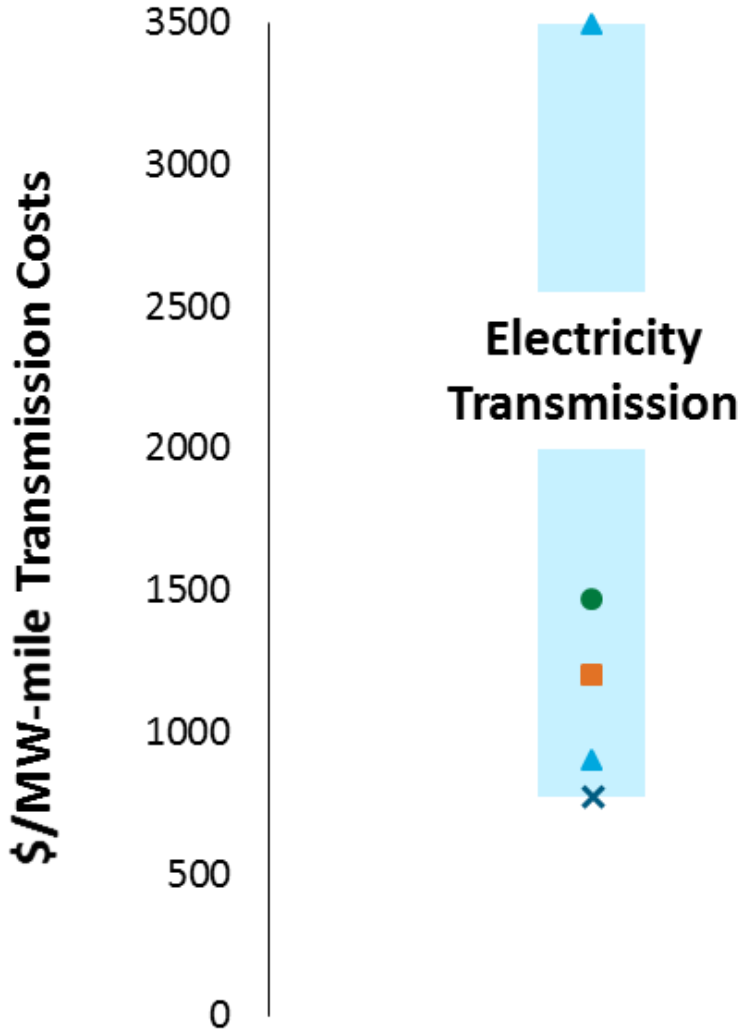
Where we find abundant solar and wind energy

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

Where energy is consumed



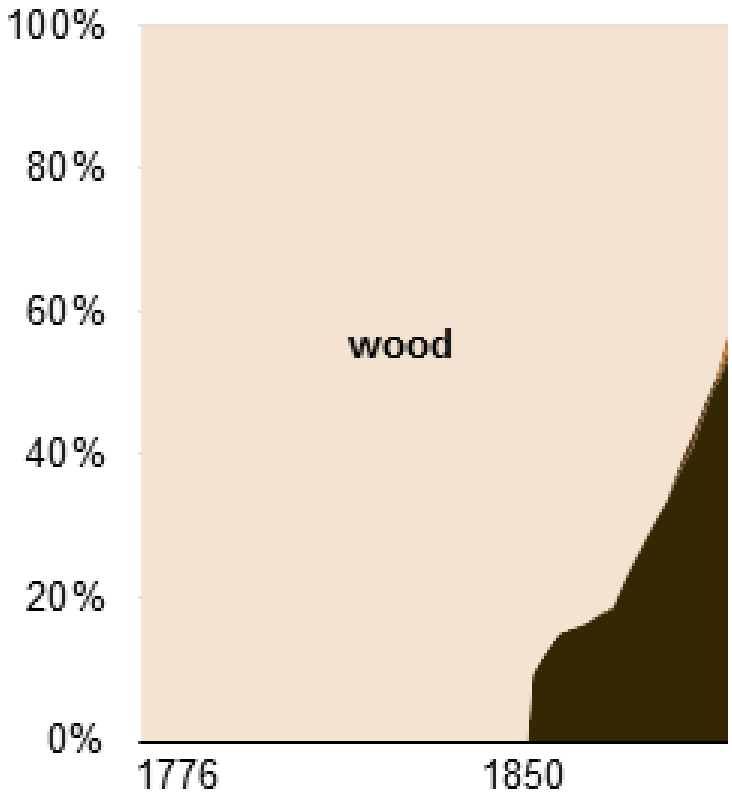
Analysis underway to guide future plans



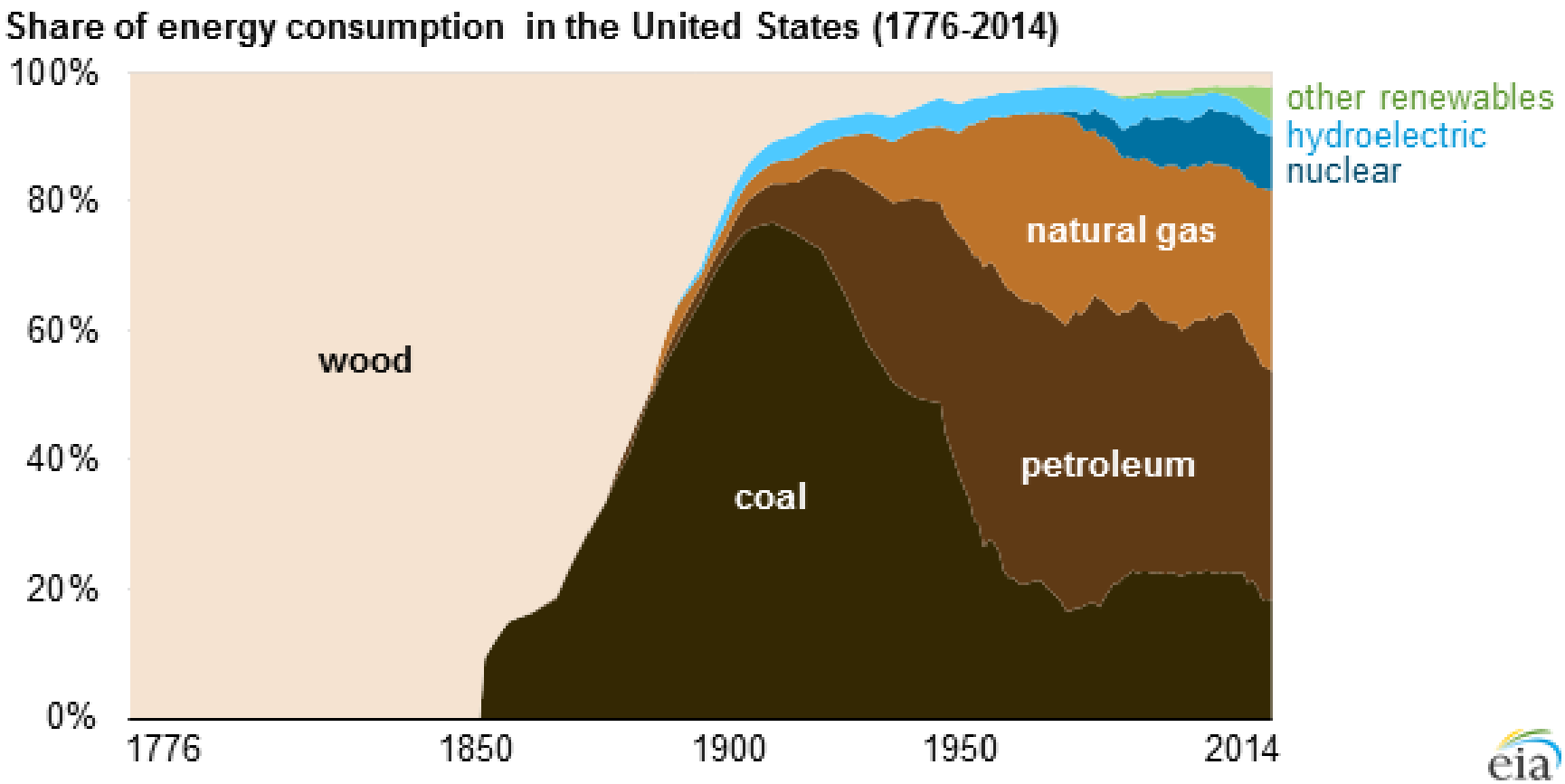
Cost of long distance electricity transmission is high

Can H_2 or H_2 carriers be an option?

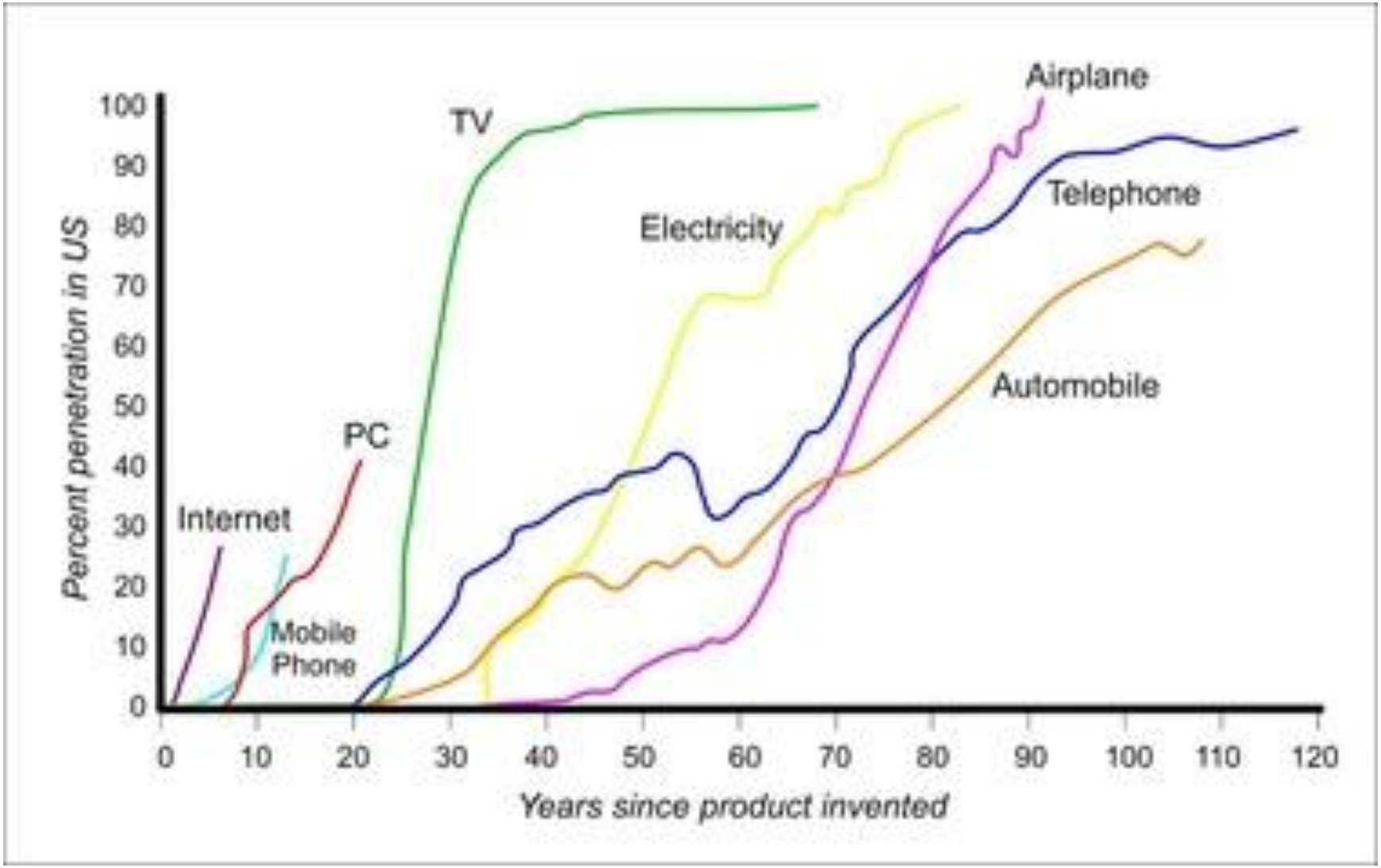
History of energy consumption in the U.S.



History of energy consumption in the U.S.



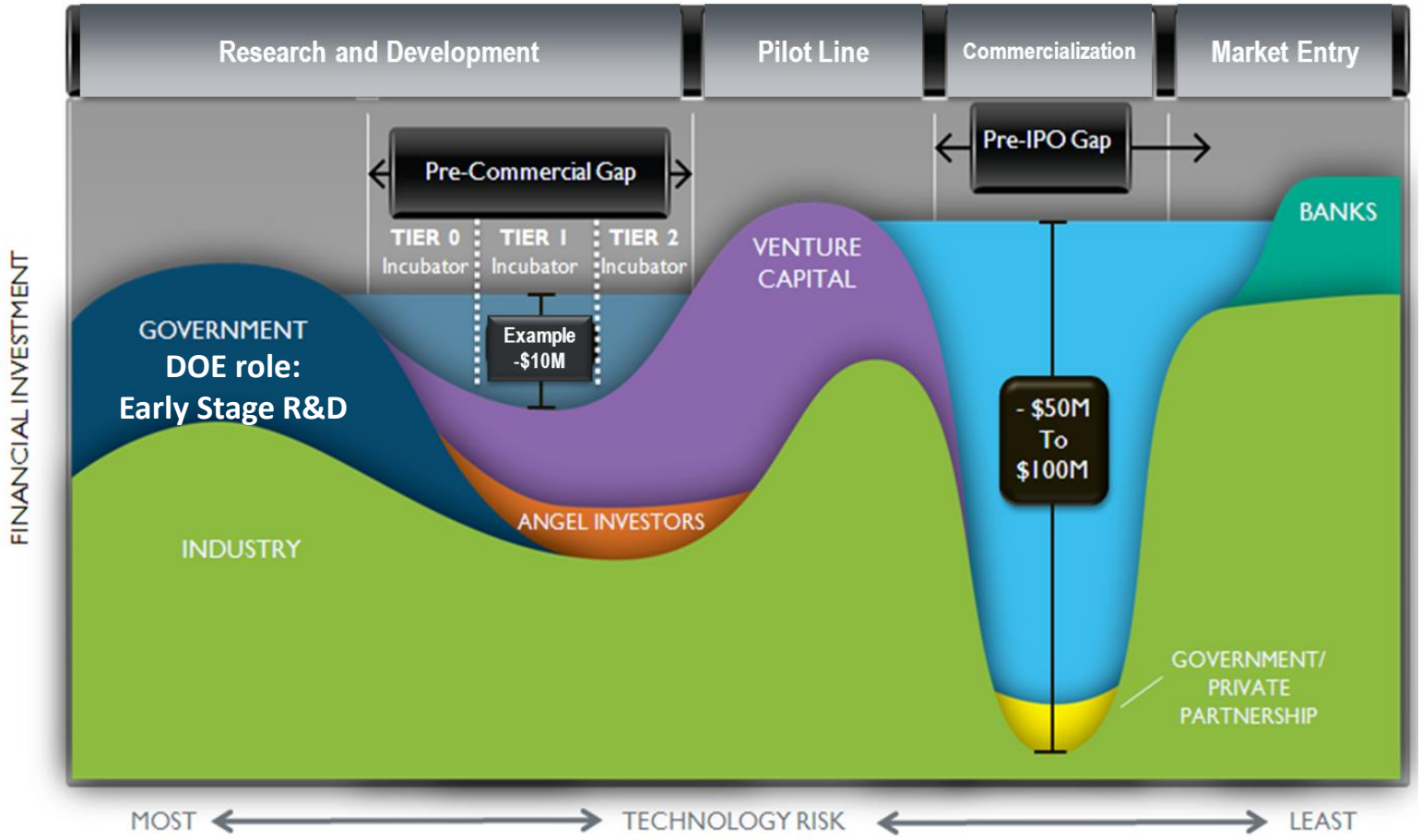
Technology Adoption Curves



4. Collaboration

Government vs. Private Sector Roles

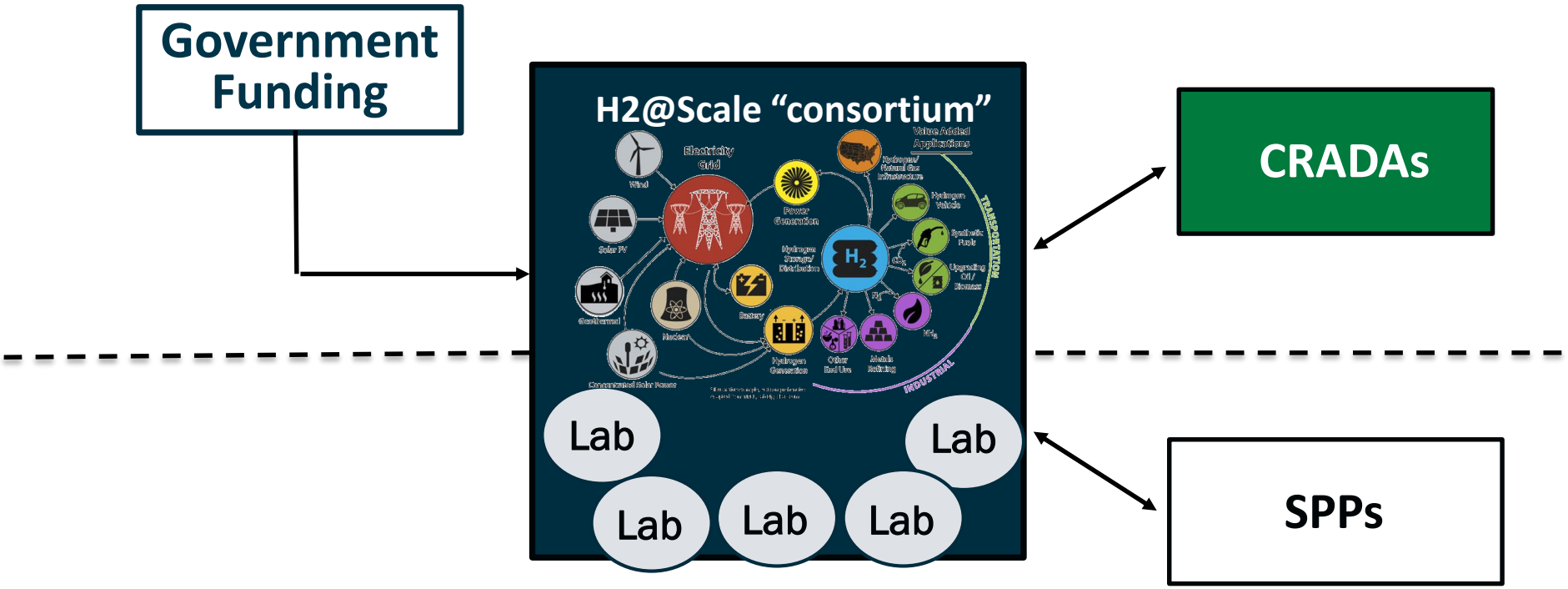
Example— illustrative timeline for innovation & commercialization



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

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. Over 20 new projects.**



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

Example: Innovation Driving Impact

Innovation

730 H_2 and fuel cell **patents** **enabled by DOE funds**

Approx. **35%** of H_2 and fuel cell patents **come from National Labs**

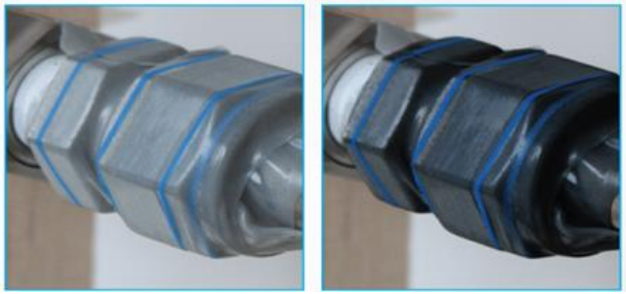
Market Impact

More than **30** **Technologies** commercialized by private industry

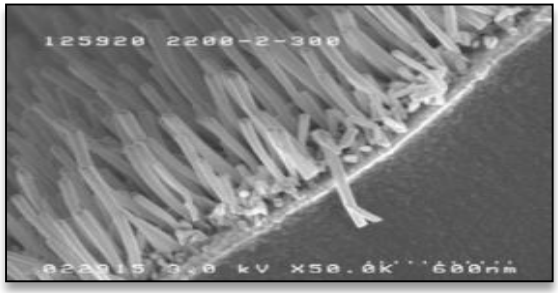
and over **75** **with potential** to be commercial in the next 3-5 years

can be traced back to DOE R&D

Innovation to Market Technologies - Examples



Hydrogen Detection Tape – Element One

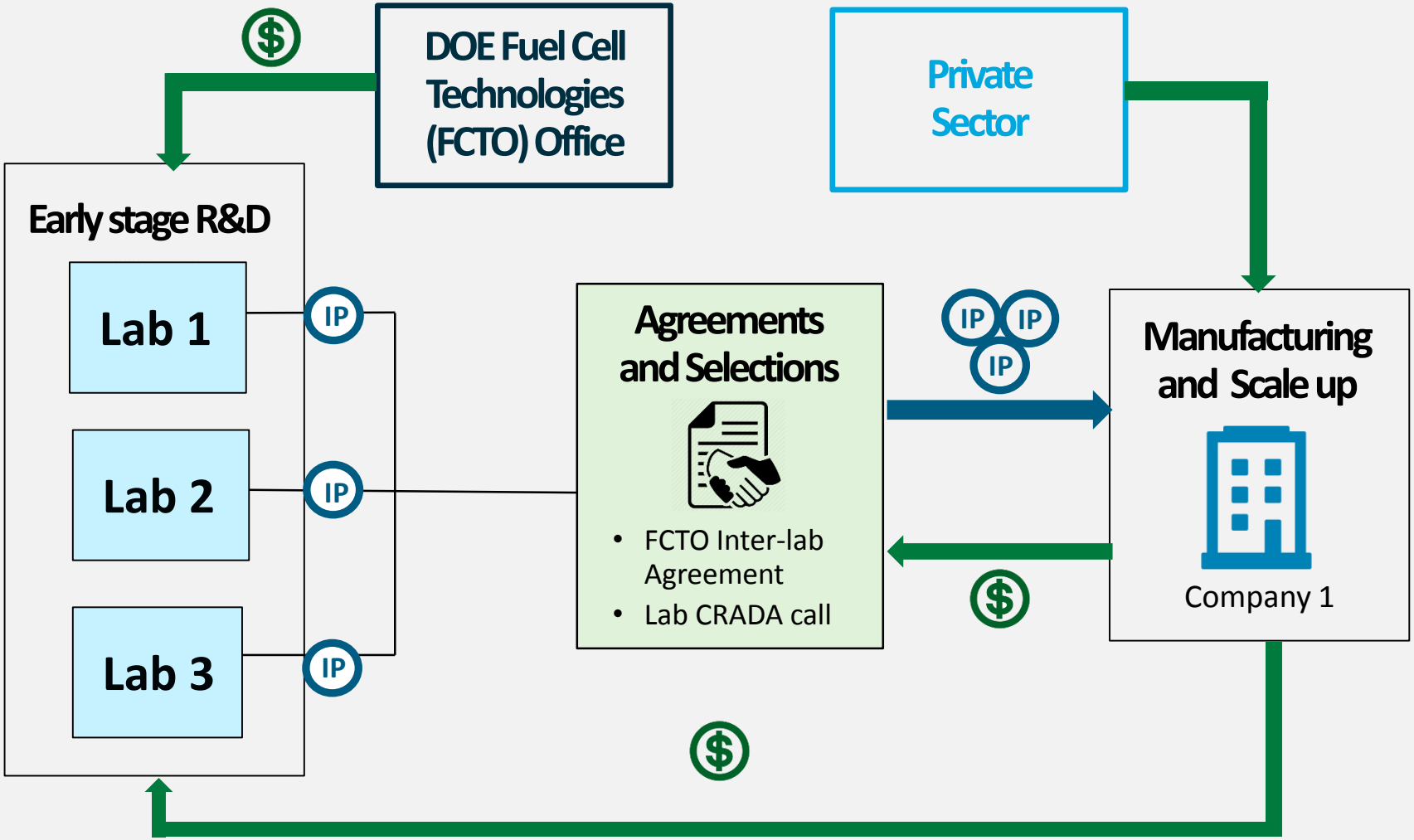


Catalyst and Supports for PEM Fuel Cells – 3M

Hydrogen Tube Trailers – Hexagon Lincoln

Innovations Provided to Industry & Investors

L'Innovator= "Lab Innovator" FCTO Pilot

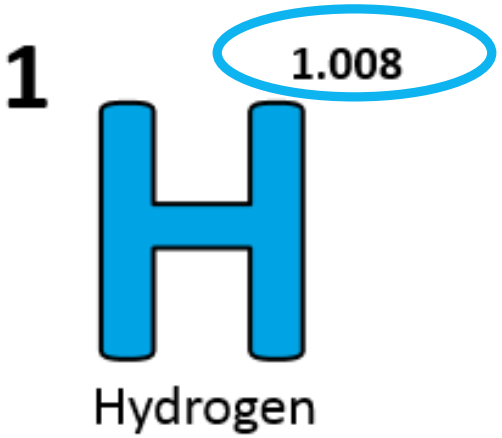


Opportunities for outreach and to increase awareness

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

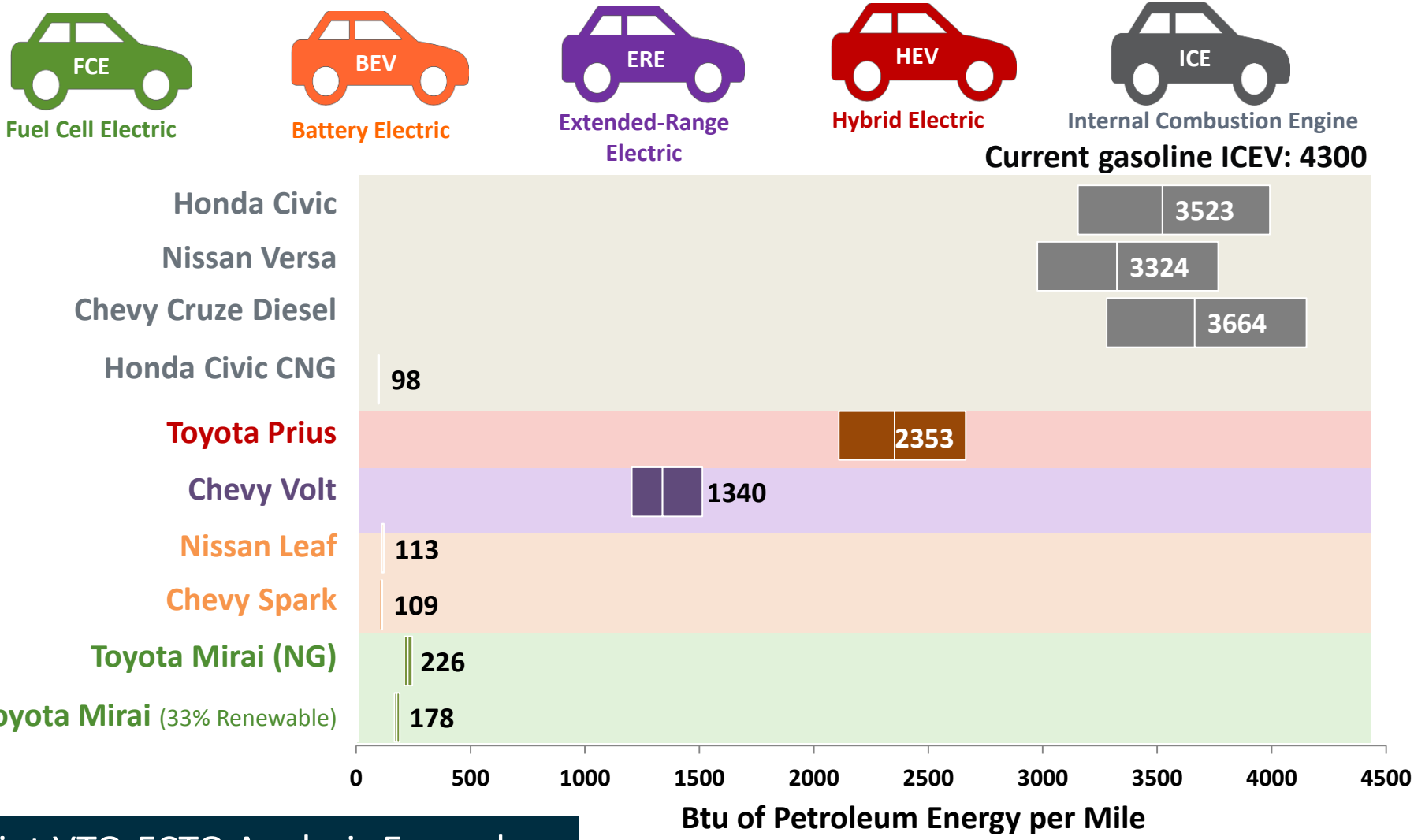
Thank You

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

www.hydrogen.energy.gov

H_2 and fuel cells potential to reduce petroleum use

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

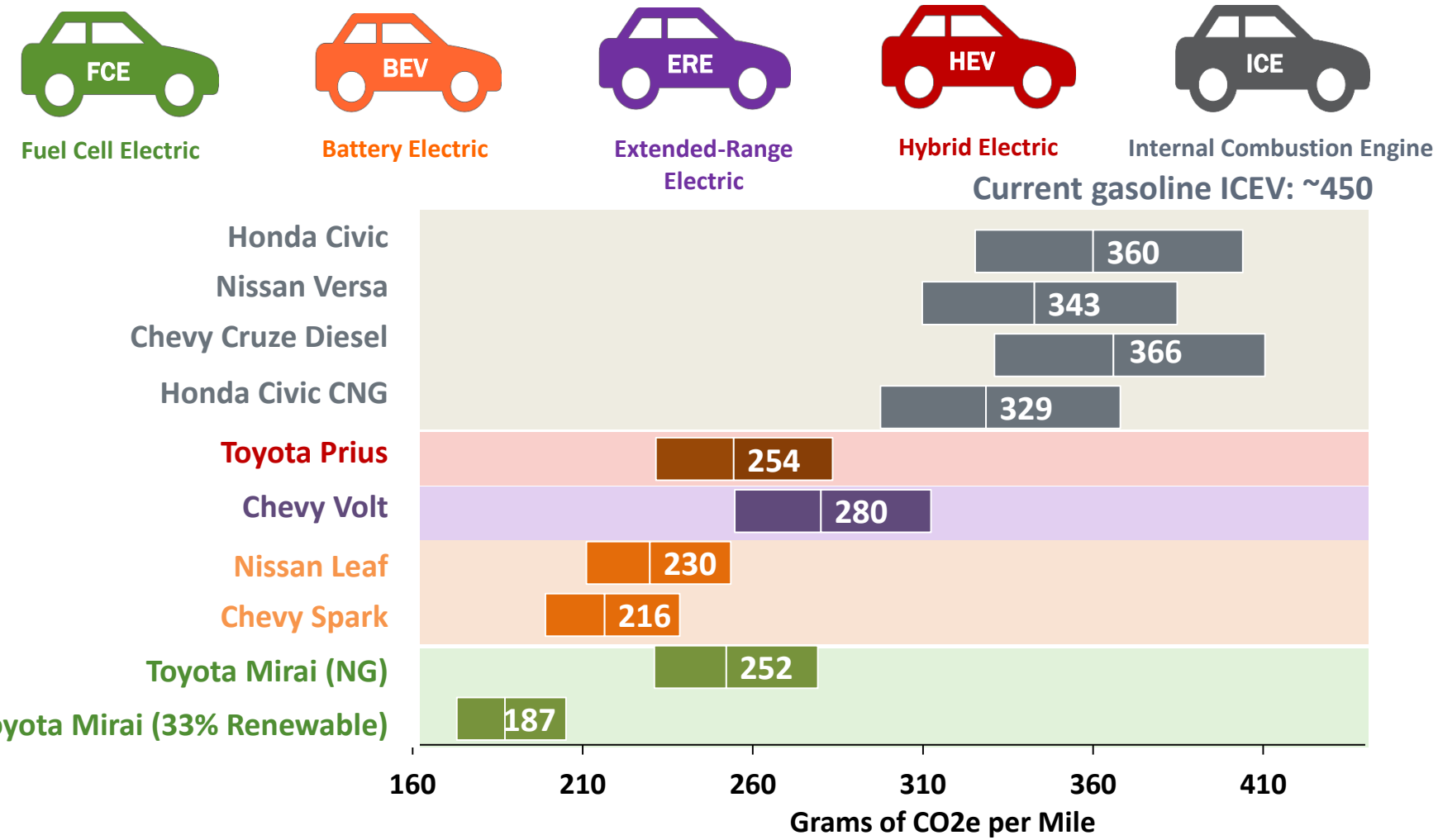


Joint VTO-FCTO Analysis Example

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

And lifecycle emissions

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)