H_2 Educate
Student Guide

2015-2016

National Energy Education Development Project

INTERMEDIATE AND SECONDARY

NEED

National Energy
Education Development

1.800.875.5029
www.NEED.org

Hydrogen: A Fuel for Today and Tomorrow

The Energy Picture in the United States Today

The United States consumes a lot of **energy**, more energy than any other country in the world. We use over two million dollars worth of energy each minute, 24 hours a day, every day of the year. With less than five percent of the world's population, we consume just under 20 percent of the world's total energy production.

The average American uses just over 4 times more energy than the world's average per capita figure. We use energy to power our homes, businesses, and industrial plants, and to move people and goods from one place to another.

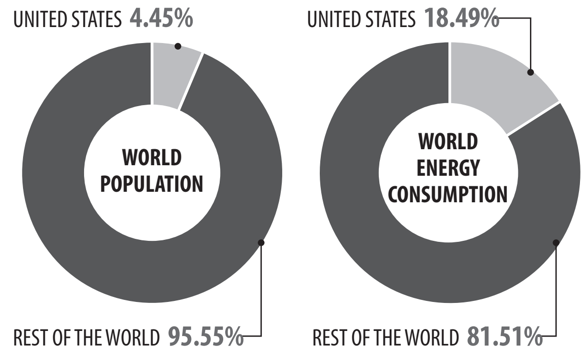
We rely on energy to make our lives productive, comfortable, and enjoyable. Sustaining this quality of life requires that we use our energy resources wisely and find new sources of energy for the future. If we as consumers make good decisions about the energy we use at home and in business and industry, we can accomplish even more with the same amount of energy.

Today, most of the energy we use—almost 91 percent—comes from **nonrenewable** energy sources such as coal, natural gas, petroleum, and uranium. About 82 percent of the energy we use comes from **fossil fuels**, which can pollute the environment when they are burned. The industry and transportation sectors of our economy are the largest consumers of energy in the United States. Transportation consumes just under 28 percent of the U.S.'s total energy, while industry accounts for approximately 32. These two sectors rely heavily on fossil fuels.

In addition, the world has limited reserves of nonrenewable energy sources. They take millions of years to form, so we cannot make more to meet our future needs. It is estimated that, at the current rate of consumption, the United States has about 180-250 or more years of coal reserves, and about 85 years of natural gas reserves.

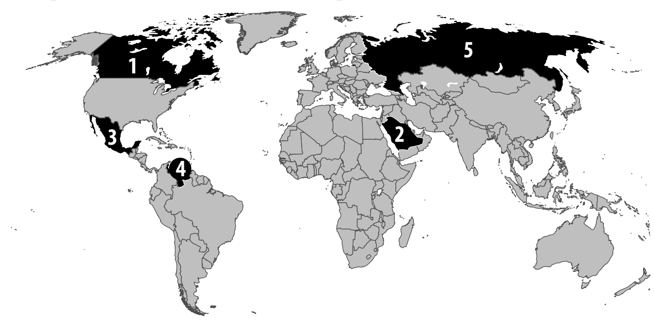
We cannot produce enough petroleum to meet our needs. Today we are importing 41 percent of our crude oil supply from foreign countries. Many experts predict that oil production will soon begin to decrease worldwide and demand will continue to increase, as countries like China and India become more industrialized. There will be increasing competition for the available petroleum. In ten years, five dollars a gallon for gasoline might seem like a real bargain!

Population Versus Energy Consumption, 2013



Data: Energy Information Administration

Top Sources of U.S. Imported Oil, 2013



1. Canada, non-OPEC
2. Saudi Arabia, OPEC
3. Mexico, non-OPEC
4. Venezuela, OPEC
5. Russia, non-OPEC

Percentage of Imports from the Middle East Region: 20.27%
Percentage of Imports from OPEC Nations: 37.74%

Data: Energy Information Administration

U.S. Energy Consumption by Source, 2013

NONRENEWABLE

PETROLEUM 35.20%
Uses: transportation, manufacturing

NATURAL GAS 26.59%
Uses: heating, manufacturing, electricity

COAL 18.52%
Uses: electricity, manufacturing

URANIUM 8.47%
Uses: electricity

PROPANE 1.69%
Uses: heating, manufacturing

RENEWABLE

BIOMASS 4.73%
Uses: heating, electricity, transportation

HYDROPOWER 2.62%
Uses: electricity

WIND 1.63%
Uses: electricity

SOLAR 0.31%
Uses: heating, electricity

GEOTHERMAL 0.23%
Uses: heating, electricity

Data: Energy Information Administration

Looking to the Future

To meet future energy challenges, the United States is expanding the use of **renewable** energy sources such as solar, wind, **biomass**, hydropower, and geothermal energy, and considering the increased use of nuclear power. The government and many private enterprises are also conducting research to use nonrenewable energy sources more cleanly and efficiently and to use alternative fuels such as **hydrogen**.

Many people think that hydrogen will be an important fuel in the future because it meets so many requirements of a good energy system. Experts agree the ideal energy system should include the characteristics listed below.

The Ideal Energy System...

- should rely on domestic energy sources.
- should be able to utilize a variety of energy sources.
- should produce few harmful pollutants and greenhouse gas emissions.
- should be **energy efficient** (high energy output compared to the energy input).
- should be accessible (easy to find, produce, or harness).
- should result in stable energy prices.

What is Hydrogen?

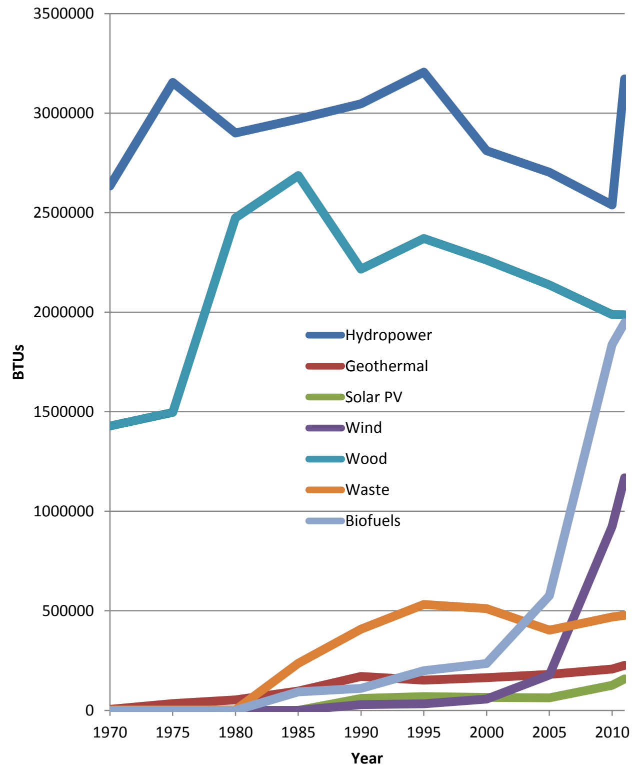
Hydrogen is the simplest **element** known to exist. Most **atoms** of hydrogen have one **proton** and one **electron**. It is the lightest element and a gas at normal temperature and pressure. Hydrogen is also the most abundant element in the universe and the source of all the energy we receive from the sun. Hydrogen has the highest energy content of any common fuel by weight, but the lowest energy content by volume.

The sun is basically a giant ball of hydrogen and helium gases. In the sun's core, the process of **fusion** is continually taking place. During fusion, smaller hydrogen nuclei fuse to become one larger helium atom of a higher atomic number. This transformation of matter releases energy as radiation.

This **radiant energy** is our most important energy source. It gives us light and heat and makes plants grow. It causes the wind to blow and the rain to fall. It is stored as **chemical energy** in fossil fuels. Most of the energy we use originally came from the sun's radiant energy.

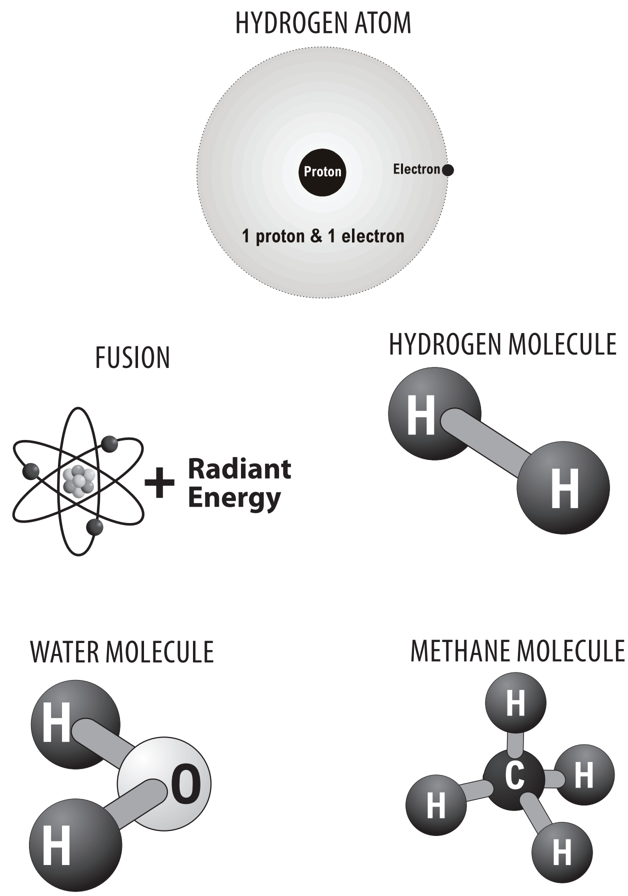
On Earth, hydrogen is found only in **compound** form. Combined with **oxygen**, it is **water (H_2O)**. Combined with carbon, it forms organic compounds such as **methane (CH_4)**, coal, and petroleum. It is also a component of all growing things—biomass.

Growth of Renewable Energy Sources



Data: Energy Information Administration

Hydrogen



Atomic Structure

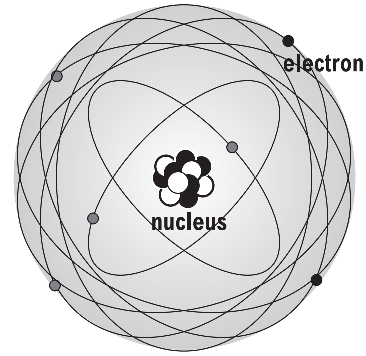
What exactly is the force we call **electricity**? It is moving electrons. Everything in the universe is made of **atoms** or particles of atoms—every star, every tree, every animal. The human body, water, and air are made of atoms, too. Atoms are the building blocks of the universe. They are so small that millions of them would fit on the head of a pin. Atoms are made of even smaller particles. The center of an atom is called the **nucleus**. It is made of **subatomic** particles called protons and **neutrons**. The protons and neutrons are very small, but electrons, which spin around the nucleus at great distances, are much smaller. If the nucleus were the size of a marble, the atom would be 100 yards in diameter—the length of a football field—and the electrons themselves would be too small to see.

If you could see an atom, it would look a little like a tiny center of balls surrounded by giant clouds (**energy levels**). Electrons are held in their energy levels by an electrical force. The protons and electrons are attracted to each other. They both carry an **electrical charge**. An electrical charge is a force within the particle.

Protons have a positive charge (+) and electrons have a negative charge (–). The positive charge of the protons is equal to the negative charge of the electrons. Opposite charges attract each other. When an atom is in balance, it has an equal number of protons and electrons. The neutrons carry no charge and their number can vary. Neutrons act as glue to hold the nucleus together.

An element is a substance in which all of the atoms are chemically identical. The number of protons in an atom determines the kind of atom or element it is. The stable **isotope** form of hydrogen, for example, has one proton and one electron, with no neutrons. Every stable isotope of carbon has six protons, six electrons, and six neutrons.

Carbon Atom



The electrons usually remain at a relatively constant distance from the nucleus in well defined regions according to their energy levels. The level closest to the nucleus can hold two electrons. The outer levels can hold up to eight. The electrons in the levels closest to the nucleus have a strong force of attraction to the protons. Sometimes, the electrons in the outermost levels do not. The electrons farthest from the nucleus are called **valence electrons** and are the electrons involved in chemical reactions.

Atoms are more stable when their outer levels are full. Atoms with one, two, or three valence electrons can lose those electrons to become more stable. Atoms with five, six, or seven valence electrons can gain electrons to become more stable. Less stable atoms can also share electrons with other atoms to become more stable.

Ions are atoms or groups of atoms that have gained or lost electrons and are electrically charged. An atom that has lost an electron has lost a negative charge and is a positive ion. An atom that has gained an electron has gained a negative charge and is a negative ion.

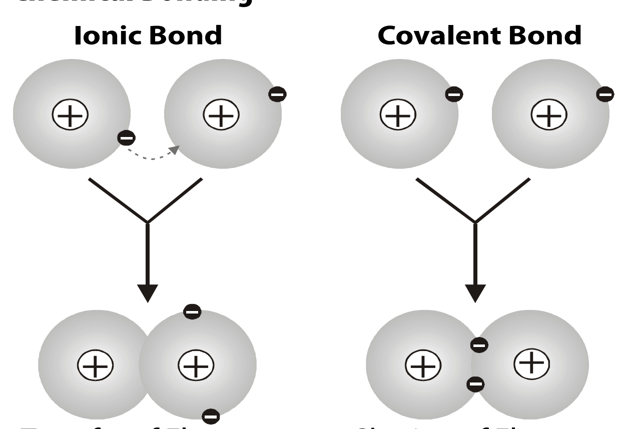
Chemical Bonding

Chemical compounds are formed when two or more atoms join together in a chemical bond. In chemical bonds, atoms can either transfer or share their valence electrons. Stable compounds are formed when the total energy of the compound is less than that of the separate atoms.

Ionic Bond—An ionic bond is formed when valence electrons from one atom are removed and attached to another atom. The resulting ions have opposite charges and are attracted to each other. Ionic bonds are common between metals and nonmetals to form compounds such as sodium chloride or salt—NaCl.

Covalent Bond—A covalent bond is formed when two atoms share electrons. Covalent bonds usually occur between two nonmetals. Water—H_2O—is an example of covalent bonding.

Chemical Bonding



The Periodic Table of the Elements

In 1869, Dmitri Mendeleev, a Russian scientist, introduced the first **periodic table**. Mendeleev had arranged the elements according to their **atomic mass**—the average mass of one atom of the element. He then put the elements in rows according to their chemical and physical properties. Mendeleev's periodic table was not perfect, but it led to the periodic table used by scientists today.

The modern periodic table is arranged according to the **atomic numbers** of the elements, as well as according to patterns of properties of the elements. The properties of the elements repeat in each horizontal row, or period. The elements in each vertical column, or group, have similar properties as well, although the similarities are stronger in some groups than in others.

Each element of the periodic table is represented by a rectangular box. The box includes information about that element. The information listed in the periodic table below includes the element's atomic symbol, atomic number, atomic mass, and name.

The atomic symbol is a one or two-letter symbol that identifies the element. Many elements are named after the scientists that discovered them. The atomic number of an element is the number of protons in the nucleus of the atom. The atomic mass is the average mass of one atom of the element.

The Periodic Table of the Elements

Atomic Number: 58
Symbol: Ce
Name: Cerium
Atomic Weight: 140.116

Period	Group 1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8 VIII	9 VIII	10 VIII	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1	1 H Hydrogen 1.00794																	2 He Helium 4.002602
2	3 Li Lithium 6.941	4 Be Beryllium 9.012182											5 B Boron 10.811	6 C Carbon 12.0107	7 N Nitrogen 14.0067	8 O Oxygen 15.9994	9 F Fluorine 18.9984032	10 Ne Neon 20.1797
3	11 Na Sodium 22.989770	12 Mg Magnesium 24.3050											13 Al Aluminum 26.981538	14 Si Silicon 28.0855	15 P Phosphorus 30.973761	16 S Sulfur 32.065	17 Cl Chlorine 35.453	18 Ar Argon 39.948
4	19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.955910	22 Ti Titanium 47.867	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938049	26 Fe Iron 55.845	27 Co Cobalt 58.933200	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.409	31 Ga Gallium 69.723	32 Ge Germanium 72.64	33 As Arsenic 74.92160	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.798
5	37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90585	40 Zr Zirconium 91.224	41 Nb Niobium 92.90638	42 Mo Molybdenum 95.94	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.90550	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.90447	54 Xe Xenon 131.293
6	55 Cs Cesium 132.90545	56 Ba Barium 137.327		72 Hf Hafnium 178.49	73 Ta Tantalum 180.9479	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.078	79 Au Gold 196.96655	80 Hg Mercury 200.59	81 Tl Thallium 204.3833	82 Pb Lead 207.2	83 Bi Bismuth 208.98038	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)
7	87 Fr Francium (223)	88 Ra Radium (226)		104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (266)	107 Bh Bohrium (264)	108 Hs Hassium (277)	109 Mt Meitnerium (268)	110 Ds Darmstadtium (281)	111 Rg Roentgenium (280)	112 Cn Copernicium (285)	113 Uut Ununtrium (284)	114 Fl Flerovium (289)	115 Uup Ununpentium (288)	116 Lv Livermorium (293)	117 Uus Ununseptium (294)	114 Uuo Ununoctium (294)

Lanthanides	57 La Lanthanum 138.9055	58 Ce Cerium 140.116	59 Pr Praseodymium 140.90765	60 Nd Neodymium 144.24	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.92534	66 Dy Dysprosium 162.500	67 Ho Holmium 164.93032	68 Er Erbium 167.259	69 Tm Thulium 168.93421	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.967
Actinides	89 Ac Actinium (227)	90 Th Thorium 232.0381	91 Pa Protactinium 231.03588	92 U Uranium 238.02891	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (262)

How is Hydrogen Made?

Since hydrogen gas is not found by itself on Earth, it must be manufactured. There are many ways to do this. The fact that hydrogen can be produced using so many different domestic resources is an important reason why it is a promising **energy carrier**. With hydrogen, we will not need to rely on a single resource or technology to meet our energy needs.

STEAM REFORMING: Industry produces hydrogen by steam reforming, a process in which high-temperature steam separates hydrogen atoms from carbon atoms in methane (CH_4), as shown to the right.

Today, most of the hydrogen produced by steam reforming is not used as fuel but in industrial processes. Steam reforming is the most cost-effective way to produce hydrogen today and accounts for about 95 percent of the hydrogen produced in the U.S. Because of its limited supply, however, we cannot rely on natural gas to provide hydrogen over the long term. Instead, we will need to produce hydrogen using other resources and technologies, such as those listed below.

ELECTROLYSIS: Another way to make hydrogen is by electrolysis—splitting water into its basic elements, hydrogen and oxygen. Electrolysis involves passing an electric current through water (H_2O) to separate the water molecules into hydrogen (H_2) and oxygen (O_2) gases.

The electricity needed for electrolysis can come from a power plant, windmill, photovoltaic cells, or any other electricity generator. If the electricity is produced by renewable energy or nuclear power, there is no net increase in **greenhouse gases** added to the atmosphere. Hydrogen produced by electrolysis is extremely pure, but it is very expensive because of equipment costs and other factors. On the other hand, water is renewable and abundant in many areas.

Technological advances to improve efficiency and reduce costs will make electrolysis a more economical way to produce hydrogen in the future.

PHOTOELECTROCHEMICAL PRODUCTION: Photoelectrolysis uses sunlight to split water into hydrogen and oxygen. A semiconductor absorbs solar energy and acts as an **electrode** to separate the water molecules.

BIOMASS GASIFICATION: In biomass gasification, wood chips and agricultural wastes are super-heated until they turn into hydrogen and other gases. Biomass can also be used to provide the heat.

PHOTOBIOLOGICAL MICROBIAL PRODUCTION: Scientists have discovered that some algae and bacteria produce hydrogen under certain conditions, using sunlight as their energy source. Experiments are underway to find ways to induce these microbes to produce hydrogen efficiently.

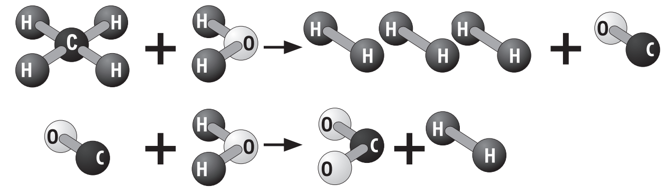
COAL GASIFICATION WITH CARBON SEQUESTRATION: In this process, coal is gasified (turned into a gas) with oxygen under high pressure and temperature to produce hydrogen and **carbon monoxide (CO)**. Steam (H_2O) is added to the CO to produce hydrogen (H_2) and **carbon dioxide (CO_2)**. The carbon dioxide is captured and sequestered (stored) to prevent its release into the atmosphere.

NUCLEAR THERMOCHEMICAL PRODUCTION: In this experimental process, the heat from a controlled nuclear reaction is used to decompose water into hydrogen and oxygen in a series of complex chemical reactions.

Steam Reforming

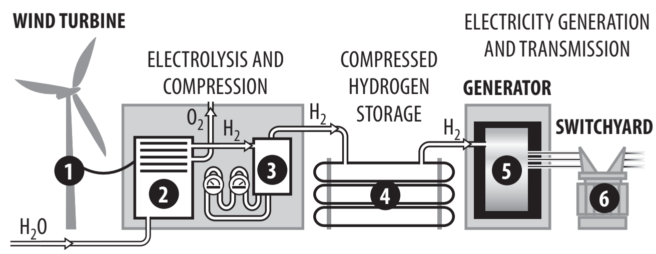
$CH_4 + H_2O$ (steam) $\quad 3H_2 + CO$

$CO + H_2O$ (steam) $\quad CO_2 + H_2$



Wind to Hydrogen

The National Renewable Energy Laboratory and Xcel Energy launched an innovative wind-to-hydrogen (Wind2H$_2$) project that uses electricity from wind turbines (or photovoltaic panels) to produce and store hydrogen, offering what may become an important new template for future energy production.



How it works:

1. Wind turbines use the wind's energy to generate electricity. Electricity is transported to the electrolysis unit.
2. Electricity is used to split water (H_20) into hydrogen (H_2) and oxygen (0_2).
3. The hydrogen diaphragm compressor compresses the hydrogen gas produced from the electrolyzers at 150 psi (pounds per square inch) to the storage pressure of 3,500 psi.
4. The hydrogen can be stored and used later to generate electricity from an internal combustion engine or a fuel cell. The steel tanks can store up to 85 kilograms of hydrogen at 3,500 psi.
5. The internal combustion engine runs on stored hydrogen and generates electricity that will be sent onto the utility grid for use during peak demand.
6. Electricity is sent to a switchyard, where a transformer increases the voltage, allowing it to travel through the electric grid.

PHOTOBIOLOGICAL MICROBIAL PRODUCTION

Image courtesy of DOE/NREL, credit Warren Gretz

Researchers are using green algae to produce hydrogen.

Hydrogen as a Fuel

Many experts believe that hydrogen is an important fuel for the future. It is abundant, clean, flexible, and can be produced from many different domestic resources. The advantages of hydrogen include the following:

1. Hydrogen resources are abundant in the United States and the world.
   - Hydrogen is a component of many abundant compounds on Earth, including water, hydrocarbons, and carbohydrates.
   - It can be produced from a variety of resources (water, fossil fuels, biomass) and is a by-product of other chemical processes.
   - All regions of the world have hydrogen-containing resources.
2. Hydrogen is a domestic fuel.
   - The United States has a wide variety of hydrogen resources, including plentiful water, biomass, natural gas, and coal. This diversity and abundance would help keep energy prices stable.
   - Every area of the country has the ability to produce hydrogen from regional resources.
   - Using domestic energy resources increases national security.
3. Hydrogen is a clean fuel.
   - Using hydrogen as a transportation fuel can significantly reduce air pollution—hydrogen fuel cell vehicles produce no tailpipe emissions except heat and water.
   - If hydrogen is produced by electrolysis using renewable energy sources, there are no harmful emissions.
   - Using hydrogen as a fuel can reduce greenhouse gas emissions, especially if it is produced using renewable resources, nuclear energy, or fossil fuels such as coal coupled with carbon sequestration (capturing the carbon-based emissions and preventing them from entering the atmosphere).
   - If hydrogen is produced from fossil fuels at large centralized facilities, it is much easier to minimize emissions at these sites than it is to reduce emissions from individual petroleum-fueled vehicles.

HYDROGEN FUEL CELL VEHICLE

Image courtesy of DOE/NREL, credit Keith Wipke

4. Hydrogen is a flexible fuel.
   - Hydrogen can be produced from a variety of resources.
   - Hydrogen can be produced on–site in small quantities for local use (**distributed generation**) or in large quantities at production plants (**centralized generation**).
   - Hydrogen can be used in **fuel cells** to generate electricity, with only water and heat as by-products, and fuel cells can be used to power almost anything, from laptops to buildings to vehicles.
   - Hydrogen can be used as a transportation fuel for motor vehicles. It can be used to power forklifts and airport baggage trucks.
   - Hydrogen can be used to provide electricity and heat for buildings, and can be used in place of batteries for video cameras and radios.
   - Hydrogen can be used in manufacturing processes in the industrial sector.
   - Hydrogen fuel cells can be used in remote places that cannot be reached by power lines.
   - Hydrogen, like electricity, is an efficient energy carrier, although it is not a primary energy source.

What is an Energy Carrier?

An energy carrier is a substance or system that moves energy in a usable form from one place to another. Electricity is the most well-known energy carrier. We use electricity to move the energy in coal, uranium, and other energy sources from power plants to homes and businesses. We use electricity to move the energy in flowing water from hydropower dams to consumers. It is much easier to use electricity than the energy sources themselves.

Some energy sources can also be energy carriers. Petroleum and natural gas, for example, are energy sources. They are also energy carriers because we transport them from place to place and they are in usable form. Uranium, on the other hand, can be transported from place to place, but we cannot really use it at home to produce usable energy. It is an energy source, but not an energy carrier.

Hydrogen is an energy carrier, not an energy source. Like electricity, hydrogen must be produced from another substance, so it is not considered an energy source. Electricity is difficult to store in sufficient quantities for long periods of time. Once hydrogen has been produced, however, it can be stored and transported to where it is needed. Its potential for storing and transporting renewable energy is especially high.

Uses of Hydrogen

The U.S. hydrogen industry currently produces about four million cubic feet of hydrogen per day. Most of this hydrogen is used for industrial applications such as refining, treating metals, and food processing.

Hydrogen-powered vehicles are on the road today, but it will be a while before you can walk into your local car dealer and drive away in one. There are only 40 hydrogen fueling stations operating today and only 13 stations are open to the public, most of which are located in California.

Can you imagine how huge the task would be to quickly change the gasoline-powered transportation system we have today? Just think of the thousands of filling stations across the country and the production and distribution systems that serve them. Changing the nation's transportation system will take lots of time and money.

In the future, hydrogen will join electricity as an important energy carrier since it can be made safely from a variety of energy resources and is virtually non-polluting. It can be used as a fuel for zero-emissions vehicles, to heat homes and offices, to produce electricity for buildings and portable devices, and to fuel aircraft.

As the production of electricity from renewable energy sources increases, so will the need for energy storage and transportation. Many of these sources—especially solar and wind—are located far from population centers and produce electricity only part of the time. Hydrogen, which can be produced by electrolyzing water using renewable energy, may be the perfect carrier for this energy. It can store the energy and distribute it to wherever it is needed.

Before hydrogen can make a significant contribution to the U.S. energy picture, many new systems must be designed and built. There must be sufficient production facilities and a distribution system to support widespread use, and consumers must have the technology and confidence in its safety to use it.

SPACE SHUTTLE

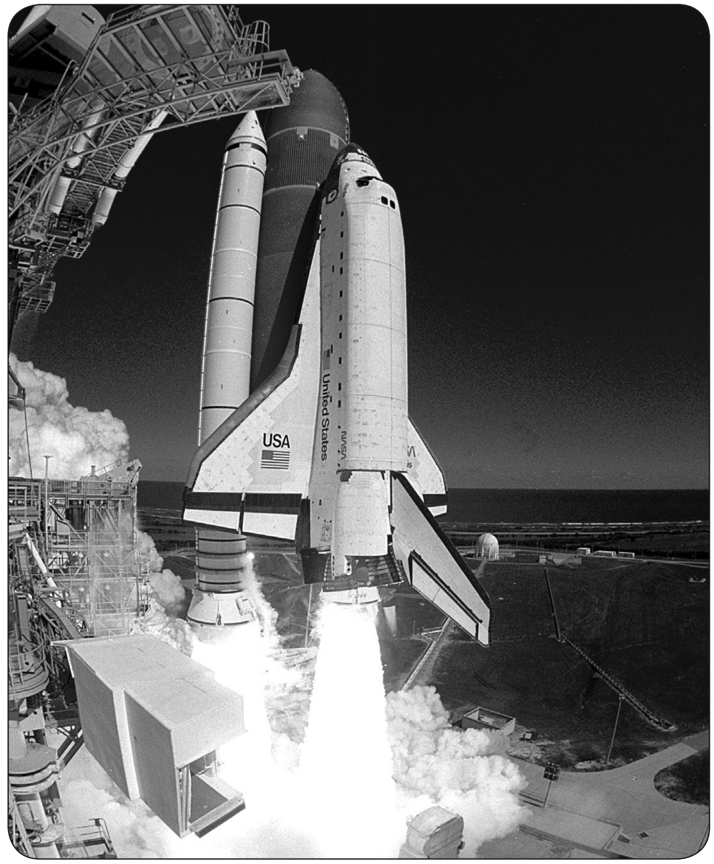
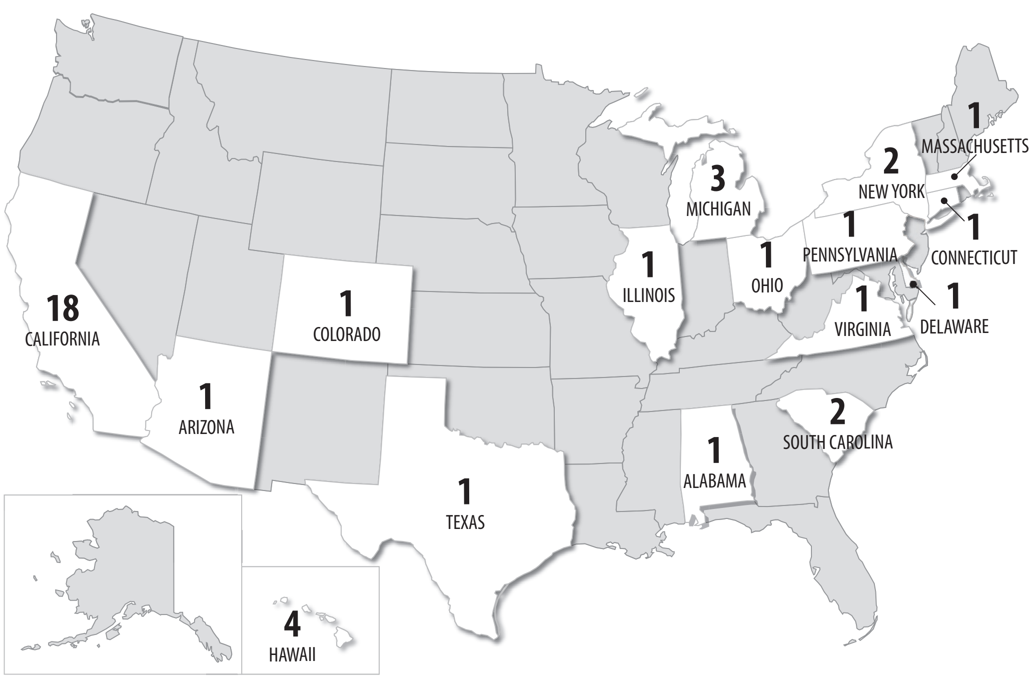


Image courtesy of NASA

Hydrogen was used as the fuel for NASA space shuttles and rockets, beginning in the 1980s. While the U.S. shuttles have since been retired, hydrogen is still used internationally to launch satellites and as a space fuel. Hydrogen is a perfect fuel for space travel as it has very high energy density while keeping weight down.

Number of Hydrogen Fueling Stations by State, 2015



Data: U.S. Department of Energy, Alternative Fuels Data Center

What is a Fuel Cell?

A fuel cell is a device that produces a chemical reaction between substances, generating an electric current in the process. It is an **electrochemical energy conversion device**. Everyone uses another electrochemical energy conversion device—a battery. A battery contains substances that produce an electric current as they react. When all of the substances have reacted, the battery is dead; it must be replaced or recharged.

With a fuel cell, the substances (in this case, hydrogen and oxygen) are stored outside of the device. As long as there is a supply of hydrogen and oxygen, the fuel cell can continue to generate an electric current, which can be used to power motors, lights, and other electrical appliances. There are many types of fuel cells, but the most important technology for transportation applications is the **polymer electrolyte** (or proton exchange) **membrane** or **PEM** fuel cell. A PEM fuel cell converts hydrogen and oxygen into water, producing an electric current during the process.

The **anode** is the negative side of the fuel cell. The anode has channels to disperse the hydrogen gas over the surface of the **catalyst**, which lines the inner surfaces of the anode and **cathode**. Hydrogen gas under pressure enters the fuel cell on the anode side and reacts with a catalyst.

The catalyst is a special material—usually made of platinum—that facilitates the reaction of hydrogen and oxygen. The catalyst splits the hydrogen gas into two hydrogen ions ($2H^+$) and two electrons ($2e^-$). The electrons flow through the anode to an external **circuit**, through a load where they perform work, to the cathode side of the cell.

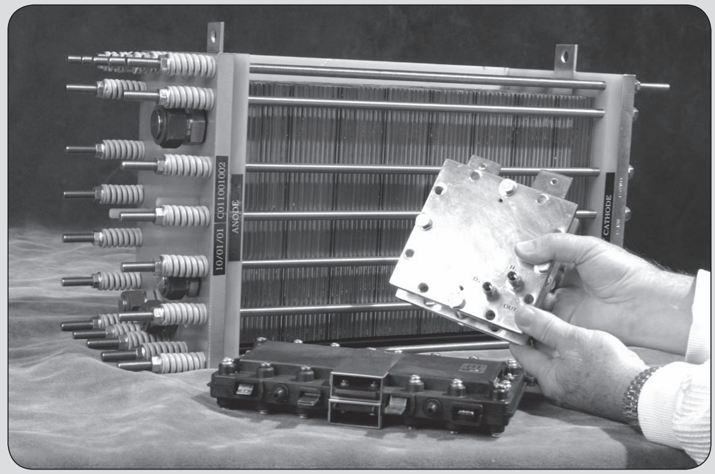


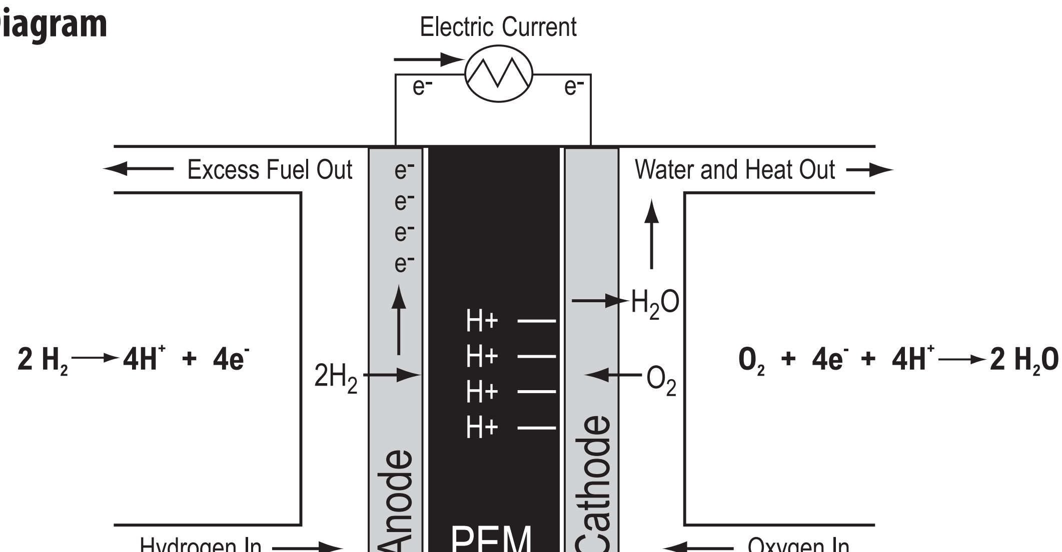
Image courtesy of DOE/NREL, credit Matt Stiveson

A 5 kW fuel cell (large cell), 25 watt fuel cell (three cell stack), 30 watt fuel cell (smaller cell held in hands).

The polymer electrolyte membrane is a specially treated material that conducts positive ions (protons), but blocks electrons from flowing through the **membrane**. Electrons flow through a separate circuit (that can be used to do work) as they travel to the cathode.

The cathode is the positive side of the fuel cell. It has channels to distribute oxygen gas to the surface of the catalyst. The oxygen reacts with the catalyst and splits into two oxygen atoms. Each oxygen atom picks up two electrons from the external circuit to form an oxygen ion (O^{--}) that combines with two hydrogen ions ($2H^+$) to form a water molecule (H_2O).

PEM Cell Diagram



The Challenges of Hydrogen

Hydrogen Storage

Hydrogen can be stored in many ways, but all have advantages and disadvantages. Safety, cost, efficiency, and ease of use are important considerations.

- Hydrogen can be stored as a gas at standard temperature and pressure. Hydrogen can be stored safely this way, but it is not efficient; a small amount of hydrogen energy takes up a very large amount of space.
- Hydrogen gas can be compressed and stored in high-pressure tanks. Hydrogen gas takes up less space when it is compressed, but it still has much lower energy content than the same volume of gasoline. A compressed hydrogen tank would have to be many times larger than a gasoline tank to hold an equivalent amount of energy. It also takes energy to compress the gas, and the storage tanks to hold the hydrogen must meet strict safety standards since any compressed gas can be dangerous.
- Hydrogen gas can be liquefied (turned into a liquid) by compressing it and cooling it to a very low temperature (–253°C). But it requires a lot of energy to compress and cool the gas, and storage tanks must be reinforced and super-insulated to keep the liquid hydrogen cold.
- Hydrogen can also be stored using materials-based technologies—within the structure or on the surface of certain materials, as well as in chemical compounds that undergo chemical reactions to release the hydrogen. With these technologies, hydrogen is tightly bound with other elements in a compound (or storage material), which may make it possible to store larger quantities of hydrogen in smaller volumes at low pressure at near room temperature.

Hydrogen can be stored in materials through **absorption**, in which hydrogen is absorbed directly into the storage material; **adsorption**, in which hydrogen is stored on the surface of the storage material; or in compound form, in which hydrogen is contained within a chemical compound and released in a chemical reaction.

HYDROGEN STORAGE TANK

Image courtesy of DOE/NREL, photo credit Keith Wipke

Hydrogen can be stored in high-pressure tanks.

PIPELINES

Hydrogen can be transported via pipeline, truck, rail, and barge.

Hydrogen Distribution

Today, most hydrogen is transported short distances, mainly by pipeline. There are about 1,213 miles of hydrogen pipelines in the United States. Longer distance distribution is usually by tanker trucks carrying hydrogen in liquefied form. There is no nationwide hydrogen **distribution system**.

The cost of building a new nationwide system of pipelines for hydrogen would be very costly. Researchers are looking into ways to use the existing natural gas pipeline system, but there are problems to be solved. Hydrogen can permeate the natural gas pipes and fittings, causing them to become brittle and rupture.

For many applications, distributed generation (producing hydrogen where it will be used) may be a solution. Buildings and fueling stations can use small reformers to produce the hydrogen they need from other fuels such as natural gas and ethanol.

Wind turbines, solar panels, and other renewables can power electrolyzers (systems that split water into hydrogen and oxygen by electrolysis) to also produce hydrogen close to where it will be used.

Hydrogen Safety

Like any fuel we use today, hydrogen is an energy-rich substance that must be handled properly to ensure safety. Several properties of hydrogen make it attractive compared to other volatile fuels when it comes to safety. Important hydrogen properties relating to safety are described below.

- Hydrogen is much lighter than air and rises at a speed of almost 20 meters per second—two times faster than helium and six times faster than natural gas. When released, hydrogen quickly rises and dilutes into a non-flammable concentration.
- An explosion cannot occur in a tank or any contained location that contains only hydrogen; oxygen would be needed.
- Hydrogen burns very quickly, sometimes making a loud noise that can be mistaken for an explosion.
- The energy required to initiate hydrogen **combustion** is significantly lower than that required for other common fuels such as natural gas or gasoline.
- Hydrogen is odorless, colorless, and tasteless—so it is undetectable by human senses. Hydrogen equipment, and facilities where hydrogen is used, have leak detection and ventilation systems. Natural gas is also odorless, colorless, and tasteless; industry adds an odorant called mercaptan to natural gas so people can detect it. Odorants cannot be used with hydrogen, however, because there is no known odorant "light enough" to travel with hydrogen (remember, it's the lightest element in the universe).
- Although the flame itself is just as hot, a hydrogen flame produces a relatively small amount of radiant heat compared to a hydrocarbon flame. This means that hydrogen flames can be difficult to detect (they're also nearly invisible in daylight) but, with less radiant heat, the risk of sparking secondary fires is reduced with a hydrogen flame.
- Any gas except oxygen can cause asphyxiation (oxygen deprivation) in high enough concentrations. Since hydrogen is buoyant and diffuses rapidly, it is unlikely that a situation could occur in which people were exposed to high enough concentrations of hydrogen to become asphyxiated.
- Hydrogen is non-toxic and non-poisonous. It will not contaminate groundwater and a release of hydrogen is not known to contribute to air or water pollution.

Hydrogen and Our Energy Future

Hydrogen offers the promise of a clean and secure energy future, but its widespread use by consumers nationwide will require major changes in the way we produce, deliver, store, and use energy.

Some fuel cells are commercially available today for specific applications—fueling fork lifts, providing emergency back-up power, and powering some portable equipment—but there are several important technical challenges that must be solved before we see hydrogen at local fueling stations and fuel cell vehicles in auto dealer showrooms.

HYDROGEN FLAME

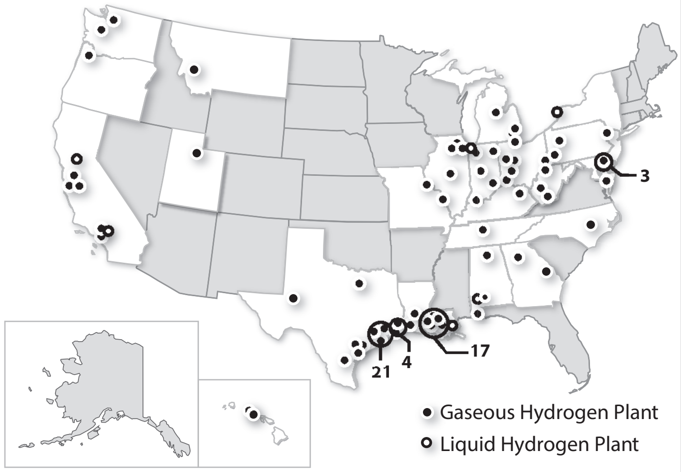
Image courtesy of DOE/NREL, photo credit Warren Gretz

RESEARCH AND DEVELOPMENT

Image courtesy of DOE/NREL, photo credit Robert Remick

Researchers are designing and testing hydrogen sensors. Because hydrogen is colorless and odorless, sensors are key safety elements of hydrogen facilities.

Hydrogen Production Plants



Data: U.S. Department of Energy Hydrogen Analysis Resource Center

Reducing the cost of hydrogen: The cost of hydrogen, including the cost of producing and delivering it, must be similar to or less than the cost of fuels we use today. Researchers are working to lower the cost of production equipment and to find ways to make production processes more efficient, which will lower the cost of hydrogen for consumers.

Reducing fuel cell cost and improving durability: Fuel cells are currently more expensive than conventional power systems such as the engines used in cars today. Researchers are working to develop technologies that will lower the cost of fuel cells and ensure that fuel cell systems can operate reliably for long periods of time in a wide range of weather and temperature conditions.

Improving hydrogen storage technology: Most people expect to be able to drive their cars more than 300 miles before having to refuel. Even in a highly efficient fuel cell vehicle, today's hydrogen storage technology does not allow drivers to travel more than 300 miles between fill-ups. Scientists are researching ways to improve storage technology and to identify new ways to store hydrogen on board a vehicle to achieve a 300+ mile driving range.

Educating consumers: In addition to research, hydrogen education is also necessary to support a hydrogen economy. Consumers must be familiar with hydrogen in order to feel as comfortable driving and refueling a hydrogen fuel cell vehicle as they do driving and refueling a gasoline vehicle. Government, industry, and the education system also need knowledgeable students with an interest in hydrogen to become the future researchers, engineers, scientists, technicians, and educators.

Jobs in Fuel Cell Technologies

Adapted from the U.S. DOE Office of Energy Efficiency and Renewable Energy

Currently, fuel cell technologies are in small, specific markets. However, as research and development continues to bring the cost of fuel cell technologies down, it is expected that the industry will grow significantly. In one scenario, vehicle applications of fuel cells could open up 675,000 new jobs between 2020 and 2050.

Employment opportunities will open up in businesses that develop, manufacture, operate, and maintain the fuel cell systems. Jobs will also become available in business that produce and deliver the hydrogen and other fuels used by these systems.

Fuel Cell Technology Jobs

- Mechanical engineers
- Chemists
- Chemical engineers
- Electrical engineers
- Materials scientists
- Laboratory technicians
- Factory workers
- Machinists
- Industrial engineers
- Power plant operators
- Power plant maintenance staff
- Bus, truck, and other fleet drivers
- Vehicle technicians
- Fueling infrastructure installers
- Hydrogen production technicians

For more information on training programs, colleges, and universities offering programs in fuel cell and hydrogen science, visit www.fuelcells.org/education-and-careers/#ed.

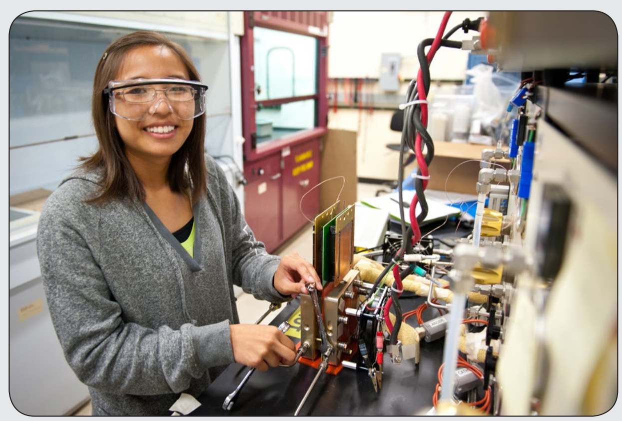


Image courtesy of DOE/NREL, photo credit Dennis Schroeder

Today, many jobs related to hydrogen are found in science labs. In the future, a wide variety of jobs will be available.

Hydrogen Information Web Links

Ames Laboratory: www.ameslab.gov

Argonne National Laboratory: www.anl.gov

Brookhaven National Laboratory: www.bnl.gov

California Fuel Cell Partnership: http://cafcp.org

Energy Information Administration: www.eia.gov

Fuel Cells 2000: www.fuelcells.org

Fuel Cell and Hydrogen Energy Association: www.fchea.org

Hydrogen and Fuel Cells Interagency Working Group: www.hydrogen.gov

International Partnership for the Hydrogen Economy: www.iphe.net

Lawrence Berkeley National Laboratory: www.lbl.gov

Lawrence Livermore National Laboratory: www.llnl.gov

Los Alamos National Laboratory: www.lanl.gov

National Energy Technology Laboratory: www.netl.doe.gov

National Renewable Energy Laboratory: www.nrel.gov/hydrogen

Oak Ridge National Laboratory: www.ornl.gov

Pacific Northwest National Laboratory: www.pnl.gov

Sandia National Laboratory: www.sandia.gov

Savannah River National Laboratory: http://srnl.doe.gov

The National Energy Education Development Project: www.need.org

U.S. Department of Energy Hydrogen and Fuel Cells Program: www.hydrogen.energy.gov

Hydrogen in Society

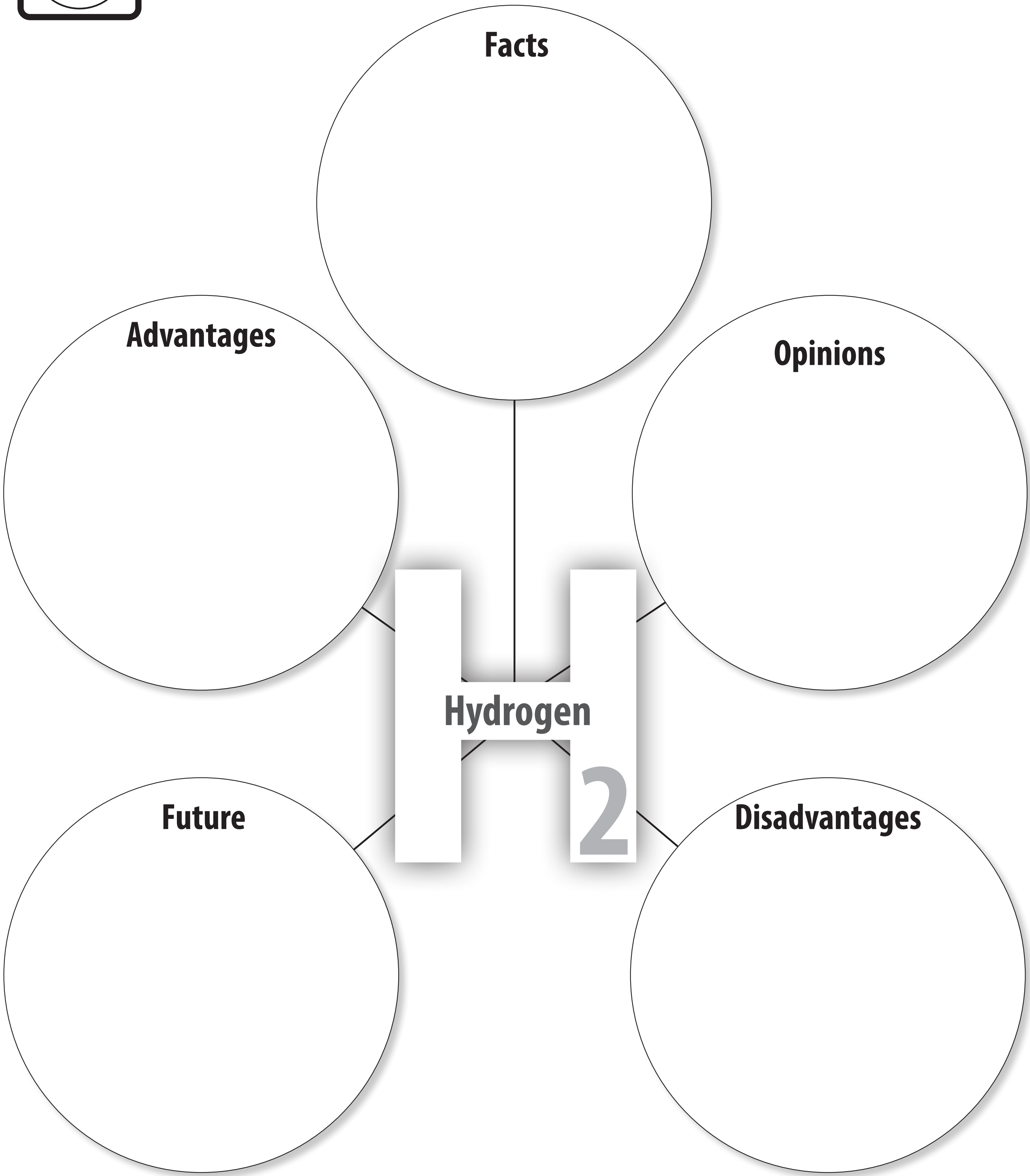
Role Group: ______________________

Question 1	Question 2	Question 3	Question 4

Essential Details	Essential Details	Essential Details	Essential Details

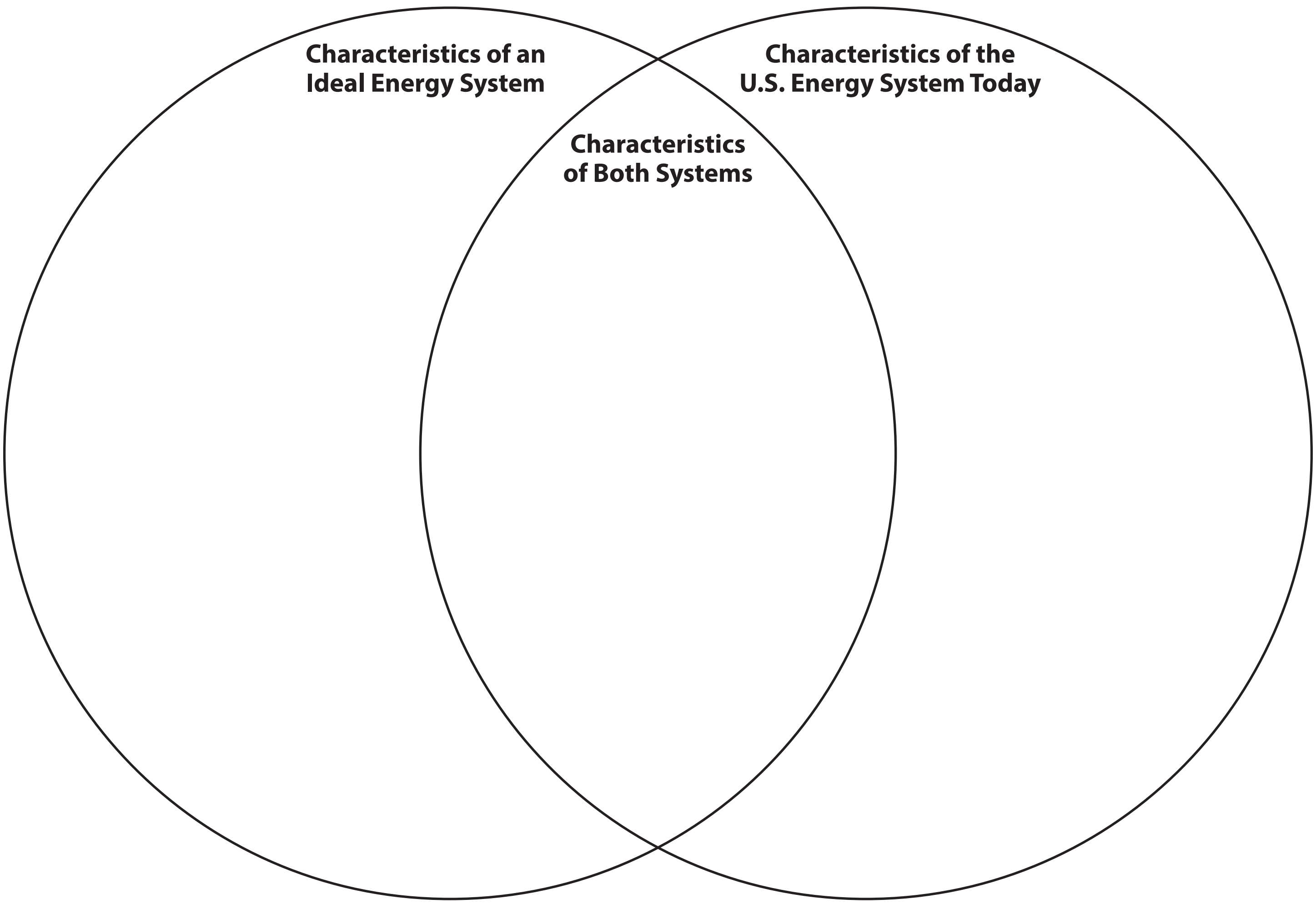
So What? What's important to understand about this?

Hydrogen in Society Presentation Organizer



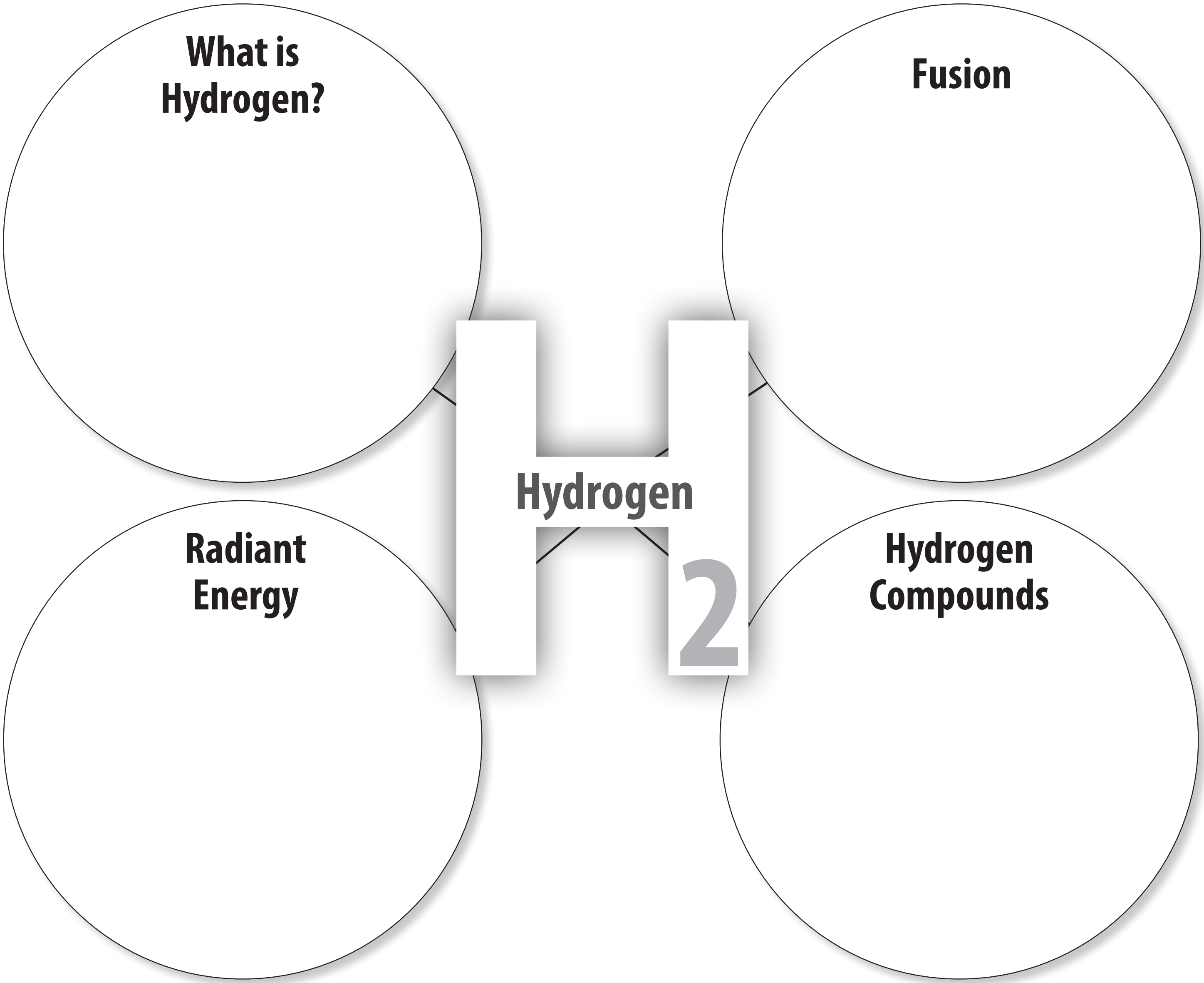
Comparing Energy Systems

Use the information in the informational text and complete the Venn diagram below to compare the U.S. energy system today to an ideal energy system. Underline the most important problem with the U.S. energy system today and write a paragraph explaining why you think it is important and what you think should be done to solve the problem.

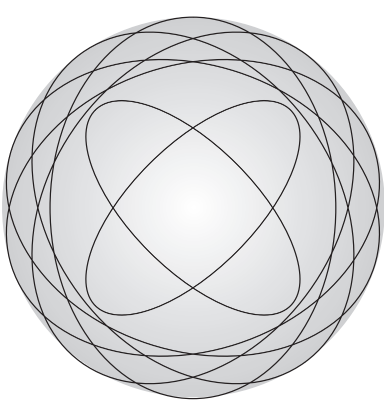


The Science of Hydrogen

As you read the informational text, complete the activities below.



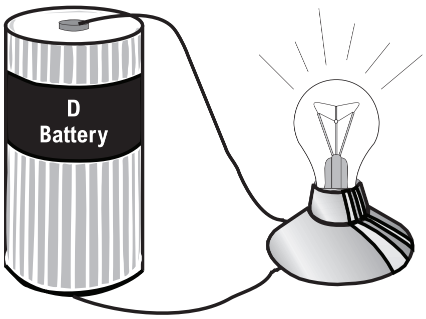
Draw an atom of nitrogen. Make the protons black, the neutrons green, and the electrons red.



Discover a new element, name it, give it a symbol, and put it in the Periodic Table.

Electrochemistry and Electrolysis

Electrochemistry is a branch of chemistry that studies the production of electricity by chemical reactions (such as the reactions in batteries and fuel cells) and chemical changes that can be produced by electric current (such as the electrolysis of water).



Voltaic cells, such as batteries or fuel cells, convert chemical energy into electrical energy. The primary parts of a voltaic cell are electrodes and an electrolyte. An **electrode** is a **conductor** that can carry electrons to or from a substance and has a chemical reaction that occurs on its surface. The negative electrode, which is attached to the part of the battery in which free electrons are produced, is called the **anode**. The reaction that creates free electrons is called **oxidation**.

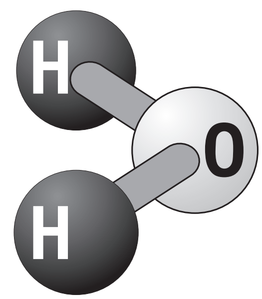
The electrode on which electrons are consumed is called the **cathode** and is labeled as the positive electrode. The reaction that consumes free electrons is called **reduction**. If the battery is attached to a **circuit**, free electrons from the anode travel through the circuit to the cathode. These moving electrons are **electricity** and can be used to do work (lighting a bulb in a flashlight, for example).

An **electrolyte** is used to separate the electrodes and carry ions between them. An **ion** is an atom or group of atoms that has lost or gained one or more electrons, giving it a positive or negative charge, respectively. Many different ions can be used in voltaic cells. The batteries used in cell phones, laptop computers, or iPods, have lithium ions, while PEM (polymer electrolyte membrane) fuel cells have protons (hydrogen ions).

There are several types of voltaic cells. A **dry cell** is a voltaic cell in which the electrolyte is a paste. A flashlight battery is an example of a dry cell. Lead-acid storage batteries, such as those used in cars, have a liquid electrolyte and contain a group of cells connected together. **Fuel cells** are voltaic cells in which an external fuel (usually hydrogen) undergoes a chemical reaction—oxidation—producing an electric current.

Electrolysis is the opposite process of that which occurs in a voltaic cell. Electrolysis is a process that uses an electric current to produce a chemical reaction. The container in which electrolysis is carried out is called an **electrolytic cell**.

Distilled water does not conduct well because distilled water contains few ions. The atoms in water are held together by **covalent bonds** (shared electrons) and are more difficult to break apart than atoms with **ionic bonds** (electronic attraction). The addition of a small amount of an electrolyte such as sodium chloride (NaCl—table salt), sodium hydroxide (NaOH—caustic soda), or sodium sulfate (Na_2SO_4) allows water to conduct ions more easily. In water, these electrolytes **dissociate** (form negative and positively charged species in solution) and allow for ion conduction.

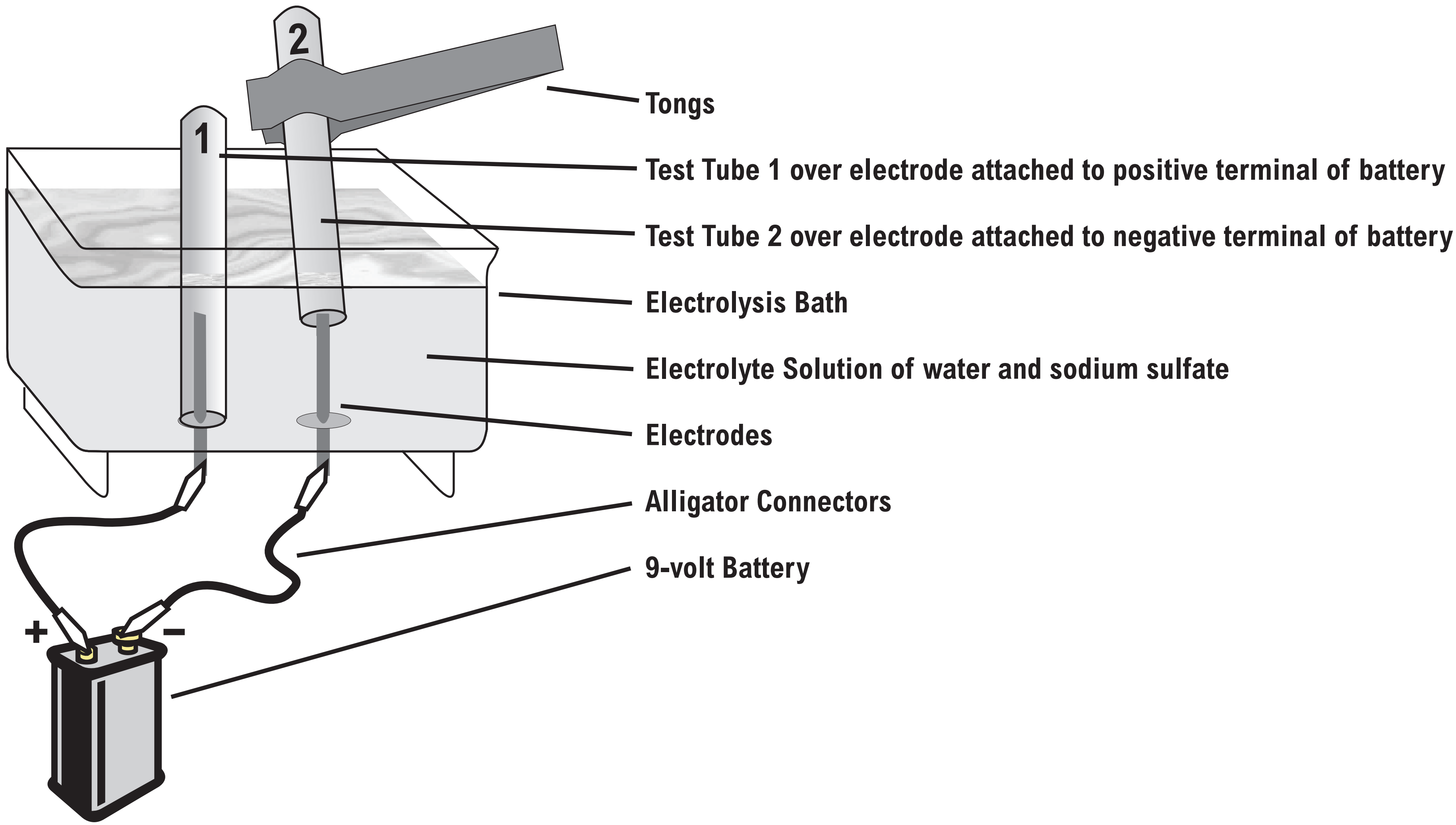


The chemical formula for water is H_2O. A water molecule is a **polar molecule**—the hydrogen atoms have a positive character and the oxygen atom has a negative character. During electrolysis, the water molecules undergo a **decomposition reaction**, producing hydrogen (H_2) and oxygen (O_2), by applying an electric driving force. This decomposition is an **endothermic reaction** that requires the constant addition of energy to sustain.

In the experiment you will conduct, a battery will provide the driving force and energy for the electrolysis of water. In a circuit, electrons flow from the anode to the cathode. When an electric current is passed through water with an electrolyte, positively charged hydrogen ions (H^+) are drawn to the cathode. At the cathode, two hydrogen ions (H^+) gain two electrons to form molecules of hydrogen gas (H_2), which bubble up from the cathode. Oxygen gas is produced at the anode as the oxygen ions in water give up electrons and combine to form oxygen molecules (O_2).

Hydrogen gas is lighter (less dense) than air and is combustible—it burns quickly when an ignition source such as a flame is introduced. Oxygen gas is about the same density as air and facilitates combustion. When a glowing ember, for example, is introduced into a high concentration of oxygen, the ember will re-ignite.

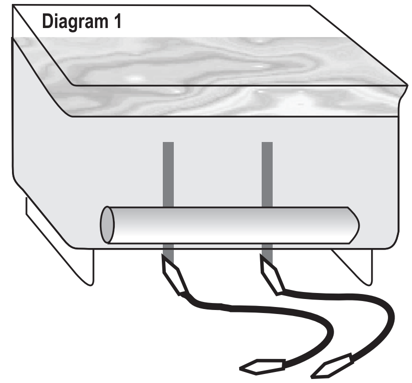
Electrolysis Apparatus



Electrolysis Exploration

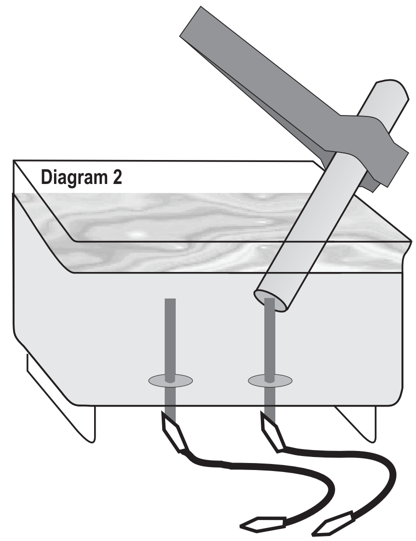
Safety Warning

WEAR EYE PROTECTION. FOLLOW ALL LAB SAFETY PROCEDURES. The electrolyte solution you will be using is diluted sodium sulfate (Na_2SO_4). It can irritate body tissues. If the solution gets into your eyes, wash out your eyes in an eyebath immediately and report the incident to your teacher. If any solution comes into contact with your skin, immediately wash your skin well to remove the solution. You will also be using an open flame.



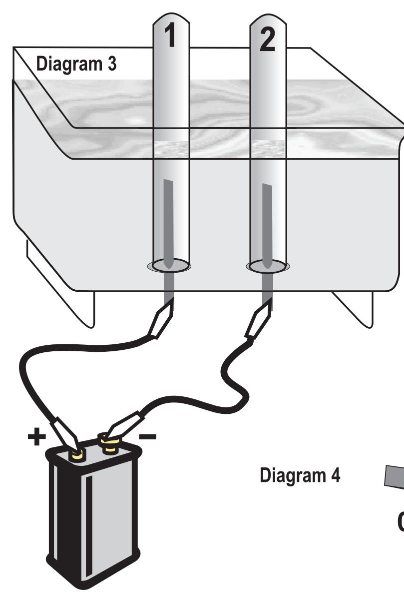
Preparation

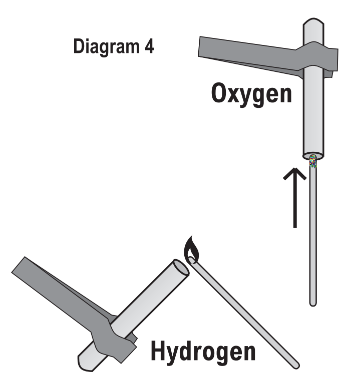
- Attach the alligator clips to the electrodes on the bottom of the electrolysis apparatus. (Diagram 1)
- Fill the electrolysis apparatus with the electrolyte solution to about 1 cm above the tips of the electrodes. (Diagram 1)
- Immerse one test tube into the electrolysis apparatus to fill it with the electrolyte solution. (Diagram 1)
- Grip the test tube with the tongs and invert it onto one of the electrodes, without lifting the mouth of the tube out of the electrolyte solution. Ensure that the tube remains filled with the solution. Fill the other test tube in the same manner. (Diagram 2)
- Connect the alligator clips to the terminals of the 9-volt battery. (Diagram 3)
- You should immediately observe bubbles rising into both tubes. If you do not observe them, check your connections.



✔Procedure

1. Note on the *Electrolysis Data Recording Form* which electrode is connected to the anode of the battery and which one is connected to the cathode, using Tube 1 and Tube 2 designations.
2. Record the gas volumes in the test tubes at 3–minute intervals for 30 minutes or until one of the test tubes is nearly full of gas.
3. Disconnect the battery from the apparatus.
4. Record the color of the gases in the test tubes.
5. From your reading, determine which test tube contains hydrogen gas and which one contains oxygen gas.
6. These procedures must be conducted quickly or the gas will escape! Have your partner light a splint. Use the tongs to lift the oxygen tube straight up, keeping it inverted. Quickly shake the tube to remove excess liquid and have your partner blow out the flame on the splint. Insert the splint straight up into the tube without touching the sides. Record your observations. (Diagram 4)
7. Remove the hydrogen tube using the tongs and keep it inverted. Have your partner re-light the splint. Turn the tube to a 45° angle tilted up, and immediately bring the splint close to the mouth of the tube. Record your observations. (Diagram 4)





Electrolysis Data Recording Form

Anode Connection: Test Tube # ______________ **Cathode Connection: Test Tube #** ______________

Hypothesis—Gas in Tube 1: ______________ **Gas in Tube 2:** ______________

Data

Physical Property—Color of Gas Produced

Hydrogen: ______________

Oxygen: ______________

Chemical Property

Hydrogen—Burning Splint: ______________

Oxygen—Glowing Splint: ______________

Gas Volumes Produced and Ratios

TIME (MIN)	VOLUME OF TUBE 1 *(cc or mL)*	VOLUME OF TUBE 2 *(cc or mL)*	RATIO *(Hydrogen Volume: Oxygen Volume)*
3			
6			
9			
12			
15			
18			
21			
24			
27			
30			

Element Models

Background

A covalent bond exists between atoms that share electrons. An ordinary hydrogen atom has one proton and one electron. Hydrogen gas (H_2) is a **diatomic** (two atom) **molecule** that shares the two electrons. An ordinary oxygen atom has eight protons, eight neutrons, and eight electrons. Oxygen gas (O_2) is a diatomic molecule that shares four electrons in the outer levels of the atoms to form a double bond. In a water molecule (H_2O), the single electron of each hydrogen atom is shared with one of the six outer-energy level electrons of the oxygen, leaving four electrons that are organized into two non-bonding pairs.

Key Terms

- covalent bond
- diatomic
- molecule
- energy level (shell)
- atom
- proton
- neutron
- electron
- molecule

Overview

In this activity, you will create clay models of hydrogen and oxygen atoms, and hydrogen and water molecules.

Materials

- 3 Colors of modeling clay
- Plastic straws
- Scissors

✔Procedure

1. Use one color of clay to represent protons, another color to represent neutrons, and a third color to represent electrons. *Remember that protons and neutrons are much bigger than electrons when you're making your models*.
2. Use different lengths of plastic straws to represent the chemical bonds between atoms and the electron energy levels, attaching the electrons to the ends of the straws representing the energy levels. *Remember that the first energy level can hold two electrons and the second energy level can hold up to eight electrons.*
3. Create three-dimensional clay models of a hydrogen atom, a hydrogen molecule, an oxygen atom, and a water molecule, in that order. Your teacher will direct you to create one model at a time, approving each model before you move to the next model.
4. Draw diagrams of each of your models and label each part in the space below or in your science notebook.

Hydrogen Atom **Hydrogen Molecule** **Oxygen Atom** **Water Molecule**

What is a Fuel Cell?

Background

In principle, a fuel cell operates like a battery. Unlike a battery, a fuel cell does not run down or require recharging. It can produce energy in the forms of electricity and heat as long as fuel is supplied. A fuel cell consists of an electrolyte membrane sandwiched between two catalyst–coated electrodes. Oxygen passes through one electrode and hydrogen through the other, generating electricity, water, and heat.

Hydrogen gas (H_2) from a storage tank is fed into the anode of the fuel cell. When the gas comes in contact with the catalyst, the hydrogen molecules split into hydrogen ions (H^+) and electrons (e^-). The positively charged hydrogen ions, attracted by the negatively charged oxygen ions, pass through the electrolyte membrane to the cathode. The membrane does not allow electrons to pass through, so the electrons flow through a separate circuit (that can be used to do work) as they travel to the cathode. Oxygen molecules from the air enter the fuel cell through the cathode, split into oxygen atoms, and pick up two electrons to become oxygen ions (O^{--}). At the cathode, two hydrogen ions and one oxygen ion combine to form a molecule of water, which exits the fuel cell through the cathode.

Overview

In this activity, students will assume roles to simulate a fuel cell system. Fifteen students are needed for the simulation to assume the following roles:

- 2 Anodes (A hang tags)
- 2 Cathodes (CA hang tags)
- 2 Polymer Electrolyte Membranes—PEMs (P hangtags)
- 4 Hydrogens (hang tags with H on one side and H^+ on the other)
- 2 Oxygens (hang tags with O on one side and O^{--} on the other)
- 3 Circuit Members (C hang tags)

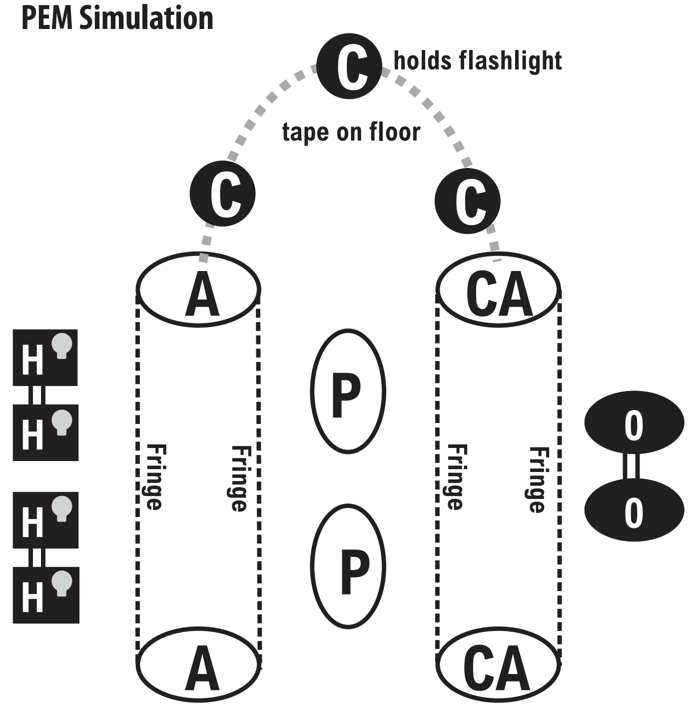
Materials

- 4 Pieces of fringe six feet long to represent the anode and cathode
- 4 Flashing bulbs to represent electrons
- 1 Flashlight to represent work being done
- 1 Piece of colored tape 12 feet long to represent the external circuit
- 15 Hang tags (see roles above)

Procedure

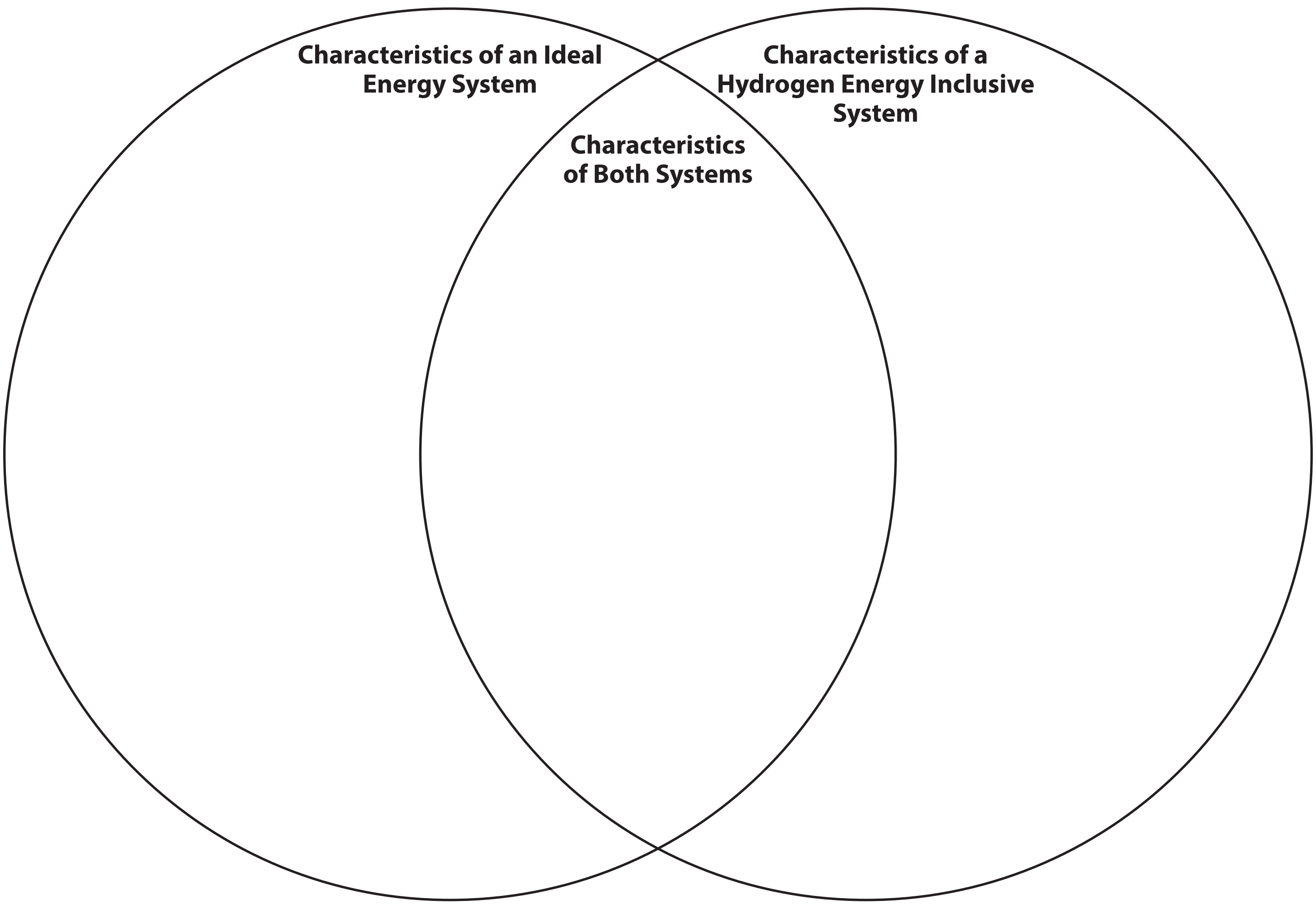
1. Choose roles, put on hang tags, hold the equipment you need, and use the diagram to set up the activity.
2. Simulate the fuel cell system several times, switching students' roles after each simulation.
3. Draw a diagram of a fuel cell and explain how it works using all of the roles in the simulation.

PEM Simulation



Hydrogen in Our Energy System

Use the informational text and complete the Venn diagram below to compare an ideal energy system to one that incorporates the use of hydrogen. Underline the most important problem with reaching the goal of a hydrogen economy and write a paragraph explaining why you think it is important and what you think should be done to solve the problem.



Glossary

absorption	a process in which one substance permeates another
adsorption	the attachment of molecules of gases, liquids, or dissolved substances to a solid surface
anode	the electrode of a fuel cell or battery that produces electrons
atom	the smallest unit of an element that can exist alone or in combination
atomic mass	the average mass of one atom of an element
atomic number	the number of protons in an atom's nucleus
biomass	organic materials used as fuel
biomass gasification	process in which wood chips and agricultural wastes are superheated until they turn into hydrogen and other gases
carbon dioxide (CO_2)	a colorless, odorless, incombustible gas formed during respiration, combustion, and organic decomposition; an important greenhouse gas
carbon monoxide (CO)	a colorless, odorless, poisonous gas, produced by incomplete burning of carbon-based fuels, including gasoline, oil, and wood
catalyst	a substance that increases the rate of a chemical reaction without being produced or consumed in the reaction
cathode	the electrode of a fuel cell or battery that consumes electrons
centralized generation	generation of electricity that is produced in large quantities off-site and then distributed to the consumers
chemical energy	the potential energy that is stored in the bonds of molecules
circuit	the path through which an electric current flows
coal gasification	process of turning coal into gases using high temperature and pressure, then mixing the gases with steam to produce hydrogen
combustion	rapid chemical reaction of oxygen with a substance, producing light and heat
compound	two or more elements chemically bonded together
conductor	a substance that conducts heat or electricity
covalent bonding	bonds that occur when atoms are held together with shared electrons
decomposed	broken down into basic elements
decomposition reaction	a reaction that separates a substance into two or more different substances
diatomic molecule	a molecule with two atoms
dissociate	the breaking of a compound into its components
distributed generation	generation of electricity at or near the location of consumption
distribution system	the network of wires and other equipment that delivers electricity
dry cell	a voltaic cell in which the electrolyte is a paste
electrical charge	a force within a particle
electricity	a form of energy that is created by the flow of electrons
electrochemical energy conversion device	a device such as a battery or fuel cell that uses a chemical reaction to produce electricity
electrochemistry	branch of chemistry studying production of electricity by chemical reactions and chemical changes
electrode	a conductor that can carry electrons to or from a substance
electrolysis	a process that uses an electric current to break a molecule apart
electrolyte	a substance whose water solution conducts an electric current due to the presence of ions
electrolytic cell	a device that converts electrical energy into chemical energy through electrolysis
electron	a subatomic particle that has a negative charge found in an orbit around the nucleus

element	a substance in which all of the atoms are chemically identical
endothermic reaction	a chemical reaction that requires the input of energy
energy	the capacity to do work or make a change
energy carrier	a substance or system that moves energy in a usable form from one place to another (for example, electricity)
energy efficiency	the ratio of output energy per unit of input energy
energy level (shell)	an orbit around the nucleus of an atom in which electrons are found
fossil fuel	a fuel created by the decomposition of ancient organic materials
fuel cell	a device that produces a reaction between chemicals and generates an electric current in the process; a fuel cell does not run down or require recharging
fusion	a process in which atomic nuclei combine and release a large amount of energy
greenhouse gas	a gas that causes heat to be trapped in the atmosphere, inhibiting the cooling of the Earth's surface
hydrogen	the lightest and most abundant element; most hydrogen atoms consists of one proton and one electron
ion	an atom that has a net charge due to the loss or gain of an electron
ionic bonding	an attraction between oppositely charged ions that bonds two atoms
isotope	atoms of the same element, with differing numbers of neutrons
membrane	a material that forms a barrier and allows selective materials to pass
methane (CH_4)	a greenhouse gas that is a main ingredient in natural gas
molecule	the smallest particle of a covalently bonded compound; consists of atoms joined by covalent bonds
neutron	a subatomic particle that has no electrical charge found in the nucleus
nonrenewable	a resource that cannot be replenished in a short time and is considered finite
nuclear thermochemical production	process in which extremely high heat produced from a controlled nuclear reaction is used to decompose water into hydrogen and oxygen gases
nucleus	the center of an atom that includes the neutrons and protons
oxidation	a chemical reaction in which atoms or ions lose electrons
oxygen	a colorless, odorless gas; stable oxygen atoms consist of eight protons, eight neutrons, and eight electrons
periodic table	the arrangement of chemical elements by their physical and chemical properties
photobiological microbial production	a process in which algae and bacteria under certain conditions use sunlight to produce hydrogen
photoelectrolysis	a process that uses sunlight to split water into hydrogen and oxygen
polar molecule	a molecule that has both negative and positive poles
polymer	a large molecule made of many small repeating molecules
polymer electrolyte or proton exchange membrane (PEM)	an electrolyte membrane that conducts positive ions and blocks negative ions
proton	a subatomic particle with a positive charge found in the nucleus
radiant energy	energy in the form of electromagnetic waves; energy from the sun
reduction	a chemical reaction in which atoms or ions gain electrons
renewable	a resource that is inexhaustible or can be replenished in a short period of time
steam reforming	an industrial process that uses high-temperature steam to separate hydrogen from the carbon atoms in methane (CH_4)
subatomic	smaller than an atom
valence electron	electron in the outermost energy level
voltaic cell	a cell that converts chemical energy to electricity; a battery
water (H_2O)	a clear, colorless, odorless, tasteless liquid that is essential for most plant and animal life; composed of chemically bonded hydrogen and oxygen

National Sponsors and Partners

American Electric Power
Arizona Public Service
Arizona Science Center
Armstrong Energy Corporation
Association of Desk & Derrick Clubs
Audubon Society of Western Pennsylvania
Barnstable County, Massachusetts
Robert L. Bayless, Producer, LLC
BP America Inc.
Blue Grass Energy
Boulder Valley School District
Brady Trane
California State University
Cape Light Compact–Massachusetts
Chevron
Chugach Electric Association, Inc.
Colegio Rochester
Columbia Gas of Massachusetts
ComEd
ConEdison Solutions
ConocoPhillips
Constellation
Cuesta College
Daniel Math and Science Center
David Petroleum Corporation
Desk and Derrick of Roswell, NM
Dominion
DonorsChoose
Duke Energy
East Kentucky Power
Eastern Kentucky University
Elba Liquifaction Company
El Paso Corporation
E.M.G. Oil Properties
Encana
Encana Cares Foundation
Energy Education for Michigan
Energy Training Solutions
Eversource
Exelon Foundation
First Roswell Company
FJ Management. Inc.
Foundation for Environmental Education
FPL
The Franklin Institute
Frontier Associates
Government of Thailand–Energy Ministry
Green Power EMC
Guilford County Schools – North Carolina
Gulf Power
Gerald Harrington, Geologist
Granite Education Foundation
Harvard Petroleum
Hawaii Energy
Houston Museum of Natural Science
Idaho Power
Idaho National Laboratory
Illinois Clean Energy Community Foundation
Independent Petroleum Association of America
Independent Petroleum Association of New Mexico
Indiana Michigan Power – An AEP Company
Interstate Renewable Energy Council
James Madison University
Kentucky Clean Fuels Coalition
Kentucky Department of Education
Kentucky Department of Energy Development and Independence
Kentucky Power – An AEP Company
Kentucky River Properties LLC
Kentucky Utilities Company
Kinder Morgan
Leidos
Linn County Rural Electric Cooperative
Llano Land and Exploration
Louisiana State University Cooperative Extension
Louisville Gas and Electric Company
Maine Energy Education Project
Massachusetts Division of Energy Resources
Michigan Oil and Gas Producers Education Foundation
Miller Energy
Mississippi Development Authority–Energy Division
Mojave Environmental Education Consortium
Mojave Unified School District
Montana Energy Education Council
NASA
National Association of State Energy Officials
National Fuel
National Grid
National Hydropower Association
National Ocean Industries Association
National Renewable Energy Laboratory
Nebraska Public Power District
New Mexico Oil Corporation
New Mexico Landman's Association
Nicor Gas – An AGL Resources Company
Northern Rivers Family Services
North Shore Gas
NRG Energy, Inc.
Offshore Energy Center
Offshore Technology Conference
Ohio Energy Project
Opterra Energy
Oxnard School District
Pacific Gas and Electric Company
Paxton Resources
PECO
Pecos Valley Energy Committee
Peoples Gas
Petroleum Equipment and Services Association
Phillips 66
PNM
Providence Public Schools
Read & Stevens, Inc.
Renewable Energy Alaska Project
Rhode Island Office of Energy Resources
River Parishes Community College
RiverQuest
Robert Armstrong
Roswell Geological Society
Salt River Project
Sandia National Laboratory
Saudi Aramco
Science Museum of Virginia
C.T. Seaver Trust
Shell
Shell Chemicals
Society of Petroleum Engineers
Society of Petroleum Engineers – Middle East, North Africa and South Asia
David Sorenson
Southern Company
Space Sciences Laboratory of the University of California Berkeley
Tennessee Department of Economic and Community Development–Energy Division
Tioga Energy
Toyota
Tri-State Generation and Transmission
TXU Energy
United States Energy Association
University of Georgia
United Way of Greater Philadelphia and Southern New Jersey
University of Nevada–Las Vegas, NV
University of North Carolina
University of Tennessee
University of Texas - Austin
University of Texas - Tyler
U.S. Department of Energy
U.S. Department of Energy–Office of Energy Efficiency and Renewable Energy
U.S. Department of Energy–Wind for Schools
U.S. Department of the Interior–Bureau of Land Management
U.S. Energy Information Administration
West Bay Exploration
West Virginia State University
Yates Petroleum Corporation