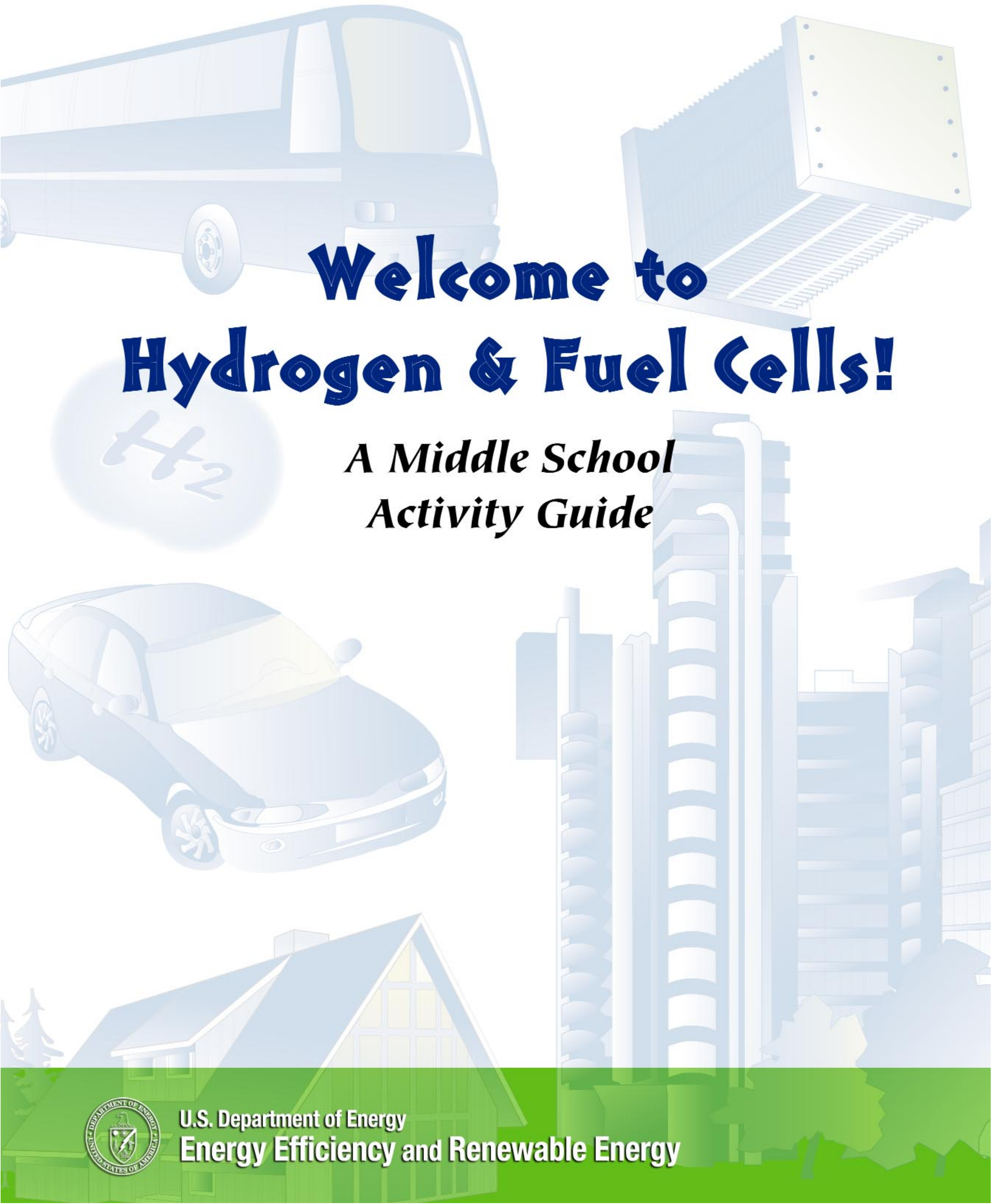

Welcome to Hydrogen & Fuel Cells!

A Middle School Activity Guide

U.S. Department of Energy
Energy Efficiency and Renewable Energy

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Welcome to the World of Hydrogen and Fuel Cells!

The U.S. Department of Energy is pleased to present this Hydrogen and Fuel Cell Activity Guide, created to help interested teachers bring the exciting world of hydrogen and fuel cells to their students.

Fuel cells use hydrogen and oxygen to create electricity, with only water and heat as byproducts. Hydrogen — abundant, clean, and efficient — can be derived from diverse domestic resources such as natural gas and water. Hydrogen fuel cell technology offers the promise of a world in which energy is abundant, clean, reliable, and affordable.

Hydrogen and fuel cells are topics not often covered in classrooms or traditional textbooks. The U.S. Department of Energy has designed this guide to include the following concepts:

1. In a "hydrogen economy," hydrogen is used to power our cars, homes, and businesses.
2. Hydrogen can be made from abundant and diverse resources found in the United States.
3. Fuel cells use hydrogen to create electricity with the only byproducts being water and heat (no pollutants or other emissions are released).
4. Fuel cells can be used to power almost anything from laptops and phones to cars and homes.
5. Just like gasoline and other fuels, hydrogen can be used safely.

Note to Teachers:

Teachers and students may recognize a few of the activities found in this guide. Great efforts have been made, however, to adapt traditional lessons to follow an inquiry-based approach and actively engage students in the subject material. This activity guide uses several techniques to encourage students to document their thoughts, ideas, and questions. Class discussions follow most activities, which allow students to discuss and share their thoughts — and learn from each other. Common misunderstandings may emerge in these discussions, and teachers can address them at that time or in follow-up lessons. Traditional activity sheets are also provided for most lessons as an alternative to using inquiry-based science journaling or note-taking techniques described in the extension section at the end of this guide.

The Pre-Knowledge Inventory provided in this guide is intended for students prior to instruction to gauge their baseline knowledge (and should not be graded). The Post-Knowledge Inventory should be administered after completing the lessons to measure what has been learned. Teachers may wish to use this as a formal graded assessment.

This guide maps to the National Research Council's National Science Teaching Standards, as well as National Standards in Language Arts and Social Studies.

Four basic sections comprise the guide:

I. Introduction
II. Hydrogen
III. Fuel Cells
IV. Putting It All Together — The Vision of the Hydrogen Economy

This CD contains the multimedia support files referenced in this guide. Where PowerPoint slides are indicated, the actual PowerPoint files are located on the CD. Notes pages with thumbnails of each slide and its accompanying text are included in this guide for your reference. For display purposes, you can either show the slides from the CD or print transparencies from the CD.

We hope that you will share our excitement in educating young people about hydrogen and fuel cells and encourage you to share this guide with colleagues and others. Additional copies are available free of charge from DOE's Energy Efficiency and Renewable Energy Information Center at 877-EERE-INF(O) and can be downloaded from DOE's hydrogen and fuel cell web site, *www.eere.energy.gov/hydrogenandfuelcells/education.html.*

We would appreciate your feedback regarding the usefulness of this activity guide, suggested changes, and results from the pre- and post-knowledge inventories. To share your comments and to remain on our mailing list, please visit *www.eere.energy.gov/hydrogenandfuelcells/education.html.*

Pre-Knowledge Inventory

Directions to students:
This knowledge inventory is designed to help you and your teacher understand what you already know about hydrogen and fuel cells. This will not be graded. You will have another opportunity to answer the same questions and demonstrate what you have learned after completing this unit.

1. What is meant by the hydrogen economy? Circle the best answer.
- a. Stocks rise and are said to be "lighter than air."
- b. Paper money can be produced using hydrogen as its main ingredient.
- c. Hydrogen will be used to provide our power needs.
- d. Shares of hydrogen will be traded on the stock market.

2. How is hydrogen produced? Circle the best answer.
- a. By using electricity to separate water molecules into hydrogen and oxygen.
- b. Naturally, using certain types of algae.
- c. By extracting it from natural gas, coal, and other fossil fuels.
- d. All of the above.

3. What are the benefits of using hydrogen as a form of energy? Circle the best answer.
- a. Hydrogen can be found in the U.S. in pockets concentrated in the Pacific Northwest.
- b. Hydrogen can be used to create electricity cleanly — with only water and heat as byproducts.
- c. Hydrogen-powered fuel cells have moving parts that wear out very quickly.
- d. Hydrogen is currently cheaper to produce than gasoline.

True or False

_________ 4. Fuel cells have been used by NASA to provide power aboard the Space Shuttle.

_________ 5. When handled properly, hydrogen is safe to use in our personal vehicles.

_________ 6. Hydrogen is the heaviest element on earth.

_________ 7. Fuel cells produce electricity.

_________ 8. Hydrogen is a gas and does not exist as a liquid.

_________ 9. There are many kinds of fuel cells.

_________10. Fuel cells have no moving parts and operate completely silently.

11. Circle all of the following items that could be powered safely by hydrogen fuel cells.

a. Cars

b. CD players

c. Vacuum cleaners

d. Industrial equipment

e. Street lights

f. Homes

g. Buses

h. Motorcycles

i. Power tools

Post-Knowledge Inventory

Directions to students:
This knowledge inventory is designed to help you and your teacher understand what you have learned about hydrogen and fuel cells. This is the same Knowledge Inventory you completed at the beginning of this unit and will be used to compare your knowledge before and after completing the activities.

1. What is meant by the hydrogen economy? Circle the best answer.

a. Stocks rise and are said to be "lighter than air."
b. Paper money can be produced using hydrogen as its main ingredient.
c. Hydrogen will be used to provide our power needs.
d. Shares of hydrogen will be traded on the stock market.

2. How is hydrogen produced? Circle the best answer.

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b. Naturally, using certain types of algae.
c. By extracting it from natural gas, coal, and other fossil fuels.
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g. Buses

h. Motorcycles

i. Power tools

Hydrogen Introductory Activity — Mystery Scientist

A. Activity Summary
In the following activity, students discover a famous "mystery" scientist. The story is designed to give students clues as to the scientist's identity and engage them in the history of science.

This activity can be used as part of a science, history, or language arts class. If your school uses a team or theme approach to teaching, non-science teachers may wish to use this activity to supplement the theme taught in the science class.

Students should develop and document their plans for how they will identify the scientist before they attempt to solve the mystery. They can revise their approaches as they work but should document adjustments to their plans. As a separate language arts activity, teachers may wish to conduct a class discussion or journaling activity in which students explain how they solved the mystery.

B. Standards
Science

• Science and Technology Content Standard E
  - ✔ As a result of activities in grades 5–8, all students should develop —
    - -Science in Personal and Social Perspectives

• History and Nature of Science Content Standard G
  - ✔ As a result of activities in grades 5–8, all students should develop an understanding of —
    - -Science as a Human Endeavor
    - -Nature of Science
    - -History of Science

C. Teacher Background
The mystery scientist in this selection is Henry Cavendish.

D. Materials
Copies of Mystery Scientist #1 for each student

E. Activity Steps
1. Introduce the activity to students — tell them they are going to read about a mystery scientist.

2. Explain that students should develop a plan for how they will identify the mystery scientist (they can document their plan in their science journals).

3. Explain to students that the class will discuss the mystery scientist's significant accomplishments once his or her identity is revealed.

Mystery Scientist

This scientist was born on October 10, 1731, in Nice, France. His parents were British, but his family moved to Nice, on the coast of France, to help improve his mother's health. He descended from two great and wealthy families — his mother was Lady Anne Gray, daughter of the Duke of Kent, and his father was Lord Charles, son of the second Duke of Devonshire. He was able to trace his family tree back eight centuries and was connected to many aristocratic families of Great Britain.

Despite his family's wealth, however, this man's early life was not easy. When he was only two years old, his mother died after giving birth to his brother Frederick. At the age of 18, he entered St. Peter's College at the University of Cambridge. He studied there for four years but did not receive a degree, probably because he refused to declare his loyalty to the Church of England.

After four years of college education and little to show for his efforts, this scientist decided to drop out of academic life and tour Europe with his brother. When he tired of traveling, he moved in with his father, Lord Charles, and lived in the SoHo section of London. It was during this time in SoHo that he conducted most of his electrical and chemical research, first as Lord Charles' assistant. A remarkable scientist, Lord Charles received praise from many great men of his time, including Benjamin Franklin. Even though his father was very wealthy, he did not like to spend money frivolously, so they lived a frugal life. In 1783, upon his father's death, this mystery scientist suddenly found himself a millionaire and in control of a fortune. He has been called, "the richest of all learned men, and very likely also the most learned of all the rich."

Upon receiving his inheritance, this mystery scientist could afford to buy anything he pleased, so he moved to a villa and set up a well-stocked laboratory and library. His house included an outdoor wooden stage, from which he could climb a large tree to view the sky and make astronomical observations, and a large telescope on the roof could be seen for miles around.

This scientist, an eccentric millionaire physicist and chemist, conducted experiments in many fields —

- He demonstrated that water is made of oxygen and "inflammable" air, called hydrogen, which he is credited with discovering and determining its specific gravity.
- He demonstrated the composition of air and various properties of electricity.
- He showed that hydrogen and oxygen, both gases, when combined, form water, and that the weight of the water produced is equal to that of the gases. This led to the discovery that water is a compound and not an element.
- He performed experiments with carbon dioxide, known then as "fixed air."
- He is also believed to have discovered nitric acid in 1785.
- He investigated the physical properties of gold alloys to help the government understand the loss of gold in coins due to wear.
- He devised new astronomical instruments to study the heavens.
- He even measured the density and mass of the Earth using a method known today as the ___________ (his last name) experiment. Sir Isaac Newton had discovered the Law of Universal Gravitation before he died in 1726. However, Newton's law included a missing "unknown constant" which this mystery scientist discovered using this experiment.

Even though this mystery scientist was wealthy beyond belief, his father had raised him strictly, so as not to spoil him. Used to living on a small allowance, he did not spend money on personal luxuries. But he was quite generous to others. Once, when attending a christening, he learned it was customary to give the nurse a gift. He stuck his hand in his pocket and gave her a handful of gold coins, without bothering to count how much he gave her. When making contributions to charities, he would ask what the highest donation had been and would match it exactly. Aside from his donations, he spent most of his money on scientific equipment and books which he kept in a large library and made available to other scientists. Can you imagine having all the money you could ever want? Can you imagine being able to spend as much as you wanted on your hobby? Can you imagine the pursuit of scientific discovery as a hobby?

This mystery scientist was viewed by those outside the scientific community as a shabby, strange, quiet, and shy man. He chose to live a solitary life, perhaps because he spoke with hesitation and difficulty in a thin, squeaky voice. He almost never appeared in public and was so terrified of women that he communicated with his female servants using written notes that usually described what he wanted for dinner - "a leg of mutton." He even went so far as to order all of his female help to stay out of his sight. Needless to say, he never married or had close friendships outside of his family. His only social activity was the weekly dinner meeting conducted by the Royal Society Club, a casual organization for scientists, scholars, politicians, and patrons of science and learning. This group became very influential throughout the 1800s, increasing knowledge of the natural sciences and advising the English Government on scientific matters. Even though he rarely missed these meetings, he seldom spoke and would not allow a formal self-portrait to be painted. The only likeness of him known to exist today was sketched during one of the Royal Society dinners without his knowledge. He was an active member of the Royal Society from 1760 until his death in 1810 at the age of 78.

The outside world had little effect on this man. He usually wore a very outdated outfit that consisted of a faded, crumpled violet suit with a high collar and frilled cuffs, worn with a three-cornered hat. This appeared just as strange in his time as it would in ours and led people to regard him as a truly "mad scientist."

Because of his quiet nature, reluctance to publish his findings, and lack of contact with the scientific community, credit for his discovery of the composition of water was nearly given to two other scientists who had carried out similar investigations after he did. He was forced to prove that he was responsible for the discovery — and learned a valuable lesson about communication. Despite this experience, he still lacked a desire to formally publish his research findings (he published only twenty articles and no books), and the credits for many of his important conclusions about electricity were given to scientists Faraday, Coulomb, and Ohm, who became quite famous for these discoveries. This mystery scientist's electrical experiments included studies of current strength. He measured the strength of electrical currents by giving himself a series of shocks and documenting the amount of pain! (He truly suffered for his science). He carried out his experiments simply to satisfy his own curiosity, often repeating an experiment many times to ensure the accuracy of his findings. This scientist was not the sort of man who sought fame or credit — but he finally received the recognition he deserved when, in the late 19th century, the University of Cambridge named a new laboratory after him. This laboratory has produced some of the finest nuclear physics discoveries of our time and has proven worthy of his name and memory.

Even as he lay dying, this man chose to be alone so that he could observe and record the progress of illness throughout his body. When he felt his time was near, he sent his servant out of the room and told him to check back later — if the servant found him dead, he was to notify his family. This mystery scientist left his fortune to his relatives, most of it to the son of his first cousin. He is buried in what is now Derby Cathedral, England.

Who is this mystery scientist?

Hydrogen Mini Lesson — What is Hydrogen?

A. Activity Summary

This lesson is designed to introduce students to hydrogen and why it is special. Students will learn basic concepts, participate in a class discussion, and write a hydrogen-related poem to demonstrate what they have learned. The discussion will begin with what students know, or think they know, about hydrogen and should lead them to correct scientific concepts. Teachers may wish to have students take notes in their science journals as the discussion progresses to help them remember details about hydrogen to use in their poetry writing.

B. Standards

Science

- Science in Personal and Social Perspectives Content Standard F
  - ✔ As a result of activities in grades 5–8, all students should develop an understanding of —
    - -Populations, resources, and environments
    - -Risks and Benefits

- Physical Science Content Standard B
  - ✔ As a result of their activities in grades 5–8, all students should develop an understanding of —
    - -Properties and changes of properties in matter
    - - Transfer of Energy

- Physical Science Content Standard B
  - ✔ As a result of their activities in grades 5–8, all students should develop an understanding of —
    - -Transfer of Energy

Language Arts

- Standard for the English Language Arts #12
  - ✔ Students use spoken, written, and visual language to accomplish their own purposes (e.g., for learning, enjoyment, persuasion, and the exchange of information).

C. Teacher Background

This lesson consists of a discussion that leads students to a basic understanding of hydrogen and its unique qualities. Hydrogen is the simplest and lightest element — #1 on the periodic table. An atom of hydrogen contains only one electron and one proton. Hydrogen is the most abundant element in our universe. Although it is readily available in the United States, it does not exist by itself in nature. It must be separated from compounds such water, natural gas, coal, or biomass. Moving to a hydrogen economy, in which we use hydrogen to meet our energy needs, would reduce our Nation's dependence on foreign oil.

D. Materials

- Paper and pencils for writing poems
- Discussion script for teacher

E. Activity Steps

1. Use the teacher script below to conduct a class discussion that introduces students to hydrogen.

2. Once students are comfortable with their knowledge of hydrogen, they can begin to write a poem. Any form of poetry will do — but this should be a fun activity in which students can demonstrate what they have learned about hydrogen. Students may wish to conduct further research about hydrogen to add to their poem. The web sites listed in the glossary (see Appendix) will give students a place to start to find further information about both hydrogen and fuel cells.

3. Sample Poem:

Tiny, Powerful, Hydrogen

Hydrogen, Hydrogen
How special you are,
When run through a fuel cell,
You can power a car.

Hydrogen, Hydrogen
A medal you deserve,
Wait, you're not a metal,
You're gas, How absurt!

Hydrogen, Hydrogen
You never find just one,
Attached to an oxygen,
Then water it becomes.

Hydrogen, Hydrogen
You're number one
On the periodic table,
And you're made by the sun.

Hydrogen, Hydrogen
The power you bear,
You're odorless and colorless
We can't tell if you're there.

F. Assessment

Assessment should be based on the scientific accuracy and number of facts presented in student poems.

Discussion Script

Teacher: Has anyone ever heard of something called "hydrogen?" What do you know about hydrogen?

Responses to elicit: Hydrogen is an element which exists naturally as a gas. It is the simplest and lightest element. It is lighter than air, odorless, and colorless.

Teacher: Where is hydrogen on the periodic table?

Responses to elicit: It is number one on the periodic table.

Teacher: What smaller particles make up every atom of hydrogen?

Responses to elicit: Hydrogen is made up of one electron and one proton.

Teacher: How do we use hydrogen?

Responses to elicit: Hydrogen is used in industry (petroleum refining, chemical production, treating metals).

Hydrogen can also be used as an energy carrier, or a fuel, to provide power. NASA has used hydrogen for many years aboard the space shuttle to power equipment using a fuel cell. Fuel cells use hydrogen and oxygen to create electricity that can power a motor or do other work. The only emission is water, and on board the Space Shuttle, the water produced as a byproduct of the fuel cell is used for the astronauts' drinking water — it's that clean!

Teacher: Where do we find hydrogen?

Responses to elicit: Hydrogen is present in a number of different resources — water, fossil fuels (hydrocarbons — hydrogen and carbon), biological material, etc. But even though it is found just about everywhere, it doesn't exist by itself in nature — it is found attached to other atoms in compounds and must be separated from the other atoms.

Today, most of the hydrogen produced in the U.S. is made from natural gas.

FACT: The U.S. hydrogen industry produces about 9 million tons of hydrogen annually. That's enough hydrogen to power 20–30 million cars or 5–8 million homes.

Teacher: Is there a lot of hydrogen in our world?

Responses to elicit: It is the most abundant element in the universe. But it doesn't exist by itself on Earth — it is always found with other elements in the form of compounds. Hydrogen is found in water, H_2O, combined with oxygen. It is also combined with carbon in methane (natural gas), CH_4, which many people used to heat their homes. Hydrogen also combines with carbon to form propane (C_3H_8).

Teacher: How is hydrogen produced or separated from the compounds in which it exists?

Responses to elicit: Since hydrogen doesn't exist on Earth by itself, we must make it. We make it by separating it from compounds such as water, biomass (wood, garbage, and agricultural waste), or natural gas. Scientists have even discovered that some algae and bacteria produce hydrogen.

Teacher: Why do we care so much about hydrogen?

Responses to solicit: Most of the energy we use today in the United States comes from fossil fuels that we must import from other countries. The U.S. imports over 50% of its petroleum. Using hydrogen made from resources found in the United States will reduce our dependence on other countries to meet our energy needs.

Teacher: How can use hydrogen as a fuel — what can it power?

Responses to solicit: Hydrogen can power just about anything, from small portable equipment to buildings and even cars and trucks.

Hydrogen — How Do We Produce, Deliver, and Store Hydrogen?

A. Activity Summary

In this activity students view a PowerPoint slide presentation while the teacher reads a prepared script to learn about the production and storage of hydrogen. An activity sheet is provided for students to complete as they view the slides, or teachers may have students take notes in their science journals using the format mentioned in the extension section of this guide.

B. Standards

<u>Science</u>

• Science and Technology Content Standard E

- ✔ As a result of activities in grades 5–8, all students should develop —
  -Understanding about science and technology

• Science in Personal and Social Perspectives Content Standard F

- ✔ As a result of activities in grades 5–8, all students should develop an understanding of —
  -Populations, resources, and environments
  -Risks and Benefits
  -Science and Technology in Society

<u>Social Studies</u>

• Teaching Standard #8 — Science, Technology, and Society

- ✔ Social studies teachers should possess the knowledge, capabilities, and dispositions to organize and provide instruction at the appropriate school level for the study of science, technology, and society.

<u>Language Arts</u>

• Standards for English Language Arts #1

- ✔ Students read a wide range of print and non-print texts to build an understanding of texts, of themselves, and of the cultures of the United States and the world; to acquire new information; to respond to the needs and demands of society and the workplace; and for personal fulfillment. Among these texts are fiction and nonfiction, classic and contemporary works.

• Standards for the English Language Arts #8

- ✔ Students use a variety of technological and information resources (e.g., libraries, databases, computer networks, video) to gather and synthesize information and to create and communicate knowledge.

• Standards for the English Language Arts #12

- ✔ Students use spoken, written, and visual language to accomplish their own purposes (e.g., for learning, enjoyment, persuasion, and the exchange of information).

C. Teacher Background

Hydrogen is the most abundant element in the universe, but it does not exist by itself in nature. Instead, it is found bonded to other elements in compounds such as water, natural gas, coal, or biological material. This presents one of the major challenges to hydrogen and fuel cell commercialization, and achieving the vision of a hydrogen economy – how to economically extract pure hydrogen from its naturally existing state. Hydrogen has been used in the chemical and refining industries for many years. Today's U.S. hydrogen industry produces more than 9 million tons of hydrogen annually. With the exception of a handful (but growing) number of demonstration projects, NASA is the primary user of hydrogen as an energy carrier. In addition to the cost-effective production of hydrogen, several other technical challenges remain. Among them are developing a hydrogen delivery and refueling infrastructure (drivers need conveniently-located fueling stations for their vehicles), and improving hydrogen storage technologies to enable vehicles to travel just as far on a "tank" of hydrogen as they do on a tank of gasoline. Reducing the cost of fuel cells is also important. The PowerPoint presentation on the enclosed CD is designed to give students a brief overview of hydrogen production, delivery, and storage technologies. This presentation can also be downloaded off the internet at this address: *www.eere.energy.gov/hydrogenandfuelcells/education.html*

D. Materials

• Hydrogen production, delivery, and storage technology PowerPoint presentation
• PowerPoint script for teacher to read to class as the slides are shown

E. Activity Steps

1. Introduce Power Point presentation. *Note: To move from one slide to the next, "left-click" the mouse or press the "enter" or "down-arrow" key. Each slide will run automatically once it starts, but a new slide will not appear without using the mouse or pressing the appropriate key. This is designed to allow you and your class as much time as needed on each slide.

2. Run through the presentation once, completely, without asking students to take notes. Show the presentation a second time and ask students to record their thoughts and questions either in a science journal format, or on the activity sheet included.

3. Ask students to share any of their questions or thoughts to initiate a discussion.

4. When you're ready, break students into groups of three and assign each group one of the following production methods: water electrolysis, steam methane reforming, biological production, photobiological processes (algae), and nuclear power. Ask each group of students to create a news brief on its hydrogen production method. This should be done as a group activity in which all three members of the group agree on the final news brief. A news brief is a short science article of less than five paragraphs, intended to give the essential facts. Each group should write a rough draft first, followed by a group edit with the teacher — the teacher should read drafts aloud, and together with students, agree on changes to the final draft. Students could create artwork or photographs to accompany the final article. Articles can be published in a class newsletter to send home to parents, a district newsletter that informs patrons of student activities, an internal school district newsletter, or a local newspaper that highlights student accomplishments. You will end up with more than one news brief on each of the production methods, which will allow students to compare what other groups thought was important.

F. Extension Ideas

Have students research other hydrogen storage methods that are not fully discussed in the PowerPoint presentation. Two possible topics that should interest students are metal hydrides and carbon nanotubes. Information may be found on U.S. Department of Energy web sites and U.S. Department of Energy national laboratory web sites.

PowerPoint Script

The script for the PowerPoint slides follows the Activity Sheet and Answer Sheet on page 23; it shows each slide and its accompanying text. The PowerPoint file is on the CD.

Production and Storage Slide Show — Activity Sheet

Name: ______________________________

1. What is the lightest and most abundant element in our universe?

2. Hydrogen does not exist by itself in nature, but its atoms are attached to other atoms to form compounds. List two of these compounds.

3. What is the most abundant compound on earth?

4. What is the chemical formula for water?
What does this mean?

5. What is electrolysis?

6. How is most of the hydrogen currently produced in the United States?

7. List one other way to produce hydrogen.

8. List one barrier scientists must solve before we can use hydrogen widely.

9. What are the two things needed for a fuel cell to produce electricity?

10. What is the only exhaust produced by a fuel cell?

11. List two different applications that could be powered by a fuel cell.

12. Imagine one thing in your current life that would be different if it was powered by a fuel cell. How would this change affect your life? Be creative!

Production and Storage Slide Show — Activity Sheet — Answer Sheet

Name: ____

1. What is the lightest and most abundant element in our universe?
   Hydrogen

2. Hydrogen does not exist by itself in nature, but its atoms are attached to other atoms to form compounds. List two of these compounds.
   Any fossil fuel such as oil, natural gas, coal;
   Biological materials such as corn, wheat, oats, barley, etc.;
   Any plant material such as trees, flowers, and food crops;
   Water

3. What is the most abundant compound on earth?
   Water

4. What is the chemical formula for water? **H_2O**
   What does this mean?
   In every molecule of water, there are two atoms of hydrogen and one atom of oxygen. This also means that there is twice as much hydrogen as oxygen in one molecule of water.

5. What is electrolysis?
   Using an electric current to split water into hydrogen and oxygen

6. How is most of the hydrogen currently produced in the United States?
   Steam methane reforming which uses high temperature steam to break apart methane or other fuel into hydrogen and carbon monoxide.

7. List one other way to produce hydrogen.
   Breaking down biological material (also called Biomass) using heat;
   Algae produces hydrogen naturally in the presence of sunlight;
   Splitting water using sunlight, solar heat, wind power, or heat from a nuclear power plant.

8. List one barrier scientists must solve before we can use hydrogen widely.

Cost of production;
Safe storage of hydrogen;
Storage tanks need to store enough hydrogen to enable a car to travel 300–350 miles, as our current gasoline powered vehicles do;
Storage tanks cannot be so large that they take up all the trunk space;
New pipelines may need to be built to transport hydrogen to where it is needed.

9. What are the two things needed for a fuel cell to produce electricity?

Hydrogen and Oxygen

10. What is the only exhaust produced by a fuel cell?

Water

11. List two different applications that could be powered by a fuel cell.

Anything that currently uses electricity, battery power, or gasoline, such as automobiles, trucks, cell phones, laptop computers, home heating and air conditioning, powering factories, etc.

12. Imagine one thing in your current life that would be different if it was powered by a fuel cell. How would this change affect your life? Be creative!

Answers will vary.

Hydrogen and Fuel Cells

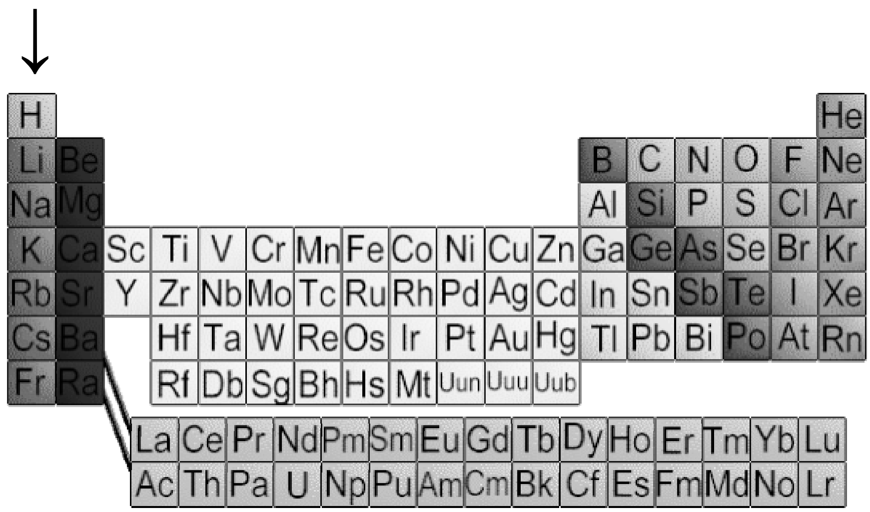
How is Hydrogen Produced, Delivered, and Stored?

Brought to you by –

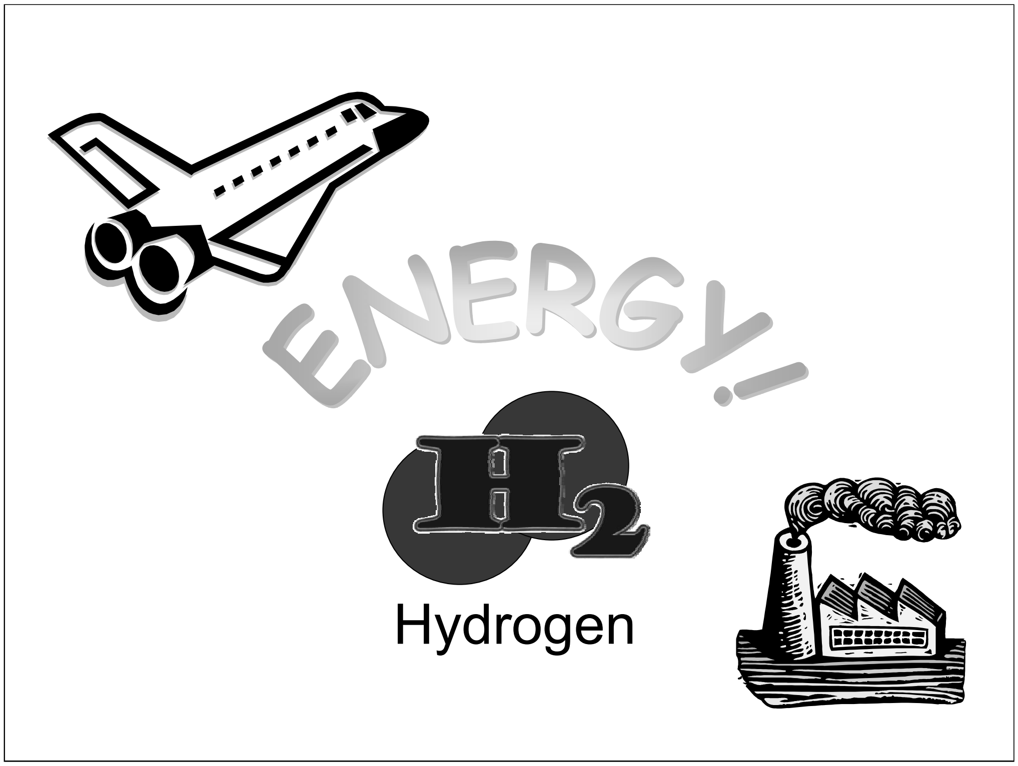
U.S. Department of Energy
Energy Efficiency and Renewable Energy

Welcome to the world of hydrogen! In this slide show, you will learn about hydrogen as a form of energy — and how it can be safely produced, stored, and delivered.

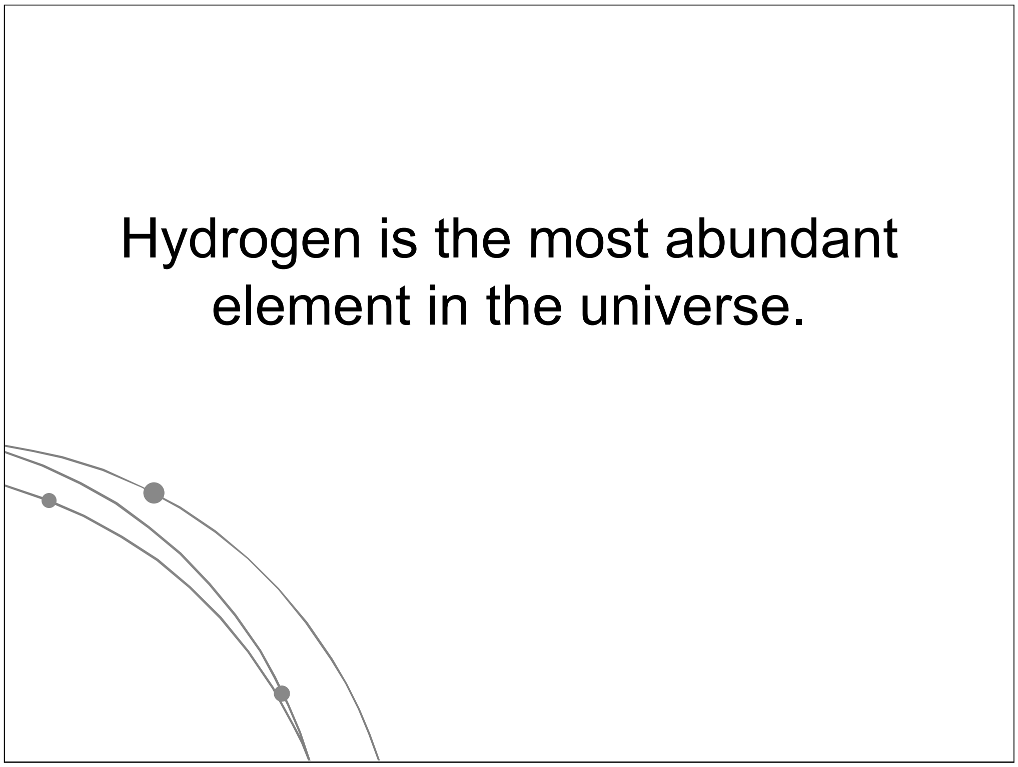
Hydrogen is #1 on the Periodic Table



Hydrogen — first and lightest element on the periodic table.



Hydrogen has been used in the chemical and refining industries and the space program for many years, but its most exciting use is as a form of energy. When used in fuel cells to create electricity, hydrogen offers the promise of a safe, clean, and sustainable energy future. But in order to benefit from using hydrogen as a form of energy, we must be able to safely and efficiently produce, store, and deliver it.



Hydrogen is the most abundant element in our universe.

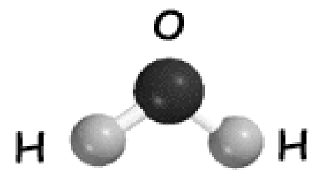
Hydrogen does not exist in nature by itself, but it is found as part of a compound in abundant and diverse resources such as the fossil fuels natural gas and coal.

- What is the most *abundant* compound on earth?

It is also found in a great number of diverse resources on earth — and in the United States. But hydrogen does not exist by itself in nature. Hydrogen atoms are always found with other atoms, as part of a compound. Hydrogen can be found in fossil fuels, such as natural gas and coal, in biological or plant materials, and in other compounds. Can you name the most abundant compound on earth?

That's right, it's water. And water contains hydrogen.

Water = H_2O



Two Hydrogen Atoms **One Oxygen Atom**

Electrolysis:	The process of using an electrical current to split water into hydrogen and oxygen.

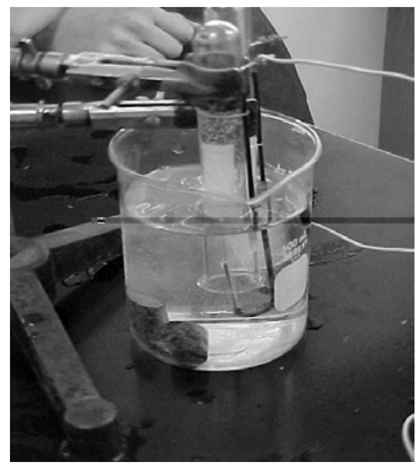
The chemical formula of water is H_2O. This means that in every molecule of water, there are two atoms of hydrogen and one atom of oxygen. One way to produce hydrogen involves using an electrical current to split water into its component parts, hydrogen and oxygen. This process is called electrolysis.

When the electricity needed for electrolysis is generated using wind or solar power, for example, electrolysis can be a clean and renewable way to produce hydrogen.

wind farm

solar panels

Electrolysis



Electrolysis can be a clean and renewable way to produce hydrogen — the electricity needed for the process can be generated using pollution-free, renewable energy technologies, such as wind or solar power.

Scientists worldwide are researching ways to produce hydrogen safely, cleanly, efficiently, and cost-effectively.

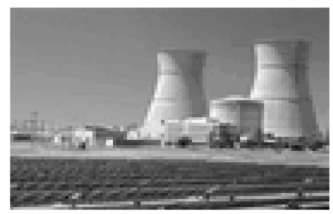
Steam Methane Reforming –

- This method involves using high temperature steam to extract hydrogen from natural gas.
- Both hydrogen and carbon monoxide are produced.
- Today, 95% of the hydrogen produced in the United States is made through steam methane reforming.

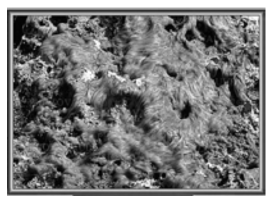
In addition to electrolysis, scientists in the United States and around the world are researching ways to produce hydrogen cleanly, inexpensively, and efficiently. In fact, most of the hydrogen produced today in the United States is extracted through a process called steam methane reforming, in which hydrogen-rich fuels, such as natural gas and coal, are converted into hydrogen and carbon monoxide.

Other hydrogen production technologies use various resources…

biological material



nuclear energy



algae

Other ways to produce hydrogen include —

- Using heat to break down biological material or coal into a gas that is then used to generate hydrogen
- Using certain kinds of algae that produce hydrogen in the presence of sunlight
- And other water-splitting processes, which don't use electricity, but instead use some other form of energy, such as sunlight, solar heat, or heat from a nuclear power plant.

With so many ways to produce hydrogen, the question becomes, “why don’t we use more of it today?”

Challenge = Cost

One of the challenges to using hydrogen as a form of energy is the cost of production. When compared to the fuels we use today, such as gasoline, natural gas, and coal, hydrogen is expensive to produce. Researchers are studying each of the different technologies to reduce the cost of producing hydrogen.

Hydrogen can be produced at small stations…or at large plants and delivered to users.

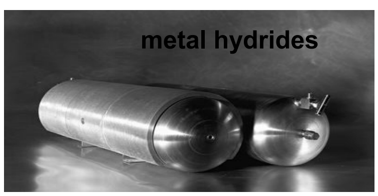
Small amounts of hydrogen can be produced in a distributed manner — or at the point of use, such as a fueling station, for example. But hydrogen can also be produced in greater volumes at large, central plants. Once it's produced at the plant, however, it must be safely and easily stored and delivered to users.

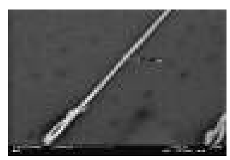
Hydrogen Storage

Hydrogen can be stored as a gas, liquid, and even in a chemical compound.

compressed hydrogen gas tank

liquid hydrogen tank





carbon nanotubes

Hydrogen can be stored as a gas, liquid, and even in a chemical compound. The most common way to store hydrogen is as a compressed gas, in tanks. Liquid hydrogen can also be stored in tanks. Scientists are also researching ways to store hydrogen in chemical compounds.

The Hydrogen Storage Challenge:

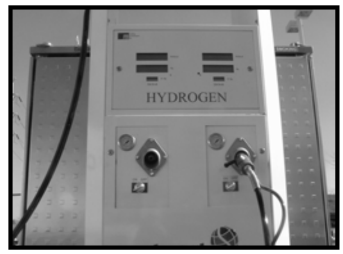
To store enough hydrogen on-board a vehicle to enable drivers to travel 300-350 miles before refueling

When considering the different ways we can use hydrogen as a form of energy, storage presents a technical challenge. The storage tanks on a vehicle must hold enough hydrogen to enable drivers to travel about 300–350 miles before refueling.

Hydrogen storage tanks

But the tanks, which in many prototype hydrogen vehicles are held in the trunk of the car must be small and compact — so as not take up too much trunk space. With a big tank in the back, where would you put your luggage…or your shopping bags…or your golf clubs? Scientists are still working to develop hydrogen storage technologies that will give drivers the range that they're used to, without sacrificing trunk space.

Hydrogen Delivery

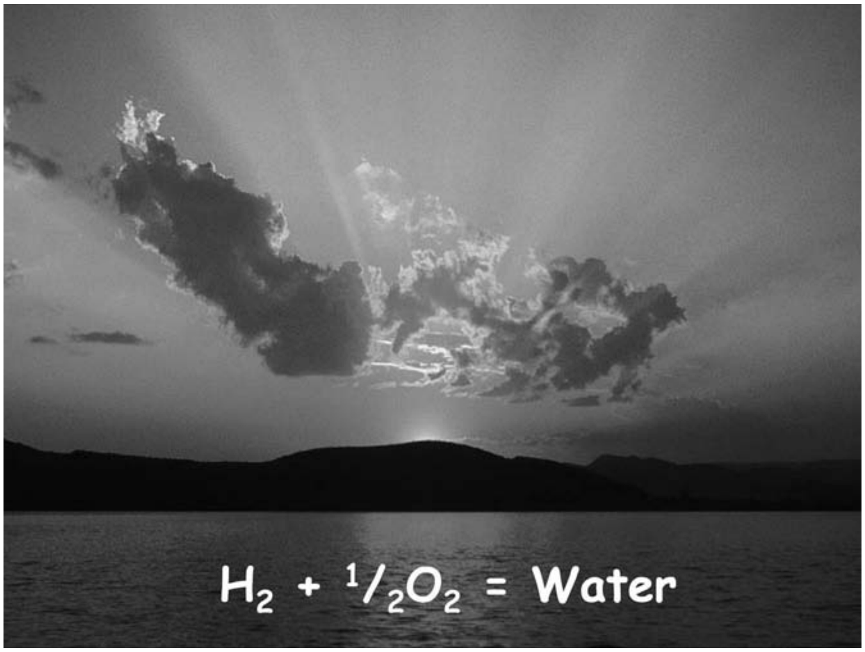


Hydrogen pipelines exist only in certain regions of the country.

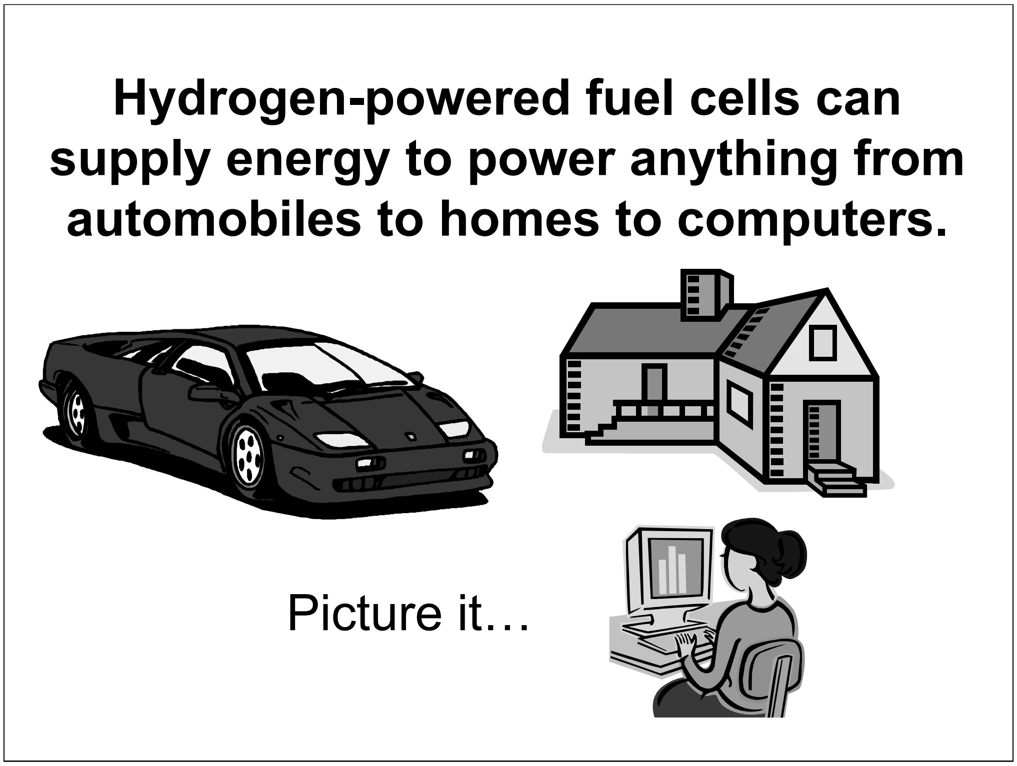
Hydrogen can be transported through pipelines from large production plants to the locations where it will be used. But unlike our network of pipelines for natural gas and other fuels, today's hydrogen pipeline network is small and limited to only certain regions of the country. To enable widespread use of hydrogen, new pipelines may need to be built. Hydrogen can also be stored and delivered by trucks, on railcars, or by ships.

Once hydrogen has been easily produced and safely stored, it can generate electricity using a fuel cell.

So how can we use hydrogen once it has been safely produced, stored, and delivered? One of the most promising possibilities is in a fuel cell.

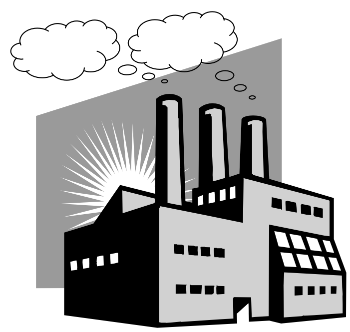


Fuel cells use hydrogen and oxygen – from air – to generate electricity, with the only byproducts being water and heat. There are no harmful pollutants.

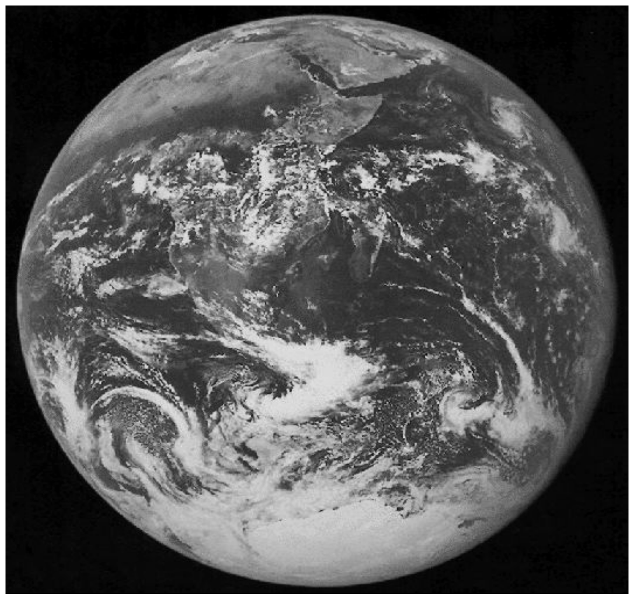


And fuel cells can power just about anything – from small applications, like cell phones and laptop computers, to larger ones, like cars, trucks, buildings, and factories.

Hydrogen is a clean form of energy. It can be used in fuel cells to create electricity with the only byproducts being water and heat.



Hydrogen is a clean form of energy. It can be used in fuel cells to create electricity with the only byproducts being water and heat. There are no harmful pollutants, no black smoke from smokestacks or your school bus tailpipe. That's better for our lungs and better for the health of our planet.



With hydrogen, we can realize the vision of a safe, clean, abundant, and affordable energy future.

Hydrogen — Electrolysis Experiment

A. Activity Summary

This activity is a hands-on experiment in which students will split water into hydrogen and oxygen. Students will make a very small (and very safe) amount of hydrogen through electrolysis. We recommend that students perform this activity by themselves or in small groups, rather than view a demonstration in the front of the room. Students can document observations in their science journals or complete the activity sheet provided (the activity sheet can also be used as an assessment tool once the experiment is complete).

B. Standards

Science

• Science as Inquiry Content Standard B

- ✔ As a result of activities in grades 5–8, all students should develop —
  - -Abilities necessary to do scientific inquiry
  - -Understandings about scientific inquiry

• Physical Science Content Standard B

- ✔ As a result of their activities in grades 5–8, all students should develop an understanding of —
  - -Properties and changes of properties in matter
  - -Transfer of Energy

• History and Nature of Science Content Standard G

- ✔ As a result of activities in grades 5–8, all students should develop understanding of —
  - -Nature of Science

Social Studies

• Teacher Standard #7 — Production, Distribution, and Consumption

- ✔ Social studies teachers should possess the knowledge, capabilities, and dispositions to organize and provide instruction at the appropriate school level for the study of how people organize for the Production, Distribution, and Consumption of goods and services.

• Teacher Standard #8 — Science, Technology, and Society

- ✔ Social studies teachers should possess the knowledge, capabilities, and dispositions to organize and provide instruction at the appropriate school level for the study of science, technology, and society.

Language Arts

• Standard for the English Language Arts #12

- ✔ Students use spoken, written, and visual language to accomplish their own purposes (e.g., for learning, enjoyment, persuasion, and the exchange of information).

C. Teacher Background

As students learned in the previous lesson, hydrogen can be produced via electrolysis, whereby electricity is used to separate water into hydrogen and oxygen.

A molecule of water has two atoms of hydrogen and one atom of oxygen. Passing an electrical current through water between two electrodes (a negative cathode and positive anode) will split each water molecule into its component parts — hydrogen and oxygen. This type of reaction is known as a *decomposition reaction*.

The chemical equation for electrolysis is energy (electricity) + 2 $H_2O \longrightarrow O_2 + 2\ H_2$. The energy, or electricity, can come from a variety of primary energy sources, including solar, wind, or geothermal, for example (in the experiment below, it is electrical energy stored in a battery). In electrolysis, electrical pressure (potential) at the negatively charged electrode, or cathode, pushes electrons into the water. The anode, which is positively charged, attracts electrons. Water, however, is not a good conductor — in order for a charge to flow in a circuit, water molecules near the cathode split into positively-charged hydrogen ions (H^+) and negatively-charged hydroxide ions (OH^-) (equation: $H_2O \longrightarrow H^+ + OH^-$).

The hydroxide ion (OH^-) has a negative charge rather than a neutral charge. This is because the oxygen atom needs the hydrogen electron in order to be stable, with a completely-filled outer shell. The hydrogen ion (H+) is therefore free to pick up an electron from the cathode and become a neutral hydrogen atom (equation: $H^+ + e^- \longrightarrow H$). Each hydrogen atom combines with another hydrogen atom to form hydrogen gas molecules, which are visible as bubbles at the cathode (equation: $H + H \longrightarrow H_2$).

While hydrogen gas is being produced at the cathode, the positively charged anode attracts (negatively charged) hydroxide ions. At the anode, each hydroxide ion loses an electron and combines with other three other hydroxide molecules to form one molecule of oxygen gas and two molecules of water (equation: $4OH^- \longrightarrow O_2 + 2\ H_2O + 4e^-$).

Note: *There is a PowerPoint file containing slides with the chemical equations for this experiment on the CD. The script for the PowerPoint slides follows the experiment, Activity, and Answer Sheets on page 57; it shows each slide and its accompanying text.*

D. Materials

(1 set of the following materials for each student group)

- One 6-volt lantern battery. You can also use a solar panel and either a reading lamp or the sun as your energy source.
- Tap water
- Two wire test leads with double-ended alligator clips. If you are using a solar panel as your energy source, you will need a wire with an alligator clip at only one end.
- Aluminum foil — 2 pieces, each about 6 cm x 10 cm
- Salt
- 400–1000 milliliter (ml) clear beaker or small, clear plastic tub

E. Activity Steps

1. Introduction: Tell students that they will conduct an experiment using electricity and water. Explain that they will be putting electricity into a tub of water (H_2O), causing it to split into hydrogen and oxygen.

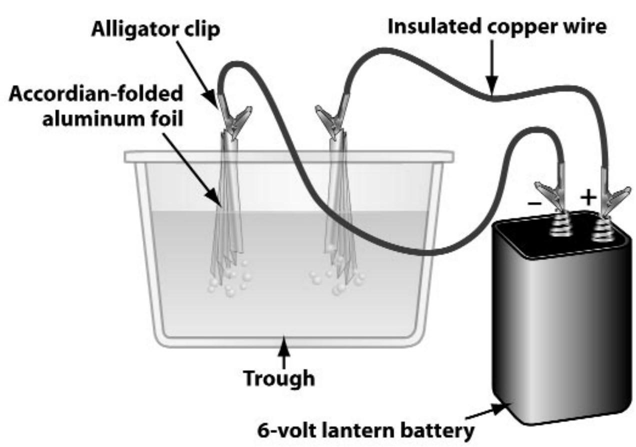
2. After students check their materials list, ask them to fill in Prediction #1 on their laboratory activity sheets regarding safety concerns. Conduct a discussion based on these concerns where the teacher helps students understand that the amount of electricity they will be using is so small that there is no danger of electrocution.

3. Set-up:
   a. Next, ask students to make their experimental "electrodes" using a 6 cm x 10 cm piece of aluminum foil and the following steps:
      - Fold each piece length-wise, accordion style, into a piece about 1 cm wide
      - Press hard together as if making a small paper fan
      - Measurements and folds do not need to be exact, but the two electrodes should be approximately the same size

   b. Fill the clear container with tap water until it is about $^3/_4$ full.

   c. Attach one of the alligator clips from each wire (remember that your wire should have an alligator clip on both ends) to your source of power.
      - If you are using a lantern battery, attach one alligator clip to each of the terminals.
      - If you are using a solar panel, attach two wires to the back of the panel if they are not already attached.

   d. Attach the other end of the wire, using the alligator clip, to one short end of each of the electrodes.



4. Predictions:
   a. Ask students to predict the following either in their science journals or on the activity sheet:
      - What will happen when we place the electrodes, with wires and battery attached, in the water?

   b. Discuss their predictions. Try to not give any clues as to what might happen; instead solicit and record as many ideas as possible — even if student responses are scientifically incorrect. Misconceptions will be corrected as the experiment progresses.

5. Experiment: Ask students to place the aluminum foil electrodes in the water. You can bend the tops of the electrodes over the side of your container to help them stay in place. You can also secure the wire to the side of the container with an extra alligator clip. Do not let the electrodes touch each other. Discuss students' predictions on why it is important to not let the electrodes touch each other.

6. Discuss student observations. Ask students why nothing seems to be happening.

7. Next, have students add salt until the water becomes cloudy. Salt acts as a catalyst which causes this experiment to work much more quickly than it did without the salt. Discuss with students why they think they added salt to the water using the term "catalyst" in their predictions.

8. After a short time delay, one of the electrodes should show a fairly powerful gas production. This time delay is called the "induction period" and can be a vocabulary word documented in their science journals or at the end of the laboratory activity sheet. Discuss their observations.

9. Discuss student explanations of how the experiment is different after the salt is added.

10. Ask students to predict in science journals or on the laboratory activity sheet which electrode is producing hydrogen and which is producing oxygen. How do they know this?

> ***Note:*** The electrode producing the largest amount of gas is the negative electrode, or cathode. The gas produced is hydrogen. The other electrode should be producing a comparably smaller amount of gas; this electrode is the anode and the gas produced is oxygen. Students should remember the chemical formula for water is H_2O and realize that there twice as much hydrogen as oxygen is being produced. Remember that your power source provides an electric current, which is conducted through the two aluminum electrodes that are not connected to each other. Current can flow only when a circuit is closed. Water does not readily conduct an electric current, however — electrons will not flow easily. Dissolving salt in the water increases conductivity. The sodium and chloride atoms (ions) in salt make the water more conductive.

11. Ask students to explain why they know that gas is being produced at the electrodes.

12. Ask students to document all of their observations in their science journals or on the laboratory activity sheets.

13. Answer any questions that students may have after the experiment is finished.

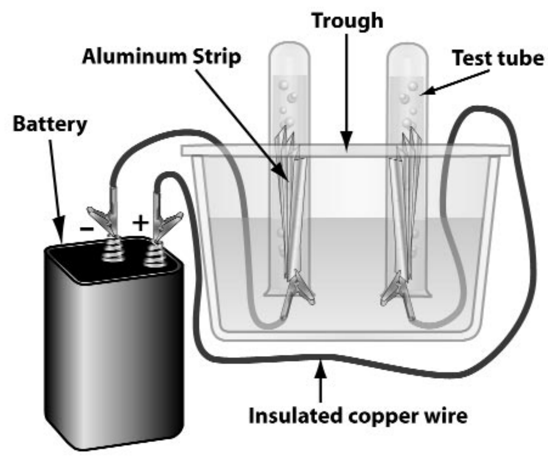
Extension Activity: Collecting the Gases

• Continue this experiment using 10–15ml test tubes to collect the gases produced.
  - Submerge the test tubes in the water so that each is completely filled.
  - Turn each tube upside-down.
  - Lift the full tubes slightly out of the water, keeping them turned upside-down, so that no air can leak into the tubes (leave the open end of the tube under water).

-Insert (i.e., bend) an electrode in the open end of each tube. (It is sometimes difficult or awkward to keep the electrode in the tube, but if you have extra alligator clips and wire, you can attach the inverted test tube to the side of the tub or container and leave it until one of the tubes is completely full).

- Gas produced at each electrode will collect and displace the water in each tube. It is important for your students to realize why the water level drops in the tube — gas collecting in the tube, which is lighter than water, is forcing the water out of the tube. Students should already know why one tube fills with gas first (and which gas it is).

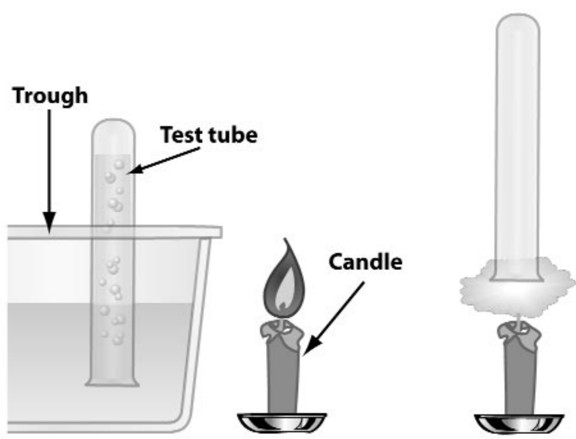
• When the tube has filled with hydrogen, you can test for the presence of hydrogen using a candle.



Note: *The amount of gas collected is very small — there is no risk of explosion with the following activity.*

-Light a candle and carefully set it beside the water container.

-Pull the tube out of the water, keep it upside down, and hold it over the candle. (Hydrogen will escape from the tube very quickly once it is out of the water, so try to do this as quickly as possible). There should be an audible "puff." Move the tube away from the candle for a few seconds and hold it over the candle a second time. You should hear nothing.



• Ask students to predict in their science journals or at the end of their activity sheets why they heard a "puff" the first time but not the second time.

Electrolysis Experiment Activity Sheet

Name:____

1. In this experiment, you will be using electricity to split water into hydrogen and oxygen. You will make two electrodes using aluminum foil and attach each to a power source using wires and alligator clips. You will then place your electrodes in a container filled with tap water (and some salt).

2. Check your supplies with the following list to make sure you have everything you will need to conduct this experiment.

Supply List:

a) One 6-volt lantern battery or a solar panel with either a lamp with an exposed bulb or the sun as the energy source
b) Tap water
c) Two wire test leads with double-ended alligator clips. If you are using the solar panel as your energy source, you will need two wires with alligator clips on only one end.
d) Aluminum foil — 2 pieces, each about 6 cm x 10 cm
e) Salt
f) 400–1000 milliliter (ml) clear beaker or small, clear plastic tub

3. Prediction #1: List any safety concerns that you believe you should consider during this experiment. Be prepared to share your concerns with the class in a discussion which will follow.

4. Setting up the Experiment

• **Step 1** — Make the electrodes

a) Take the two pieces of aluminum foil and fold them along the short side in an accordion fashion as if you were making a paper fan. Your electrode should be about 2 cm x 6 cm.
b) Press the folds hard together so that the electrode is flat.
c) Measurements and folds do not need to be exact, but the two electrodes should be approximately the same size.

• **Step 2** — Fill the clear container with regular tap water until it is about $^3/_4$ full.

- **Step 3** — Attach the electrodes. Attach one alligator clip to the end of each electrode, and attach the alligator clip at the end of each wire to the electrodes on the battery. If you are using a solar panel, attach the ends of each wire without the alligator clips to the terminals on the back of the panel (if they are not already attached), and attach the clips at the other end of both wires to each of your electrodes.

- **Step 4** — Prediction #2: What do you think will happen when you attach your electrodes to your power source and place them in the water?

- **Step 5** — Place your electrodes, attached to your power source, into the water. Do not let your electrodes touch each other. Why is it important to keep the electrodes from touching each other when they are placed in the water?

Record your observations and be prepared to discuss them with the entire class.

- **Step 6** — Remove the electrodes from the water and add salt until the water becomes cloudy. Stir the water and wait for a minute or two until most of the salt is dissolved.

- **Step 7** — Prediction #3: Why did you add salt to the water? Use the term catalyst in your explanation.

- **Step 8** — Place the electrodes back into the water. Record your observations.

- **Step 9** — How is the experiment different after you added the salt to the water?

- **Step 10** — Prediction #4: How can you tell that gas is produced at the electrodes?

- **Step 11** — Prediction #5: At which electrode is hydrogen produced? How can you tell? Use the chemical formula for water — H_2O — in your explanation.

- **Step 12** — Prediction #6: At which electrode is the oxygen produced? How can you tell? Use the chemical formula for water — H_2O — in your explanation.

- **Step 13** — List any questions you have while conducting this experiment.

Electrolysis Experiment Activity Sheet — Teacher Answer Sheet and Common Responses

Name:____

In this experiment, you will be using electricity to split water into hydrogen and oxygen. You will make two electrodes using aluminum foil and attach each to a power source using wires and alligator clips. You will then place your electrodes in a container filled with first tap water and then salt water.

Prediction #1

List any safety concerns that you believe you should consider during this experiment.
Be prepared to share your concerns with the class in a discussion which will follow.

Make sure students understand that it will be safe to use the very small amount of electricity in the water, but that the voltage of electrical appliances at home is much higher and should not be used with or near water at any time. The most students can expect may be a small tingle if they place their fingers in the water while the electrodes are in the water and attached to the power source.

Prediction #2

What do you think will happen when you attach your electrodes to your power source and place them in the water?

Students will write their predictions, so all ideas should be accepted. The correct answer is that the electricity will separate water molecules into hydrogen and oxygen.

Step 5 —Place your electrodes, attached to your power source, into the water bath. Do not let your electrodes touch each other. Why is it important to keep the electrodes from touching each other when they are placed in the water?

This would short the circuit, making the flow of electricity impossible. The electrodes must remain separate so electricity can flow between them using the "salt bridge" in the water. If students do not understand what is needed to form a complete simple circuit, it might be helpful to review basic electrical concepts.

Record your observations and be prepared to discuss them with the entire class.

Observations should include that not much of anything is happening. Since water does not readily conduct electricity, the reaction will be very slow. It might appear that nothing at all is happening.

Prediction #3

Why did you add salt to the water? Use the term catalyst in your explanation.
How would the experiment be different if you did not add salt to the water?

The salt — a catalyst — increased the conductivity of the water and caused the reaction to proceed more quickly. Without the salt, water is much less conductive and the flow of electricity would take longer.

Step 8 — Place the electrodes back into the water. Record your observations.

Accept all observations. Students should document that they observed bubbles produced at the aluminum electrodes. As the experiment progresses, they may also begin to see a color change in the water and one of the aluminum electrodes may start to fall apart.

Step 9 — How is the experiment different after you added the salt to the water?

The production of bubbles is much more powerful and clearly visible. More oxygen and hydrogen are produced – the salt, a catalyst, forms a "bridge" so that the electricity can travel in a continuous circuit through the water.

Step 10 — Prediction #4: How can you tell that gas is produced at the electrodes?

Bubbles rise from the aluminum electrodes.

Step 11 — Prediction #5: At which electrode is hydrogen produced? How can you tell?
Use the chemical formula for water — H_2O — in your explanation.

Hydrogen is produced at the negative electrode, also known as the cathode. Each water molecule (H2O) consists of two hydrogen atoms and one oxygen atom — or twice the amount of hydrogen atoms as oxygen atoms. The electrode at which the most gas is produced is the cathode.

Step 12 — Prediction # 6: At which electrode is oxygen produced? How do you know?
Use the chemical formula for water — H_2O — in your explanation.

Oxygen is produced at the positive electrode, or anode. Each water molecule (H_2O) consists of two hydrogen atoms and one oxygen atom — or twice the amount of hydrogen atoms as oxygen atoms. The electrode at which the least amount of gas is produced is the anode.

Step 13 — List any questions you have while conducting this experiment.

Answer any student questions that remain once the experiment is complete.

$$\text{energy (electricity)} + 2\,H_2O \rightarrow O_2 + 2\,H_2$$

Chemical Formula for Electrolysis

$$H_2O \rightarrow H^+ + OH^-$$

For charges to flow in a circuit, each water molecule near the cathode splits into a positively charged hydrogen ion (H^+) and a negatively charged hydroxide ion (OH^-).

$$H^+ + e^- \rightarrow H$$

The hydrogen ion (H^+) picks up an electron from the cathode and becomes a neutral hydrogen atom.

$$H + H \rightarrow H_2$$

Each hydrogen atom combines with another hydrogen atom to form a hydrogen gas molecule, visible as bubbles at the cathode.

$$4OH^- \rightarrow$$
$$O_2 + 2\,H_2O + 4e^-$$

At the anode, each hydroxide ion loses an electron and combines with three other hydroxide molecules to form one molecule of oxygen gas and two molecules of water.

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Hydrogen Safety – Hindenburg Activity

A. Activity Summary

In this activity, students will first define "myth" and "reality." They will then read two different accounts of the Hindenburg disaster and decide which one is myth and which one is reality. For homework, students will discuss with at least three people what they know about the Hindenburg disaster. Finally, students will write their own factual and fictional accounts of the Hindenburg using information gained from this activity and additional research. This activity addresses common misunderstandings about the safety of hydrogen and introduces students to new evidence suggesting that hydrogen was not the cause of the Hindenburg tragedy.

B. Standards

Science

- Science and Technology Content Standard E
  - ✔ As a result of activities in grades 5–8, all students should develop —
    - -Understandings about science and technology
- Science in Personal and Social Perspectives Content Standard F
  - ✔ As a result of activities in grades 5–8, all students should develop understanding of —
    - -Natural Hazards
    - -Risks and Benefits
    - -Science and Technology in Society
- History and Nature of Science Content Standard G
  - ✔ As a result of activities in grades 5–8, all students should develop understanding of —
    - -Science as a human endeavor
    - -History of Science

Social Studies

- Teaching Standard #8 — Science, Technology, and Society
  - ✔ Social studies teachers should possess the knowledge, capabilities, and dispositions to organize and provide instruction at the appropriate school level for the study of science, technology, and society.

Language Arts

- Standards for the English Language Arts #1
  - ✔ Students read a wide range of print and non-print texts to build an understanding of texts, of themselves, and of the cultures of the United States and the world; to acquire new information; to respond to the needs and demands of society and the workplace; and for personal fulfillment. Among these texts are fiction and nonfiction, classic and contemporary works.

• Standards for the English Language Arts #2
  - ✔ Students read a wide range of literature from many periods in many genres to build an understanding of the many dimensions (e.g., philosophical, ethical, aesthetic) of human experience.

• Standards for the English Language Arts #5
  - ✔ Students employ a wide range of strategies as they write and use different writing process elements appropriately to communicate with different audiences for a variety of purposes.

• Standards for the English Language Arts #7
  - ✔ Students conduct research on issues and interests by generating ideas and questions, and by posing problems. They gather, evaluate, and synthesize data from a variety of sources (e.g., print and non-print texts, artifacts, people) to communicate their discoveries in ways that suit their purpose and audience.

• Standards for the English Language Arts #8
  - ✔ Students use a variety of technological and information resources (e.g., libraries, databases, computer networks, video) to gather and synthesize information and to create and communicate knowledge.

• Standards for the English Language Arts #12
  - ✔ Students use spoken, written, and visual language to accomplish their own purposes (e.g., for learning, enjoyment, persuasion, and the exchange of information).

C. Teacher Background
On May 6, 1937, the Hindenburg airship was destroyed by fire as it prepared to land in Lakehurst, New Jersey. One-third of the passengers and crew were killed. For many years, the prevailing theory blamed hydrogen, which was used to inflate the sixteen interior gas cells that gave lift to the ship, for the tragedy. A growing number of scientists and engineers, however, now believe the disaster was caused by something other than hydrogen. The Hindenburg was covered with a cotton fabric skin, coated with chemicals used to protect and strengthen it. These chemicals, similar to the components of rocket fuel, ignite easily with an electrical arc. Recent studies suggest that a static electricity spark produced by an approaching lightening storm caused the Hindenburg's coated "skin" to catch fire. Many believe now that the hydrogen burned only after the ship had already caught fire, and it burned up and away from the ship. Despite these studies and evidence, the Hindenburg tragedy has tarnished public perception about the safety of hydrogen use — a challenge that must be overcome for hydrogen to succeed in the marketplace as an energy carrier.

Make sure that students only give the Hindenburg questionnaire to people who have actual knowledge of the Hindenburg incident.

The following page contains a Hydrogen Safety Fact Sheet developed by the California Fuel Cell Partnership, for further background information or for students to use in their research (if appropriate). Do not distribute the hydrogen safety sheet to students until after they begin writing their own factual and fictional pieces at the end of the activity.

HYDROGEN USE AND SAFETY

Updated October 2003

The lightest and most common element in the universe, hydrogen has been safely used for decades in industrial applications. Currently, over 9 million tons of hydrogen are produced in the U.S. each year and 3.2 trillion cubic feet are used to make many common products. They include glass, margarine, soap, vitamins, peanut butter, toothpaste, and almost all metal products. Hydrogen has been used as a fuel since the 1950s by the National Aeronautics & Space Administration (NASA) in the U.S. space program.

Hydrogen — A Safe, Clean Fuel for Vehicles

Hydrogen has another use — one that can help our nation reduce its consumption of fossil fuels. Hydrogen can be used to power fuel cell vehicles.

When combined with oxygen in a fuel cell, hydrogen generates electricity used by the vehicle's clean electric motor to create a smooth, quiet ride — and the only emission from the tailpipe is water vapor.

Hydrogen is an excellent vehicle fuel for many reasons. The U.S. Department of Energy compares hydrogen very favorably to other fuels. Hydrogen is not toxic, poisonous or corrosive. As a result of hydrogen's benign nature, it doesn't harm the environment or public health. If hydrogen were to leak it would disperse into the air almost immediately because it is so light. Contrast that with the effects of oil and gasoline spills, and it's easy to see why hydrogen offers such an exciting future!

Misconceptions About the Past

The fire that destroyed the Hindenburg back in 1937 gave hydrogen a misleading reputation. Hydrogen was used to keep the airship buoyant, but hydrogen did not cause the fire. NASA scientists have found that the Hindenburg's outer shell was coated with a compound similar to what is now used in solid rocket fuel. When the ship docked, an electrical charge ignited the coating. Hydrogen, as a fuel, was not the cause of the tragedy.

Respecting Flammable Fuels

As with any fuel, hydrogen's physical qualities must be respected and understood. The very property that makes all fuels useful also makes them potentially dangerous. So it's important to remember to safely handle energy carriers like gasoline, diesel, natural gas, and hydrogen. Fortunately, we have over 100 years of experience using motor fuels. Today, all fuel production and distribution systems have built-in safety systems. Vehicles do too.

The main rule of thumb in fuel safety is to avoid a leak. Without a leak, there's no opportunity for the fuel to ignite. Fuel cell cars and hydrogen fueling stations are designed to prevent hydrogen from leaking, and with redundant systems to shut down automatically if an accident occurs. The operation of these shut-off safety systems will be verified through testing and real-life experience.

D. Materials
Copies of student readings #1 and #2 and Hindenburg questionnaire

E. Activity Steps
1. Hold a class discussion about the difference between myths and reality, or facts and fiction. Develop a class definition for each word.

2. Ask students to read both readings #1 and #2. Ask them to predict which reading they believe is fact and which is fiction and describe why.

3. Together as a class, discuss student predictions of which reading is fact, which is fiction, and the supporting reasons.

4. Most of the class will likely identify the first reading as fact and the second reading as fiction. This activity, however, is designed to be tricky. Both readings are factual pieces excerpted from actual research conducted on the Hindenburg disaster. Most students will identify the second reading as fiction because of the style in which it is written — but both readings are accurate.

5. For homework, have the class ask three to five people what they believe they know about the Hindenburg — anything at all that relates to the disaster. A questionnaire has been provided to give students direction in their questions. Let the students know that they are simply asking questions to see what people believe about the Hindenburg. Students should document all responses, both correct and incorrect, that will be used in the next step of the activity.

6. When questionnaires are complete, invite students to discuss what they discovered from the people they questioned and the prevailing opinion with regard to the cause of the Hindenburg tragedy.

7. In the final steps of this activity, students will write their own factual and fictional accounts of the Hindenburg disaster, from two different perspectives. They can use the information they learned from the first two student readings, further research conducted either in the library or on-line, and their questionnaires. This would be a great research topic to use during computer lab time if your class is assigned weekly time in your school computer lab.

8. Design a scoring rubric with students before they begin to write so they understand the expectations ahead of time.

Student Reading #1

At 7:25 in the evening of May 6, 1937, the Hindenburg airship was destroyed by fire as it was about to land in Lakehurst, New Jersey. Of the 97 passengers and crewmembers, 62 survived. The Hindenburg was nearing its mooring mast at the landing site after a thunderstorm. Four minutes after the bow landing ropes were dropped, the stern (back) section of the airship erupted in flames. The "high landing approach," a first for the Hindenburg, together with the nearby storm conditions, created an extreme electrical potential on the airship surface. When the fire broke out, some passengers jumped, some crewmembers fell, and others on board waited until the airship hit the ground. Thirty-six people, including one member of the ground crew, died after suffering severe burns caused by the burning of the airship.

Until recently, this tragedy was blamed on the use of hydrogen, a flammable gas used to inflate the sixteen interior gas cells that gave the ship its lift. Witness observations, however, indicate something other than hydrogen was the culprit. Testimony from many observers describes an intense, red-orange-yellow fire. But hydrogen burns almost invisibly. Even though the Hindenburg was, and still is, the largest airship ever to have flown, it took only 37 seconds for the zeppelin to be destroyed by fire.

The Hindenburg was scheduled to fly from Germany to the United States using helium gas, instead of hydrogen. Helium does not burn as hydrogen does, but it also does not produce as much lift as hydrogen, so more gas is required. The Hindenburg never received its helium, however, because at the time, in the late 1930s, helium was difficult to produce. The United States was the only country that could manufacture helium gas and would not sell it to Germany for fear it would be used for war purposes. The zeppelin was redesigned for hydrogen and underwent structural changes to minimize the possibility of fire.

When the Hindenburg arrived in Lakehurst, New Jersey, the weather conditions were not suitable for landing, so the captain diverted the flight southeast until the commanding officer on the ground decided it was safe to land. When the ship was about 275 feet from the ground, the first flames were visible toward the tail of the ship. Soon, the hydrogen gas bags caught fire and the entire back half of the ship was engulfed in a mass of flame and smoke that shot hundreds of feet into the sky. As the hydrogen burned, the ship lost its lift and fell to the ground. Passengers jumped from windows and ran to safety.

Both the United States and Germany investigated the cause of the disaster. Officials concluded that a hydrogen leak, ignited by a spark of static electricity, was the cause. Both governments wanted to put the disaster behind them so as not to cause an international incident or embarrass the Germans who may have designed a faulty ship.

Sources:

United States Department of Energy: *http://www.eren.doe.gov*
Fuel Cell Store: *http://www.fuelcellstore.com/information/hydrogen_safety.html*
National Hydrogen Association: *http://www.hydrogenus.com/advocate/ad22zepp.htm*
What You Need to Know About: *http://history1900s.about.com/library/weekly/aa102600a.htm*

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Student Reading #2

In 1937, Herbert Morrison reports for radio station WLS in Chicago: "I'm standing here, on location, at the Naval Air Station in Lakehurst, New Jersey, awaiting the arrival of the great zeppelin airship, Hindenburg. The ship was scheduled to arrive from Germany quite some time ago, but because of thunderstorms in the area, the landing has been postponed until the weather clears. We can hear ships far away in the harbor blast greetings to the airship as she passes overhead. We expect to catch our first glimpse of the ship in about forty minutes."

"While we are awaiting the ship's arrival, let me give you some background information regarding the Hindenburg. The ship is carrying 36 passengers and a crew of 61. In the rear of the ship are the crew quarters and officers' mess (kitchen and dining room). Passenger cabins are quite small when compared with those aboard ocean liners, but most of the time the passengers are elsewhere in the ship, so large cabins are not necessary. Each room is equipped with an upper and lower berth, which are folding beds that can be placed against the wall for more room to move about when not sleeping. There is a collapsible writing table, folding wash basin, and a signal used for calling the steward. A lounge, decorated with a large wall mural tracing the paths of famous explorers and a baby grand piano, is used for the passengers' entertainment. There is a reading and writing room, which provides a quiet place to write letters on special Hindenburg stationery. The smoking room is kept under positive pressure to prevent any of the flammable hydrogen from leaking into the room. There is a single electric light to provide light for a pipe, cigar, or cigarette. The promenade provides passengers with an amazing view of the earth below, and all guests can be seated for meals at the same time in the large dining area."

"The weather today has been rainy, with strong thunderstorms earlier. However, the airship is now coming into view and it looks as if they are ready to land."

"It's practically standing still now. They've dropped ropes out of the nose of the ship, and a number of men have taken hold of the ropes down on the field. It's starting to rain again; the rain had slacked up a little bit. The back motors of the ship are just holding it, just enough to keep it from…"

"It burst into flames! It's on fire and it's crashing! It's crashing…terrible! Oh, my! Get out of the way, please! It's burning…bursting into flames and it's falling on the mooring mast. This is terrible! What a catastrophe! There's smoke, and there are flames, now, and the ship's frame is crashing to the ground, not quite to the mooring mast….oh, the humanity, and all the passengers screaming around here! I'm signing out."

The year is now 1997, and Addison Bain, a retired NASA engineer, has been studying hydrogen for many years. He has conducted extensive research on the Hindenburg, using NASA's latest investigative techniques to analyze the wreckage. He has conducted interviews with the few living survivors, examined original film footage, and visited the airship's former mooring sites in Lakehurst and Akron, Ohio. Some of the details of his findings follow.

While there is evidence of a hydrogen fire, the Hindenburg did not explode, but burned very rapidly in an upward direction. The airship remained aloft and upright for many seconds after the fire began, with falling pieces of fabric dropping in flames. The very bright color of the flames seemed to be similar to those of a forest fire, and not a hydrogen fire. Hydrogen has no visible flame. Two factors may have contributed to this disaster. The atmospheric conditions of thunderstorms (with lightning still in the area) and the high-altitude landing where the ship was moored created a ground-to-cloud electrical path. These conditions, combined with evidence gained from the fabric skin used to cover the ship, is a recipe for disaster.

It seems that the fabric skin was a type of cotton treated with chemicals to make it waterproof and allow it to stretch. The coating is very similar to a mixture used to power solid fuel rockets. In other words, the Hindenburg was painted with rocket fuel. It is difficult to prove that a bomb caused the disaster. Regardless of the cause, the Hindenburg tragedy brought an end to passenger airships. The zeppelin, which was once thought to be the transportation mode of the future, is now a vessel of the past and clouded in mystery and myth.

Sources:

National Hydrogen Association: *http://www.hydrogenus.com/advocate/ad22zepp.htm*
PBS: *http://www.pbs.org/wnet/secrets/html/e 3-resources.html*
Vidicom Media Productions: *http://www.vidicom-tv.com/tohiburg.htm*
Navy Lakehurst Historical Society, INC: *http://www.nlhs.com/hindenburg.htm*
What You Need to Know About: *http://history1900s.about.com/library/weekly/aa102600a.htm*

Hindenburg Questionnaire

Name:____

Give this questionnaire to at least three people to learn what they know about the Hindenburg disaster. Record their answers. You may talk to both adults and students.

Name of person who answered this questionnaire:__________________________________

Relation to student:____

1. What do you know about the Hindenburg?

2. How did you get your information about the Hindenburg?

3. What do you know about the cause of the Hindenburg fire and crash?

4. Would you be nervous about using hydrogen as a fuel because of what you know about the Hindenburg disaster? Why or why not?

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Hindenburg Extension Activity

If you have more time, the following research project, in which students learn more about the properties of hydrogen and hydrogen safety, can be assigned as an extension or in place of the "myth" and "reality" activity described above.

- Divide students into groups of three and tell them that they are now research teams assigned by Department of Energy to investigate the Hindenburg disaster. Each team must decide, based on evidence it collects and additional research on the Hindenburg and the properties of hydrogen, if hydrogen is to blame for the tragedy. (If you use this assignment instead of the myth and reality activity, you can choose whether to distribute one of the student readings or briefly explain what happened and allow students to conduct more of their own research).

- Students must read various accounts of what happened in 1937. Each team must formulate a hypothesis, develop and implement a work plan, and write a scientific report to explain its research and conclusions. The student teams can present their findings in presentations to the class.

- Questions to prompt students' thinking include the following:
  -Is hydrogen to blame for the Hindenburg tragedy? What evidence exists to back that claim?
  -If you do not think a hydrogen explosion caused the Hindenburg disaster, what did? How can you prove it? What evidence is there to back your theory?

- Additional research could include eyewitness accounts of the disaster; the properties of hydrogen; electrostatic charges associated with lightning; and materials used to construct the Hindenburg airship.

Fuel Cells — Introductory Activity — Mystery Scientist

A. Activity Summary

In the following activity, students discover a famous "mystery" scientist. The story is designed to give students clues as to the scientist's identity and engage them in the history of science.

This activity can be used as part of a science, history, or language arts class. If your school uses a team or theme approach to teaching, non-science teachers may wish to use this activity to supplement the theme taught in the science class.

Students should develop and document their plans for how they will identify the scientist before they attempt to solve the mystery. They can revise their approaches as they work but should document adjustments to their plans. As a separate language arts activity, teachers may wish to conduct a class discussion or journaling activity in which students explain how they solved the mystery.

B. Standards

Science

• Science and Technology Content Standard E
  - ✔ As a result of activities in grades 5–8, all students should develop —
    - -Science in Personal and Social Perspectives

• History and Nature of Science Content Standard G
  - ✔ As a result of activities in grades 5–8, all students should develop an understanding of —
    - -Science as a Human Endeavor
    - -Nature of Science
    - -History of Science

C. Teacher Background

The mystery scientist is Sir William Grove.

D. Materials

Copies of Mystery Scientist #2 for each student

E. Activity Steps

1. Introduce the activity to students — tell them they are going to read about a mystery scientist.

2. Explain that they should develop a plan for how they will identify the mystery scientist and document the plan in their science journals. Once they have developed their plan, they can begin to solve the mystery.

3. Explain to students that the class will discuss the mystery scientist's significant accomplishments when his or her identity is revealed.

Mystery Scientist
This mystery scientist was born in Swansea, Wales, on July 11, 1811, and has come to be known as the "Father of the Fuel Cell."

He was an English judge and man of science who, in his youth, was educated by private tutors. He attended Brasenose College in Oxford, where he received an ordinary degree in 1832. Three years later, he became a lawyer. Because his poor health prevented him from practicing law full time, he spent much of his life studying science. Can you imagine spending your free time conducting science experiments?

One of this scientist's discoveries involved water electrolysis — the use of an electrical current to separate water into its two components, hydrogen and oxygen. In conducting these experiments, he began to wonder if the process could work in reverse. Could a chemical reaction using hydrogen and oxygen form water and produce electricity? He described this theory at the annual meeting of the British Association for the Advancement of Science in 1842. This led to the idea of Conservation of Energy, which states that energy can be neither created nor destroyed.

In the early 1840s, this mystery scientist felt great pressure to devote himself to his legal career and give up his scientific research. But fortunately, his good friend and fellow electrical researcher, John P. Gassiot, persuaded him to continue his scientific pursuits, and his discoveries led to advancements in not only fuel cell technology, but photographic science as well (see box).

A fuel cell is a device that uses hydrogen and oxygen to create electricity by an electrochemical process. The first fuel cell, discovered by this mystery scientist, was not known as a fuel cell at the time, but instead bore his name and was called the ___________ (his last name) Cell. Frustrated by the inconsistency of his cell's performance, this scientist spent much time experimenting with different materials to produce a more constant current. He shouldn't have felt too discouraged, though, because today's scientists and engineers are still working to overcome these same technical challenges! He was dedicated to his science and firmly believed that an energy production method using hydrogen could replace coal and wood, the primary energy sources of his time.

His nitric acid cell became the favorite energy source of the early American telegraph from 1845–1860 because it offered a strong current. The ___________ Cell provided nearly double the voltage of the Daniell cell (that was created by another scientist during that time). By the Civil War, the ___________ Cell was again replaced. As the use of the telegraph increased, it was found that the ___________ Cell discharged poisonous nitric dioxide gas that filled large telegraph offices which had rows of these cells in use. This scientist used a number of his cells in a stack to exhibit

The Science of Photography
In 1841, this mystery scientist began experimenting with daguerreotype plates for photomechanical printing, work that led to what we know today as the printing industry, enabling books, magazines, and newspapers to print photos. He described his prints as being "drawn by Light and engraved by Electricity." He felt his discoveries in photography would have great effects on future generations and knew that permanently documenting actions (in photographs) would make a profound impact on science, history, and government.

the electric arc light to the London Institution. His demonstration earned him an appointment to the Institute's Professorship of Experimental Philosophy (known today as Professor of Physics), a position he held for seven years, from 1840 to 1847. During that time, he continued his research using fuel cells and invented several different types. One such type was known as the ___________ (his last name) Gas Battery. Based on his observations that an electric current could be produced using a couple of platinum plates, acidic water, hydrogen, and oxygen, the modern fuel cell was born. This mystery scientist presented his findings in many lectures at the Institution, and in 1846, published his work in The Correlation of Physical Forces. The book explains how the energy of nature, including light, heat, and electricity, can convert into another form without losing any of the initial energy.

Even though this man was consumed with his scientific research, he continued to practice law, and specifically, patent law. In 1871, he was named a judge in the Common Pleas court, and he was knighted in 1872. In 1887, his ill health again interrupted his law career and forced him to retire as a judge. He continued to study science, his true love, until he died in London on August 1, 1896.

The term fuel cell wasn't used until 1889, when scientists Ludwig Mond and Charles Langer attempted to build the first practical device using hydrogen to produce electricity. Their fuel cell used industrial coal gas to produce the hydrogen used in the cell. The first truly successful fuel cell, however, resulted from inventions made in 1932 that improved the technology used by Mond and Langer.

In the mid-twentieth century, NASA began experimenting with fuel cell technology to develop a power source for the Apollo moon missions. Fuel cells are also used in NASA's space shuttle program. Today, scientists and engineers in government and industry are working to advance fuel cell technologies for use in everyday appliances, such as computers and cell phones, as well as to power homes, office buildings, and even vehicles.

What do you think that this scientist would have thought if he had known that his fuel cells would be used aboard spacecraft? Since he died before the turn of the 20th century, can you imagine the technological advances that he never lived to see? Do you think that he could have imagined his fuel cells being used to power buildings, automobiles, and even in outer space?

Who is this mystery scientist?

Fuel Cells — How Do Fuel Cells Work?

A. Activity Summary
In this activity, students will learn how a fuel cell works by viewing an animation led by the teacher, and then constructing a model of a fuel cell.

B. Standards
Science
• Science and Technology Content Standard E
- ✔ As a result of activities in grades 5–8, all students should develop —
  -Understandings about science and technology

• Science in Personal and Social Perspectives Content Standard F
- ✔ As a result of activities in grades 5–8, all students should develop understanding of —
- ✔ As a result of activities in grades 5–8, all students should develop —
  -Risks and Benefits
- ✔ As a result of activities in grades 5–8, all students should develop —
  -Science and Technology in Society

• Physical Science Content Standard B
- ✔ As a result of their activities in grades 5–8, all students should develop an understanding of —
- ✔ As a result of activities in grades 5–8, all students should develop —
  -Transfer of Energy

Language Arts
• Standards for the English Language Arts #8
- ✔ Students use a variety of technological and information resources (e.g., libraries, databases, computer networks, video) to gather and synthesize information and to create and communicate knowledge.

• Standards for the English Language Arts #12
- ✔ Students use spoken, written, and visual language to accomplish their own purposes (e.g., for learning, enjoyment, persuasion, and the exchange of information).

- ✔ As a result of activities in grades 5–8, all students should develop understanding of —
  -Risks and Benefits
  -Science and Technology in Society

C. Teacher Background
A fuel cell is a device that uses hydrogen (or a hydrogen-rich fuel) and oxygen to create electricity. Like a battery, a fuel cell has electrodes and electrolyte. But while batteries only store energy, fuel cells produce energy and don't need recharging. As long as fuel (hydrogen) and air (oxygen) are supplied to a fuel cell, it will continuously produce electricity.

There are four main types of fuel cells, which are categorized by the electrolyte used. The four fuel cell types are Polymer Electrolyte Membrane (PEM), Molten Carbonate (MCFC), Phosphoric Acid (PAFC) and the Solid Oxide Fuel Cell (SOFC). We will study PEM fuel cells in this unit.

In a PEM fuel cell, hydrogen is fed to the anode, where a catalyst separates hydrogen's negatively charged electrons from positively charged ions (protons).

The electrons cannot pass through the membrane to the positively charged cathode; they must travel around it via an electrical circuit to reach the other side of the cell. This movement of electrons is an electrical current.

The protons, however, move through the electrolyte to the cathode, where they combine with oxygen and electrons, producing water and heat.

The amount of power produced by a fuel cell depends on several factors, including fuel cell type, cell size, the temperature at which it operates, and the pressure at which the gases are supplied to the cell. Still, a single fuel cell produces enough electricity for only the smallest applications. To provide the power needed for most applications, individual fuel cells are combined in series into a fuel cell stack. A typical fuel cell stack may consist of hundreds of fuel cells.

Direct hydrogen fuel cells produce pure water as the only emission. This water is typically released as water vapor. Fuel cells release less water vapor than internal combustion engines producing the same amount of power.

In the electrolysis activity, students learned that electricity can separate water into its components, hydrogen and oxygen. The reverse process occurs in a fuel cell to create electricity. Hydrogen is fed to the fuel cell, electricity is produced, and water and heat are the end-products.

D. Materials

- Fuel Cell Animation (on CD, also available online at: *www.gm.com/company/gmability/edu_k-12/popups/fc_energy/fuelcell_interactive.html)*
- Animation talking points (below)
- Science journals or activity sheets for each student

E. Activity Steps:

1. Review the CD and talking points included in this activity prior to using with students.

2. Explain to students that fuel cells are devices that use hydrogen to produce electricity. Fuel cells can be built in many different sizes and "stacked" together to power a wide variety of applications, from small electronic equipment to buildings to cars and trucks. Explain that you will use the CD animation to describe how individual fuel cells work, how they can combine in a stack, and how a fuel cell stack can power a vehicle. (The next lesson includes information about fuel cells for portable, stationary, and transportation applications).

3. Suggested teacher talking points for the animation are below. During the discussion and/or animation demonstration, teachers may wish to have students take notes in their science journals or use the activity sheet provided at the end of this lesson. Students can also highlight vocabulary words as you proceed through the animation.

4. Students create a hands-on model of a fuel cell. This can be done with materials brought from home, or has a homework assignment. It should be a three-dimensional model that may have working parts and should be more than a picture representing the parts of a fuel cell.

GMAbility Fuel Cell Animation — Suggested Teacher Talking Points

Note: Most of the type in this animation is very small and can be hard to read. These suggested talking points are provided for you to use as an option or to supplement the language provided in the animation. The animation provides a general-to-specific illustration — you will see how a fuel cell system is positioned in a vehicle, followed by the stack and parts of an individual fuel cell, and finally, the chemistry that makes it all work.

<u>Part 1: Fuel Cell Systems</u>

First Screen: Fuel Cell Systems

An introduction. Note that, on the outside, the car shown looks similar to the cars we see on the road today. But on the inside and under the hood, it's actually quite different. Students will first explore the major components of a car's fuel cell system, and then dig deeper into the inner workings of a fuel cell.

To move to the next slide, simply follow the links at the bottom of the slide (left-click the blinking orange title, "What Happens Inside the Vehicle?").

Second Screen: Fuel Cell Systems

This slide has several small windows *(you can advance to each one using the "Continue" links on the bar at the bottom of the animation).*

- The first box will open automatically when you begin the slide. It is titled "Fuel Cell Stack."
    - Students have already learned the basics of how fuel cells work. An individual fuel cell generates only a small amount of electricity. To power most applications, individual cells are combined in series to form a fuel cell stack. In a vehicle, the fuel cell stack will have as many as 200 individual cells and will replace the internal combustion engine.
- Second box: Electric Motors
    - The fuel cell stack generates electricity, which powers an electric motor that turns the wheels (and propels the vehicle).
- Third box: Battery Pack
    - Like today's vehicles, fuel cell vehicles have a battery.
- Fourth box: Fuel Tank
    - The fuel tank contains hydrogen, which is fed to the fuel cell. On-board hydrogen storage tanks go through very rigorous safety testing. Some tests involve shooting tanks with bullets and dropping them from great heights to make sure that they are safe and can withstand great impacts, such as those that could be sustained in a car crash.

Part 2: The Fuel Cell (Parts)

First Screen: The Fuel Cell

- First box: As noted earlier, a single fuel cell produces only a small amount of electricity. To provide the amount of power needed for a vehicle, many fuel cells are combined in series to form a stack.
  Note: *To advance to the next view, use the "Continue" link at the lower left corner of the screen*

- Second box: This view shows cells stacked together *(*Note: the next view will show an individual fuel cell and begin to illustrate how a fuel cell works).*

Second Screen: The Fuel Cell – Inside the Fuel Cell

Note: *in this section, you will view the parts that comprise an individual fuel cell; the next section illustrates the reactions that occur and what happens when hydrogen fuel is fed to the cell.*

- First box: Anode
  -Each individual fuel cell is made of an electrolyte sandwiched between two electrodes. The anode is the negative electrode, at which hydrogen enters the fuel cell.
- Second box: Catalyst
  -A catalyst causes a chemical reaction to occur more quickly. Platinum, a precious metal, is often used as the catalyst in a PEM fuel cell. The catalyst coats both sides of the membrane
- Third box: Proton Exchange Membrane (also called Polymer Electrolyte Membrane, or PEM)
  -The PEM looks something like plastic wrap and will only allow positively-charged protons to pass through it. The PEM will not allow electrons to pass through — instead electrons are routed through an outside circuit. (More on this later).
- Fourth box: Cathode
  -The cathode, or positive electrode, sits at the other side of the fuel cell — separated from the anode by the electrolyte membrane. Oxygen enters the fuel cell at the cathode.

Part 3: Fuel Cell Chemistry

Note: *After learning about the parts of a fuel cell, now students will see what happens when hydrogen is fed to the fuel cell and the reactions that occur to produce electricity. (As in earlier sections, advance to the next box or view by using the "Continue" link at the bottom left corner of the page).*

First Screen (left side): What happens on the anode side

- First box: Hydrogen gas (H2) enters the anode side of the fuel cell and is forced through the catalyst.
- Second box: As each hydrogen molecule reaches the catalyst, the atoms break apart into positively charged ions, or protons (shown as large yellow circles) and negatively charged electrons (shown as small yellow circles).
- Third box:
  -Electrons move through the anode but cannot pass through the membrane — instead they are routed through an external circuit.
  -This flow of electrons is an electrical current, which, in a vehicle, is used to power an electric motor. The electrons then return to the cathode side of the fuel cell.

• Chemistry: Note the equation, $2H_2 \longrightarrow 4H^+ + 4e^-$. Each hydrogen atom is attached to another hydrogen atom, which is represented as H_2.
   -Ask students to explain in their FaST journals what might happen if electrons are forced out of the cell through an external circuit.
   - Discuss ideas and make sure that students have at least three ideas listed.
   - Lead them to the idea that these moving electrons are an electric current.

First Screen (right side): What happens on the cathode side

• First box: Oxygen gas (O_2, shown as blue circles) from the air enters the fuel cell at the catho side. It is forced into the catalyst.

• Second box: The catalyst splits the oxygen molecule into its two individual oxygen atoms.

• Third box: The oxygen atoms attract hydrogen protons and draw them through the membrane to the cathode side of the fuel cell.

• Fourth box:
   -At the cathode, two hydrogen protons re-unite with two hydrogen electrons (routed to the cathode side of the fuel cell through the external circuit) to re- form one hydrogen molecule
   -The hydrogen molecule bonds with one oxygen atom to form water (H_2O).

• Chemistry: Note the equation, $O2 + 4H^+ + 4H^- \longrightarrow 2H_2O$

• The process repeats as hydrogen and oxygen are continuously fed to the fuel cell. The results are electricity, which is used to power the motor that propels the vehicle; water; and heat.

Note: *The final animation showing the movement of particles through the fuel cell will continue until you decide to stop the entire animation. Close the window animation once the students have completed their activity sheets and understand how a fuel cell works.*

Activity Sheet – How Do Fuel Cell Work?

Name: ____

1. How will fuel cell vehicles differ from the vehicles we use today?

2. Name the three main parts of a fuel cell.

3. What is necessary for a fuel cell to produce electricity?

4. What does a catalyst do?

5. What happens at the anode?

6. What happens at the cathode?

7. What is a PEM? What does it do and why is it important?

8. What is a fuel cell stack and why is it important?

9. List two advantages of using fuel cell vehicles instead of our current fossil fuel vehicles.

10. List any questions that you still have about how a fuel cell works.

Fuel Cells — Fuel Cell Applications

A. Activity Summary

In this activity, students will learn more about fuel cell applications and the benefits of their use by reading student selections on the three types of applications. Students will then create an advertising brochure based on one of the fuel cell applications.

B. Standards

Science

• Physical Science Content Standard B:

- ✔ As a result of their activities in grades 5–8, all students should develop an understanding of —
  - -Transfer of Energy

• Science and Technology Content Standard E:

- ✔ As a result of activities in grades 5–8, all students should develop —
  - -Understanding about science and technology

• Science in Personal and Social Perspectives Content Standard F:

- ✔ As a result of activities in grades 5–8, all students should develop an understanding of —
  - -Populations, resources and environments
  - -Risks and Benefits
  - -Science and Technology in Society

• History and Nature of Science Content Standard G:

- ✔ As a result of activities in grades 5–8, all students should develop an understanding of —
  - -Science as a Human Endeavor
  - -Nature of Science

C. Teacher Background

One of the great advantages of hydrogen fuel cells is that they are scalable and can be used to power a wide variety of applications. Small electronic equipment — such as computers and cell phones, cars, homes, and even large buildings may all use fuel cells one day. In this activity, students will learn about fuel cell applications and the advantages of their use.

D. Materials

• Copies of Student Fuel Cell Application readings

E. Activity steps

1. Divide the class into three groups and assign each a different Fuel Cell Application reading. Have each group read and discuss their assigned selection.

2. Each group should prepare a summary of its reading. The summaries should be written on large chart paper and posted for the entire class to view. Further research should be encouraged to improve their summaries. Try to ensure that students understand how to create a summary poster that can be used to present to the class.

Sample summary poster format

- **Type of Application (transportation, stationary, or portable)**
- **Name of group members**
- **1. Main Point**
  - **a) detail**
  - **b) detail**
  - **c) detail**

- **2. Main Point**
  - **a) detail**
  - **b) detail**
  - **c) detail**

3. Ask each group to appoint a spokesperson who can present their summary to the class. Before the groups make their presentations, review what they plan to present to the class. Encourage the groups to talk about details that pertain to the main points of their posters. Tape the posters to a wall or board so that they can easily be seen by the entire class. Another option would be to have the class create PowerPoint presentations about their application instead of a poster.

4. Using the three posted summaries, create a comparison chart on the board or overhead projector. Development of the chart can be a teacher-led, whole class activity.

Sample comparison chart format

Fuel Cell Application	**Similarities**	**Differences**
Transportation		
Stationary		
Portable		

5. Using the information gained from the student readings, summaries, and comparison chart, ask students to create a sales brochure for a chosen application. Students should think about why someone would want to buy this technology, then use their creativity and technology and art skills to create a sales brochure that would appeal to consumers (for example, a tri-fold brochure advertising a new fuel cell-powered laptop computer).

Student Reading # 1 — Fuel Cells for Transportation

Can you imagine being an engineer for NASA in the beginning of the space program and you have been charged with the mission of getting a man on the moon? Scientists and engineers at that time faced many challenges — one of particular concern was how to provide a practical power source for extended missions to space. To solve the problem of portable power, NASA turned to a technology that had not been used since the Civil War era. With additional research and development, however, it proved to be a successful alternative for providing power on-board spacecraft, and it could one day power our everyday lives. This technology is hydrogen powered fuel cells.

Fuel cells generate electricity through an electrochemical reaction between hydrogen and oxygen. With oxygen from the air, as long as hydrogen is fed to a fuel cell, it will continue to produce electricity. When pure hydrogen is used, the only byproduct is water — no extra pollutants are produced. That's good for our health and the environment. Fuel cell technology is more efficient than traditional power systems, which means less energy is needed to provide the same amount of power. And because hydrogen can be produced using a wide variety of resources found right here in the United States — including natural gas, biological material, and even water — using hydrogen fuel cells reduces our dependence on other countries for fuel.

Think of all the ways you use power each day. We use power to heat and light our homes and run electronic equipment. We also need power to operate cars and trucks. The power for almost all of today's vehicles comes from gasoline or diesel fuel, but someday you may drive a vehicle powered by a hydrogen fuel cell. When used in a car, a fuel cell uses hydrogen and oxygen (from the air) to generate electricity — the electricity powers a motor that turns the car's wheels. There is no engine like your car has today, and there is no exhaust emitted from the tailpipe. Can you imagine driving up to a fueling station and filling your cars with hydrogen instead of gasoline? Using fuel cells to power our vehicles will be as revolutionary a change to our transportation system as moving from the horse and buggy to the automobile in the early 1900's.

Because they use hydrogen, fuel cell-powered cars can reduce our need to import fuel from other countries and, with no harmful pollutants as exhaust, improve the quality of the air we breathe. Fuel cell vehicles also operate nearly silently. Can you imagine how quiet the streets of your city could be without the noise of traffic?

There are several technical challenges to overcome, however, before we'll see fuel cell vehicles in our neighborhood dealerships. One of these challenges is cost. Fuel cell vehicles are expensive to produce — and therefore expensive to buy. Scientists and engineers are researching ways to reduce the cost of fuel cells in order to make fuel cell vehicles an economical choice for consumers. Another challenge is fueling. Most people have easy access to gasoline stations, so refueling is quick and convenient. Only a small, but growing number of hydrogen stations currently exist. We need to build a network of hydrogen fueling stations so filling a fuel cell vehicle is just as quick and convenient as filling your car with gasoline today. And once you fill your fuel cell vehicle, how far can you drive on a tank of hydrogen? Yet another challenge to overcome is that of developing advanced hydrogen storage technologies. This will allow us to drive just as far, or farther, on a single tank of hydrogen in a fuel cell vehicle, as we do on a single tank of gasoline in today's vehicles.

Despite these challenges, you may soon see hydrogen fuel cell vehicles on the road in your community. Every major auto company is working to develop a fuel cell vehicle and many have vehicles on the road for testing and demonstration purposes.

Student Reading #2 — Fuel Cells for Portable Power

Can you imagine being an engineer for NASA in the beginning of the space program and you have been charged with the mission of getting a man on the moon? Scientists and engineers at that time faced many challenges — one of particular concern was how to provide a practical power source for extended missions to space. To solve the problem of portable power, NASA turned to a technology that had not been used since the Civil War era. With additional research and development, however, it proved to be a successful alternative for providing power on-board spacecraft, and it could one day power our everyday lives. This technology is hydrogen powered fuel cells.

Try to imagine all the ways that you use power in your. Just the uses of electricity would make a seemingly endless list. Our demand for electricity continues to grow. Laptops now have DVD players, personal digital assistants (PDAs) are even smaller in size, cell phones take pictures and come equipped with video games programmed into them. As new electronic equipment arrives on store shelves each day, our demand for portable electric power rapidly increases. Now imagine your vacuum cleaner without a plug. Or imagine not having to worry when your laptop or cell phone battery wears down and needs a recharge. Hydrogen-powered fuel cells will one day make that vision a reality. Imagine running a laptop computer for 40 hours without needing to recharge the battery. That's nearly two days!

Major consumer electronics firms and other companies are developing fuel cells, that will provide continuous electric power for nearly ten times longer than the batteries we use today. These fuel cells could then be used in a variety of small, portable devices such as cell phones, PDAs, laptops, digital cameras, video cameras, and even vacuum cleaners. Imagine the freedom this would allow us to have.

Although there are still technical challenges to tackle before fuel cells will be readily available to consumers, the first fuel cell applications you'll see are likely to be used in portable power devices such as laptops, cell phones, and vacuums, as stated above.

Fuel cells for portable power will have greater uses than what most people will see on store shelves. Our military forces rely on portable, high-tech, electronic devices for battlefield operations. Troops spend many hours in the field — longer-lasting power sources would reduce the weight of their gear, and more importantly, alleviate any concerns about running out of power when it's most needed. One answer to the military's growing power need is the micro fuel cell. Unlike today's batteries, which store electricity, micro fuel cells generate electricity through a chemical reaction between hydrogen and oxygen (from the air). The fuel cell will continue to generate electricity as long as fuel is provided.

Several critical technical challenges must be solved, however, before we'll see fuel cells in stores. Scientists are still researching ways to reduce the costs and improve the durability and reliability of fuel cell systems. Can you imagine the freedom we'll have when this technology arrives?

Student Reading #3 — Fuel Cells for Stationary Power

Can you imagine being an engineer for NASA in the beginning of the space program and you have been charged with the mission of getting a man on the moon? Scientists and engineers at that time faced many challenges — one of particular concern was how to provide a practical power source for extended missions to space. To solve the problem of portable power, NASA turned to a technology that had not been used since the Civil War era. With additional research and development, however, it proved to be a successful alternative for providing power on-board spacecraft, and it could one day power our everyday lives. This technology is hydrogen powered fuel cells.

Fuel cells generate electricity through an electrochemical reaction between hydrogen and oxygen. With oxygen from the air, as long as hydrogen is fed to a fuel cell, it will continue to produce electricity. When pure hydrogen is used, the only byproduct is water — no extra pollutants are produced. That's good for our health and the environment. Fuel cell technology is more efficient than traditional power systems, which means less energy is needed to provide the same amount of power. And because hydrogen can be produced using a wide variety of resources found right here in the United States — including natural gas, biological material, and even water — using hydrogen fuel cells reduces our dependence on other countries for fuel.

Think of things you use that require power. The lights in your house, an electric stove, your refrigerator and freezer, the television — just the ways in which you use electricity in your home is a seemingly endless list. Most of us receive our electricity from power plants, where it is generated and then carried through wires that connect to our home. Now think about using something completely different for all of your power needs. Hydrogen and fuel cells could completely revolutionize the way we power our daily lives — including the way we generate and receive the electricity needed to heat and power our homes, offices, and other "stationary applications."

Do you remember the last time a fierce storm downed power lines in your neighborhood? Have you ever experienced a blackout? Your home was probably without electricity until power crews could manually repair the lines, or fix the problem with the power grid or central power station. With a fuel cell system at home to provide your heat and electrical needs, as long as the hydrogen supply is constant, the supply of power will be constant as well. What's more, fuel cell systems are quiet, so there is no loud noise to keep homeowners up at night or to distract workers at the office!

Using a fuel cell system for home electricity and heating may offer some families a financial benefit. Some states have, or are considering, laws that allow building owners to sell surplus electricity back to the power grid. So if your home fuel cell system produces more power than you need, you can sell that extra power to the power company. Stationary fuel cell systems also offer benefits to people who live in rural or remote places where the power supply is unreliable. Buildings in remote locations may not have access to power lines — but they often have access to natural gas or other resources from which hydrogen can be produced. Hydrogen fuel cell systems can provide those building or home owners with new — and reliable — power choices.

Putting It All Together – The Vision of a Hydrogen Economy

A. Activity Summary

In this activity, students will envision the hydrogen economy. They will answer a series of questions to give focus to their vision and help them develop a classroom presentation.

B. Standards

Science

- Science and Technology Content Standard E
  - ✔ As a result of activities in grades 5–8, all students should develop —
    - -Understanding about science and technology
- Science in Personal and Social Perspectives Content Standard F
  - ✔ As a result of activities in grades 5–8, all students should develop an understanding of —
    - -Populations, resources, and environments
    - -Natural Hazards
    - -Risks and Benefits
    - -Science and Technology in society

Language Arts

- Standards for English Language Arts #5
  - ✔ Students employ a wide range of strategies as they write and use different writing process elements appropriately to communicate with different audiences for a variety of purposes.
- Standards for English Language Arts #7
  - ✔ Students conduct research on issues and interests by generating ideas and questions, and by posing problems. They gather, evaluate, and synthesize data from a variety of sources (e.g., print and non-print texts, artifacts, people) to communicate their discoveries in ways that suit their purposes and audience.
- Standards for English Language Arts #8
  - ✔ Students use a variety of technological and information resources (e.g., libraries, databases, computer networks, video) to gather and synthesize information and to create and communicate knowledge.
- Standards for English Language Arts #12
  - ✔ Students use spoken, written, and visual language to accomplish their own purposes (e.g., for learning, enjoyment, persuasion, and the exchange of information).

Social Studies

- Teacher Standard #2 — Time, Continuity, and Change
  - ✔ Social studies teachers should possess the knowledge, capabilities, and dispositions to organize and provide instruction at the appropriate school level for the study of time, Continuity, and Change

- Teacher Standard #7 — Production, Distribution, and Consumption
  - ✔ Social studies teachers should possess the knowledge, capabilities, and dispositions to organize and provide instruction at the appropriate school level for the study of how people organize for the Production, Distribution, and Consumption of goods and services.

- Teacher Standard #8 — Science, Technology, and Society
  - ✔ Social studies teachers should possess the knowledge, capabilities, and dispositions to organize and provide instruction at the appropriate school level for the study of science, technology, and society.

- Teacher Standard #9 — Global Connections
  - ✔ Social studies teachers should possess the knowledge, capabilities, and dispositions to provide instruction at the appropriate school level for the study of Global Connections and Interdependence.

C. Teacher Background

"A hydrogen economy will mean a world where our pollution problems are solved and where our need for abundant and affordable energy is secure….and where concerns about dwindling resources are a thing of the past."

— Spencer Abraham, Secretary of Energy

The hydrogen economy is a world fundamentally different than the world we know now. Picture it…

- Hydrogen is available to everyone, everywhere — from the corner fueling station to the large industrial facility.
- The United States is not so dependent on a single source of fuel.
- Hydrogen is produced, domestically, cleanly and cost-effectively, from a variety of sources including renewables, such as biomass and water; fossil fuels such as methane, coal, and oil, using advanced technologies to ensure that any carbon released in the process not escape into the atmosphere; and nuclear energy.
- Hydrogen is delivered and stored routinely and safely.
- Hydrogen-powered fuel cells and engines are as common as the gasoline and diesel engines of the late 20th century — they power our cars, trucks, buses, and other vehicles, as well as our homes, offices, and factories.
- U.S. companies that for decades invested in hydrogen technologies now export commercial products and services around the world. And developing countries have access to clean, sustainable, and economical hydrogen-based energy systems to meet their growing energy demands.

There are many challenges to building a hydrogen economy. It's not a vision that will be realized tomorrow, next month, or next year — but it is achievable. Government and industry partners are working to make it happen. Today's students will be the first generation of hydrogen-fuel cell technology users. There may be applications for fuel cells that scientists and engineers have not yet developed — your students may have creative ideas of their own.

D. Materials
• Copies of the student activity sheet for each student
• Art materials such as construction paper, markers, and colored pencils

E. Activity Steps
1. Remind students that in the fuel cell unit they have just completed, they caught a glimpse of the future. They learned about a new technology that may one day power our lives from laptops to homes, and even our cars.

2. Ask students to look back over their science journals or activity sheets and describe what they have learned about hydrogen and fuel cells. Conduct a class discussion about what students have learned. Make sure students discuss the following points:

   a. How do fuel cells work?
   b. How can fuel cells be used?
   c. What is required for fuel cells to work? What are the benefits of using hydrogen fuel cells for our power needs?
   d. How can hydrogen be produced?
   e. How can hydrogen be delivered and stored?
   f. Is hydrogen safe?

3. Explain to students that now they will use this new knowledge to create their own vision of the future. By answering questions on the worksheet, students can focus their thoughts on what the hydrogen economy might look like. Encourage them to use their imaginations and creativity.

4. Have students draw a picture of their vision of the hydrogen economy. What will the world be like? To further develop this project, students can write an essay to support the images in their pictures or develop a presentation board for a classroom presentation which includes a layout with written information and pictures.

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Activity Sheet

Fuel cells can be used in portable, stationary, and transportation applications. What would our world look like if our homes, businesses, industrial buildings, cars, trucks, buses, and even electronic equipment used hydrogen fuel cells? The vision of our world powered by hydrogen is called the vision of a "hydrogen economy." How would our lives be different? What would be the same?

Now it's time for you to get creative and imagine what a hydrogen-powered world might look like. Think about something we use today that would be transformed by using a hydrogen fuel cell. Are there things we can't do today that might be possible with a fuel cell? It might be the way you drive a car or the way we power our homes. It might be something entirely different. Try to picture all of the possible changes in a world using hydrogen fuel cells.

Answer the questions below and then draw a picture, write an essay, or create a classroom presentation that illustrates what you have imagined. Have fun and be creative. The possibilities are endless.

1. What is the name of your fuel cell application?

2. Describe how your application would make life easier or benefit society.

3. What does your application look like?

4. What current technology would your application replace?

5. How much would your application cost and how would you plan to market it?

6. Where would your hydrogen come from – how would it be produced?
   Would it need to be stored? If so, how?

Appendix A

Extension ideas on journaling, note taking, and further information

Inquiry-Based Student Journaling

One inquiry-based approach, called Focused and Systematic Thinking (FaST) journaling allows students to look back on their thoughts from previous science activities, review them, and if needed, correct the scientific concepts introduced in the experiments.

A typical FaST journaling activity is as follows:

1. Introduction and set-up by teacher

The teacher explains the demonstration, experiment, or activity and provides students with enough background information to enable their educated predictions.

2. Prediction and Class Discussion

Using student FaST journals, students make predictions of what will happen in the experiment. (Students should list at least one idea of their own, but may list as many as they like). In the class discussion that follows, students share their predictions. These ideas can all be their own or a combination of their ideas and those of their classmates. Some ideas will be correct and some ideas will be incorrect — but all ideas should be accepted and discussed. Students should explain why they think their predictions are correct. Their justifications do not need to be scientifically correct, but students should be encouraged to share their ideas and explain the experiment in as many ways as possible. By the end of the discussion, each student should have at least three different predictions listed in his/her journal.

3. Hands-on demonstration, experiment, or activity and follow-up questions

After the prediction and class discussion, students perform the experiment. Upon completion, using their FaST journals, students answer a series of questions designed to prompt their thinking about why the experiment "worked" as it did. Note: some sections of this guide include additional background and notes for teachers.

4. Class discussion

A class discussion follows in which students are encouraged to share their answers to the follow-up questions and the ideas in their FaST journals. When students complete the experiment, teachers should ensure that students have documented in their FaST journals the correct scientific concepts. (One way to do this is by using a highlighter to draw attention to certain concepts).

5. Journal Assessment

Teachers can assess FaST journals in several different ways, depending on their needs. In general, students should not be evaluated on the merits of their predictions but rather on their participation in the thoughts/predictions and follow-up phases. Teachers should evaluate journals for scientifically correct concepts in the last section, "Class Discussion," in which correct concepts should be highlighted. Journal grading can be time-consuming. Specific grading techniques include the following:

- Holistic grading — This method is a quick and easy way for teachers to ensure their students complete FaST journals correctly. Teachers can collect the journals weekly, bi-weekly, monthly, before each grading period, or as often as the teacher feels is necessary. The journals can be graded holistically by quickly checking to ensure students have documented at least three ideas in the prediction phase, answered the follow-up questions, and highlighted correct scientific concepts.
- Lesson grading — This method requires teachers to grade each lesson in students' FaST journals. This may be a good idea for the first lesson so that students have feedback that may help them better understand what is expected in the FaST journals.
- Fact grading — Certain facts, scientific concepts, and answers to questions can be checked for accuracy.

Student Engagement Through Note-Taking — NaTs (Notes and Thoughts)

In addition to FaST journaling, Notes and Thoughts (NaTs) can engage students in science. In NaTs, students are immersed in the content not only by taking notes on the main ideas presented in the piece, but also by documenting their thoughts and questions. Using their FaST journals, students divide each sheet of paper in half with a vertical line. They use the left side of the page for "regular" note-taking on the important themes or points of the reading. They use the left side for writing any questions, thoughts, concerns, or comments that arise as they read. The questions and thoughts can be used in subsequent class discussions. NaTs enables a more complete understanding of the topic — it prompts students to inquire about what they are studying, allows students to tap into their prior knowledge, and provides fodder for class discussions that may be otherwise lost in traditional note-taking.

Appendix B

Web Resources

Glossary – *www.eere.energy.gov/hydrogenandfuelcells/glossary.html*

General Information — Hydrogen (Production, Delivery, Storage, Safety) and Fuel Cells
DOE's Hydrogen, Fuel Cells, and Infrastructure Technologies Program —
www.eere.energy.gov/hydrogenandfuelcells
(see Students and Teachers section for additional education links)

Fuel Cells
- Fuel Cells 2000 — *www.fuelcells.org*
- How Stuff Works — *www.howstuffworks.com/fuel-cell.htm*
- General Motors — *www.gmability.com*
- California Fuel Cell Partnership — *www.cafcp.org*

Hydrogen and Hydrogen Safety
- National Hydrogen Association — *www.hydrogenus.org*
- Navy Lakehurst Historical Society, Inc. (About the Hindenburg) — *www.nlhs.com/hindenburg.htm*
- Fuel Cell Store
  - Hydrogen Storage — *www.fuelcellstore.com/information/hydrogen_storage.html*
  - Hydrogen Safety — *www.fuelcellstore.com/information/hydrogen_safety.html*