U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

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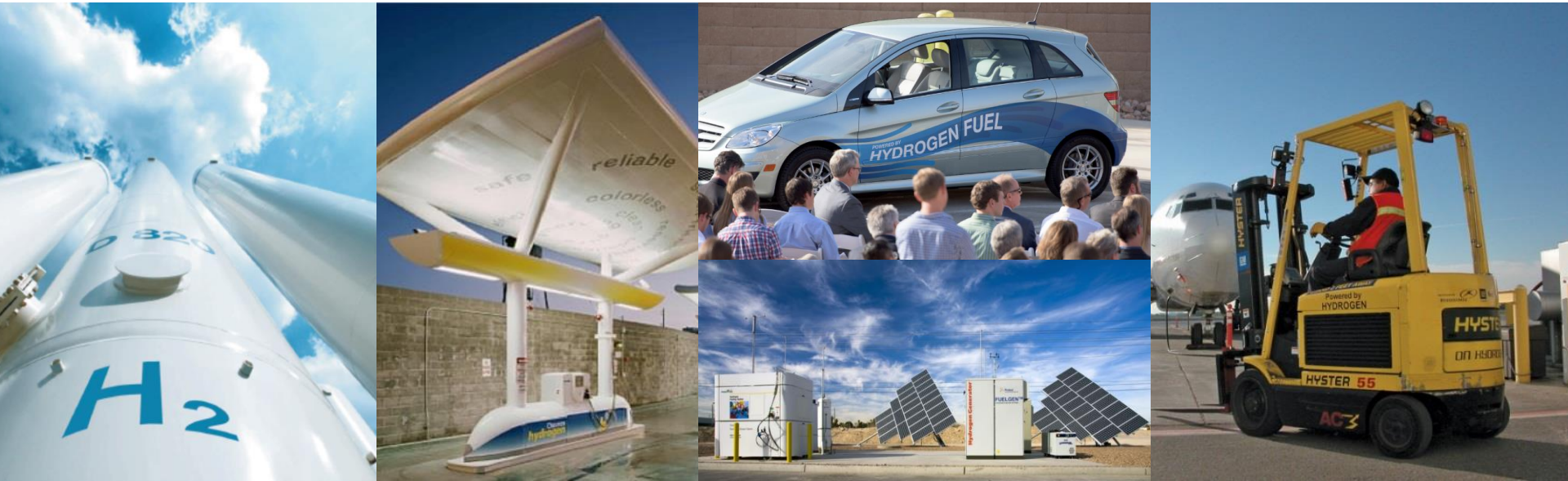
Hydrogen and Fuel Cells Overview

Vanessa (Trejos) Arjona, Contractor (AST); **Simon Thompson**, ORISE Fellow

Fuel Cell Technologies Office

Smithsonian Teachers Academy Seminar
July 13, 2018 – Washington, D.C.



What is a fuel cell?

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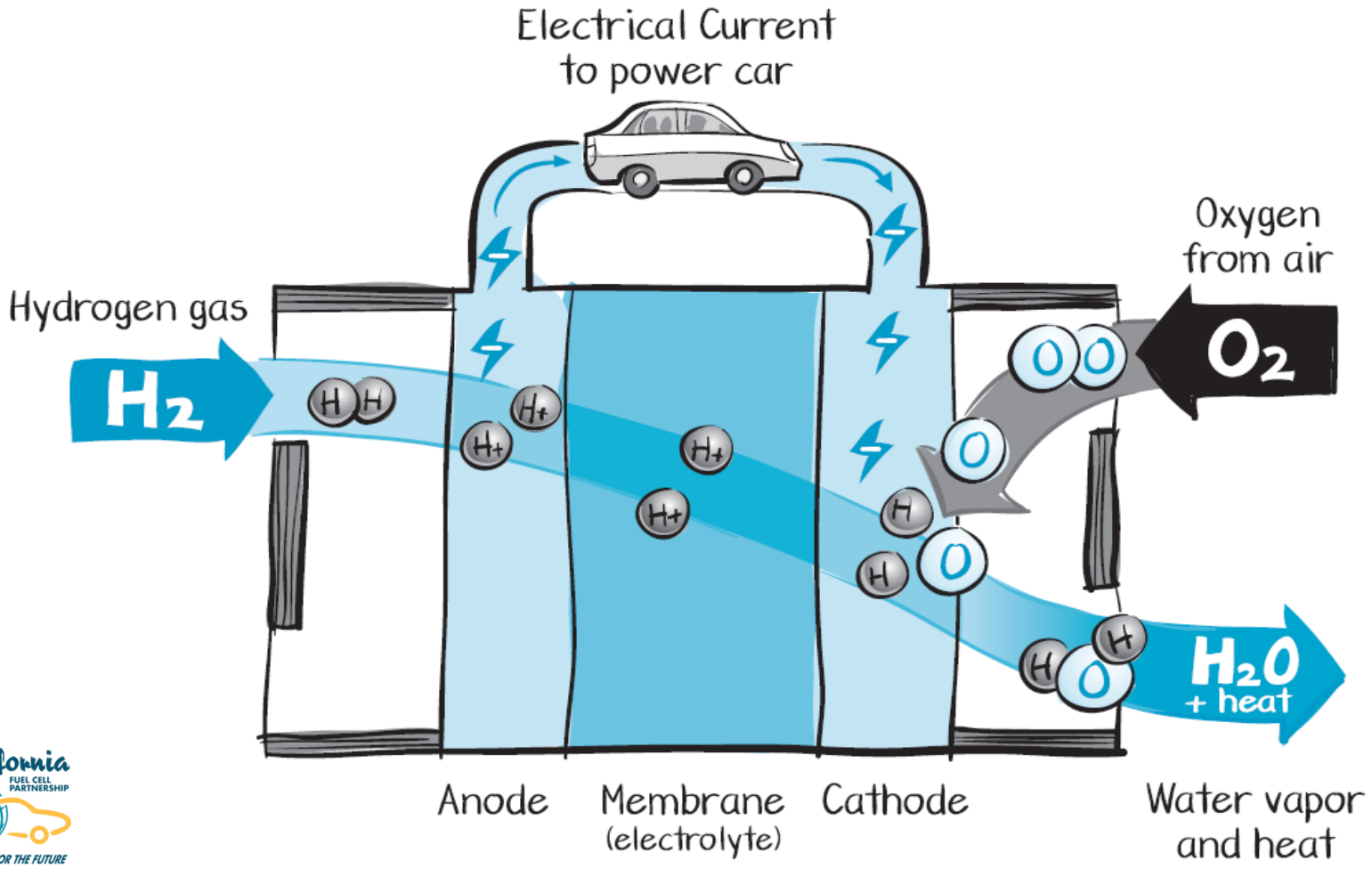
Takes hydrogen in and puts electricity and water vapor out



California Fuel Cell Partnership
DRIVING FOR THE FUTURE

Fuel Cells are more energy efficient

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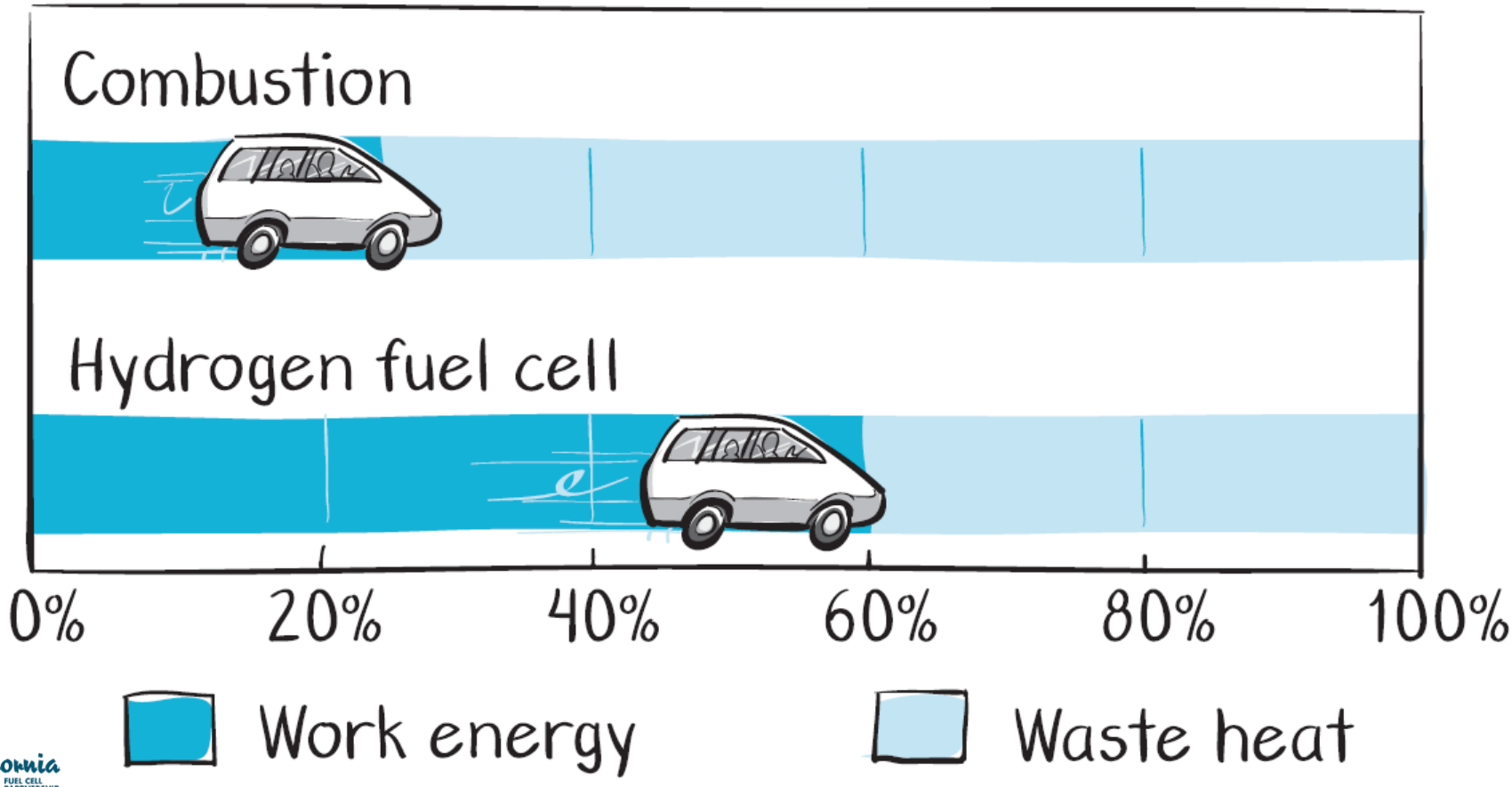
Twice as efficient as a gasoline car and water out of tailpipe



California Fuel Cell Partnership
Driving for the Future

What is hydrogen?

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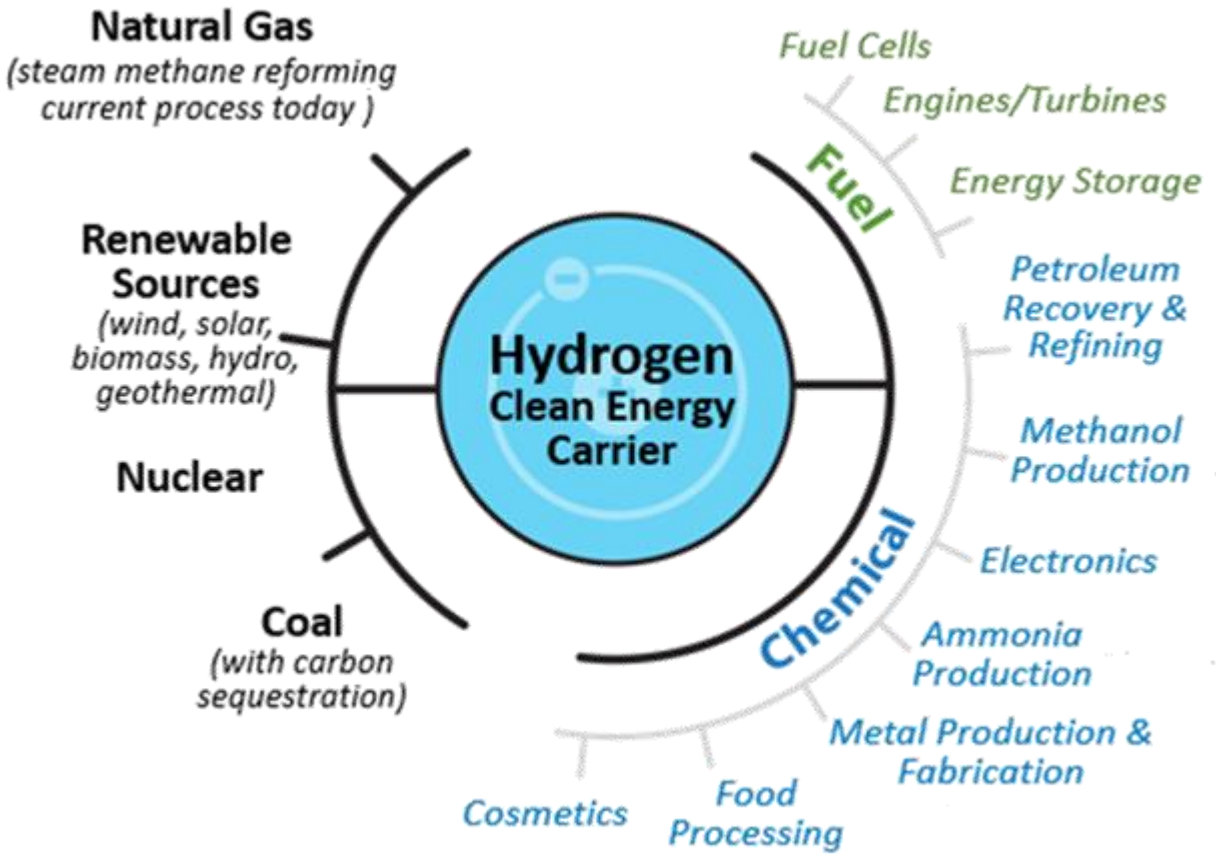
Lightest of all gases and a versatile, clean and flexible energy carrier



Produced from diverse domestic resources and used in many applications

Hydrogen's Energy Content

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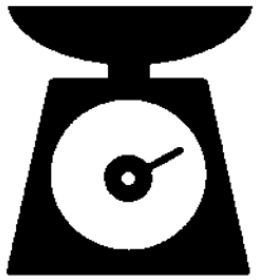
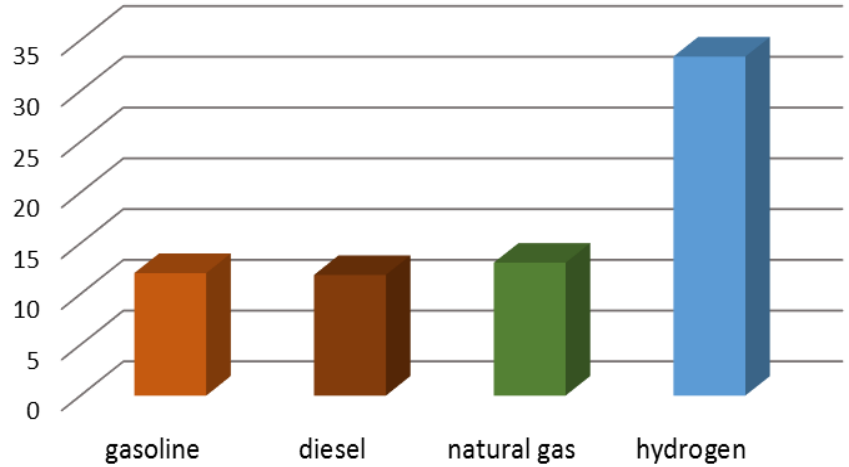
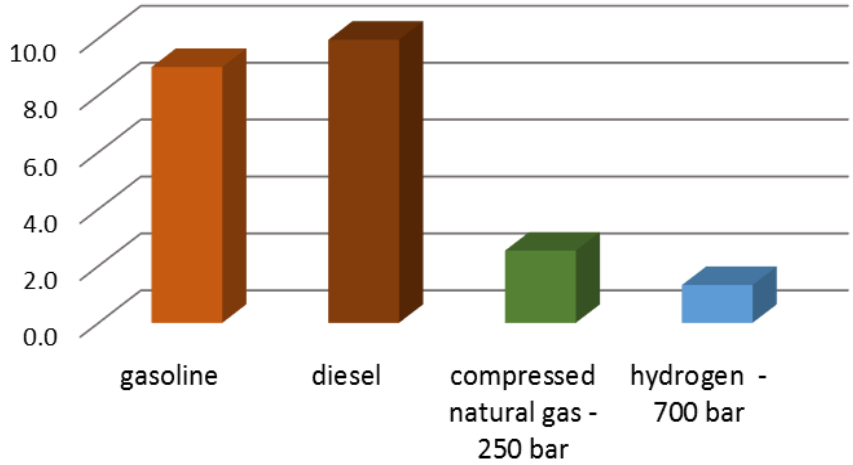
High Energy by Mass, Low Energy by Volume



Approx.
3X more
energy content
by mass
than gasoline

Approx.
4X less
energy content
by volume
than gasoline





Why Hydrogen and Fuel Cells?

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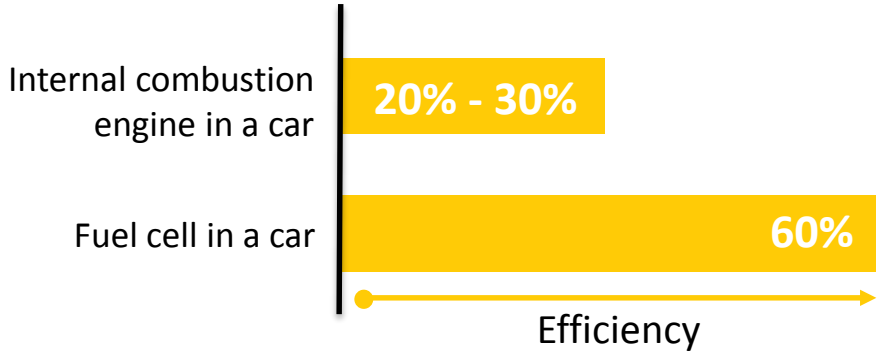
Efficient



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

Real World Applications – In the U.S.

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Photo Credit: UPS

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

Photo Credit: FedEx

First fuel cell tow truck fleet at airport in Memphis

World's first fuel cell for maritime ports in Hawaii

Photo Credit: Sandia National Laboratories

Real World Applications – In the U.S.

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Fuel cell powered lights at Super Bowl in CA

Fuel cell buses in California surpass 19M passengers

Photo Credit: NREL

Industry demonstrates first heavy duty fuel cell truck in CA

Photo Credit: Toyota

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

Photo Credit: General Motors

Real World Applications – In the U.S.

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

Fuel cells used to power World Trade Center in NYC

Increasing orders of fuel cell forklifts by warehouses and stores in the U.S.

Photo Credit: BMW Manufacturing

Backup power installed all over the country for cell phone towers, railroads and utilities

Photo Credit: NREL

Fuel cells operating all over the U.S.

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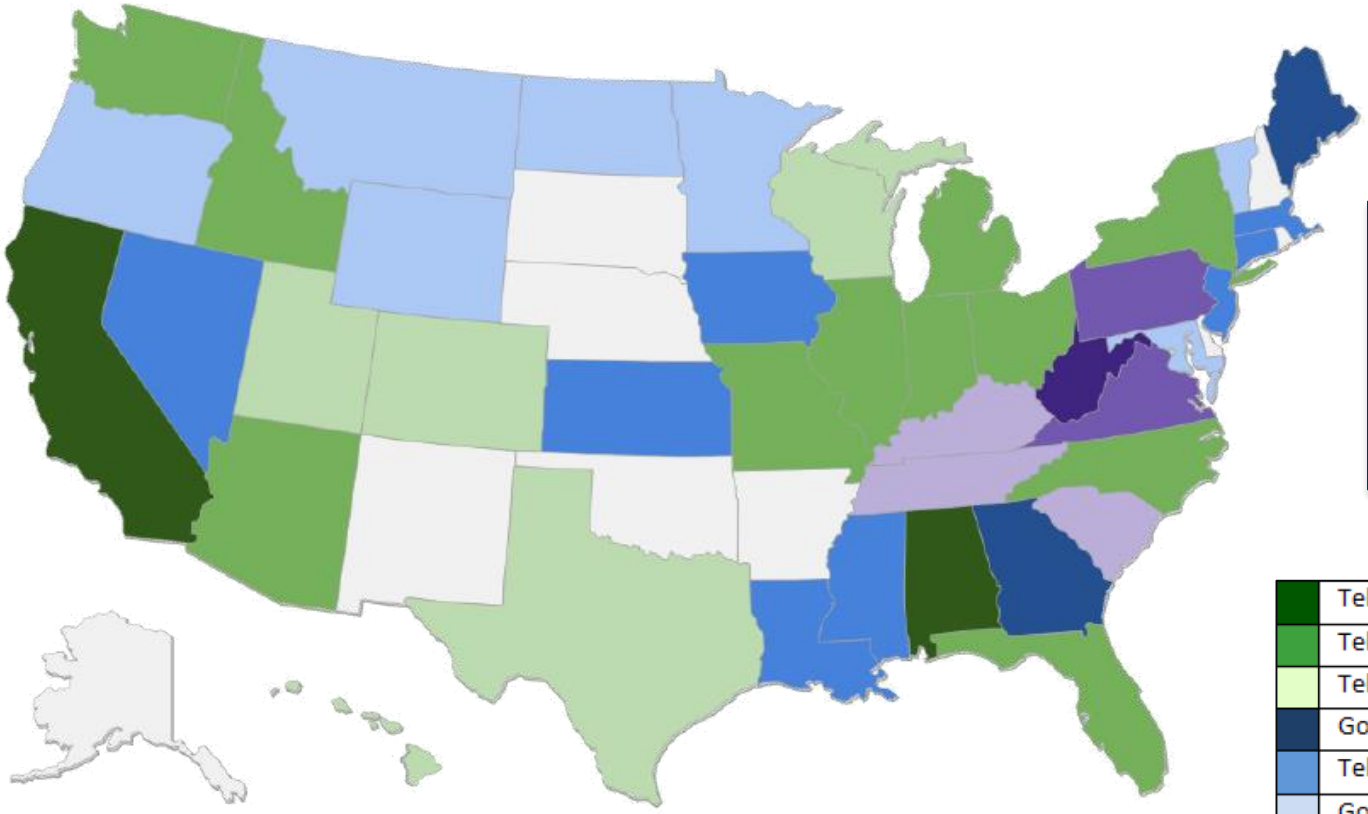
Fuel cells used for backup power in more than 40 states



Over 240MW

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

Real World Applications – Abroad

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World's first 4-seater fuel cell plane takes off at German Airport

Photo Credit: Christoph Schmidt/dpa via AP and phys.org.

Fuel cell cab fleet launched in Paris, France

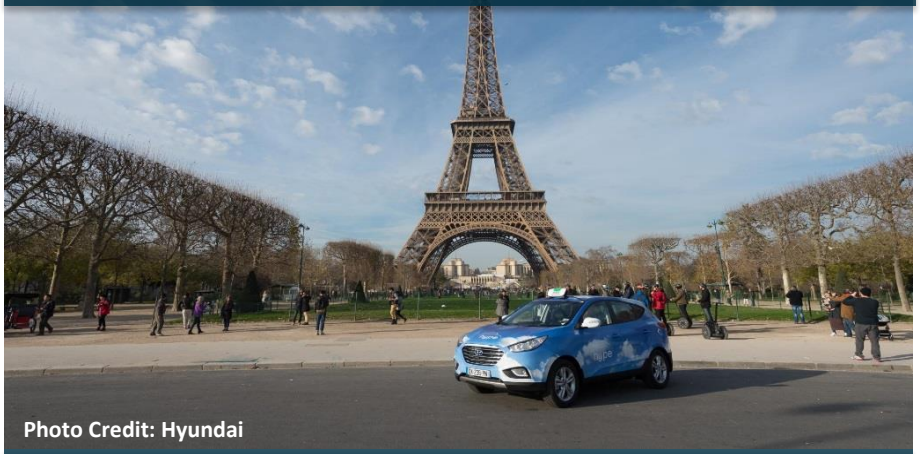

Photo Credit: Hyundai

A town in in Fukuoka, Japan running on hydrogen

Photo Credit: Fukuoka Pref.

World's first hydrogen fuel cell train in Germany

Photo Credit: Hydrogenics and Alstom

Fuel Cell Market Growth

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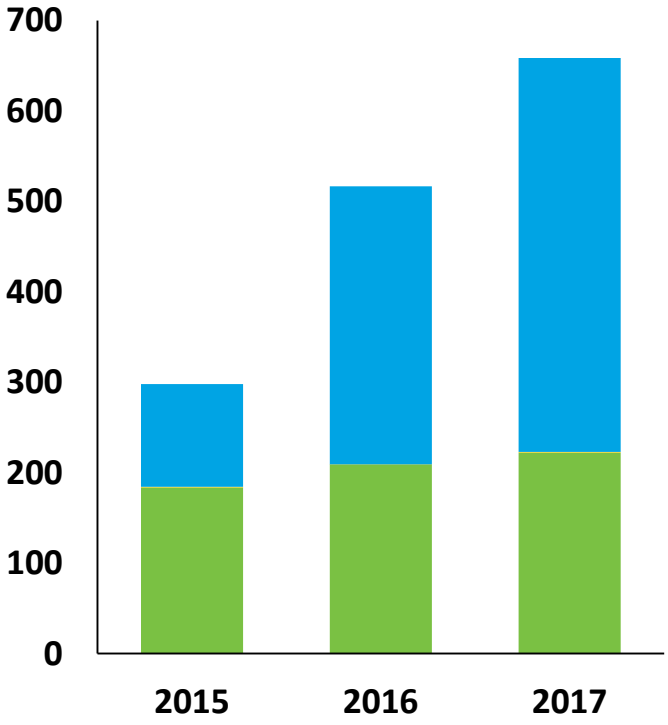
Fuel Cell Power Shipped Worldwide (MW)



Source: Navigant Research (2011-2013) & E4tech (2014-2016)

Transportation



Photo credit: Hyundai, Toyota and Honda

Stationary

Photo credit: NREL

Portable

Photo credit: NREL

650 MW
fuel cell power
shipped worldwide

70,000
fuel cell units
shipped worldwide

Approximately
$2 Billion
fuel cell revenue

Source: DOE, E4tech

U.S. Fuel Cell Car Sales

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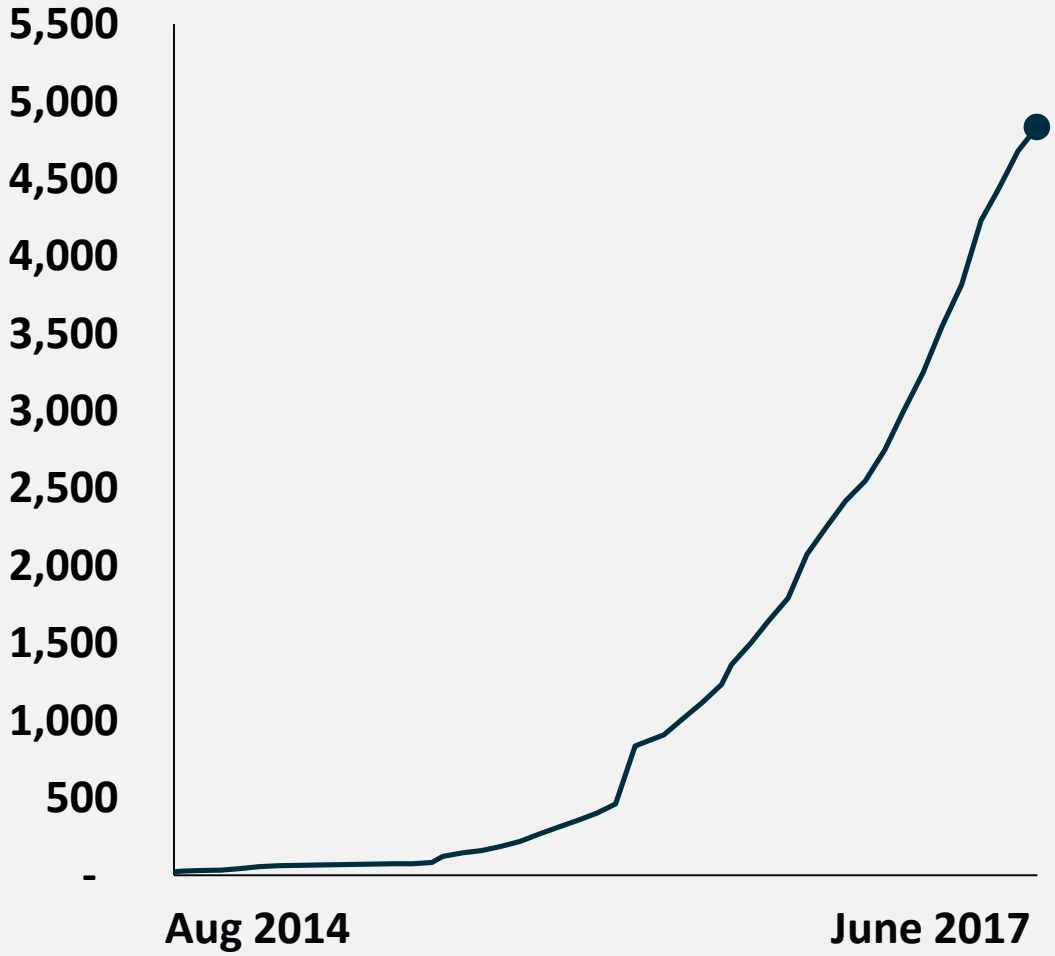
Fuel Cell Car Sales Growing



Note: Cumulative number of vehicles sold/leased. Source: hybridcars.com

5,000 fuel cell cars

sold or leased in the U.S.

First time fuel cell electric mobility ranks

#1 trend

in 2018 automotive executives survey

KPMG, Global Automotive Executive Survey 2018

A Simple Example: Gasoline vs. Fuel Cell Car

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Gasoline Car

$$20 \frac{\text{Miles}}{\text{Gallon}} \times 15 \frac{\text{Gallon}}{\text{Tank}} = 300 \text{ miles}$$

$$15 \text{ Gallons} \times 4 \frac{\text{Dollars}}{\text{Gallon}} = \$60$$

Note: Illustrative example, does not reflect current gasoline prices

Fuel Cell Car

$$60 \frac{\text{Miles}}{\text{Kg (gge)}} \times 5 \frac{\text{Kg (gge)}}{\text{Tank}} = 300 \text{ miles}$$

$$5 \frac{\text{Kg}}{\text{Tank}} \times 10 \frac{\text{Dollars}}{\text{Kg (gge)}} = \$50$$

GGE: gallon of gasoline equivalent

Note: 1 kg of hydrogen has the same amount of energy as 1 gallon of gasoline

DOE Hydrogen and Fuel Cells Program

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Early R&D Focus

Applied research, development and innovation in emerging 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

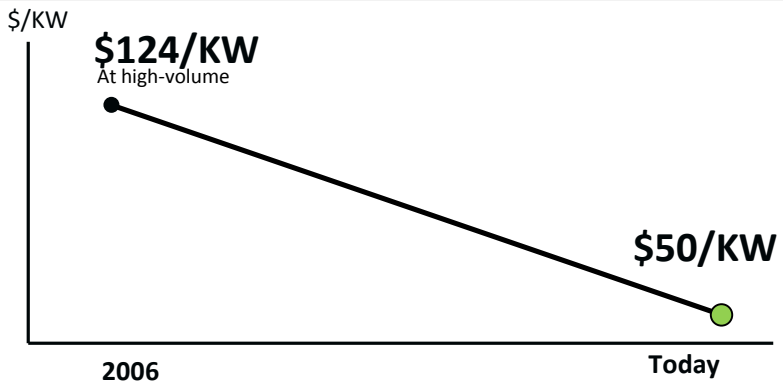
- Production pathways
- Delivery components
- Advanced materials for storage

PGM = Platinum group metals

MEA = Membrane Electrode Assembly

Early R&D Impact

60% Lower Fuel Cell Cost



Greater Fuel Cell Durability

4X more hours

of fuel cell lifetime since 2006

80% Lower Electrolyzer Cost

for H_2 production since 2002

Examples of Technology Enabled by DOE

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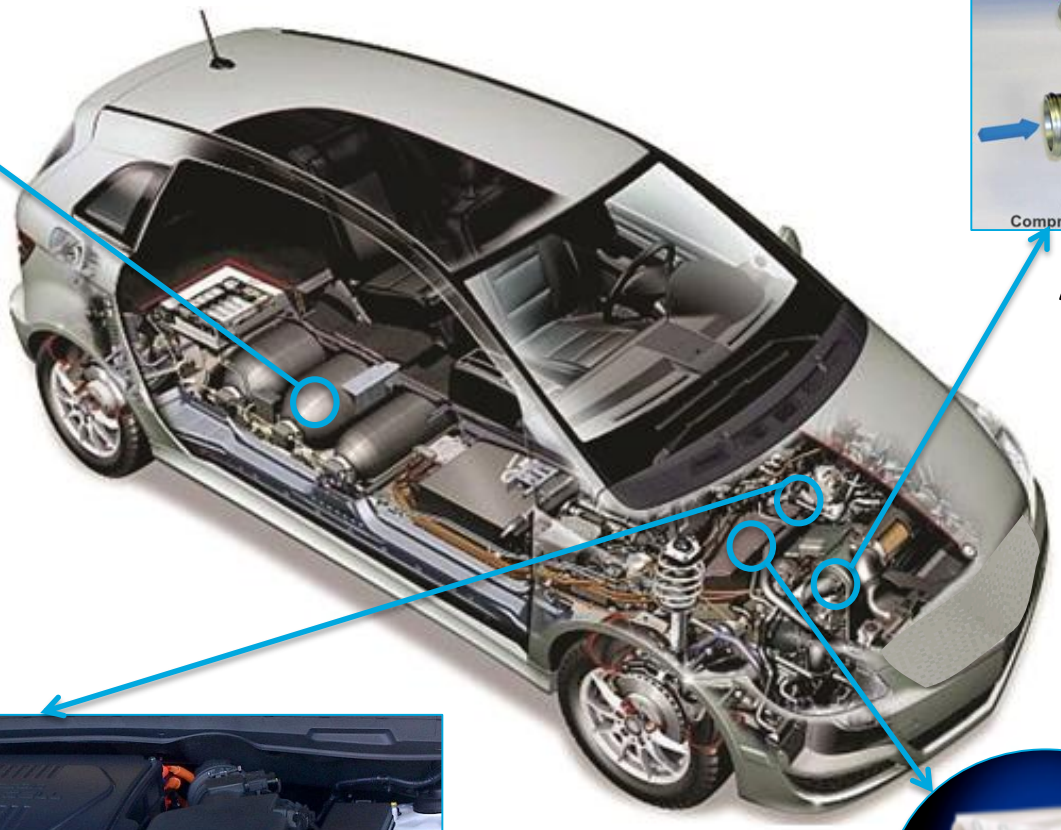
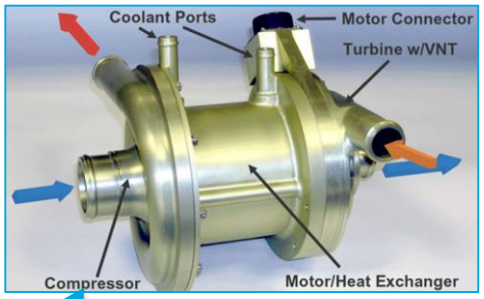
700 bar pressure vessels





Air Compressors

Fuel Cell Stack Systems

Humidifiers

DOE: Department of Energy

Hydrogen is an industrial commodity

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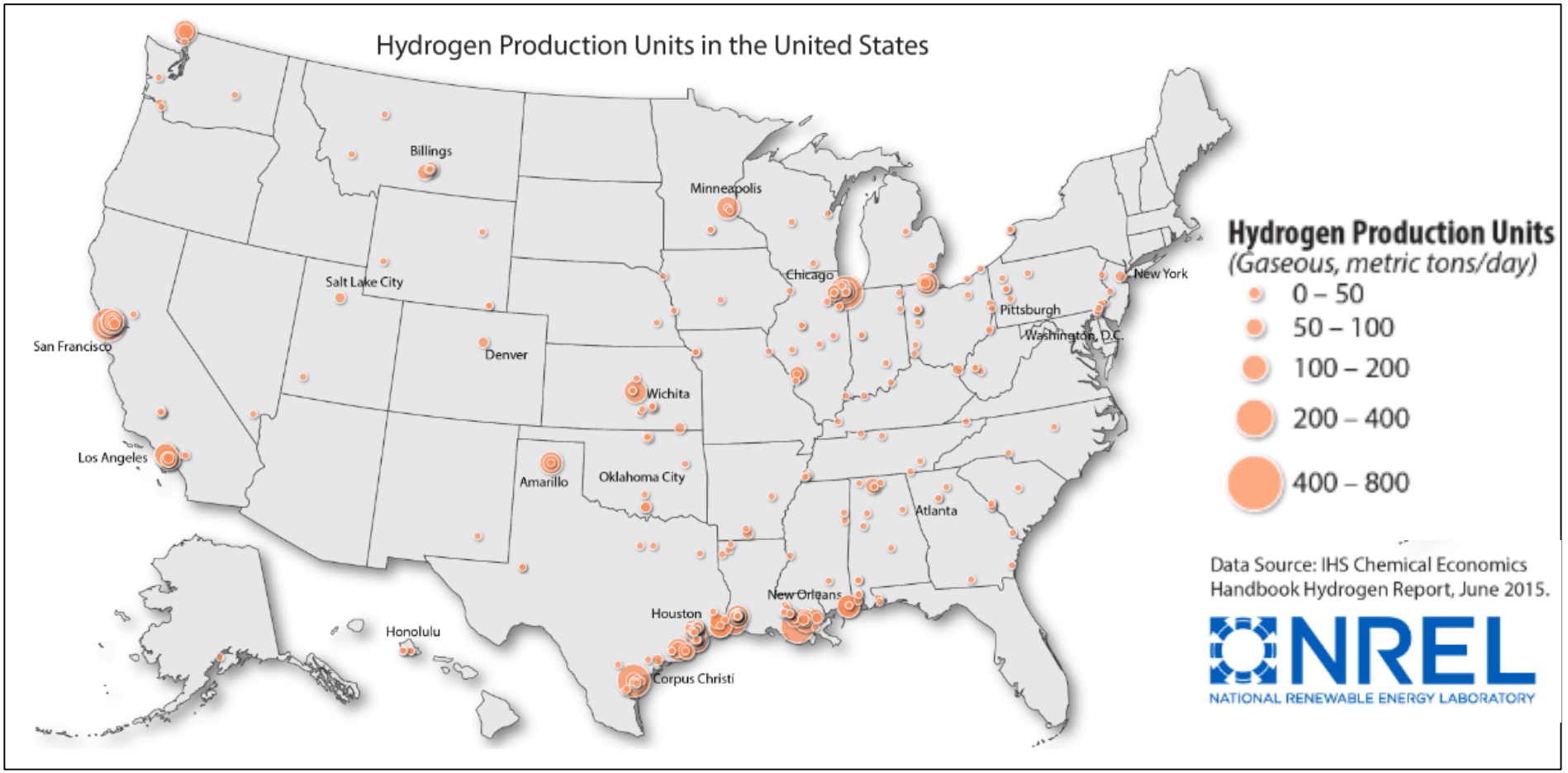

U.S. annual hydrogen production

10 million metric tons

Largest Users in the U.S.

Petroleum Processing	68%	Fertilizer Production	21%

H_2 stations now open in selected U.S. regions

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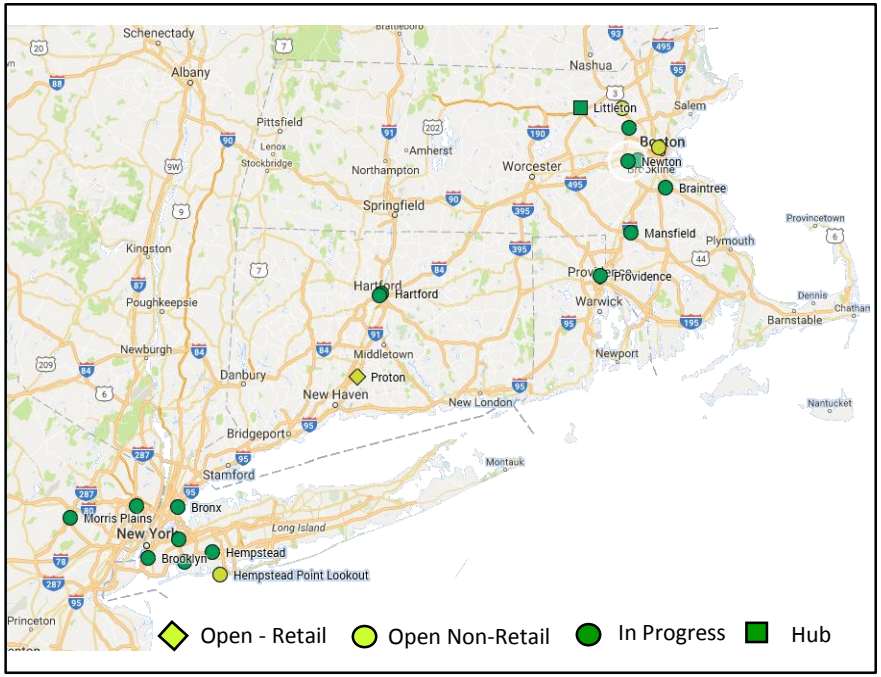
California

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

H_2 stations look similar to regular gas stations

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Photo courtesy: CaFCP

What does hydrogen refueling look like?

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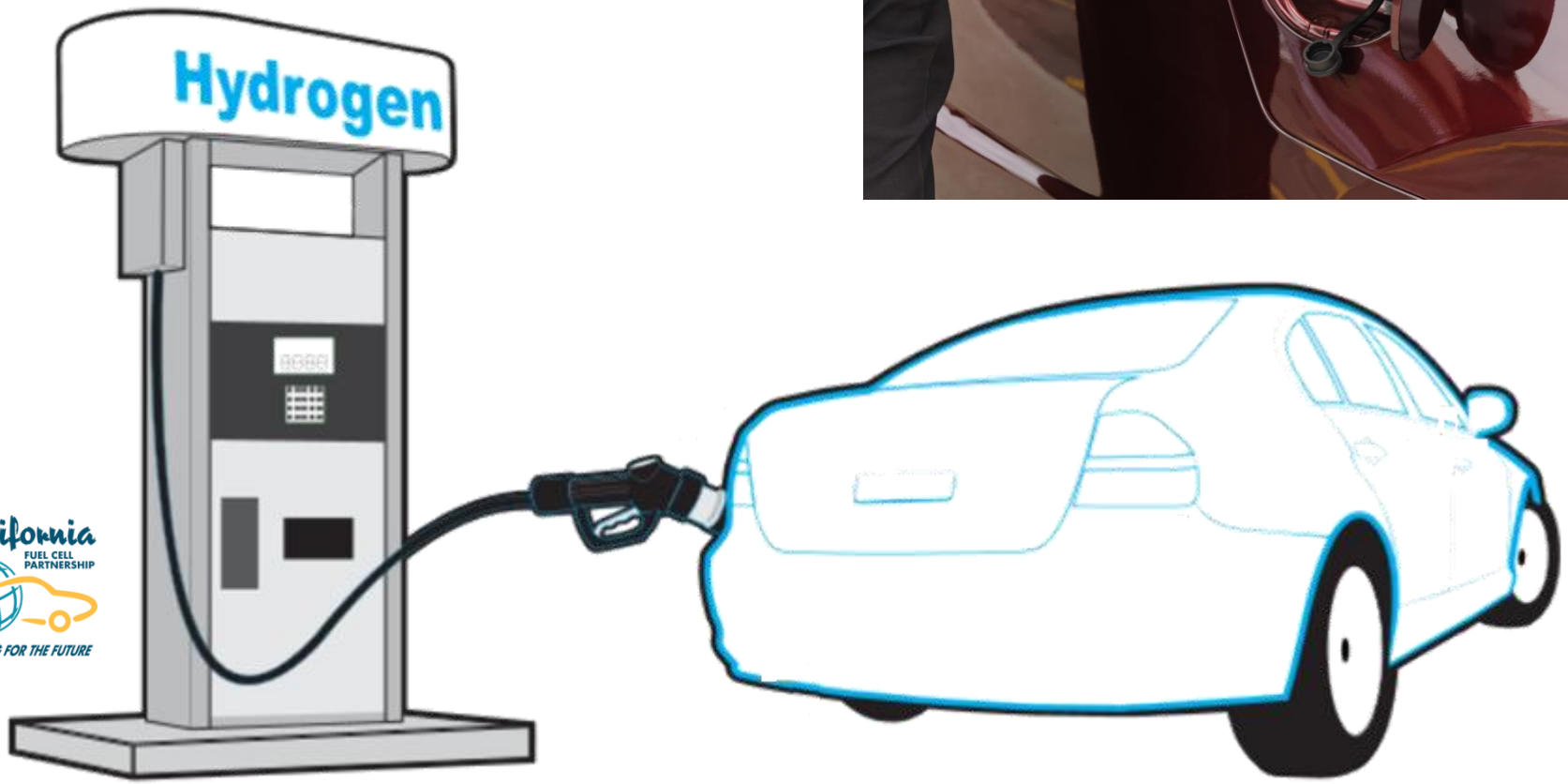
- Takes minutes
- Similar dispenser to gasoline
- Safe and familiar process



Many Energy Sources for Hydrogen

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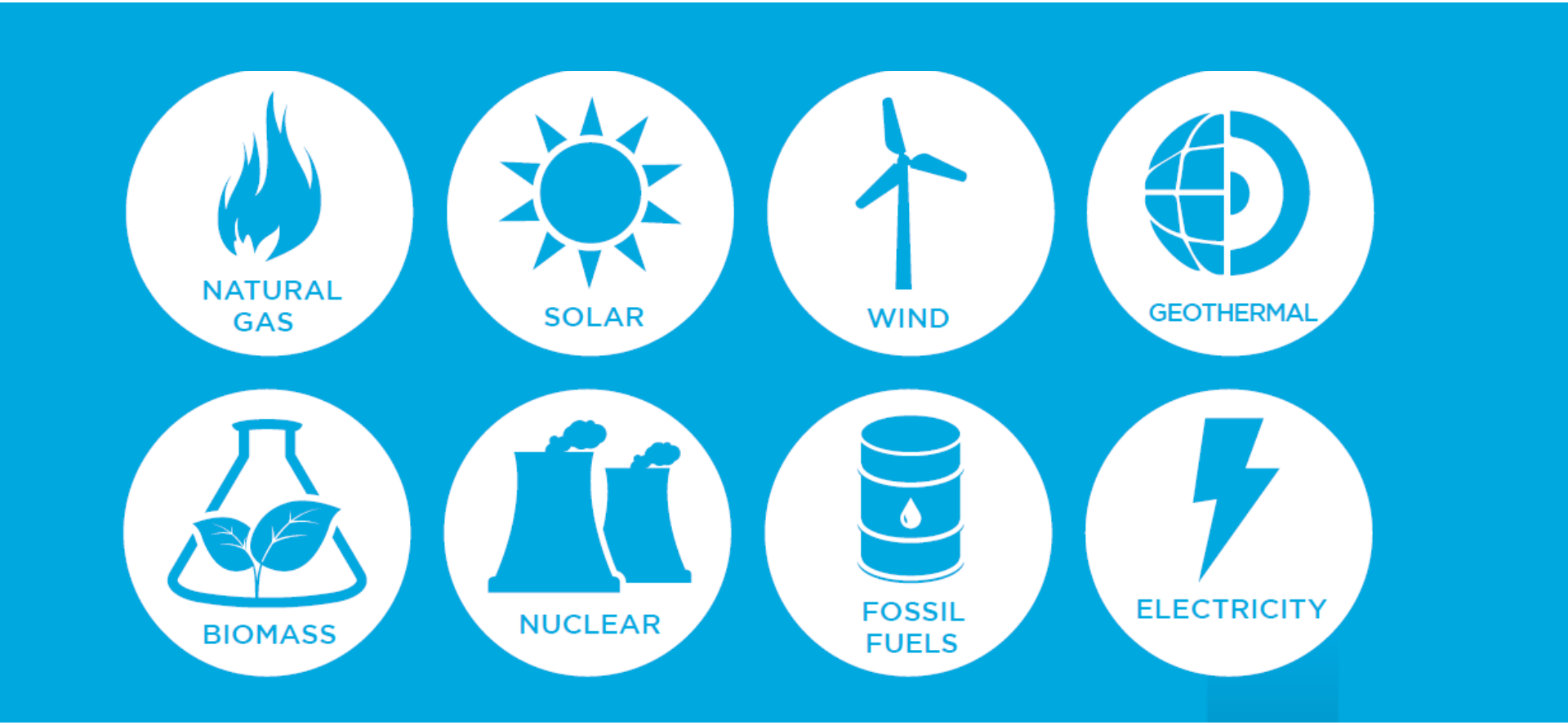
Domestic energy sources can be used to produce hydrogen

Most of today's hydrogen comes from natural gas



Learn more at: http://www.energy.gov/eere/fuelcells/hydrogen-resources

Many Ways to Produce Hydrogen

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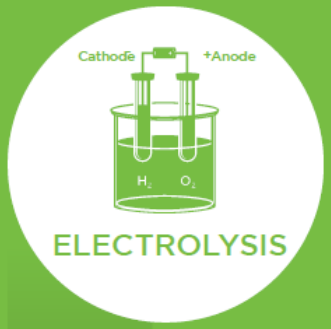
Most of today's hydrogen is produced through Steam Methane Reforming



Electricity separates water into oxygen and hydrogen

Microbes or enzymes break down plants and produce hydrogen

Energy from direct sunlight and sun heat splits molecules

Steam and hydrocarbons come together under high temperature

Learn more at:
http://www.energy.gov/eere/fuelcells/hydrogen-production-processes

Multiple Uses for Hydrogen

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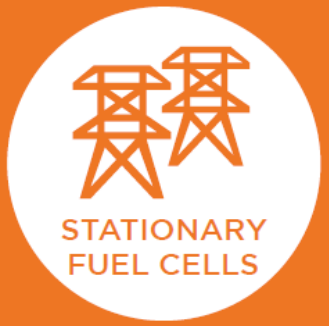
Hydrogen can be used in many sectors throughout the economy

Including other mobile applications like buses, trucks and forklifts

Good for limiting renewable power curtailing and stabilizing grid



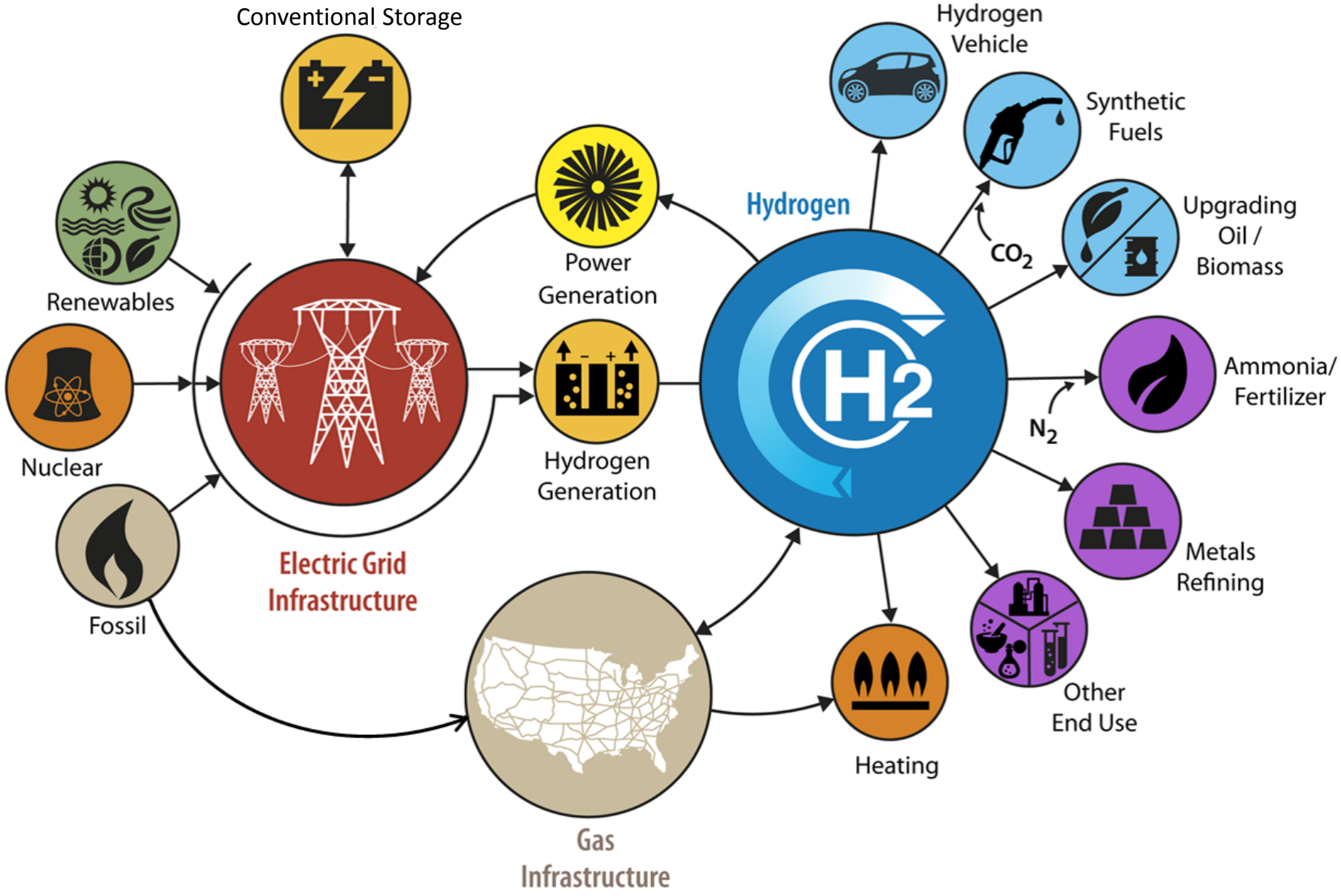
Interest from cell phone towers, data centers, hospitals and supermarkets

Largest use of hydrogen produced today

Second largest use of hydrogen produced today

Learn more at:
https://energy.gov/eere/fuelcells/fuel-cell-technologies-educational-publications

Putting it all together: H_2@Scale Vision



H_2@Scale: Enabling a reliable, affordable, secure and clean energy future

Hydrogen for Education - Resources

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Sign up to receive news and latest developments

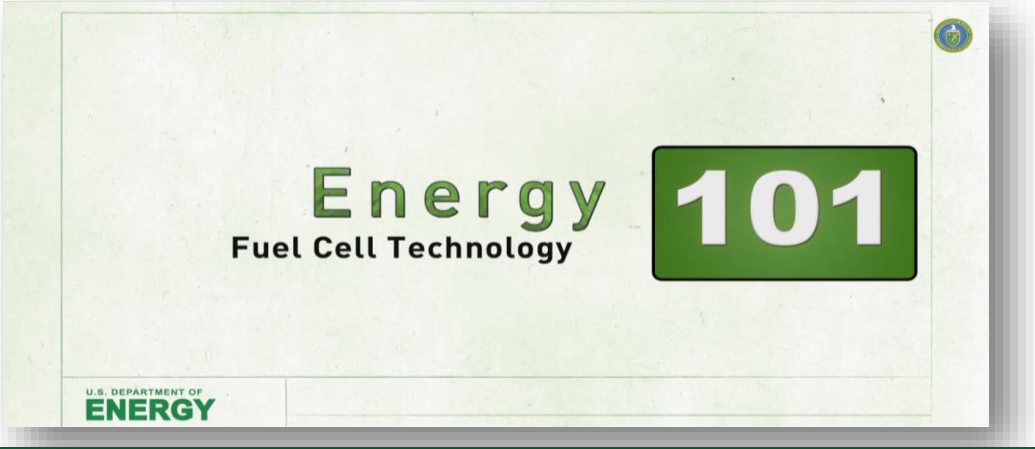
- https://energy.gov/eere/fuelcells/fuel-cell-technologies-office-newsletter

Learn more with DOE's educational resources, videos and more!

- http://www.energy.gov/eere/fuelcells/students-and-educators
- http://energy.gov/eere/videos/energy-101-fuel-cell-technology

Share the knowledge and give an *Increase your H2IQ* presentation!

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



Examples of STEM outreach in the DMV area

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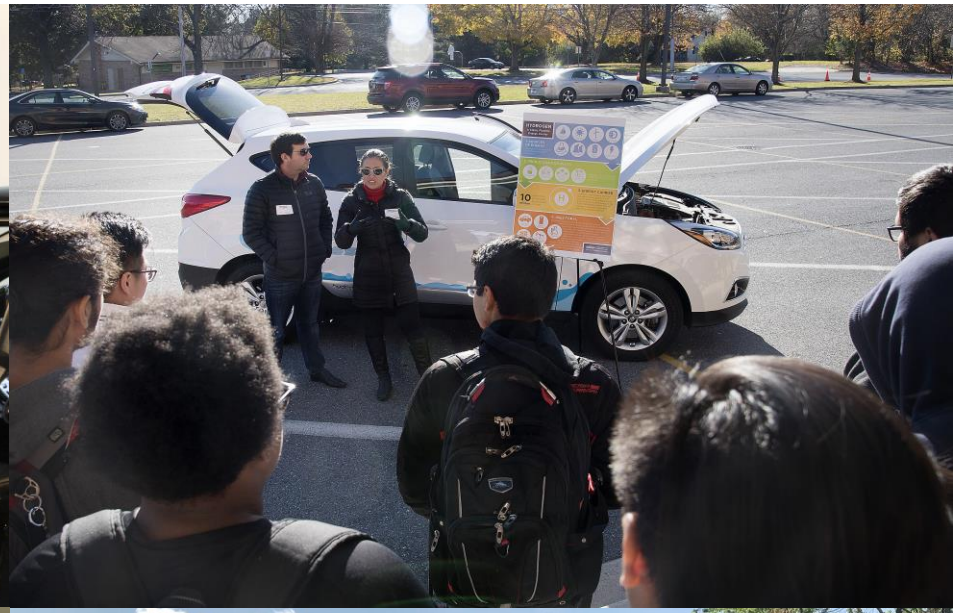

Take part in it!

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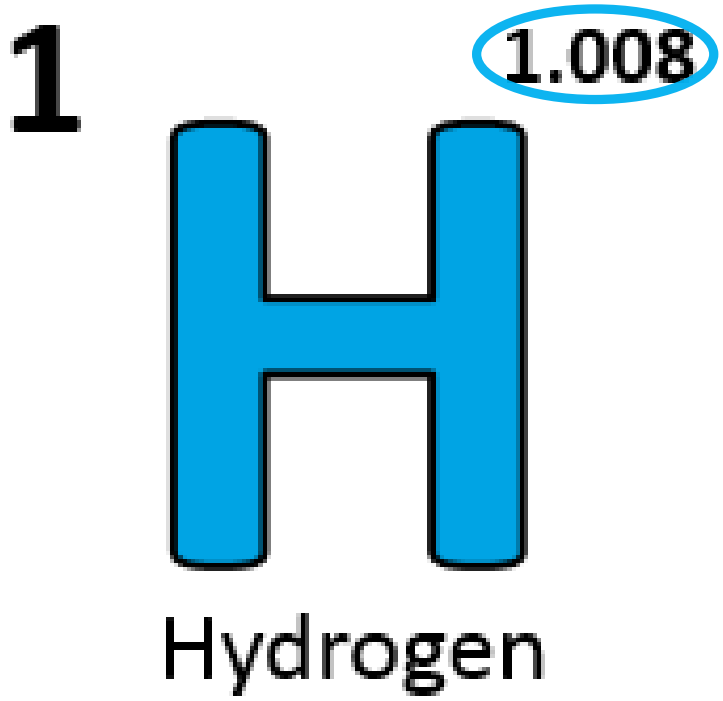

Celebrate Hydrogen & Fuel Cell Day on 10/8 or October 8
(Held on its very own atomic-weight-day)

Learn more: energy.gov/eere/fuelcells

Thank You

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Fuel Cell Technologies Office

energy.gov/eere/fuelcells

Share thoughts

#H2IQ #FuelCellsNow #HydrogenNow

Additional Information

Life-Cycle Petroleum Use- Today's Cars

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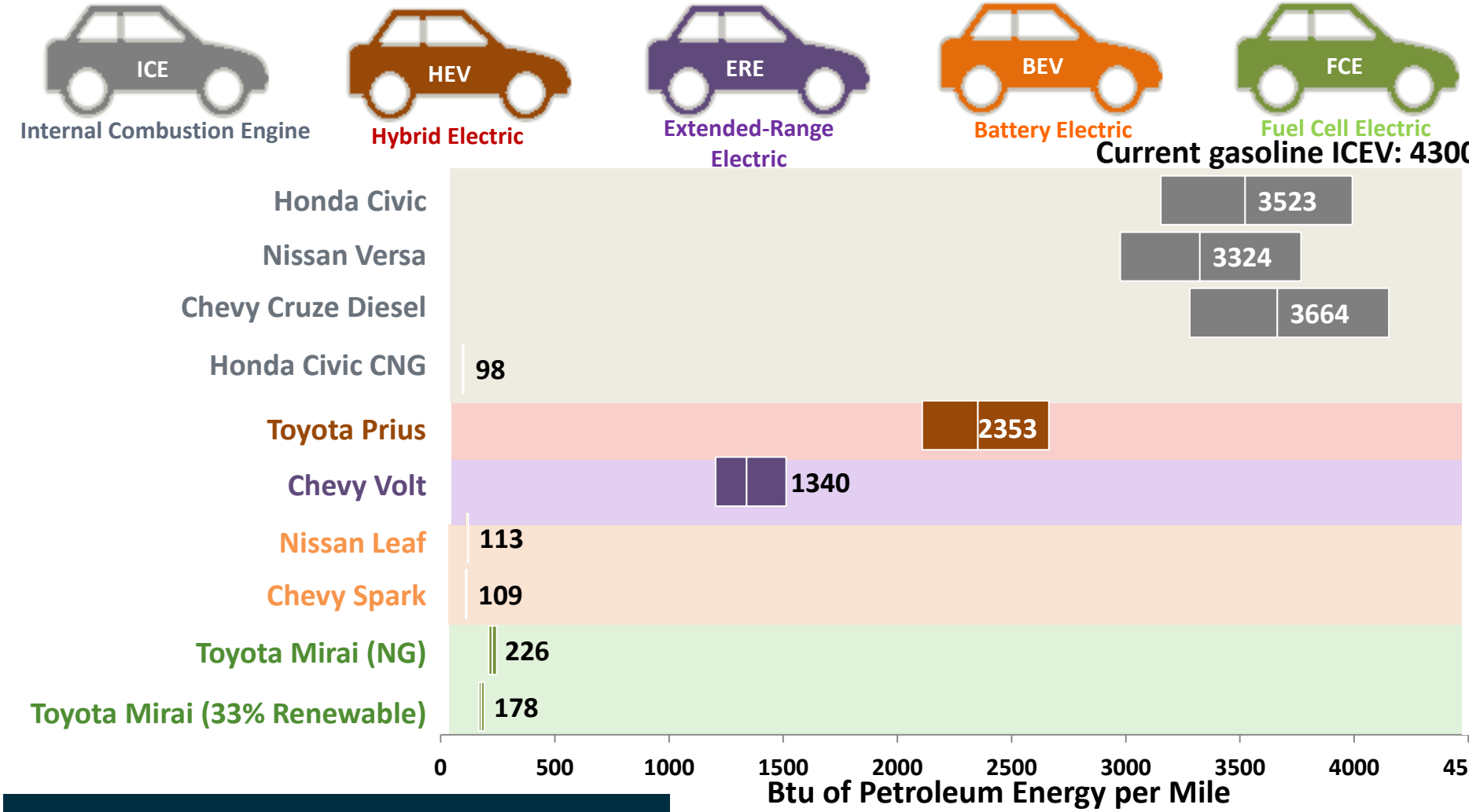
Low, Medium & High Petroleum Energy/Mile for 2015 Technology



Joint VTO-FCTO Analysis Example

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

Life-cycle Emissions- Today's Cars

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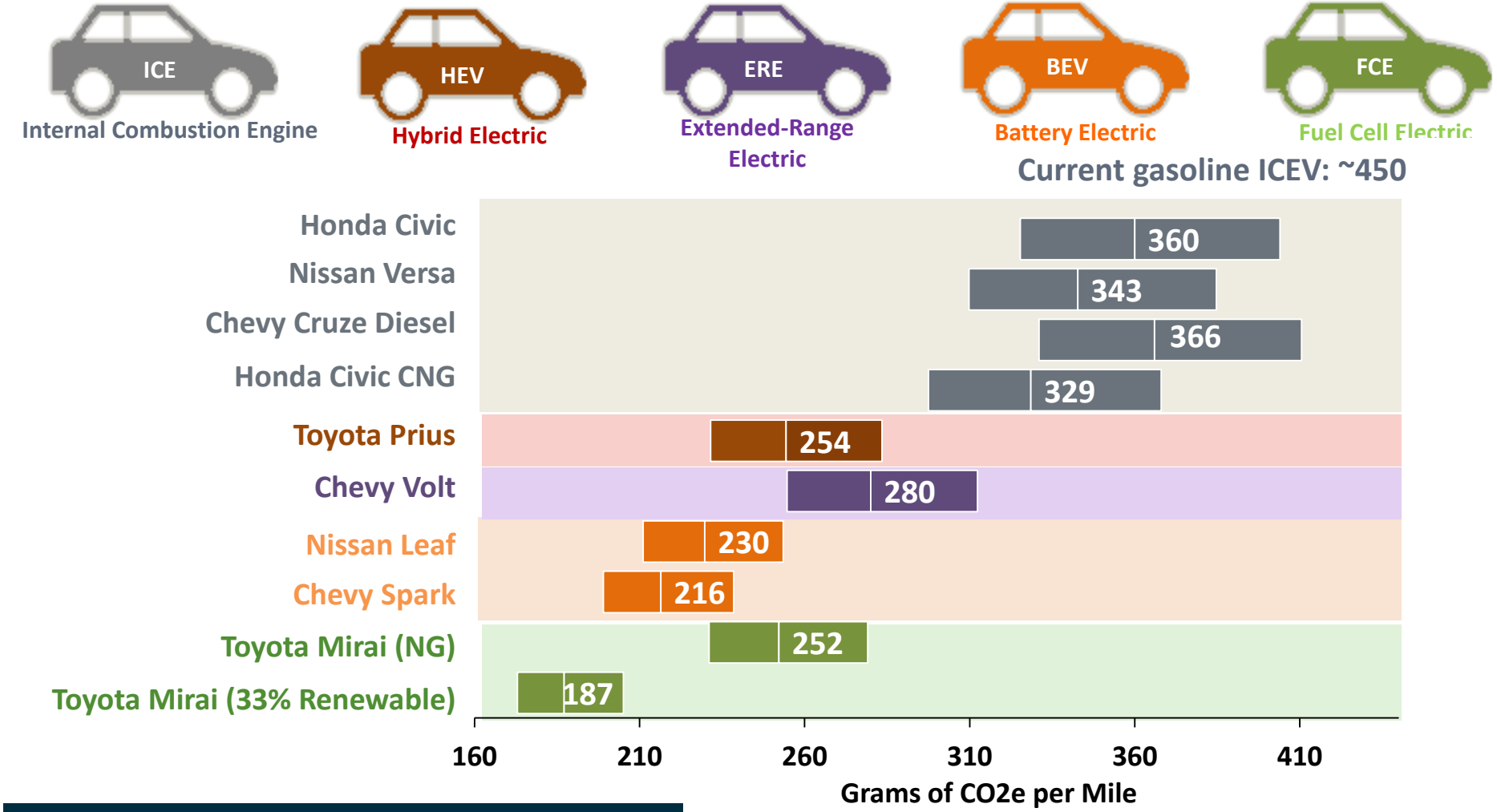
Low, Medium & High Emissions/Mile for 2015 Technology



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