FUEL CELLS IN TRANSPORTATION
TEACHER'S GUIDE

Time

1-4 class periods

This lesson is a modular design that you can tailor to suit your class and your time. You can complete the entire lesson in one class period, or use it over several classes. You can also use this lesson in conjunction with the hydrogen lesson, *Hydrogen as Fuel*.

This lesson includes a section about air quality.

Objectives

- Recognize the components of a fuel cell
- Understand how a fuel cell works
- Learn how thermodynamics apply to fuel cells
- Learn how transportation affects air quality

Content Standards

- Atomic and Molecular Structure
- Chemical Bonds
- Heat and Thermodynamics
- Electric and Magnetic Phenomena
- Air Pollution

Background

Fuel cells create electricity from hydrogen and oxygen. The only byproducts from the reaction are water and heat. Vehicles powered by hydrogen fuel cells are all-electric, zero emission cars, SUVs and buses.

In California, more than 300 passenger vehicles and transit buses have been placed in operation, Most are driven by regular people in everyday situations. The vehicles fuel at hydrogen stations in Los Angeles, Orange County, Sacramento and San Francisco Bay Area.

As with any change to the transportation system, fuel cell vehicles have challenges. This lesson is designed to introduce how fuel cells create electricity to power vehicles and one of the challenges—the degredation of the catalyst in the fuel cell.

Materials Needed

Fuel cell experiment
- Solar panels or 9-volt batteries
- Platinum or platinum-coated wire
- A 9-volt battery clip with leads
- Salt or baking powder
- A volt meter
- Tape
- Popscile stick or something similar
- Platinum or platinum-coated wire

Catalyst experiment
- Hydrogen peroxide (3%, 6% or 30%)
- Dry yeast (if using 3% or 6%)
- Potassium iodide (if using 30%)
- Large graduated cylinder or 2-liter soda bottle
- Liquid soap

Additional Student Activities/Assignments

Heliocentris makes a fuel cell model car kit that includes a teacher's manual with extensive classroom activities. The Fuel Cell Store (www.fuelcellstore.com) carries many different fuel cell model kits, as do science equipment stores.

Students can research and report about fuel cells in other applications, such as stationary power and portable power.

Resources

U.S. Department of Energy
www.energy.gov/energysources
Fuel Cells 2000
www.fuelcells.org
California Air Resources Board
www.arb.ca.gov
California Fuel Cell Partnership
www.cafcp.org
Video: *Hydrogen Nature's Fuel*
http://www.youtube.com/watch?v=76ujMtLr5Z8

Instructor Notes and Background

A Little History First

Apollo 13, launched in 1970, had an explosion in space severly damaging the oxygen tanks. If you have seen the movie, you might remember Tom Hanks giving Mission Control a status of the fuel cell power. The oxygen onboard Apollo spacecraft life, the fuel cells needed oxygen and hydrogen. With little oxygen, the fuel cells had 15 amps of power. You may remember Gary Sinese's character trying to figure out how to turn the equipment back on and stay under 15 amps.

How a Fuel Cell Works

One fuel cell makes a small amount of electricity. In vehicles, the fuel cells are placed in a stack, like slices of bread in a loaf. One fuel cell stack will have hundreds of fuel cells and make 70-90 kw of electricity.

Label a Fuel Cell

The *anode* is is the negative post of the fuel cell. The anode conducts the electron (*negative* ion) freed from the hydrogen to the *circuit***.**

The *cathode* is the positive post of the fuel cell. The cathode draws the protons (*positive* ion) through the membrane.

Channels etched into the cathode help disburse oxygen molecules to the surface of the catalyst.

The *catalyst* facilitates the reaction of oxygen and hydrogen.

The *membrane* is a specially treated material that looks something like kitchen plastic wrap. It is the *electrolyte* and must be hydrated to work.

Hydrogen electrons and protons, and oxygen combine to form *water*.

Catalyst Demonstration

Often called "elephant toothpaste," this demonstration shows how a catalyst works to make hydrogen and oxygen react. It can be messy, but it's just soap. If you omit the soap, the version of the experiment with 30% H_2O_2 will release a cloud of steam, which is useful in explaining thermodynamics.

Experiment: Build a Platinum Fuel Cell

If your school has fuel cells kits for the classroom, you can use one of the exercises that came with the fuel cell. This experiement is intended for classrooms that do not have access to fuel cells.

Please note that electrolyzing the water to make hydrogen for the fuel cell can be confusing. Some students will believe that the water is the fuel, not the hydrogen. They may also believe that fuel cells used in vehicles, and for stationary and portable power store water for onboard electrolysis. While technically possible, vehicles would have to store more water than is reasonable. Instead, electrolysis happens at a hydrogen station and the vehicles fill with compressed, gaseous hydrogen.

Questions

6. Would using copper or nickel wires for the electrodes create an electric current? *Other metals will oxidize during the reaction.*

7. Why use the fuel cell instead of the battery to create the current? *The battery stores electricty. The fuel cell creates electricity.*

Optional activities for the experiment:

1. Use a solar panel instead of a 9-volt battery.
2. Leave the battery connected. Measure the time that it takes for the battery to decrease in voltage and create a degradation curve.
3. Leave the battery connected. Measure the amount of water at the beginning of the experiment. When the battery is depleted, measure the amount of water left. Chart the amount of water used in the reaction.

Thermodynamics

This short explanation of thermodynamics is very specific in relating to a vehicle's combustion engine and a fuel cell. The point is to explain that because fuel cells do not have moving parts and do not require a high operating temperature, they are more efficient than engines.

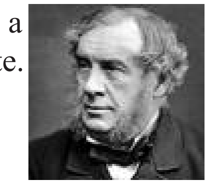
Electric Car Quick Question

A: ~6.5g of criteria pollutants

B: ~ 2.1g of criteria pollutants

Fuel Cells for Transportation

A Little History First

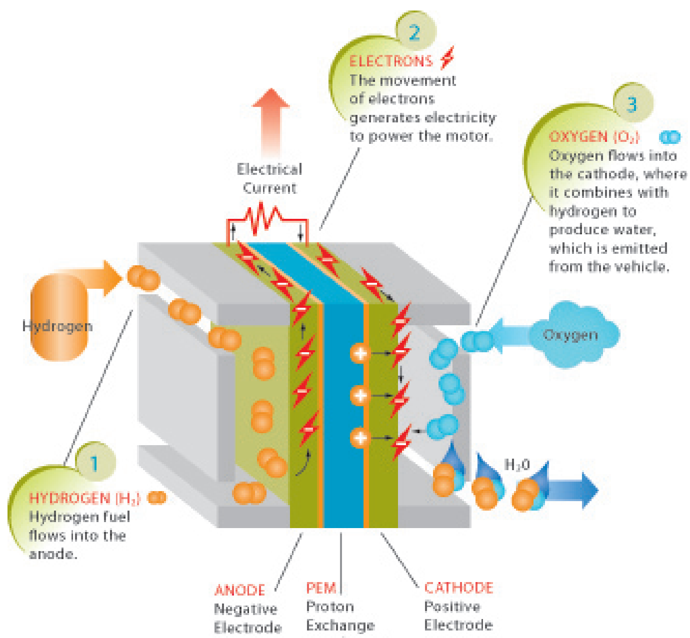


Although fuel cells sound like a modern innovation, they are actually quite old. Sir William Robert Grove created the first fuel cell in Wales in 1843. He called it the "Grove Gas Battery." For nearly a century, the fuel cell was a laboratory curiosity, although it did cause a great scientific debate. Some thought the fuel cell generated electricity because of the physical contact between materials. Others, like Swiss scientist Christian Schonbein, maintained that a chemical reaction generated electricity. Schonbein was right.

In 1959, British engineer Francis Bacon developed a fuel cell that output a decent amount of power, 5 kilowatts, which is enough to power an average home. By this time, researchers were developing several different types of fuel cells. General Electric had big breakthrough in the 1960s with a proton exchange membrane (PEM) fuel cell. NASA became the first to put fuel cells in use with the Gemini and Apollo series spacecrafts and Skylab. (The Space Shuttle.continues to use fuel cells.)

In the 1960s, auto companies began working with fuel cells in vehicles. During the oil crisis in the 1970s, automakers began seriously looking at alternative fuels and powertrains. Over the decades, fuel cells have become smaller, more powerful and longer lasting. Most of the major automakers have fuel cells in vehicles ranging from compact cars to city buses. Automakers plan to bring fuel cell vehicles (FCVs) to the consumer market in about 2015. They see FCVs as a technology that can meet consumer demand for full-function cars, SUVs and pick-up trucks that create zero pollution, reduce greenhouse gas emissions and do not depend on fossil fuels.

What is a Fuel Cell?



A fuel cell converts chemical energy into electrical energy. A fuel cell has two *electrodes*, a negative anode and a positive cathode. The electrodes are submerged in a *electrolyte*—a solution that conducts electricity well. Electricity, no matter how it's made, is a flow of *electrons*. The electrolyte facilitates the stream of electrons as they move from anode to cathode through a circuit. Fuel cells are named by the type of electrolyte they use. The illustration is a *proton* exchange membrane fuel cell, which is the type of fuel cell in cars, SUVs and buses.

Glossary

Electrode — electrical conductor that leads current into or out of an electrolyte

Electron — negatively charged particle in an atom

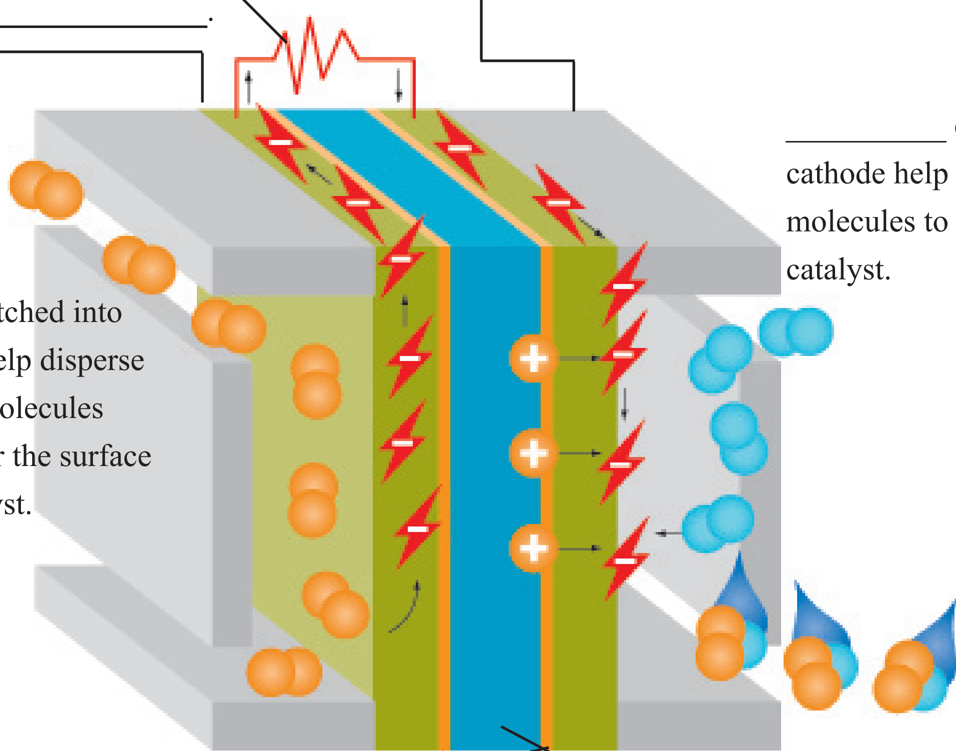
Electrolyte — soultion or substance that conducts current

Proton — positively charged particle in an atom

Label the Parts of a Fuel Cell

The ________ is the negative post of the fuel cell. The anode conducts the electron (________ ion) freed from the hydrogen to the _____________.

The _________ is the positive post of the fuel cell. The cathode draws the protons (__________ ion) through the membrane.



__________ etched into the cathode help disburse oxygen molecules to the surface of the catalyst.

Channels etched into the anode help disperse hydrogen molecules equally over the surface of the catalyst.

Hydrogen electrons and protons, and oxygen combine to form _______.

The __________ facilitates the reaction of oxygen and hydrogen. The catalyst is a very thin layer of platinum on carbon paper or cloth. The platinum-coated side of the catalyst faces the membrane.

The ____________ is a specially treated material that looks something like kitchen plastic wrap. It is the _____________ and must be hydrated to work. The membrane allows only protons to pass through.

Glossary

Anode — the negatively charged terminal

Catalyst — a substance that modifies and increases the rate of a reaction without being consumed in the process

Cathode — the positively charged terminal

Ion — an atom that has acquired a net electric charge by gaining or losing one or more electrons

Membrane — a thin pliable sheet of material, in a PEM fuel cell the membrane is the electrolyte.

Understanding the Catalyst

The catalyst is crucial to the fuel cell. Without it, hydrogen and oxygen would simply bond together without first becoming ions. In a proton exchange membrane fuel cell, the catalyst is *nanoparticles of* platinum mixed with other metals and sprayed or dotted onto carbon paper or cloth, rather like silk screening on a shirt.

Pressure forces gaseous hydrogen into the anode side of the fuel cell through a gas diffusion layer (GDL) to the catalyst. When an H_2 molecule comes in contact with the catalyst, it splits into two $H+$ ions and two electrons (e-). At the cathode, oxygen is being forced through a different GDL to the catalyst. The O_2 molecule seperates into two oxygen atoms, each with a strong negative charge. The negative charge attracts the two $H+$ ions through the membrane, where they combine with an oxygen atom and two of the electrons from the external circuit to form a water molecule (H_2O).

A fuel cell's chemical equation

Anode side: $2H_2 \Rightarrow 4H^+ + 4e^-$

Cathode side: $O_2 + 4H^+ + 4e^- \Rightarrow 2H_2O$

Net reaction: $2H_2 + O_2 \Rightarrow 2H_2O$

6 78
Pt
Platinum
195.08

The element platinum is an excellent catalyst. Platinum is a heavy, corrosion-resistant gray-white metal that can withstand extremely high temperatures. Catalytical converters in today's cars use platinum to create a similar reaction between oxygen and nitrogen, and oxygen and carbon to make tailpipe emissions less harmful. Although recycled platinum is often used for catalysts, it's still expense. Using as little as possible to helps reduce vehicle costs.

Catalyst loading—the process of applying the platinum molecules to the carbon paper—directly effects cost and durability. Think of a silk-screened T-shirt. When you buy it, the design appears to be applied evenly. As you wash and dry the shirt, over time some of the silk-screening fades. Thicker layers of ink fade less rapidly than thinner layers. Now think of silk screening with molecules of platinum instead of layers of ink. Researchers look for ways to apply the molecules to the carbon cloth in a single *homogenous* layer, which reduces manufacturing costs and increases efficiency.

A Catalyst Demonstration

What you need (in the lab)

- 30% hydrogen peroxide
- Potassium iodide (solution or solid)
- Liquid soap
- Graduated cylinder or 2-liter soda bottle
- Goggles, gloves, surface protector

1. Place container on a protected countertop.
2. Pour in ~50 mL of 30% hydrogen peroxide.
3. Add a squirt of liquid soap
4. Add ~10 mL of potassium iodide solution OR 1/4 spoon of solid potassium iodide. **Step back quickly after adding the potassium iodide!**

What you need (at home)

- 3% or 6% hydrogen peroxide
- Dry yeast
- Liquid soap
- 2-liter soda bottle
- Goggles, gloves, surface protector

1. Place soda bottle on a protected countertop.
2. Pour in 1 cup of hydrogen peroxide.
3. Add a squirt of liquid soap
4. Add one package of dry yeast. **Step back quickly after adding the yeast!**

Hydrogen peroxide (H_2O_2) is always decomposing to release oxygen and water, but it does so slowly. The potassium iodide (or yeast) is a catalyst causes the H_2O_2 to rapidly decompose. The sudden release of oxygen makes the soap foam up and releases heat. What remains in the bottom of the bottle? Does this reaction change the catalyst? What do you think you'd see if we didn't use soap?

Glossary

Homogenous — having the same consistency; uniform

Nanoparticles — microscopic particle less than about 100 nanometers (nm) in diameter

Experiment: Build a Platinum Fuel Cell

In this experiment, you will build a fuel cell using salted water as an electrolyte instead of a proten exchange membrane. You will also make the hydrogen from the same water. Vehicles carry the hydrogen in tanks and fuel at hydrogen stations, just as most vehicles carry and refill with gasoline. This experiment will show you how hydogen and oxygen make electricity, and explain how the catalyst works.

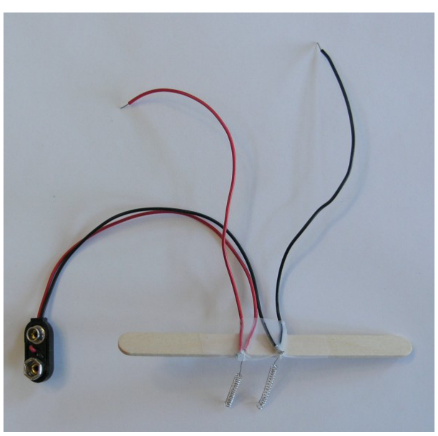
What you need

- One foot of platinum-coated or pure platinum wire
- A popsicle stick or similar
- A 9-volt battery clip
- A 9-volt battery
- Some transparent sticky tape
- A glass of water
- Salt
- A volt meter

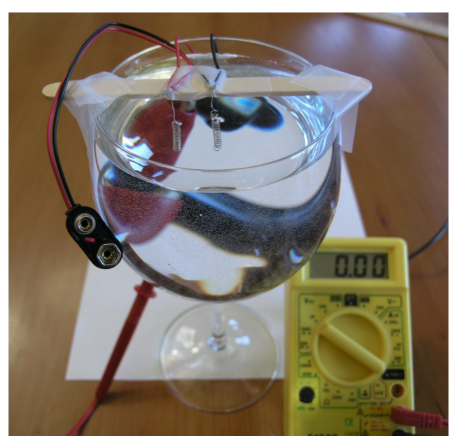
Experiment Steps

1. Cut the wire into two six-inch long pieces. Wind each piece around a pencil to make a coil spring. These are the electrodes.
2. Cut the leads of the battery clip in half and strip the insulation off of the cut ends. Twist the bare ends of both red battery lead wires onto the end of one electrode. Twist the bare ends of both black lead wires onto the end of the other electrode. (See picture 1.)
3. Tape the battery wires to the popsicle stick and place over the glass of water. The electrodes should be submerged in the water, but not the bare wires from the battery leads. (See picture 2.)
4. Connect the other bare end of the red wire to the positive terminal of the volt meter and the black wire to the negative terminal of the volt meter. The volt meter will read 0 volts or 0.01 volts.
5. Touch the 9-volt battery to the clip. This will cause electricity to flow through the anode and into the water. The water will separate into hydrogen and oxygen in a process called electrolysis. Hydrogen bubbles will cling to the anode and oxygen bubbles will cling to the cathode.
   - If electrolysis does not start in a minute or two, add salt or baking powder to the water. Low mineral content in the water or low voltage in the battery may require a catalyst to speed the electrolysis.
6. Remove the battery. Record the voltage on the volt meter and the time it takes for the voltage to decrease.

Picture 1



Picture 2



Observations and Questions

1. How long did it take for the electrolysis to start?

2. When you removed the battery, what was the initial volt meter reading?

3. Why did the voltage decrease over time?

4. If the fuel supply was steady, coming from a tank of stored fuel, would the voltage decrease?

5. What happened to the hydrogen and oxygen molecules at the end of the reaction?

6. Would using copper or nickel wires for the electrodes create an electric current? Why?

Challenge question

7. Why use the fuel cell instead of the battery to create electricity for a vehicle?

A Short Lesson on Thermodynamics

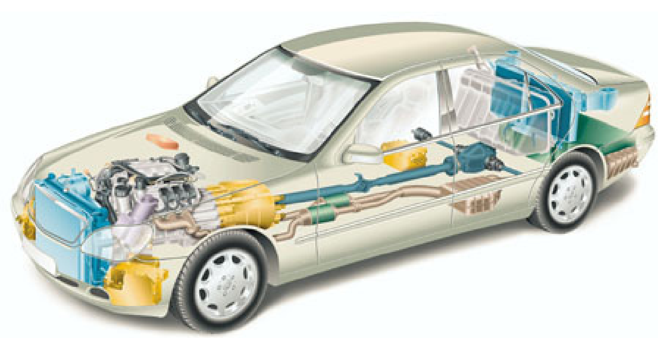
Thermodynamics is physics that deals with the relationships and conversions between heat and other forms of energy. It has four basic laws that are largely based on observation, not on experiments. The first two laws relate to differences between a combustion engine and a fuel cell.

The **first law** states that energy cannot be created or destroyed. It's transferred as either heat or work.

The **second law** states energy will always disperse. Differences in temperature, pressure, and density tend to even out in a physical system that is isolated from the outside world.

Think of a car driving on the highway. The energy is in the fuel and must be transferred to the car. A perfectly efficient vehicle would be able to turn every bit of fuel into work that moves the car down the road. Nothing, though, is 100% efficient. That's what the second law tells us. In passing energy from one system to another, some of that energy is lost.

Modern gasoline engines are 25-30% efficient. The energy is released by burning the gasoline, and about 70-75% of the energy becomes heat in the exhaust or absorbed by the motor. The "work" energy turns engine equipment and appliances, such as water and oil pumps and the generator. Each moving part in the engine has some loss of energy. Factoring in other energy losses (the friction of tires on pavement, for example), cars powered by combustion of gasoline are about 18-22% efficient.



First Law

Energy cannot be created or destroyed. It's transferred as either heat or work.

Try it

Rub your hands together very fast. They quickly become warm. *Friction* is the waste heat of kinetic energy. In a vehicle engine, parts that rub together create friction, and therefore waste heat. Fuel cells have no moving parts.

Fuel cells are 70-83% efficient. About 75% of the energy in the hydrogen is converted into work. Because a fuel cell doesn't have moving parts, it doesn't lose very much of the energy it creates. Electricity generated in the fuel cell is directed to an electric motor, and powers electrical systems (air conditioning, stereo, etc.) Electric motors are about 80-90% efficient. Factoring in the other energy losses, fuel cell vehicles are 50-75% efficient.

Second Law

Energy will always disperse.

Try it

Line up three similar objects, like books, with the same amount of space—a foot or two—inbetween them. With a good shove, push the first book into the second so that the second hits the third. Did the second and third books travel as far or as fast as the first?

Glossary

Friction — Effort expended in moving one object over another with pressure

Electric Vehicles

Electric vehicles are not new, in fact the first electric vehicles were on the market in the 1830s. The picture shows a 1900 Riker Electric Car. By the early 1900s, electric, steam and gasoline cars were available in the US. All three had their challenges—gasoline cars were difficult to change gears, steam-powered cars could take as long as 45 minutes to get started, electric cars had limited range.

By the 1920s, gasoline was cheap and plentiful, Charles Kettering invented the electric starter for gas cars, and local roads had expanded to connect towns. Henry Ford's production line made gasoline cars as cheap as $650, while electric cars started at $1,750. Ford's Model T is pictured at left. Electric vehicles disappeared by 1935.

In the 1960s and 1970s, Americans became aware of air pollution and our increasing dependency on imported oil for fuel. Several automakers begin test programs with electric vehicles. Today, automakers are bringing vehicles powered by batteries and by fuel cells to market, and transit agencies are operating buses with fuel cell or battery drive trains. Most people in transportation believe that it will take a combination of fuel cell, battery and biofuel-powered vehicles to end dependence on petroleum.

Air Pollution

In California, passenger vehicles and trucks are responsible for about 55% of our air pollution. *Criteria pollutants* and greenhouse gases are primarily in vehicle exhaust, a byproduct of combusting fuel. Some pollutants, however, are caused by evaporation. The major pollutants are:

- Volatile organic compounds (VOCs)—any *organic* compound that evaporates readily to the atmosphere. VOCs significantly contribute to *smog*.
- Carbon monoxide (CO)—a colorless, odorless, highly poisonous gas formed by the incomplete combustion of carbon.
- Oxides of nitrogen (NOx)—smog-formers and major components of acid rain produced from burning fuels including gasoline and coal. .
- Particulate matter (PM)—microscopic solid and liquid particles that remain suspended in the air for some time. *Particles* create a haze and affect visibility, and adversely affect health and the environment.
- Greenhouse gasses (GHG)—such as carbon dioxide and methane, contribute to global warming.

Electric vehicles, including fuel cells and batteries, are zero emissions vehicles. They have no tailpipe pollution. When hydrogen and electricty are made from renewable sources, like solar and wind energy, the vehicles have zero *well-to-wheels* emissions.

Quick Question

Which creates more pollution?

A. Five minutes of idling while going through the drive-through window
B. Turning off the car, running inside, and then starting the car

Glossary

Criteria pollutants—Pollutants that can injure health, harm the environment or cause property damage.
Organic—Relating or belonging to the class of chemical compounds having a carbon basis
Particles—Any substances measuring less than 100 microns in diameter.
Smog— A hazy cloud caused by heat and sunlight reacting with pollutants.
Well-to-wheels—A lifecycle of fuel from the time it is produced until it is used in the vehicles

Activity: Checking Automobile Exhaust

Fuel cell vehicles are zero emission vehicles. The only thing from the tailpipe of a fuel cell vehicle is a little distilled water. In this activity, you'll collect some tailpipe emissions from a gasoline car to see what today's vehicles produce. Try to collect emissions from a variety of vehicles: cars, SUVs, motorcycles, hybrids and alternative fuel vehicles, such as those running on E85 or biodiesel. You can also compare newer vehicles with vehicles that are 5-10 years old, or with classic cars from the 1960s or earlier.

What you need

- One or more vehicles
- An old, clean white sock for each vehicle (a few holes are OK)
- String, wire or heavy rubber bands
- One plastic bag for each sock

Activity Steps

1. With the car off, set the parking brake.
2. Put the sock over the end of the tailpipe and secure with string, wire or rubber bands.
3. Step away from the tailpipe! It gets very hot.
4. Have a licensed driver turn the car on for 30 seconds, then turn the engine off. (Do not leave the engine on for longer or the sock may burn.)
5. When the engine is off and the tailpipe is cool enough, remove the sock and immediately put it in the plastic bag.
6. Inside the classroom, turn the sock inside out. You may want to look at the sock with a magnifiying glass or under a microscope.
7. Describe what you see on your sock below. How does it compare emissions from other vehicles?

Vehicle type ________________________________ Vehicle model year __________________

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____

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