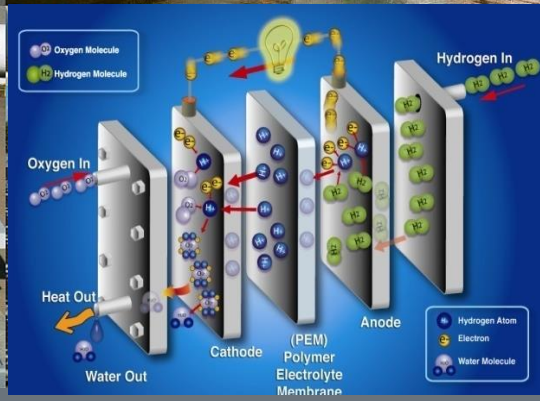
U.S Department of Energy
Fuel Cell Technologies Office (FCTO)

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy





2015 Smithsonian Science Education Academies for Teachers

Fuel Cells for the Future

Washington D.C.

July 17, 2015

Dr. Sarah Studer- *ORISE Fellow*

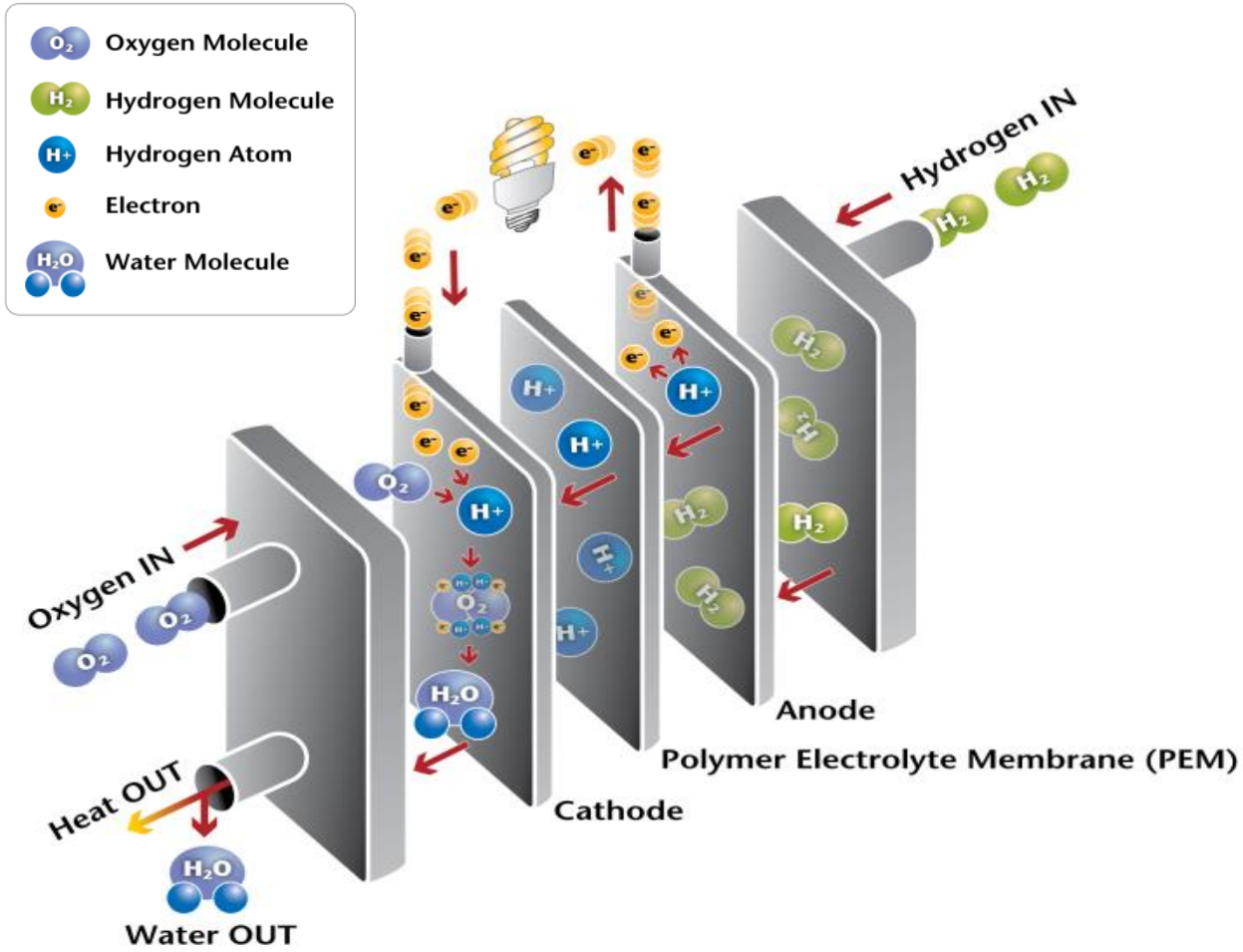
Dr. Elvin Yuzugullu- *Support Contractor (SRA)*

Vanessa Trejos- *Support Contractor (SRA)*

Malquan Gaillard- *FCTO Intern*

Fuel Cells: What and How?

How do they work?



In a nutshell…

Electricity produced **directly**

No combustion involved

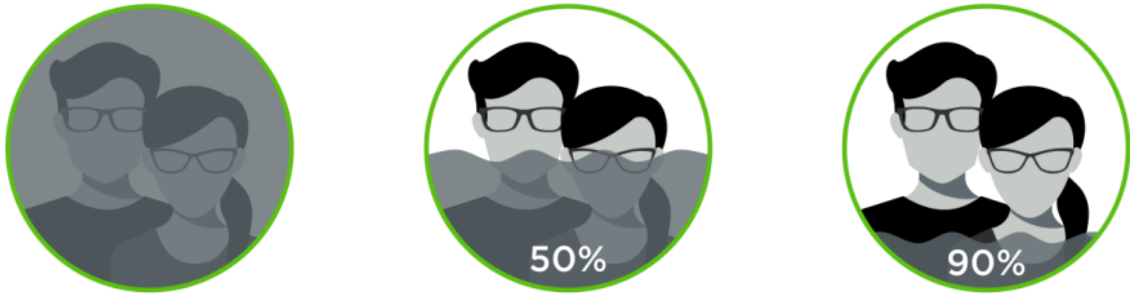
No pollution in tailpipe emissions

Water and Heat only byproducts

Similar to batteries producing electricity without combustion

Fuel Cells: Why?

Reduces Greenhouse Gas Emissions



Gasoline

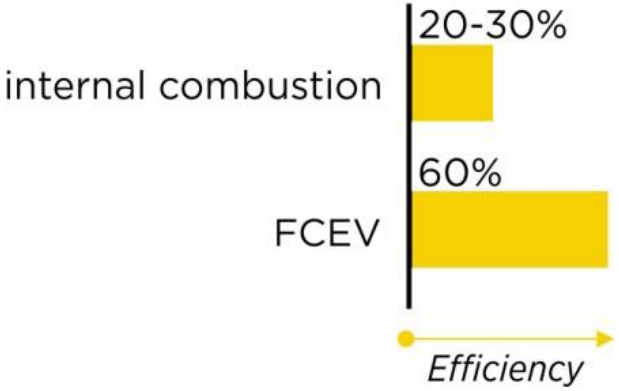
H_2 from natural gas

H_2 from Wind

Emits Only Water

from the tailpipe

Operates Efficiently



Uses Domestic Fuel

- natural gas
- biomass
- water (electrolysis)
- waste products

Scales Up Easily

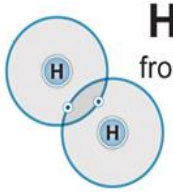
as fuel cells can be added to the stack to increase power

Runs Quietly

Many Fuel Sources and Applications for Fuel Cells

DIVERSE ENERGY SOURCES & FUELS

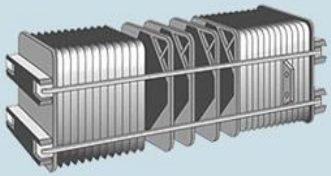
- Biomass
- Natural Gas
- Propane
- Diesel
- Other Hydrocarbons
- Methane
- Methanol



Hydrogen from renewables or low carbon resources

CLEAN, EFFICIENT ENERGY CONVERSION

Fuel Cells



- Alkaline
- Direct Methanol
- Molten Carbonate
- Polymer Electrolyte Membrane (PEM)
- Phosphoric Acid
- Solid Oxide

DIVERSE APPLICATIONS

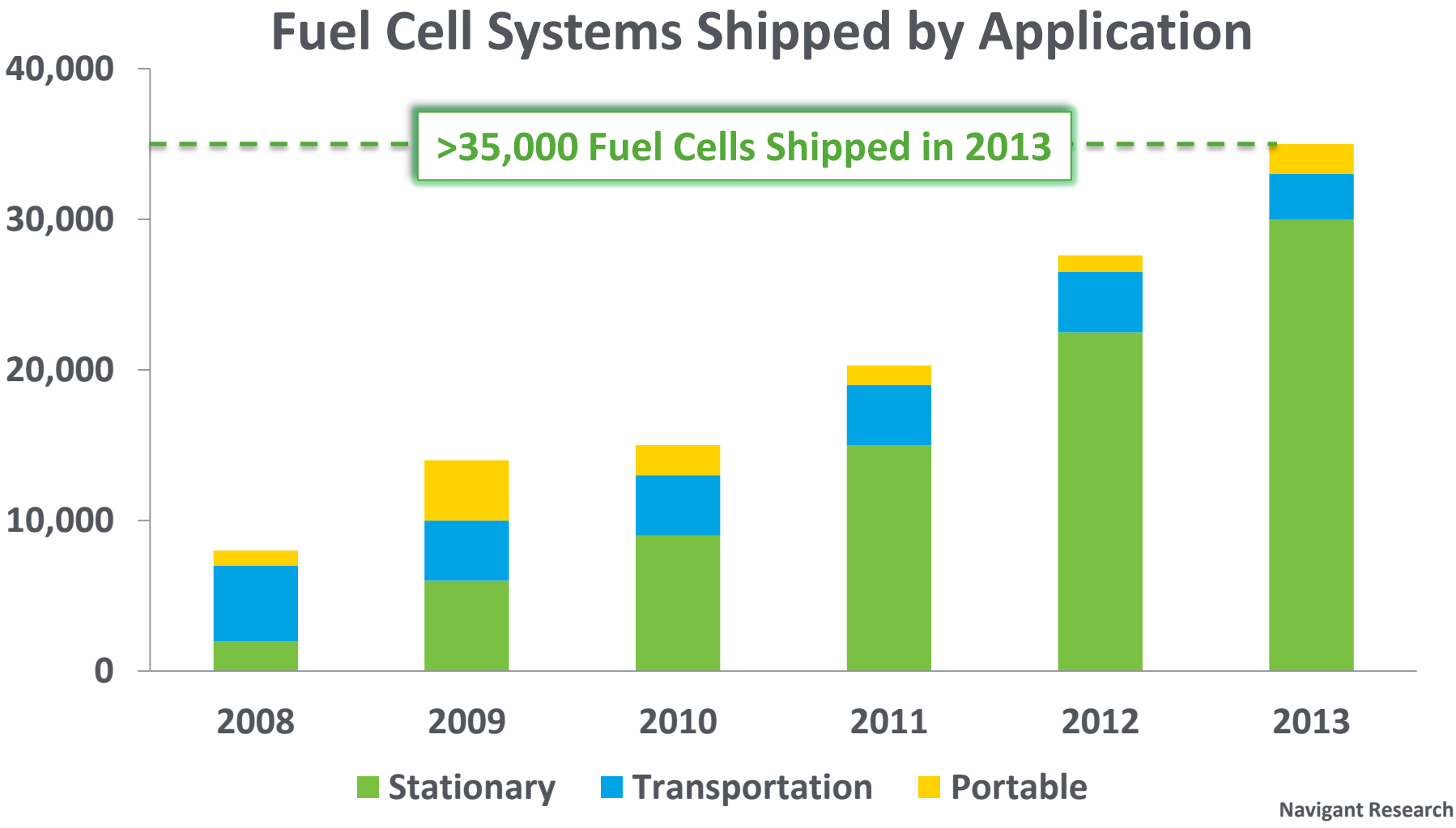
Stationary Power

Transportation

Portable Power

Fuel cells can be supported by different fuels and used in many applications

Fuel Cells … an Expanding Market



Consistent 30% annual growth since 2010

Real-World Applications

FCEV Cost Reduction Enablers

- Space Applications
- Specialty Vehicles
- Backup Power Systems
- Primary Power
- Portable Power
- APUs for Transportation
- Buses and Fleets

Wide-Commercialized FCEV

Market Penetration

World's first fuel cell cargo tractor at airport

Fuel Cells Relied on During Major Power Disruptions

800 Fuel Cells for back up power **deployed**

at cell phone towers providing **electricity**

during **1,000** Power disruptions in **23 states**

AZ CA CO CT FL GA IL IN KY LA MA MI MS NV NJ NY NC OR SC TX UT WA WY

During **Hurricane Sandy**

the largest Atlantic hurricane on record

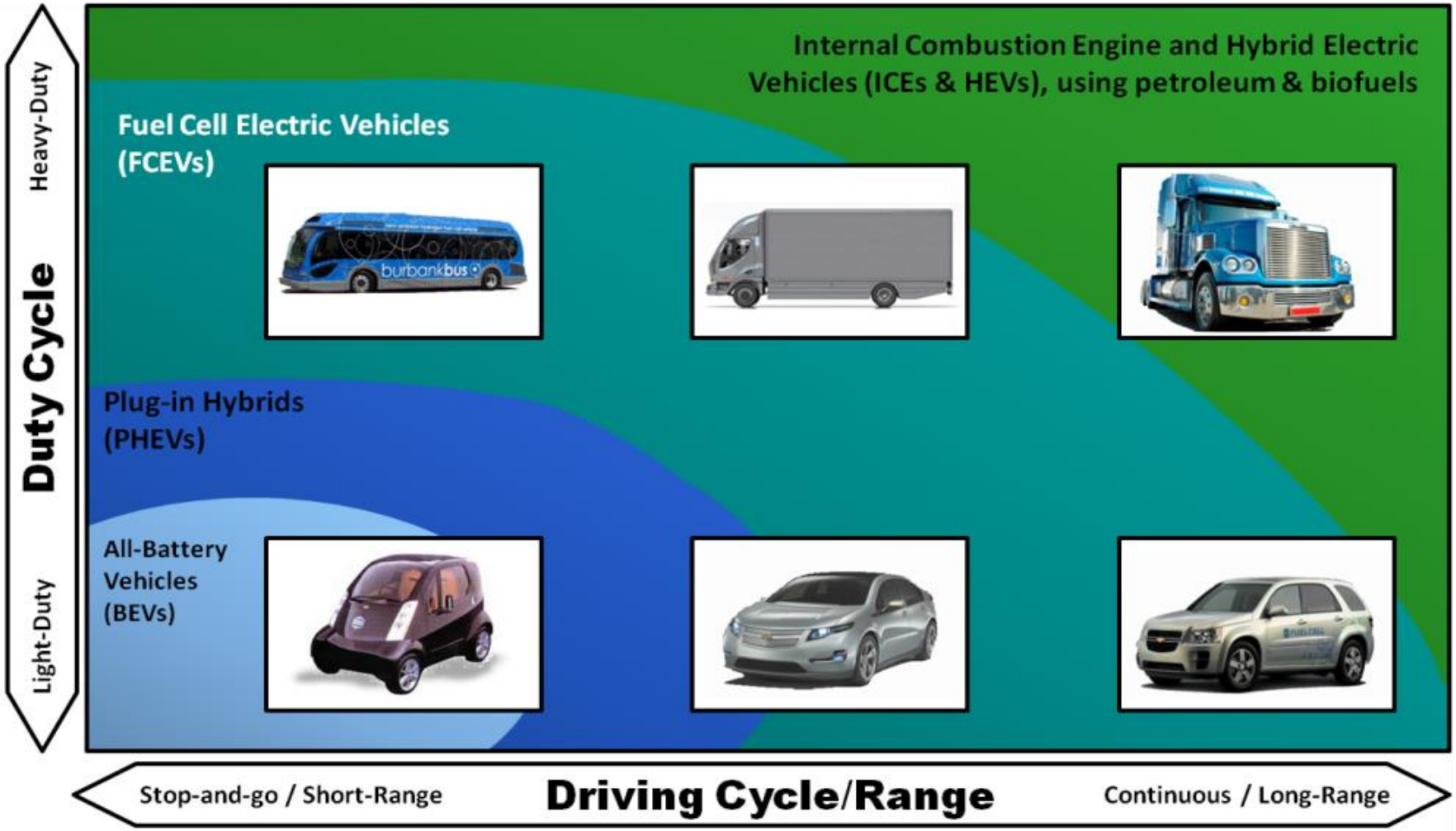
5 sites operated providing power **for over 100 hours**

as validated by NREL

Source: *"Hydrogen Fuel Cell Performance as Telecommunications Backup Power in the United States" NREL/TP-5400-60730*

Demonstrations show 99% successful start-ups for back-up power

A Portfolio of Technologies: Each has Pros and Cons



Fuel Cell Vehicles, Plug-in Vehicles and Battery Vehicles are complementary

Fuel Cells Cars are on U.S. Roads Now!

Now Leasing…

HYUNDAI Tucson Fuel Cell SUV

On Sale in the U.S. *Next Week!*

TOYOTA Mirai Fuel Cell Vehicle

In Auto Shows…

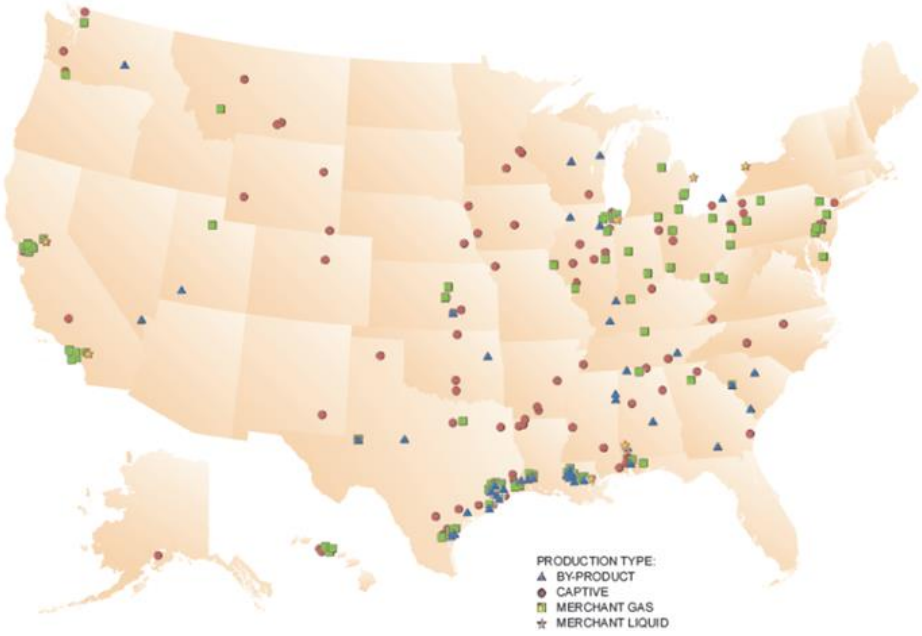
HONDA Fuel Cell Electric Vehicle

OEMs bringing fuel cells vehicles to showrooms and driveways

Where does H_2 Infrastructure stand?

Nationwide

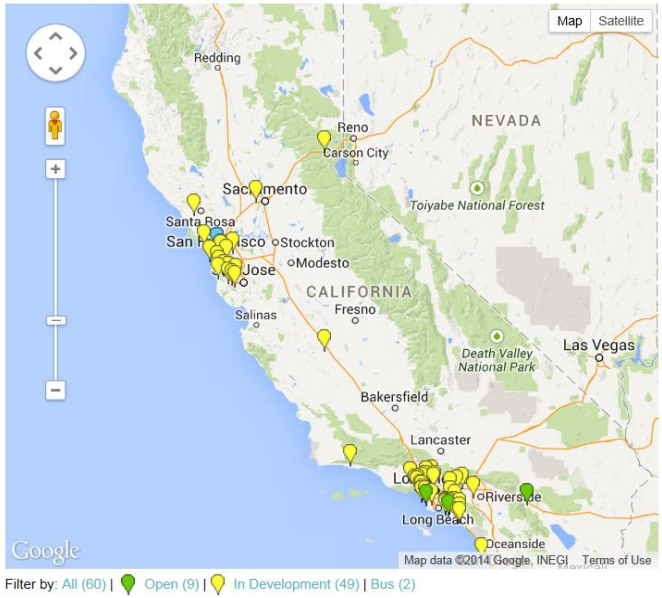
- **1500 mi.** of H2 pipeline
- **>9M** metric tons produced/yr
- **~50 stations** (~10 public)



Centralized H_2 Production Facilities (source: NREL)

States

- **CA- 100 stations, ~$100M** planned through 2023
- **8 State MOU- 3.3M ZEVs** by 2025
- **Northeast states, Hawaii**



H_2 stations in CA (source: CAFCP)

NE states, California and Hawaii have H2 infrastructure efforts underway

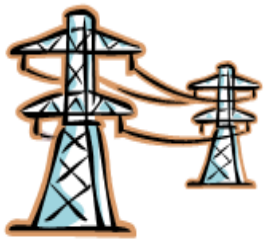
How can we get hydrogen?

Many sources

Fossil Fuels

Solar

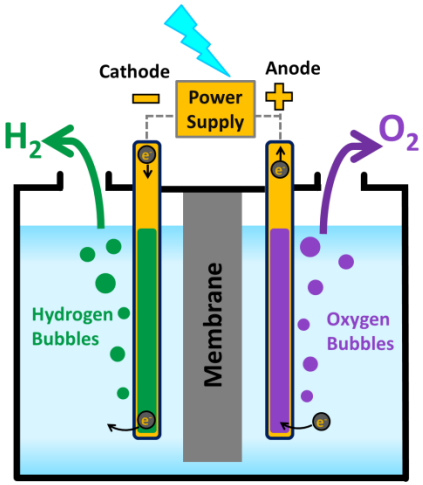
Biomass



Electricity
(Grid or Renewable)

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

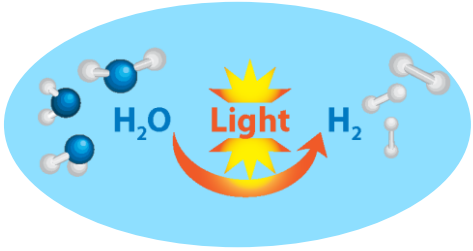
Many pathways



Electrolysis

Thermochemical

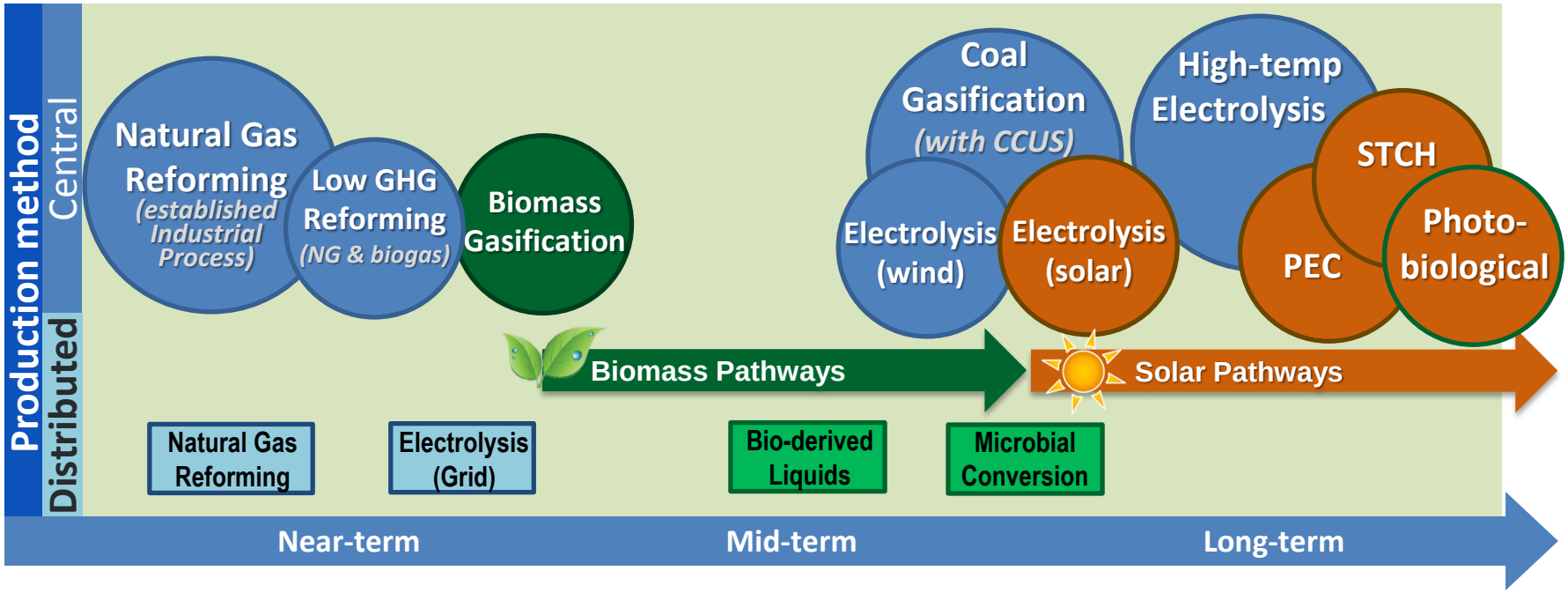
Biological



Direct Solar Water-splitting

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

Pathways for Hydrogen Production



- Distributed systems: production at or near the site of use, up to 1,500 kg/day
- Central systems: production at large facilities at 50,000-500,000 kg/day, and then delivered to the point of use

Natural gas reforming can supply hydrogen today, while scientists and engineers develop and improve large-scale renewable pathways

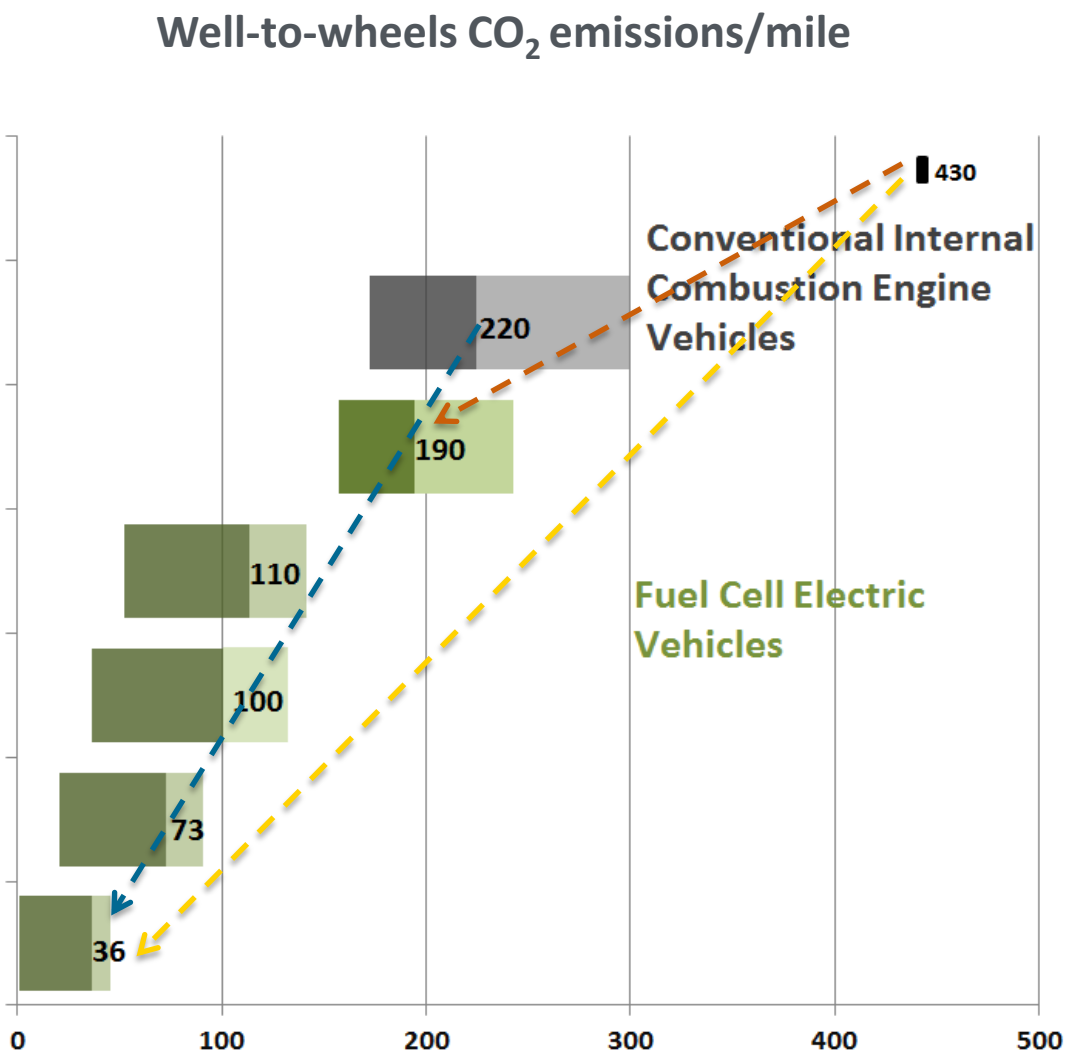
Fuel Cell Vehicles Reduce Greenhouse Gas Emissions

>50% from Distributed Natural Gas*

>80% from Renewables** (Wind)

>90% from Renewables* (Wind)

*Compared to 2012 gasoline vehicle
**Compared to 2035 gasoline vehicle



Source: http://hydrogen.energy.gov/pdfs/13005_well_to_wheels_ghg_oil_ldvs.pdf
Advanced 2035 technologies

Substantial GHG reductions with H2 produced from renewables

Energy Literacy: 7 Essential Principles

1. Energy is a physical quantity that follows precise natural laws.
2. Physical processes on Earth are the result of energy flow through the Earth system.
3. Biological processes depend on energy flow through the Earth system.
4. Various sources of energy can be used to power human activities, and often this energy must be transferred from source to destination.
5. Energy decisions are influenced by economic, political, environmental, and social factors.
6. The amount of energy used by human society depends on many factors.
7. The quality of life of individuals and societies is affected by energy choices.

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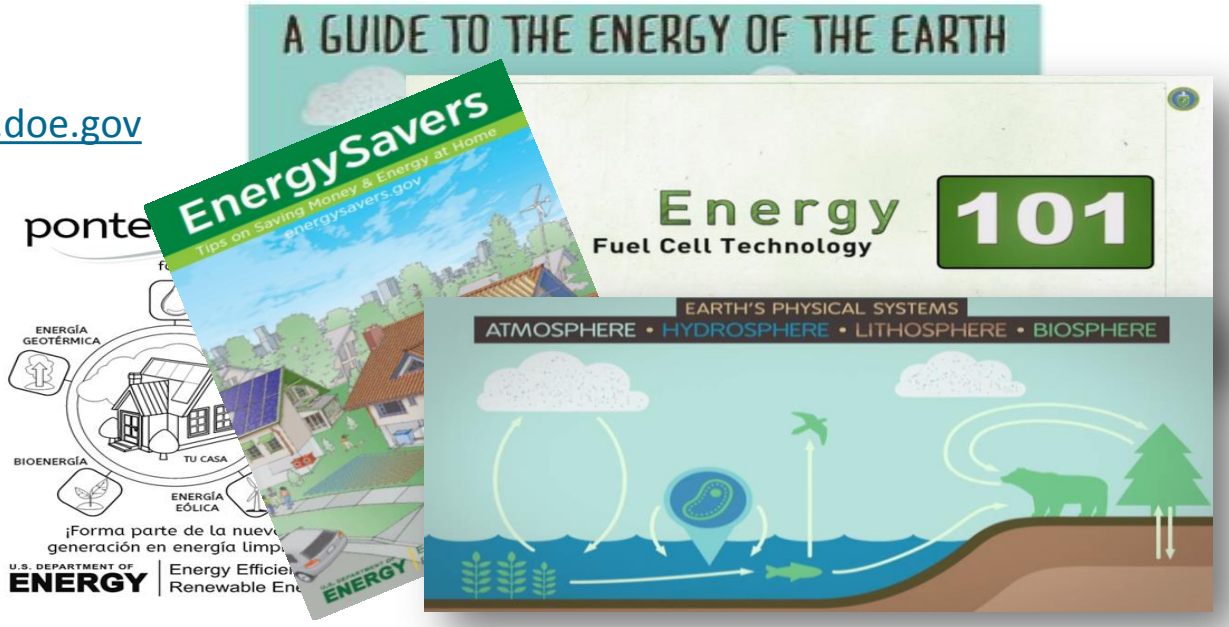
Online Educational Resources

- For information on education resources for Hydrogen and Fuel Cells:
  - http://www.energy.gov/eere/fuelcells/students-and-educators
- Energy 101: Fuel Cell Technology:
  - http://energy.gov/eere/videos/energy-101-fuel-cell-technology
- EERE Education Homepage:
  - http://energy.gov/education
- A Guide to the Energy of the Earth:
  - http://ed.ted.com/lessons/a-guide-to-the-energy-of-the-earth-joshua-m-sneideman
- Energy Literacy:
  - energy.gov/eere/education/energy-literacy-essential-principles-and-fundamental-concepts-energy-education
- Got questions?
  - Email us! energyliteracy@ee.doe.gov



Thank You

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