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
- $\text{H}_2$ from natural gas: 50%
- $\text{H}_2$ from Wind: 90%

Operates Efficiently

- Internal combustion: 20-30%
- FCEV: 60%

Scales Up Easily

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

Emits Only Water

from the tailpipe

Uses Domestic Fuel

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

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

Fuel Cell Systems Shipped by Application

>35,000 Fuel Cells Shipped in 2013

Navigant Research

Stationary  Transportation  Portable
Real-World Applications

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

Market Penetration

- Wide-Commercialized FCEV

World’s first fuel cell cargo tractor at airport
Fuel Cells Relied on During Major Power Disruptions

800 Fuel Cells deployed for back up power

at cell phone towers providing electricity during 1,000 power disruptions in 23 states

During Hurricane Sandy, the largest Atlantic hurricane on record, 5 sites operated providing power for over 100 hours as validated by NREL.


Demonstrations show 99% successful start-ups for back-up power.
A Portfolio of Technologies: Each has Pros and Cons

Fuel Cell Technologies Office

Internal Combustion Engine and Hybrid Electric Vehicles (ICEs & HEVs), using petroleum & biofuels

Fuel Cell Electric Vehicles (FCEVs)

Plug-in Hybrids (PHEVs)

All-Battery Vehicles (BEVs)

Stop-and-go / Short-Range

Driving Cycle/Range

Continuous / Long-Range

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 H₂ Infrastructure stand?

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

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

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)

Many pathways

- Thermochemical
- Electrolysis
- Biological
- Direct Solar Water-splitting

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

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

Substantial GHG reductions with H₂ produced from renewables

Well-to-wheels CO₂ emissions/mile

Source: [http://hydrogen.energy.gov/pdfs/13005_well_to_wheels_ghg_oil_ldvs.pdf](http://hydrogen.energy.gov/pdfs/13005_well_to_wheels_ghg_oil_ldvs.pdf)

*Compared to 2012 gasoline vehicle

**Compared to 2035 gasoline vehicle

Advanced 2035 technologies
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](http://www.energy.gov/eere/fuelcells/students-and-educators)

- Energy 101: Fuel Cell Technology:

- EERE Education Homepage:
  - [http://energy.gov/education](http://energy.gov/education)

- A Guide to the Energy of the Earth:

- Energy Literacy:

- Got questions?
  - Email us! [energyliteracy@ee.doe.gov](mailto:energyliteracy@ee.doe.gov)
Thank You

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