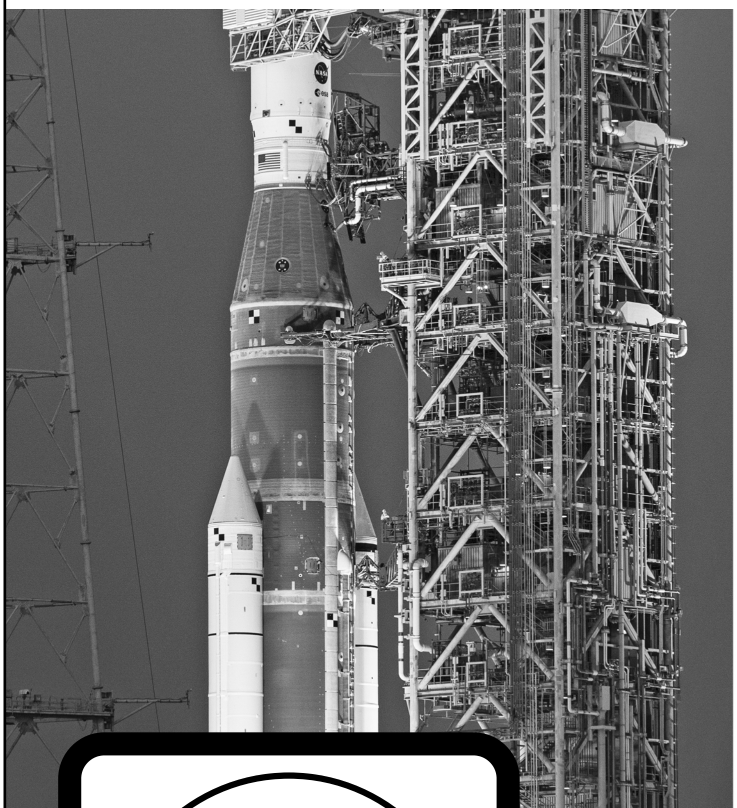
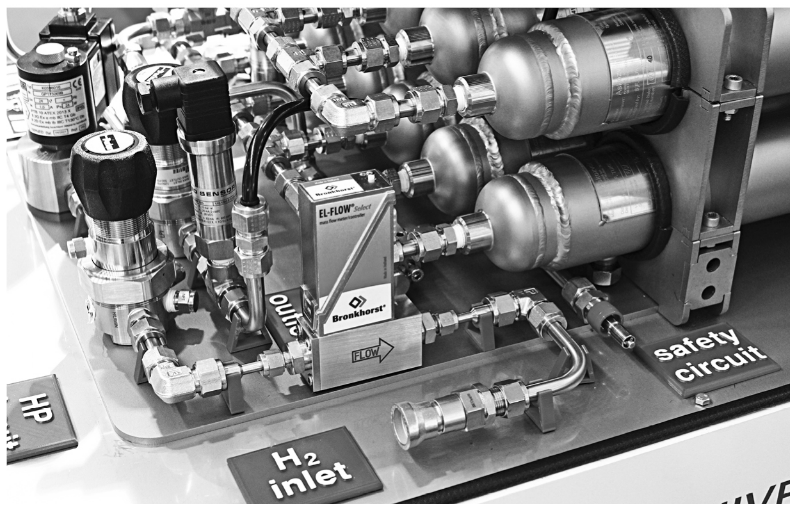
H_2 Educate

Information and hands-on activities to teach students about hydrogen as a transportation fuel, a fuel for electricity generation, and its uses in industrial processes.





Grade Levels:

- Intermediate
- Secondary

Subject Areas:

- Science
- Social Studies
- Language Arts
- Math
- Technology

NEED
National Energy Education Development Project

Teacher Advisory Board

NEED Mission Statement

The mission of The NEED Project is to promote an energy conscious and educated society by creating effective networks of students, educators, business, government and community leaders to design and deliver objective, multi-sided energy education programs.

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Teacher Advisory Board

In support of NEED, the national Teacher Advisory Board (TAB) is dedicated to developing and promoting standards-based energy curriculum and training.

Energy Data Used in NEED Materials

NEED believes in providing teachers and students with the most recently reported, available, and accurate energy data. Most statistics and data contained within this guide are derived from the U.S. Energy Information Administration. Data is compiled and updated annually where available. Where annual updates are not available, the most current, complete data year available at the time of updates is accessed and printed in NEED materials. To further research energy data, visit the EIA website at www.eia.gov.

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National Energy Education Development

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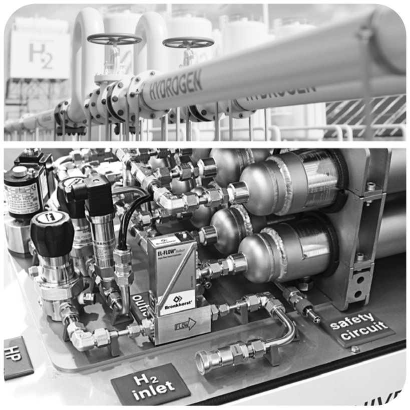


H_2 Educate
Teacher Guide

H_2 Educate was developed by NEED's Teacher Advisory Board Hydrogen Committee with funding from the U.S. Department of Energy Hydrogen Program.

H_2 Educate Kit

- 1 Brownlee Apparatus
- 2 Test tubes
- 2 #1 Rubber stoppers
- 1,000 mL Beaker
- 8 Petri dishes
- 2 Packages graphite electrodes (pencil leads)
- 16 9-volt Batteries
- 4 AA Batteries
- 1 Container sodium sulfate
- 100 ft Fringe
- 10 Flashing bulb pins
- 2 Flashlights (batteries included)
- 1Fuel cell car kit
- 1 Funnel
- 1 100 mL Beaker
- 2 Packages clay
- 25 Wooden splints
- 100 Small straws
- 10 Alligator clip sets
- 1 Teacher/Student Guide

NEED wishes to send a special thanks to long-time NEED teacher and facilitator extraordinaire, Coach Vernon Kimball of Bayfield, CO, for his expertise in adapting our electrolysis activities.

Table of Contents

Standards Correlation Information

www.NEED.org/educators/curriculum-correlations/

Next Generation Science Standards

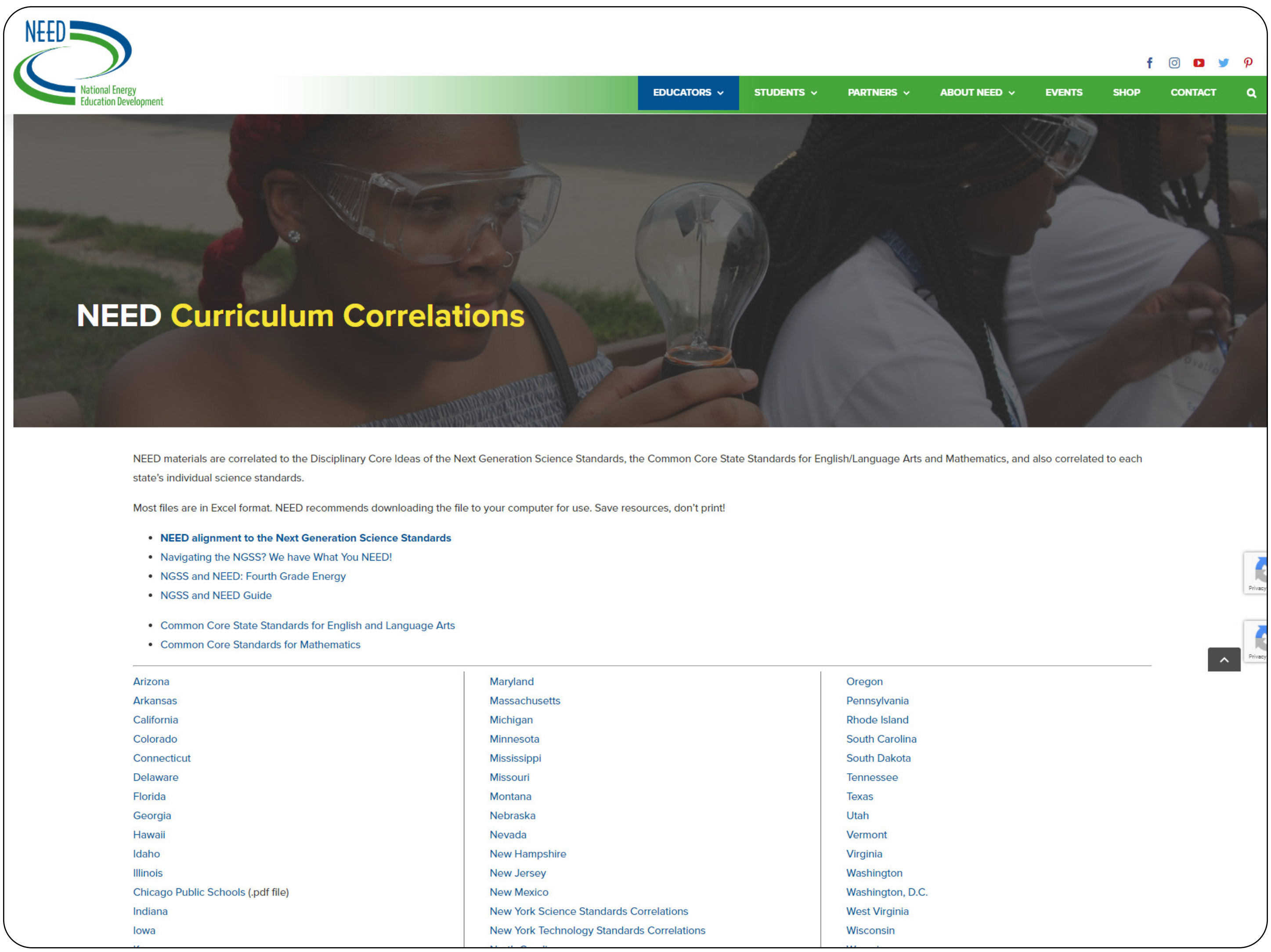
- This guide effectively supports many Next Generation Science Standards. This material can satisfy performance expectations, science and engineering practices, disciplinary core ideas, and cross-cutting concepts within your required curriculum. For more details on these correlations, please visit NEED's curriculum correlations website.

Common Core State Standards

- This guide has been correlated to the Common Core State Standards in both language arts and mathematics. These correlations are broken down by grade level and guide title, and can be downloaded as a spreadsheet from the NEED curriculum correlations website.

Individual State Science Standards

- This guide has been correlated to each state's individual science standards. These correlations are broken down by grade level and guide title, and can be downloaded as a spreadsheet from the NEED website.



H_2 Educate Materials

The table below lists activities that require kit materials and supplies other than paper and pencils. Contact NEED with any questions about kit materials or how to procure items not included within the kit.

A set of consumables is available for purchase. Materials in the consumables package are also listed below. Head to shop.NEED.org.

ACTIVITY	MATERIALS IN KIT	ADDITIONAL MATERIALS NEEDED
Setting the Stage for Hydrogen	▪Hydrogen fuel cell car ▪100 mL Beaker	▪Distilled water
Hydrogen in Society Jigsaw		▪Poster board
Electrolysis	▪Sodium sulfate (Na_2SO_4) ▪Brownlee apparatus ▪1,000 mL Beaker ▪#1 Rubber stoppers ▪Test tubes ▪Splints ▪9-volt Batteries ▪Alligator clips ▪Funnel ▪Graphite electrodes (pencil leads)	▪Distilled water ▪Safety matches ▪Safety glasses ▪Gloves ▪Tongs for test tubes ▪Universal indicator solution (optional)
Element Modeling	▪Straws ▪Clay—three different colors	▪Scissors
Fuel Cell Simulation	▪Flashing bulbs ▪Fringe ▪Flashlight	▪Colored tape ▪String ▪Scissors ▪Cardstock
Hydrogen in the Round		▪Cardstock

Warning

Do not substitute sodium sulfate with calcium chloride or any other chloride salt! If you do not have access to sodium sulfate, magnesium sulfate (Epsom salt) may be used as a substitute. Epsom salt can be purchased at most pharmacies.

Set of Consumables

- 1 Pack graphite electrodes (pencil leads)
- 16 9-volt Batteries
- 4 AA batteries
- 2 Packages clay
- 1 Container sodium sulfate
- 25 Splints
- 100 Small straws
- 100 Feet of fringe

Teacher Guide

Grade Levels

- Intermediate, grades 6–8
- Secondary, grades 9-12

Time

- Approximately 5-10 class periods, depending on activities selected and the structure of the unit

Science Notebooks

Throughout this curriculum, science notebooks are referenced. If you currently use science notebooks or journals, you may have your students continue using these.

In addition to science notebooks, student worksheets have been included in the guides. Depending on your students' level of independence and familiarity with the scientific process, you may choose to use these worksheets instead of science notebooks. Or, as appropriate, you may want to make copies of worksheets and have your students glue or tape the copies into their notebooks.

Background

This hydrogen unit is designed as a multidisciplinary curriculum with a hands-on science kit, fuel cell simulation equipment, element modeling materials, fuel cell car kit for demonstration, and language arts, social studies, and technology activities. The unit explores the energy picture in the United States today, the challenges for the future, the role of hydrogen in meeting those challenges, and the scientific basis for hydrogen as a fuel, with an exploration of electrolysis as a method to generate hydrogen.

Preparation

- Read the Teacher Guide and preview all of the activities in the unit. Familiarize yourself with the student text. Select activities you will use if not conducting the entire unit.
- Examine the equipment in the kit to become familiar with its design and to make sure nothing was damaged in shipment. Refer to the Operating Instructions and Experiment Instructions Manual in the *Fuel Cell Car Kit* to gain a more comprehensive understanding of how the car works.
- Decide how you will structure the unit—as a single class unit or as an integrated unit with other teachers. If this will be an integrated unit, meet with the other teachers to plan and schedule the activities. A suggested integrated unit is as follows:

    Pre/Post Assessment—Science

    Fuel Cell Car Demonstrations—Science

    Comparing Energy Systems—Social Studies

    Background Reading and Graphic Organizers—Language Arts

    Electrolysis and Element Modeling—Science

    Hydrogen in Society Jigsaw Activity—Social Studies

    Fuel Cell Simulation and Report—Language Arts

    Hydrogen Economy Comparison Activity—Social Studies

    Hydrogen in the Round Game—Language Arts

- Collect the materials needed for the activities selected. A listing of necessary materials can be found on page 5.
- Make copies or prepare digital copies to project for any activities that you want the students to complete.
- Prepare a copy of the *Lab Safety Rules* master for projection during lab activities.
- Pre-select student groups and assign roles as appropriate for the following activities:

    Activity 2: Jigsaw—seven role groups

    Activity 2: Jigsaw—three to five presentation groups with one representative of each role group

    Activities 5 and 6: Electrolysis and Element Modeling—groups of two lab partners

Activity 1: Setting the Stage for Hydrogen

✪ Objective

- Students will be able to identify basic information about hydrogen and energy.

Materials

- Hydrogen Fuel Cell Car
- *Assembly and Operation of the Fuel Cell Car*, page 31
- *Pre/Post Hydrogen Assessment*, page 54

✔ Procedure

1. Introduce the unit to the class. Ask students to brainstorm a list of things they associate with the word "hydrogen".
2. Demonstrate the Hydrogen Fuel Cell Car to stimulate interest. Use the assembly and operation instructions for assistance as needed. Check out **www.horizoneducational.com** for more information and hydrogen fuel cell car challeneges.
3. Have the students take the *Pre/Post Hydrogen Assessment* and collect the results.

Activity 2: Hydrogen in Society Jigsaw

✪ Objective

- Students will be able to identify basic information about hydrogen and energy.

Materials

- Poster boards
- *Rubrics for Assessment*, page 15
- *Hydrogen Information Web Links*, page 18
- Student informational text, pages 20-30
- *Jigsaw Role Questions and Presentation Questions,* page 32
- *Hydrogen in Society* role group worksheet, page 33
- *Hydrogen in Society Presentation Organizer*, page 34

✔ Procedure

1. Divide the students into seven groups. Assign each group one of seven specific roles, as listed below. These groups are the role groups. Also assign the students to presentation groups, in which they will share their role expertise. Each presentation group should include at least one member from each role group.

   Role Groups:

Physicist	Hydrogen Producer
Hydrogen Distributor	Energy Security Advisor
Energy Economist	Energy Efficiency and Reliability Expert
Environmental Scientist	

2. Explain the jigsaw assignment to the students. Give each student the list of role questions for his/her role group and a copy of the role group worksheet. Explain that the questions will guide their reading and research. Explain that they will be involved in completing the organizer over several days as they participate in the readings and other hydrogen-related activities. They will use the information they have gathered to design and present projects at the end of the unit in their presentation groups.
3. Instruct the students to use the informational text, as well as outside sources, to answer their questions as completely as possible. Guide them to the list of hydrogen websites where they can go to find additional information.
4. At the end of the electrolysis and simulation activities, after the students have read all of the text sections, and completed their research and their worksheets, have the role groups meet to discuss their findings. Instruct the students to add to their worksheets any additional information provided by group members.

CONTINUED ON NEXT PAGE

5. After the students have met in the role groups and completed their discussions, assign them to their presentation groups. Explain that the presentation groups will synthesize the information collected by the different role groups.
6. Distribute copies of the presentation questions and presentation organizer to each student. Instruct the presentation groups to work together to answer the presentation questions, using poster boards to collect members' ideas from each of the role areas.
7. After the groups have answered all of the presentation questions, instruct each presentation group to choose a format with which to present their findings. Suggested formats include a PowerPoint presentation, a brochure, an expo display board, a song or rap, a letter to the editor of the school newspaper, a persuasive essay, an advertisement, a video, or any other format acceptable to the teacher.
8. Give the groups a timeframe in which to complete and present their projects.
9. Use the *Presentation Rubric* to evaluate the projects.

Activity 3: Comparing Energy Systems

✪ Objective

- Students will be able to analyze the energy system in use in the United States and compare it to an ideal energy system.

Materials

- Student informational text, pages 20-30
- *Comparing Energy Systems*, page 35

✔ Procedure

1. Have the students read the following informational text sections:

   The Energy Picture in the United States Today and *Looking to the Future*, including "The Ideal Energy System"
2. Have the students draw Venn diagrams or use the worksheet to compare the energy system in the United States today with the ideal energy system.
3. Discuss as a class the challenges with our energy system today in its current form, and how we might tackle modernizing the system to meet future needs.
4. Brainstorm ideas for making today's energy system more ideal.

Activity 4: The Science of Hydrogen

✪ Objective

- Students will be able to identify physical and chemical properties of hydrogen.

Materials

- Student informational text, pages 20-30
- *The Science of Hydrogen* graphic organizer, page 36

✔ Procedure

1. Have the students complete the graphic organizer as they read the following background sections:

   What is Hydrogen?, Atomic Structure, Chemical Bonding, and *The Periodic Table of the Elements*
2. Discuss any questions the students have.

Activity 5: Electrolysis

✪ Objective

- Students will be able to describe how a water molecule can be separated into hydrogen and oxygen.

Materials *FOR DEMONSTRATION*

- 1 Electrolysis apparatus
- 2 Test tubes
- 1 Solid #1 rubber stopper
- 1 9-volt Battery
- Tongs
- 1 1,000 mL Beaker filled about 2/3 full with electrolyte solution

Materials *PER STUDENT / STUDENT GROUP*

- 1 Petri dish
- 2 Graphite electrodes
- 2 Alligator clips
- 1 9-volt Battery
- Approximately 100 mL 0.25 M Na_2SO_4
- Universal indicator (optional)
- Safety glasses

Materials *TEACHER AND STUDENT PAGES*

- *Lab Safety Rules* master, page 19
- *Brownlee Apparatus Setup and Instructions* Masters, pages 37-38
- *Electrochemistry and Electrolysis*, page 40
- *Small-Scale Electrolysis of Water*, page 41

Preparation

- Assign students to groups of two and give each group a lab station or element modeling station. Half of the students will participate in this lab during the first rotation and the remaining students will participate in the element modeling activity. In the second rotation, the students will switch activities. Project the *Discussion Questions* and *Variable Questions* on page 10.
- Prepare 0.25 M sodium sulfate solution by dissolving 35.5 g in 1 liter of distilled water. This will be used for the demonstration and by student groups. 100 mL is an approximate amount each group will need, but you may need to provide more depending on the petri dishes or container you may use in their place. Electrodes need to be submerged sufficiently well so the volume of gases being produced at each is apparent.
- Familiarize yourself with the setup of the Brownlee apparatus. A complete procedure with diagrams is found on pages 37-38.

Classroom Management Tips and Preparation Notes

- This activity can be completed at the same time as Activity 6: Element Modeling.
- The Na_2SO_4 solution can be saved indefinitely in a plastic container. If you are saving it in a distilled water jug, be sure to clearly mark the jug with its contents.
- The electrolysis process will proceed more quickly if the electrolyte solution is very warm or more concentrated. If the chemical reaction is too slow, the students may lose interest. It is suggested that you place the container with the electrolyte solution in a hot water bath approximately an hour before the lab is scheduled. If this is not feasible, you may increase the concentration of the solution by adding 10 cm^3 more sodium sulfate to the solution.
- The Graphite electrodes can be reused but may decompose over time with use. Take note where oxygen is being produced and replace when necessary.

⚠ Lab Safety and Warning

1. Go over the *Lab Safety Rules* master and the Material Safety Data Sheet (MSDS) for sodium sulfate (included in the kit) with the class. Reinforce any other lab safety rules that you require.
2. If sodium sulfate is not available, magnesium sulfate (Epsom salts) may be used. **Do not use a chloride-containing salt as the electrolyte.** Chlorine gas may form.

CONTINUED ON NEXT PAGE

✔ Procedure

1. Have the students read and familiarize themselves with the following informational text sections and worksheets: *How Is Hydrogen Made?, Electrochemistry and Electrolysis, Electrolysis Exploration*, and *Electrolysis Data Recording Form*. Answer any student questions and provide instructions about recording the data in the students' notebooks. If necessary, review the lab procedure on the *Small-Scale Electrolysis of Water* worksheet.
2. Set up the electrolysis demonstration using the Brownlee apparatus, explaining everything as you go. Note which tube is connected to the anode and which is connected to the cathode. Take some photos of the tubes filling with gas so they can see the different volumes forming at each electrode. Allow this to run while students do the student portion of the activity.
3. Assign student pairs to lab stations and monitor their work.
4. When the students have completed the lab, have them return the electrolyte solution to a container you designate. Graphite electrodes should be rinsed and patted dry. Alligator clips should be dried thoroughly to prevent rusting. Store the electrolyte solution in a marked container for reuse.
5. When students have returned to their seats, complete the demonstration.
6. Instruct the students to answer the *Discussion Question*s below in their science notebooks.

Discussion Questions

1. What did you learn about the composition of water?
2. Explain how electrical energy decomposes water. Use the terms anode, cathode, oxidation, and reduction in your explanation.
3. Which gas formed at the cathode and which gas formed at the anode? Explain why each gas is attracted to each electrode.
4. Balance this equation for the decomposition of water: $8\ H_20 = \_\_H_2 + \_\_O_2$. (Answer: $8\ H_2 + 4\ O_2$)

Variable Questions

1. How would using distilled water with no electrolyte affect the results?
2. How would increasing the concentration of the electrolyte affect the results?
3. How would increasing the voltage affect the results? (connecting 2-4 batteries in parallel)
4. How would increasing the current affect the results? (connecting 2-4 batteries in series)
5. How would changing the temperature of the solution affect the results?

Extensions

- Allow students to add a few drops of an acid-base indicator, like universal indicator or bromothymol blue, to the electrolyte. They should see an acidic indicator at one electrode and a basic indicator at the other. Challenge students to explain what is happening. For example, if BTB is used, you will see the solution near one electrode turn blue and the other yellow.

Activity 6: Element Modeling

Objectives

- Students will be able to construct elements to model atomic structure.
- Students will be able to describe how atoms bond to form elements.

Materials

- Straws
- Three different colors of clay
- Scissors
- Student informational text, pages 20-30
- *Element Models* master, page 42
- *Element Models* worksheet, page 43

Classroom Management Tip

- This activity works best if completed at the same time as *Activity 5: Electrolysis*, as it allows students to work in pairs.

Preparation

- Prepare one or more work areas large enough for sixteen students to complete the activity.

✔ Procedure

1. Have the students read *Atomic Structure, Chemical Bonding*, and *The Periodic Table of the Elements* in the informational text. Review the information to make sure the students understand atoms and their component particles, elements, molecules, and chemical bonds. Instruct the students to define the key terms in their science notebooks.
2. Have the students examine the Periodic Table of the Elements to find elements with which they are familiar.
3. Have the students read the *Element Models* activity. Answer any student questions. Emphasize to the students that the models will not be realistically representative of the structure of atoms and molecules.
4. Assign students to the work area and instruct them to complete the first model of the activity—a hydrogen atom. Check the students' models to make sure they are correct, as shown in the *Element Models* master. When all students have correctly created the hydrogen atom model, instruct them to create each additional model in turn, monitoring for understanding before proceeding to the next model.
5. When the students have completed the activity, which may not take as much time as the lab activity, instruct them to work on the jigsaw activity.

☑ Element Modeling Performance Assessment

- Students should be able to distinguish between atoms and molecules and draw diagrams of simple molecules. Students' knowledge of basic molecular structure should be significantly enhanced.

Extension

- To reinforce student understanding of atomic structure and the relative distance of electrons from the nucleus, have a student stand in the middle of the football field holding a marble to represent the nucleus of an atom, while other students stand at each end zone to represent the position of the electrons, emphasizing that the electrons themselves would be too small to see.

Simulation Vocabulary

- anode
- atom
- catalyst
- cathode
- circuit
- electrode
- electrolysis
- electrolyte
- electron
- hydrogen
- ion
- membrane
- molecule
- oxygen
- PEM
- polymer

Simulation Suggestions

1. Students will need a 10' x 10' open space; use a hallway, outside area, or gym to allow enough room for movement and observers. Have the students set up the simulation according to the diagram.
2. Let students determine how to conduct the simulation. Part of the learning value of this activity is allowing students to discover and learn by doing, extending, and reinforcing prior knowledge.

Activity 7: Fuel Cell Simulation

Objectives

- Students will be able to explain how hydrogen is used to carry energy and generate electricity.
- Students will be able to explain the components of a PEM fuel cell and how it works.
- Students will be able to trace the flow of the system of a PEM fuel cell by accurately drawing and labeling a diagram.

Materials

- Flashing bulbs
- Flashlight
- Fringe
- Colored tape
- Scissors
- String
- Cardstock
- Student informational text, page 20-30
- *Fuel Cell* master, page 44
- *What Is a Fuel Cell?* worksheet, page 45
- *Fuel Cell Simulation* Master, page 46
- *Hang Tag* master, page 47

Preparation

- Write or display the vocabulary list on the left onto the board.
- Prepare a copy of the *Fuel Cell* master to project for the class.
- Make four copies of the hang tag master onto cardstock, cut out the hang tags and attach string to each tag. The hydrogen and oxygen hang tags are two-sided tags, folded on the dotted lines.

Procedure

1. Have the students review the vocabulary terms using the *Glossary* in the Student Guide.
2. Use the *Fuel Cell* master to introduce the operation of a fuel cell to the students.
3. Have the students read the *What Is a Fuel Cell?* section of the informational text and the *What Is a Fuel Cell?* activity instructions. Answer any student questions.
4. Assign roles to the students using the simulation master, and proceed through the steps. Some students may be observers during the first simulation, then assume roles in a second simulation while the other students observe.

Assessment

1. After participating in and observing the simulation several times, have the students imagine they are writing to other students to explain how a fuel cell works, with an explanation of how fuel cells are used. Students must use the vocabulary words and draw diagrams to support their explanations. Alternatively, you could also assign students to write a fictional story detailing their journey through a fuel cell as hydrogen or oxygen.
2. Use the *Simulation Rubric* to assess vocabulary acquisition and understanding of concepts.

Activity 8: Hydrogen in Our Energy System

✪ Objective

- Students will be able to describe the advantages, disadvantages, and challenges to the nation moving toward a hydrogen inclusive economy.

Materials

- Student informational text, pages 20-30
- *Hydrogen in Our Energy System*, page 48

✔ Procedure

1. Have students read the following informational text sections:

   Hydrogen as a Fuel, *Uses of Hydrogen*, and *The Challenges of Hydrogen,* including all subsections.
2. Have students use the graphic organizer to compare a hydrogen economy with the ideal energy system.
3. Discuss the advantages and disadvantages of hydrogen as a part of our economy, and the challenges that the nation will have transitioning towards more hydrogen use. Ask the students for their personal opinions about the feasibility of the United States making hydrogen fuels more of a priority.

Activity 9: Hydrogen in the Round

✪ Objective

- Students will be able to properly identify hydrogen vocabulary definitions.

Materials

- *Hydrogen in the Round* cards, pages 49-52
- Cardstock

Preparation

- Make copies of the *Hydrogen in the Round* cards on cardstock.
- Cut out the individual cards.

✔ Procedure

1. Distribute the cards randomly to the students. If you have fewer than 30 students in the class, give some students two cards. All of the cards must be distributed for the game to succeed. If you have more than 30 students, assign a few students to work in pairs. These students can also serve as arbiters of disputes.
2. Explain the instructions for the game, as follows:
   - Select a student to start Round 1 by reading the first question on their card, "Who has....."
   - The student who has the answer to the question stands up and responds by reading his/her card, "I have...... Who has.....?'
   - This procedure continues until every person has read his/her card and the question has returned to the Starter, who answers the last question. It does not matter which student you start with, as the cards will go in a continuous round.
3. Use the answer key to follow along with students and help settle any disputes, if necessary. An answer key is found on page 14.
4. Proceed to play Round 2 in the same way.
5. Repeat this activity throughout the unit to reinforce vocabulary.

☑Evaluation

1. Have the students take the *Pre/Post Hydrogen Assessment* on page 54. Collect the results.
2. Play *Hydrogen Bingo* with students as a formative assessment. Instructions are found on pages 16-17 and the bingo card can be found on page 53.
3. Complete the unit *Evaluation Form* with the students on page 59.
4. Return the *Pre/Post Hydrogen Assessment* results and the *Evaluation Form* to The NEED Project.

☑Answer Key To Assessment

1. C **2.** B **3.** C **4.** B **5.** C **6.** T **7.** F **8.** D **9.** C **10.** C **11.** D **12.** F **13.** T **14.** T **15.** T

☑Hydrogen in the Round Answers

ROUND 1 – STARTING WITH HYDROGEN'S CLUE:

- Element
- Proton
- Neutron
- Electron
- Energy Level
- Radiant Energy
- Nuclear Fusion
- Steam Reforming
- Electrolysis
- Photoelectrolysis
- Biomass Gasification
- Photobiological Microbial Production
- Energy Carrier
- Fuel Cell
- Electrochemical Energy Conversion Device
- Circuit
- PEM
- Anode
- Catalyst
- Cathode
- Ion
- Ionic Bond
- Covalent Bond
- Energy
- Nonrenewable
- Renewable
- Endothermic
- Carbon Capture, Utilization, and Storage
- Periodic Table
- Hydrogen

ROUND 2 – STARTING WITH HYDROGEN'S CLUE:

- Photoelectrolysis
- Cathode
- Element
- Biomass Gasification
- Ion
- Proton
- Photobiological Microbial Production
- Ionic Bond
- Neutron
- Energy Carrier
- Covalent Bond
- Electron
- Fuel Cell
- Energy
- Energy Level
- Electrochemical Energy Conversion Device
- Nonrenewable
- Radiant Energy
- Circuit
- Renewable
- Nuclear Fusion
- PEM
- Endothermic
- Steam Reforming
- Anode
- Carbon Capture, Utilization, and Storage
- Electrolysis
- Catalyst
- Periodic Table
- Hydrogen

Rubrics For Assessment

Simulation Rubric

GRADE	SCIENTIFIC CONCEPTS	DIAGRAMS	PROCEDURES	SUMMARY
4	Written explanations illustrate accurate and thorough understanding of scientific concepts underlying inquiry.	Comprehensive diagrams are accurately and neatly labeled and make the designs easier to understand.	Procedures are listed in clear steps. Each step is numbered and is written as a complete sentence.	Summary describes information and skills learned, as well as some future applications to real life situations.
3	Written explanations illustrate an accurate understanding of most scientific concepts underlying inquiry.	Necessary diagrams are accurately and neatly labeled.	Procedures are listed in a logical order, but steps are not numbered or are not in complete sentences.	Summary describes the information learned and a possible application to a real life application.
2	Written explanations illustrate a limited understanding of scientific concepts underlying inquiry.	Necessary diagrams are labeled.	Procedures are listed but are not in a logical order or are difficult to understand.	Summary describes the information learned.
1	Written explanations illustrate an inaccurate understanding of scientific concepts underlying inquiry.	Necessary diagrams or important components of diagrams are missing.	Procedures do not accurately reflect the steps of the design process.	Summary is missing or inaccurate.

Presentation Rubric

GRADE	CONTENT	ORGANIZATION	ORIGINALITY	WORKLOAD
4	Topic is covered in depth with many details and examples. Subject knowledge is excellent.	Content is very well organized and presented in a logical sequence.	Presentation shows much original thought. Ideas are creative and inventive.	The workload is divided and shared equally by all members of the group.
3	Presentation includes essential information about the topic. Subject knowledge is good.	Content is logically organized.	Presentation shows some original thought. Work shows new ideas and insights.	The workload is divided and shared fairly equally by all group members, but workloads may vary.
2	Presentation includes essential information about the topic, but there are 1-2 factual errors.	Content is logically organized with a few confusing sections.	Presentation provides essential information, but there is little evidence of original thinking.	The workload is divided, but one person in the group did not do his/her fair share of the work.
1	Presentation includes minimal information or there are several factual errors.	There is no clear organizational structure, just a compilation of facts.	Presentation provides some essential information, but no original thought.	The workload is not divided, or several members are not doing their fair share of the work.

Hydrogen BINGO Instructions

***Hydrogen Bingo* is a great icebreaker for a NEED workshop or conference. As a classroom activity, it also makes a great introduction to an energy unit.**

Preparation

- 5 minutes

Time

- 45 minutes

Bingos are available on several different topics. Check out these resources for more bingo options!

- Biomass Bingo—*Energy Stories and More*
- Change a Light Bingo—*Energy Conservation Contract*
- Energy Bingo—*Energy Games and Icebreakers*
- Energy Efficiency Bingo—*School Energy Experts* and *School Energy Managers*
- Hydropower Bingo—Hydropower guides
- Nuclear Energy Bingo—Nuclear guides
- Offshore Oil and Gas Bingo—*Exploring Ocean Energy and Resources*
- Oil and Natural Gas Bingo—Oil and Natural Gas guides
- Science of Energy Bingo—*Science of Energy* guides
- Solar Bingo—Solar guides
- Transportation Bingo—*Transportation Fuels Infobooks*
- Wind Energy Bingo—Wind guides

Get Ready

Duplicate as many *Hydrogen Bingo* sheets (found on page 34) as needed for each person in your group. In addition, decide now if you want to give the winner of your game a prize and what the prize will be.

Get Set

Pass out one *Hydrogen Bingo* sheet to each member of the group.

Go

PART ONE: FILLING IN THE BINGO SHEETS

Give the group the following instructions to create bingo cards:

- This bingo activity is very similar to regular bingo. However, there are a few things you'll need to know to play this game. First, please take a minute to look at your bingo sheet and read the 16 statements at the top of the page. Shortly, you'll be going around the room trying to find 16 people about whom the statements are true so you can write their names in one of the 16 boxes.
- When I give you the signal, you'll get up and ask a person if a statement at the top of your bingo sheet is true for them. If the person gives what you believe is a correct response, write the person's name in the corresponding box on the lower part of the page. For example, if you ask a person question "D" and he or she gives you what you think is a correct response, then go ahead and write the person's name in box D. A correct response is important because later on, if you get bingo, that person will be asked to answer the question correctly in front of the group. If they can't answer the question correctly, then you lose bingo. So, if someone gives you an incorrect answer, ask someone else! Don't use your name for one of the boxes or use the same person's name twice.
- Try to fill all 16 boxes in the next 20 minutes. This will increase your chances of winning. After the 20 minutes are up, please sit down and I will begin asking players to stand up and give their names. Are there any questions? You'll now have 20 minutes. Go!
- During the next 20 minutes, move around the room to assist the players. Every five minutes or so tell the players how many minutes are remaining in the game. Give the players a warning when just a minute or two remains. When the 20 minutes are up, stop the players and ask them to be seated.

PART TWO: PLAYING BINGO

Give the class the following instructions to play the game:

- When I point to you, please stand up and in a LOUD and CLEAR voice give us your name. Now, if anyone has the name of the person I call on, put a big "X" in the box with that person's name. When you get four names in a row—across, down, or diagonally—shout "Bingo!" Then I'll ask you to come up front to verify your results.
- Let's start off with you (point to a player in the group). Please stand and give us your name. (Player gives name. Let's say the player's name was "Joe.") Okay, players, if any of you have Joe's name in one of your boxes, go ahead and put an "X" through that box.
- When the first player shouts "Bingo," ask them to come to the front of the room. Ask them to give their name. Then ask them to tell the group how their bingo run was made, e.g., down from A to M, across from E to H, and so on.

- Now you need to verify the bingo winner's results. Ask the bingo winner to call out the first person's name on their bingo run. That player then stands and the bingo winner asks them the question which they previously answered during the 20-minute session. For example, if the statement was "can name two renewable sources of energy," the player must now name two sources. If they can answer the question correctly, the bingo winner calls out the next person's name on their bingo run. However, if they do not answer the question correctly, the bingo winner does not have bingo after all and must sit down with the rest of the players. You should continue to point to players until another person yells "Bingo."

HYDROGEN BINGO ANSWERS

A. Knows the atomic number of hydrogen
B. Knows the percentage of U.S. energy consumption supplied by renewables
C. Knows the process that produces energy in the sun's core
D. Can define energy carrier
E. Knows what a fuel cell is
F. Can define distributed generation
G. Knows a process that separates water into hydrogen and oxygen
H. Knows the number of neutrons in a hydrogen atom
I. Knows in what form energy from the sun travels to the Earth
J. Can name four renewable energy sources
K. Knows the percentage of U.S. energy consumption supplied by fossil fuels
L. Knows the top energy carrier used in the U.S.
M. Knows the U.S. percentage of world population
N. Can name four nonrenewable energy sources
O. Knows the U.S. percentage of world energy consumption
P. Can name two ways hydrogen is used today

A the atomic number for hydrogen is 1	**B** renewables supply about 10 percent of U.S. energy consumption	**C** FUSION of hydrogen into helium produces energy in the sun's core	**D** a system or substance that moves energy from one place to another
E a device that uses chemical reaction to produce electricity - a battery	**F** distributed generation is electricity produced near the site of the consumer	**G** ELECTROLYSIS separates water into hydrogen and oxygen	**H** no neutrons in a simple hydrogen atom (deuterium and tritium isotopes have neutrons)
I energy from the sun travels to Earth in the form of radiant energy	**J** renewables: solar, wind, hydropower, biomass, geothermal	**K** fossil fuels supply about 80 percent of total U.S. consumption	**L** electricity is the top energy carrier in the U.S.
M the U.S. contains a little more than 4 percent of total world population	**N** nonrenewables: petroleum, natural gas, propane, coal, uranium	**O** the U.S. accounts for about 17 percent of total world energy consumption	**P** used by industry for refining, treating metals, and processing foods; to fuel small hydrogen fuel cells to produce electricity; hydrogen fueled vehicles

Hydrogen Information Web Links

Ames Laboratory: **www.ameslab.gov**

Argonne National Laboratory: **www.anl.gov**

Brookhaven National Laboratory: **www.bnl.gov/world/**

Energy Information Administration: **www.eia.gov**

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

Hydrogen Fuel Cell Partnership: **http://h2fcp.org**

Hydrogen Interagency Task Force: **www.hydrogen.energy.gov/interagency**

International Partnership for the Hydrogen and fuel cells in the Economy: **www.iphe.net**

Lawrence Berkeley National Laboratory: **www.lbl.gov**

Lawrence Livermore National Laboratory: **www.llnl.gov**

Los Alamos National Laboratory: **www.lanl.gov**

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

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

Oak Ridge National Laboratory: **www.ornl.gov**

Pacific Northwest National Laboratory: **www.pnnl.gov**

Sandia National Laboratory: **www.sandia.gov**

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

U.S. Department of Energy Hydrogen Program: **www.hydrogen.energy.gov/home**

Lab Safety Rules

Eye Safety

- Always wear safety glasses when conducting experiments.

Fire Safety

- Do not heat any substance or piece of equipment unless specifically instructed to do so.
- Be careful of loose clothing. Do not reach across or over a flame.
- Always keep long hair pulled back and secured.
- Do not heat any substance in a closed container.
- Always use the tongs or protective gloves when handling hot objects. Do not touch hot objects with your hands.
- Keep all lab equipment, chemicals, papers, and personal effects away from a flame.
- Extinguish a flame as soon as you are finished with the experiment and move it away from the immediate work area.

Heat Safety

- Always use tongs or protective gloves when handling hot objects and substances.
- Keep hot objects away from the edge of the lab table—in a place where no one will accidentally come into contact with them.
- Do not use the steam generator without the assistance of your teacher.
- Remember that many objects will remain hot for a long time after the heat source is removed or turned off.

Glass Safety

- Never use a piece of glass equipment that appears cracked or broken.
- Handle glass equipment carefully. If a piece of glassware breaks, do not attempt to clean it up yourself. Inform your teacher.
- Glass equipment can become very hot. Use tongs if glass has been heated.
- Clean glass equipment carefully before packing it away.

Chemical Safety

- Do not smell, touch, or taste chemicals unless instructed to do so.
- Keep chemical containers closed except when using them.
- Do not mix chemicals without specific instructions.
- Do not shake or heat chemicals without specific instructions.
- Dispose of used chemicals as instructed. Do not pour chemicals back into a container without specific instructions to do so.
- If a chemical accidentally touches you, immediately wash the area with water and inform your teacher.

Hydrogen: A Fuel for Today and Tomorrow

The Energy Picture in the United States Today

The United States consumes a lot of **energy**, more energy than any other country in the world. With less than five percent of the world's population, we consume just under 17 percent of the world's total energy production. The average American uses just under 4 times more energy than the world's average per capita figure. We use energy to power our homes, businesses, and industrial plants, and to move people and goods from one place to another.

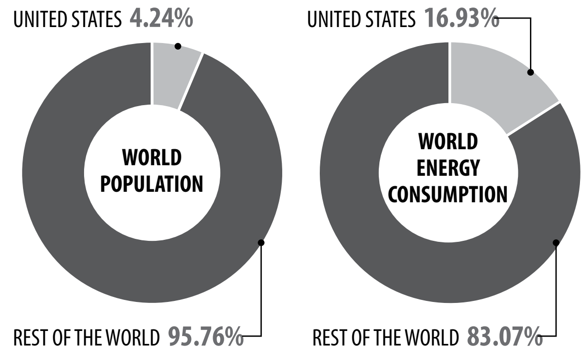
We rely on energy to make our lives productive, comfortable, and enjoyable. Sustaining this quality of life requires that we use our energy resources wisely and find new sources of energy for the future. If we as consumers make good decisions about the energy we use at home and in business and industry,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

Today, most of the energy we use—about 91 percent—comes from **nonrenewable** energy sources such as coal, natural gas, petroleum, and uranium. About 83 percent of the energy we use comes from **fossil fuels**, which release greenhouse gas emissions and other particulate pollution when burned. When factoring in electricity use, the industry and transportation sectors of our economy consume the most energy in the United States. Transportation uses about 29 percent of the nation's total energy, while industry accounts for approximately 33. Transportation, industry, and electricity generation rely heavily on fossil fuels.

In addition, the world has limited reserves of nonrenewable energy sources. They take millions to hundreds of millions of years to form, so we cannot make more to meet our future needs.

We are not producing enough petroleum to meet our needs. Today we are importing 40 percent of our crude oil supply from foreign countries. Many experts predict that oil production will soon begin to decrease worldwide and demand will continue to increase, as countries like China and India become more industrialized. There will be increasing competition for the available petroleum.

Population Versus Energy Consumption, 2021



Data: Energy Information Administration

U.S. Energy Consumption by Source, 2022

NONRENEWABLE		RENEWABLE	
PETROLEUM *Uses: transportation, manufacturing - includes propane*	37.29%*	**BIOMASS** *Uses: heating, electricity, transportation*	5.10%
NATURAL GAS *Uses: heating, manufacturing, electricity - includes propane*	35.28%*	**HYDROPOWER** *Uses: electricity*	0.94%
COAL *Uses: electricity, manufacturing*	10.40%	**WIND** *Uses: electricity*	1.57%
URANIUM *Uses: electricity*	8.50%	**SOLAR** *Uses: heating, electricity*	0.80%
PROPANE *Uses: heating, manufacturing*	*Propane consumption figures are reported as part of petroleum and natural gas totals.	**GEOTHERMAL** *Uses: heating, electricity*	0.13%

**Total does not add up to 100% due to independent rounding.
Data: Energy Information Administration

Looking to the Future

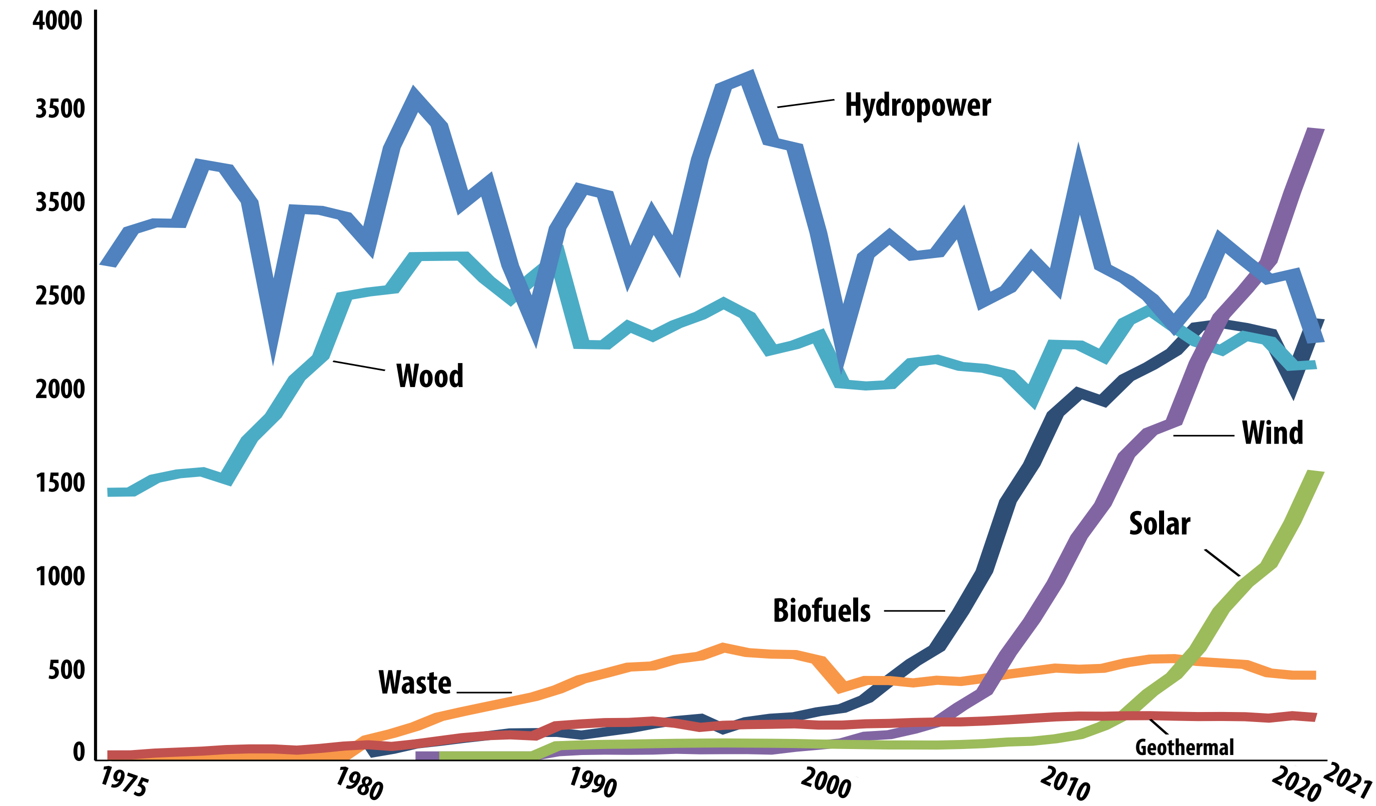
To meet future energy challenges, the United States is expanding the use of **renewable** energy sources such as solar, wind, **biomass**, hydropower, and geothermal energy, and considering the increased use of nuclear power. The government and many private enterprises are also conducting research to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

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

The Ideal Energy System...

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

Growth of Renewable Energy Sources



Data: Energy Information Administration

What is Hydrogen?

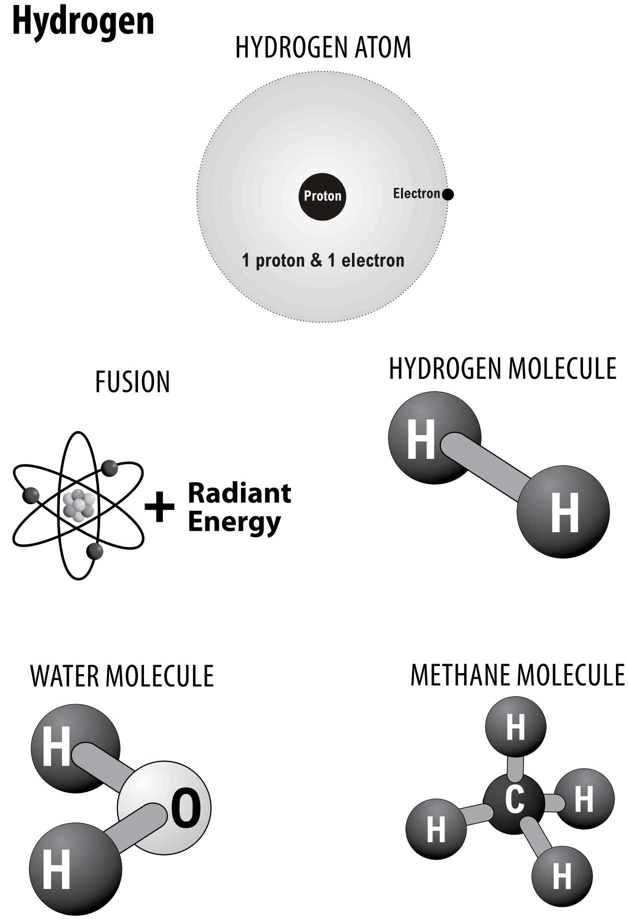
Hydrogen is the simplest **element** known to exist. Most **atoms** of hydrogen have one **proton** and one **electron**. It is the lightest element and a gas at normal temperature and pressure. Hydrogen is also the most abundant element in the universe and the source of all the energy we receive from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

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

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

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

Hydrogen



Atomic Structure

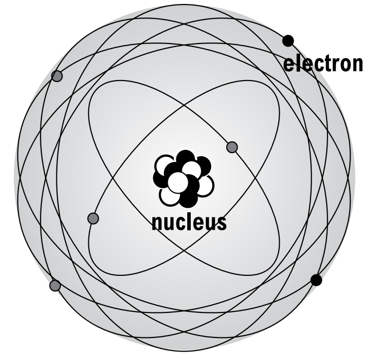
What exactly is **electricity**? It is moving electrons. Everything in the universe is made of atoms or particles of atoms—every star, every tree, every animal. The human body, water, and air are made of atoms, too. Atoms are the building blocks of the universe. They are so small that millions of them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

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

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

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

Carbon Atom



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

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

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

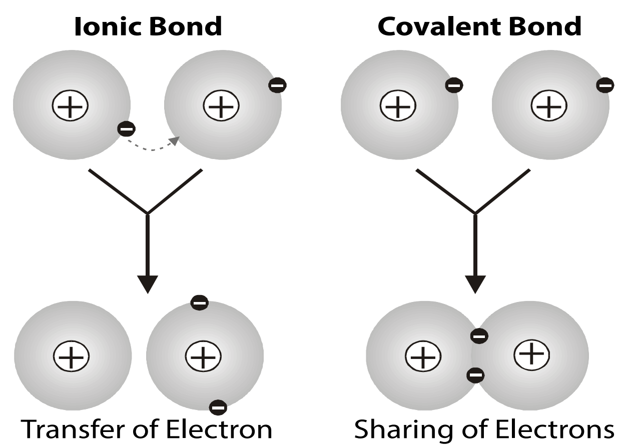
Chemical Bonding

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

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

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

Chemical Bonding



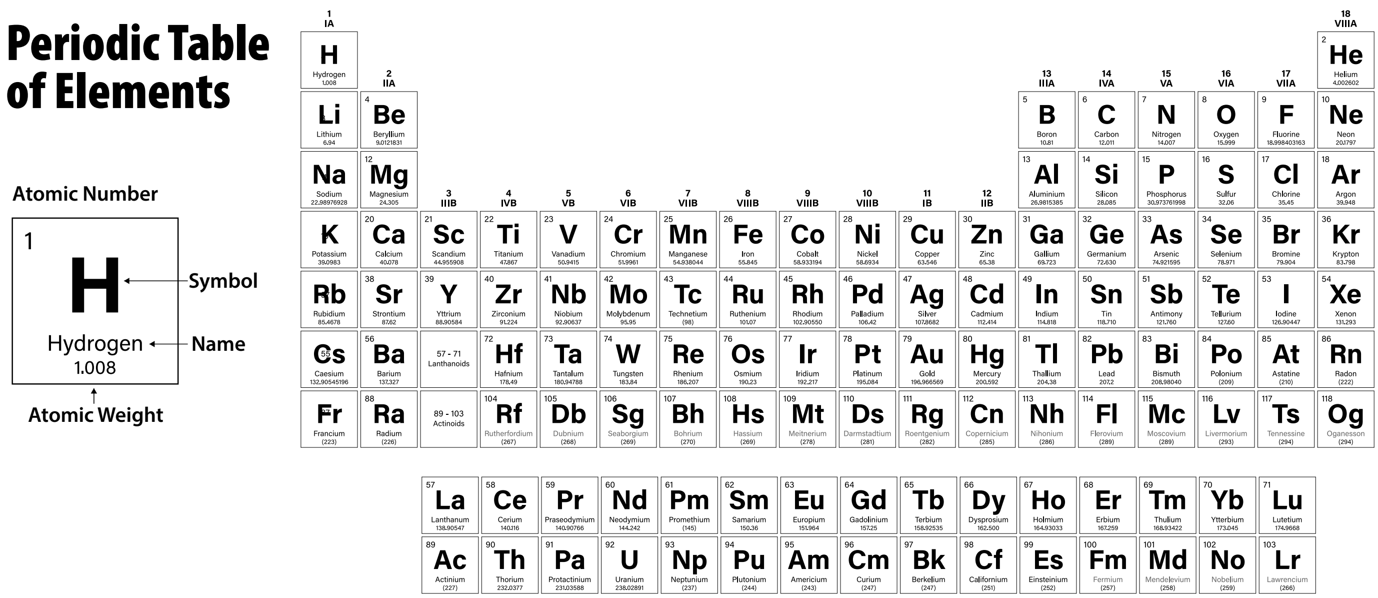
The Periodic Table of the Elements

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

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

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

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



How is Hydrogen Made?

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

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

High-temperature, high-pressure steam can also be reacted with renewable liquids, such as ethanol, to produce hydrogen. The liquid is brought to the site where it is used to produced hydrogen, and the hydrogen is used immediately.

Today, most of the hydrogen produced by steam reforming is not used as fuel but in industrial processes. Steam reforming is the most cost-effective way to produce hydrogen today and accounts for about 95 percent of the hydrogen produced in the U.S. Because of its limited supply, however, we cannot rely on nonrenewable natural gas to provide hydrogen over the long term. Instead, we will need to produce hydrogen using other resources, such as renewable natural gas and other technologies listed below. Renewable natural gas (RNG) is methane produced from the decomposition of organic matter. RNG can be used interchangeably with conventional, nonrenewable natural gas, thus it is a great source for steam reforming to create hydrogen.

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

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

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

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

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

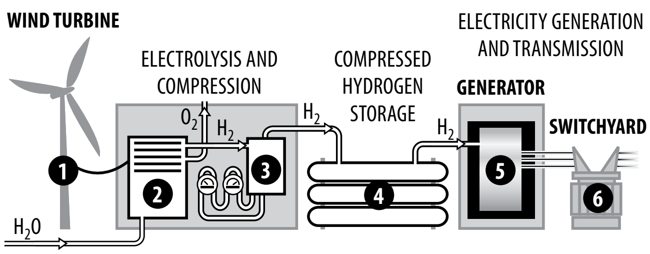
PHOTOBIOLOGICAL MICROBIAL PRODUCTION: Scientists have discovered that some algae and bacteria produce hydrogen under certain conditions, using sunlight as their energy source. Experiments are underway to find ways to induce these microbes to produce hydrogen efficiently.

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

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

Wind to Hydrogen

The National Renewable Energy Laboratory and Xcel Energy launched an innovative wind-to-hydrogen (Wind2H_2) project that uses electricity from wind turbines (or photovoltaic panels) to produce and store hydrogen, offering what may become an important new template for future energy production.



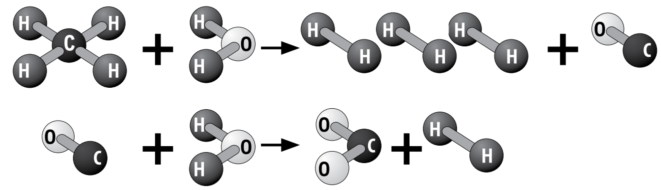
How it works:

1. Wind turbines use the wind's energy to generate electricity. Electricity is transported to the electrolysis unit.
2. Electricity is used to split water (H_2O) into hydrogen (H_2) and oxygen (O_2).
3. The hydrogen diaphragm compressor compresses the hydrogen gas produced from the electrolyzers at 150 psi (pounds per square inch) to the storage pressure of 3,500 psi.
4. The hydrogen can be stored and used later to generate electricity from an internal combustion engine or a fuel cell. The steel tanks can store up to 85 kilograms of hydrogen at 3,500 psi.
5. The internal combustion engine runs on stored hydrogen and generates electricity that will be sent onto the utility grid for use during peak demand.
6. Electricity is sent to a switchyard, where a transformer increases the voltage, allowing it to travel through the electric grid.

Hydrogen Production Chemistry

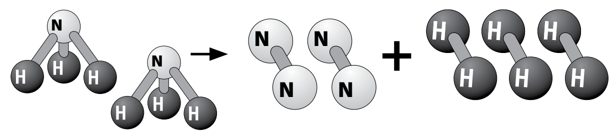
STEAM REFORMING

$$CH_4 + H_2O \text{ (steam)} \longrightarrow 3H_2 + CO$$
$$CO + H_2O \text{ (steam)} \longrightarrow CO_2 + H_2$$



AMMONIA CRACKING

$$2\,NH_3 \longrightarrow N_2 + 3\,H_2$$



PHOTOBIOLOGICAL MICROBIAL PRODUCTION

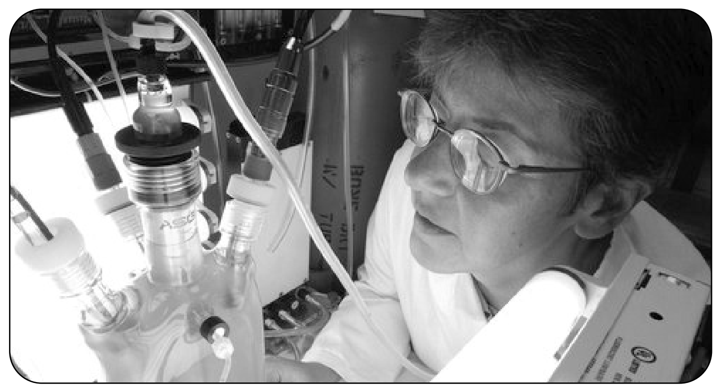


Image courtesy of DOE/NREL, credit Warren Gretz

Researchers are using green algae to produce hydrogen.

Hydrogen as a Fuel

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

1. Hydrogen resources are abundant in the United States and the world.
   - Hydrogen is a component of many abundant compounds on Earth, including water, hydrocarbons, and carbohydrates.
   - It can be produced from a variety of resources (water, fossil fuels, biomass) and is a by-product of other chemical processes.
   - All regions of the world have hydrogen-containing resources.
2. Hydrogen is a domestic fuel.
   - The United States has a wide variety of hydrogen resources, including plentiful water, biomass, natural gas, and coal. This diversity and abundance would help keep energy prices stable.
   - Every area of the country has the ability to produce hydrogen from regional resources.
   - Using domestic energy resources increases national security.

3. Hydrogen is a clean fuel.
    - Using hydrogen as a transportation fuel can significantly reduce air pollution—hydrogen fuel cell vehicles produce no tailpipe emissions except heat and water.
    - If hydrogen is produced by electrolysis using renewable energy sources, there are no harmful emissions.
    - Using hydrogen as a fuel can reduce greenhouse gas emissions, especially if it is produced using renewable resources, nuclear energy, or fossil fuels such as coal coupled with carbon sequestration (capturing the carbon-based emissions and preventing them from entering the atmosphere).
    - If hydrogen is produced from fossil fuels at large centralized facilities, it is much easier to minimize emissions at these sites than it is to reduce emissions from individual petroleum-fueled vehicles.
4. Hydrogen is a flexible fuel.
    - Hydrogen can be produced from a variety of resources.
    - Hydrogen can be produced on–site in small quantities for local use (**distributed generation**) or in large quantities at production plants (**centralized generation**).
    - Hydrogen can be used in **fuel cells** to generate electricity, with only water and heat as by-products, and fuel cells can be used to power almost anything, from laptops to buildings to vehicles.
    - Hydrogen can be used as a transportation fuel for motor vehicles. It can be used to power forklifts and airport baggage trucks.
    - Hydrogen can be used to provide electricity and heat for buildings, and can be used in place of batteries for video cameras and radios.
    - Hydrogen can be used in manufacturing processes in the industrial sector.
    - Hydrogen fuel cells can be used in remote places that cannot be reached by power lines.
    - Hydrogen, like electricity, is an efficient energy carrier, although it is not a primary energy source.

HYDROGEN FUEL CELL VEHICLE

Image courtesy of DOE/NREL, credit Keith Wipke

What is an Energy Carrier?

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

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

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

Ammonia as a Hydrogen Carrier?

As stated before, one of the major challenges of using hydrogen as an energy source is its low density, and therefore high volume for storage. Liquefying hydrogen reduces the amount of space it occupies, but over time the hydrogen can boil away. In fact, 1,000 cubic meters of liquefied hydrogen stored for 100 days will have reduced to 594 cubic meters due to boil-off. Additionally, cooling hydrogen to liquid is very energy intensive, which defeats the purpose of using hydrogen as an energy source in the first place. At first glance it would sound like hydrogen is impractical for meeting decarbonization goals.

This is where ammonia enters the stage. Ammonia, NH_3, is 17.8% hydrogen by weight. It is already manufactured in large quantities for agricultural and industrial using the Haber-Bosch process, which converts nitrogen (N_2) in the atmosphere to ammonia (NH_3) through a reaction with hydrogen. Recently, scientists have analyzed whether ammonia could be a carbonless source of hydrogen. Decomposition of ammonia is endothermic, meaning the reaction requires an input of some kind of energy, most often thermal energy.

In a process known as catalyzed ammonia cracking, or ammonia cracking, a catalyst is used to reduce the amount of energy needed to break ammonia down. Liquefied ammonia could essentially be transported in tanks that are already commercially available, and decomposed at the point of use of hydrogen, with the only "tailpipe emission" being nitrogen gas. There are five different types of catalysts scientists are researching: thermocatalytic; reforming; plasma; photocatalytic; and electrocatalytic. Thermocatalytic cracking uses a combination of temperature and pressure to decompose ammonia nearly completely into nitrogen and hydrogen. Reforming catalysts use the surface structure of the catalyst to shift bonds between atoms by temporarily bonding them with the catalyst itself. Plasmas are ionized gases; this technology uses the ions in the plasma to break the bonds in the ammonia molecule. Photocatalytic technology uses light, usually ultraviolet, to activate a metal oxide catalyst and begin the cracking process. Electrocatalytic cracking involves using electricity as the energy source for breaking the bonds in the ammonia molecule. While each have limitations and drawbacks, the most promising technology is nonthermal plasma technology because of its low operating temperatures. Electrocatalytic systems could also be useful if a renewable energy source, like solar energy in a photovoltaic system, can provide the electrical energy.

Uses of Hydrogen

The U.S. hydrogen industry currently produces about 10 million metric tons of hydrogen each year. Most of this hydrogen is used for industrial applications such as refining, treating metals, and food processing.

Hydrogen-powered vehicles are on the road today, but it will be a while before you can walk into your local car dealer and drive away in one. There are only 58 hydrogen fueling stations operating today and nearly all are located in California.

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

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

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

Before hydrogen can make a significant contribution to the U.S. energy picture, many new systems must be designed and built. There must be sufficient production facilities and a distribution system to support widespread use, and consumers must have the technology and confidence in its safety to use it. In 2023, a Regional Clean Hydrogen Hub Program recieved funding through the Bipartisan Infrastructure Law. These hubs aim to create the foundation for a clean hydrogen network across America.

SPACE SHUTTLE

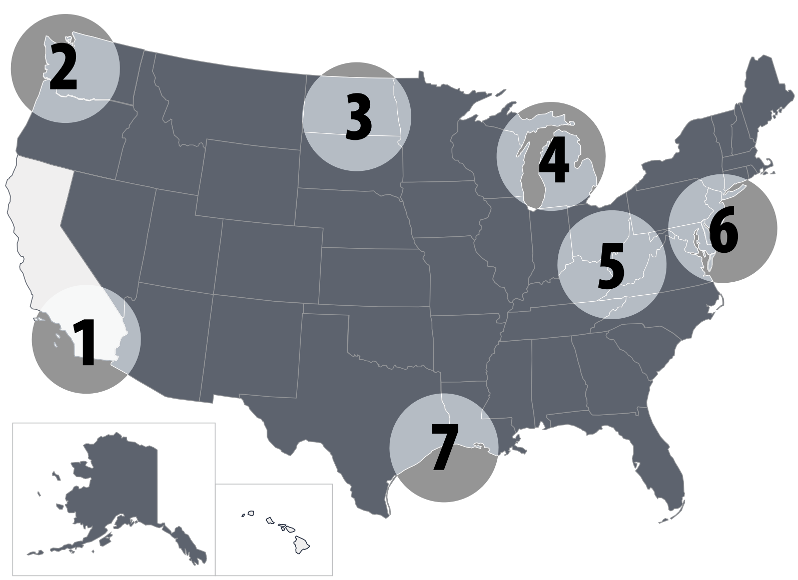
Image courtesy of NASA

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

Number of Hydrogen Fueling Stations by State, 2023

CALIFORNIA: 57

HAWAII: 1



Regional Clean Hydrogen Hubs

1. ALLIANCE FOR RENEWABLE CLEAN HYDROGEN ENERGY SYSTEMS (ARCHES)
2. PNW H2
3. HEARTLAND HUB (HH2H)
4. MIDWEST ALLIANCE FOR CLEAN HYDROGEN (MACHH2)
5. APPALACHIAN REGIONAL CLEAN HYDROGEN HUB (ARCHH2)
6. MID-ATLANTIC CLEAN HYDROGEN HUB (MACH2)
7. HYVELOCITY H2HUB

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

What Is a Fuel Cell?

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

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

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

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

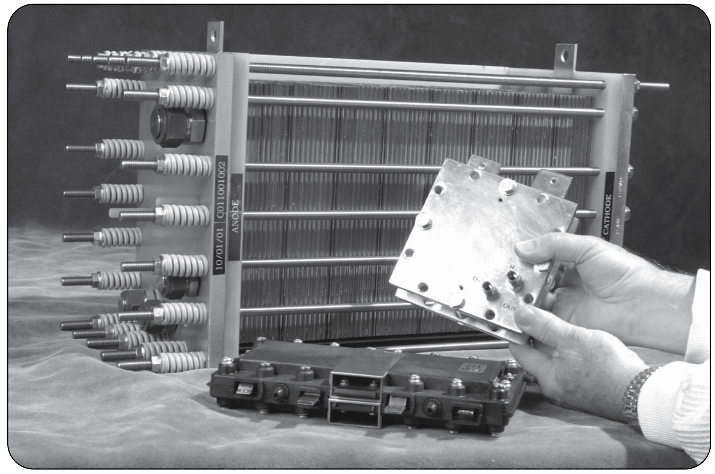


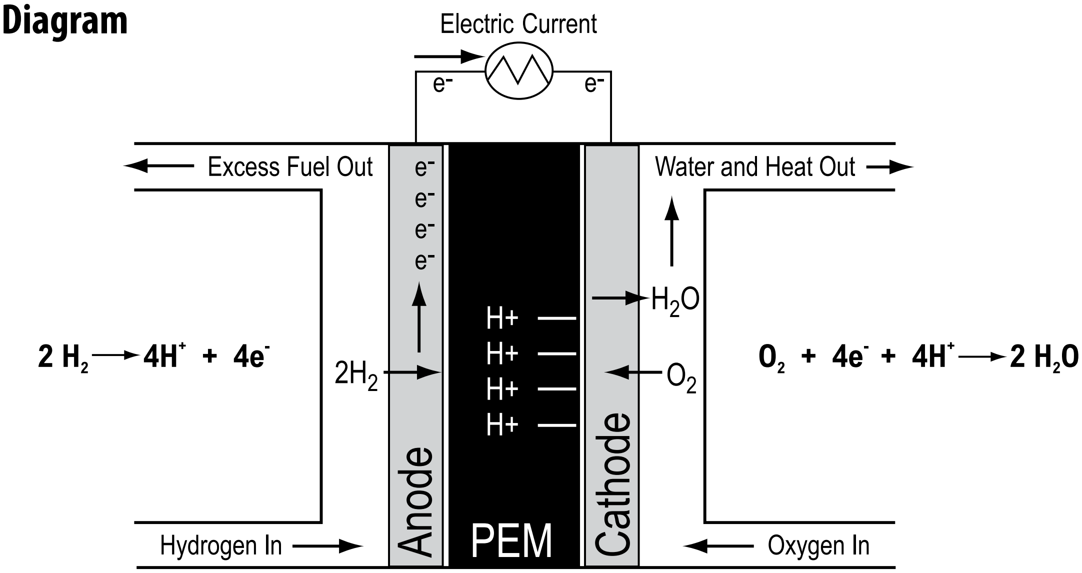
Image courtesy of DOE/NREL, credit Matt Stiveson

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

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

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

PEM Cell Diagram



The Challenges of Hydrogen

Hydrogen Storage

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

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

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

HYDROGEN STORAGE TANK

Image courtesy of DOE/NREL, photo credit Keith Wipke

Hydrogen can be stored in high-pressure tanks.

PIPELINES

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

Hydrogen Distribution

Today, most hydrogen is transported short distances, mainly by pipeline. There are about 1,600 miles of hydrogen pipelines in the United States. Longer distance distribution is usually by tanker trucks carrying hydrogen in liquefied form. There is no nationwide hydrogen **distribution system**.

The cost of building a new nationwide system of pipelines for hydrogen would be very costly. The Federal government committed $7 billion to help accelerate the use and distribution of hydrogen through the Regional Clean Hydrogen Hub Program.

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

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

Hydrogen Safety

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

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

Hydrogen and Future Energy Challenge

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

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

HYDROGEN FLAME

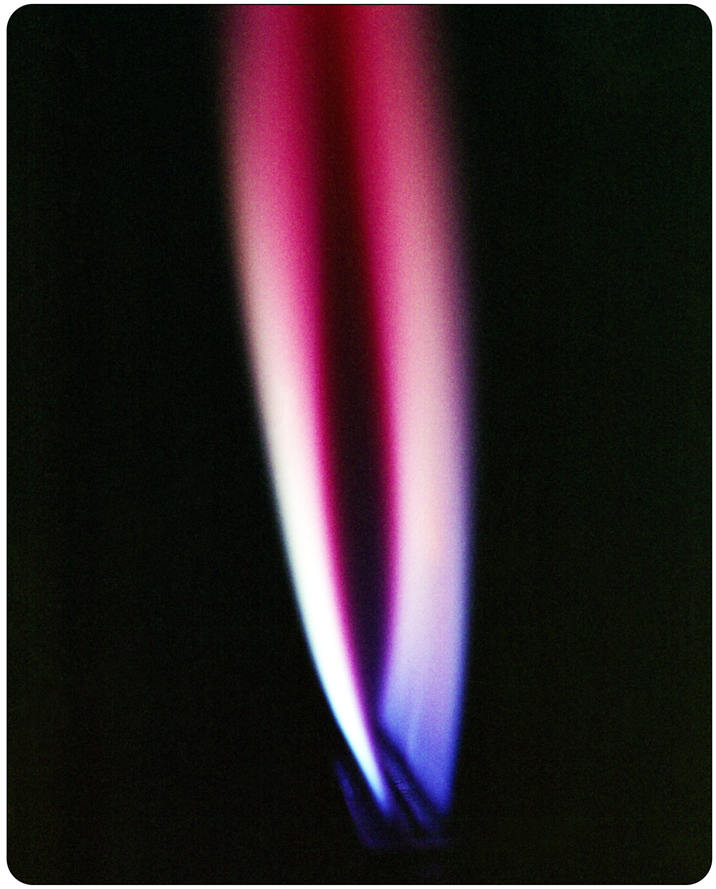


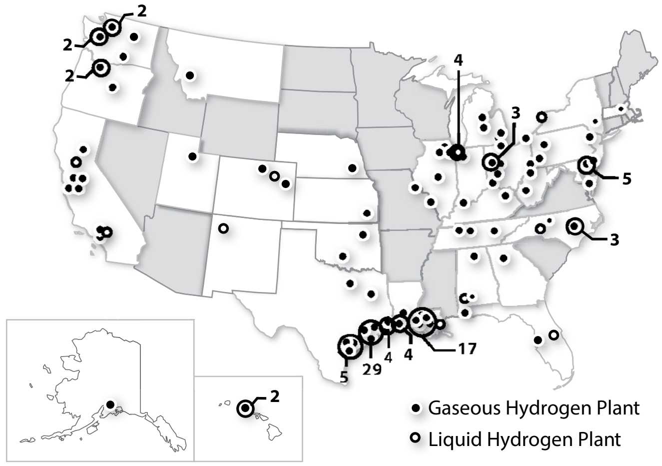
Image courtesy of DOE/NREL, photo credit Warren Gretz

RESEARCH AND DEVELOPMENT

Image courtesy of DOE/NREL, photo credit Robert Remick

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

Hydrogen Production Plants



Data: U.S. Department of Energy, H_2 Matchmaker

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

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

Improving hydrogen infrastructure: Hydrogen can be used more widely than it is presently. Since it can be produced from renewable fuels and processes, it has become appealing for many companies to consider this "green" hydrogen to offset their carbon impacts. Using hydrogen at a larger scale will require that the infrastructure for creating, storing, and transporting hydrogen to consumers is expanded. The U.S. has invested money to research and accelerate the process of expanding existing infrastructure across the country, but it may also be important to emphasize infrastructure advancements and innovations that enable economical and widespread use of hydrogen technologies that help meet clean energy ambitions. These solutions and improvements may take several years to come to full realization, but will greatly improve access to and adoption of hydrogen as a fuel.

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

Jobs in Fuel Cell Technologies

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

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

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

Fuel Cell Technology Jobs

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

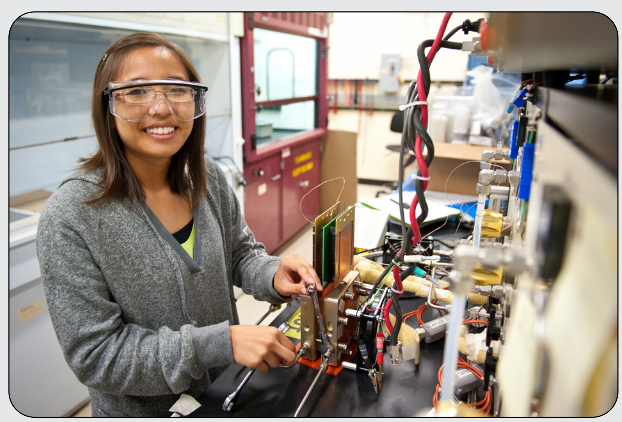


Image courtesy of DOE/NREL, photo credit Dennis Schroeder

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

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

Assembly and Operation of the Fuel Cell Car

The Fuel Cell Car should be used only by a knowledgeable teacher or by students under the supervision of the teacher. The teacher must ensure proper handling and draw attention to potential dangers. Before using the car, review the User Manual in the car kit to fully understand operational safety precautions. All participants should wear safety glasses.

The car should be assembled and operated on a solid, level surface, with the ambient temperature between 20°C and 30°C. It is recommended that you operate the car indoors to protect it from the weather.

Make sure that the Fuel Cell Car is not charged or operated near an open flame.

Visit **www.horizoneducational.com** for more information on this car and other fuel cell car challenges.

Basic Function

Here are the basics of how the fuel cell works. Refer to the User Manual for additional technical data.

1. Use ONLY THE POWER SUPPLY INCLUDED to provide the electricity to power the electrolysis process.
2. The electric current splits the water molecules into hydrogen and oxygen gases in the charge mode of the reversible fuel cell. The gases are stored in the storage cylinders.
3. In the discharge mode, the fuel cell uses the hydrogen and oxygen gases as fuel to generate an electric current that runs the electric motor of the car, producing water and heat as by-products.

Assembly of the Fuel Cell Car

MATERIALS: Fuel Cell Car Kit with User Manual, 2 AA batteries (3-volt maximum), scissors, distilled water

1. Follow the instructions on pages 6–7 of the User Manual to assemble the car.
2. To HYDRATE the fuel cell, follow the instructions on page 7 of the User Manual. *CAUTION*: Only distilled water should be used. Use of any other liquid, even tap water, may destroy the fuel cell membrane.

Electrolysis: Producing Hydrogen

MATERIALS: Assembled Fuel Cell Car, power pack with 2 AA batteries, distilled water

1. Follow the instructions on pages 8-11 of the User Manual to produce hydrogen using the fuel cell.
2. Use ONLY the power pack provided.
3. Use ONLY distilled water.
4. DO NOT PROCEED near an open flame.
5. DO NOT PROCEED until you have hydrated the fuel cell as explained in the assembly section above.

Operation of the Fuel Cell Car

MATERIALS: Charged Fuel Cell Car

1. Follow the instructions on page 12 of the User Manual to operate the Fuel Cell Car.
2. When the car stops running, it can be recharged following the Electrolysis Procedure.
3. The AA batteries in the power pack may need to be replaced after several charges.

Advice and Troubleshooting

1. Follow the advice on page 13 of the User Manual for optimal operation.
2. Use the Troubleshooting section on page 14 of the User Manual if your car does not work properly.

Jigsaw Role Questions and Presentation Questions

SUSTAINABILITY: PHYSICIST

1. What are the physical and chemical properties of hydrogen?
2. How can hydrogen be stored?
3. What are the different sources of hydrogen on Earth?
4. Which sources of hydrogen hold promise for a long-term energy solution?

PRODUCTION: HYDROGEN PRODUCER

1. What are the processes currently being used to separate hydrogen?
2. What are the challenges of producing hydrogen in large amounts?
3. What safety issues are associated with separating hydrogen?
4. How does the cost of producing hydrogen compare to other fuels?

DELIVERY/DISTRIBUTION: HYDROGEN DISTRIBUTOR

1. In what forms can hydrogen be stored and transported?
2. What distribution technologies are currently in use?
3. What are the challenges of refueling hydrogen operations?
4. Identify and explain the properties of hydrogen that make it difficult to transport.

ENERGY SECURITY: ENERGY SECURITY ADVISOR

1. What is energy security and why is it important to the United States?
2. Why is it important to reduce our dependence on imported energy?
3. How could the use of hydrogen decrease our dependence on imported energy?
4. What other alternatives would reduce our dependence on imported energy?

ECONOMICS: ENERGY ECONOMIST

1. What are the advantages of using hydrogen?
2. How would using hydrogen in our cars look different than our current system?
3. How does the cost of hydrogen applications compare to other alternative fuels?
4. What would help a transition from nonrenewable fuels to hydrogen fuels?

EFFICIENCY AND RELIABILITY: ENERGY EFFICIENCY AND RELIABILITY EXPERT

1. What current technologies use hydrogen as a fuel?
2. How would the use of hydrogen be more efficient than the fuels we currently use?
3. How does the reliability of fuel cells compare to the reliability of other power systems?
4. What technological advances would make the use of hydrogen more efficient and reliable?

ENVIRONMENT: ENVIRONMENTAL SCIENTIST

1. What are the resources from which hydrogen can be produced (extracted)?
2. What are the environmental advantages of each of these sources?
3. What are the environmental disadvantages of each of these sources?
4. How does hydrogen compare environmentally to the fuels used in the U.S. today?

PRESENTATION QUESTIONS

1. What important facts have you learned about hydrogen?
2. What are the advantages of hydrogen?
3. What are the disadvantages of hydrogen?
4. What are the ways hydrogen could be used in the future?
5. What are your opinions about hydrogen?

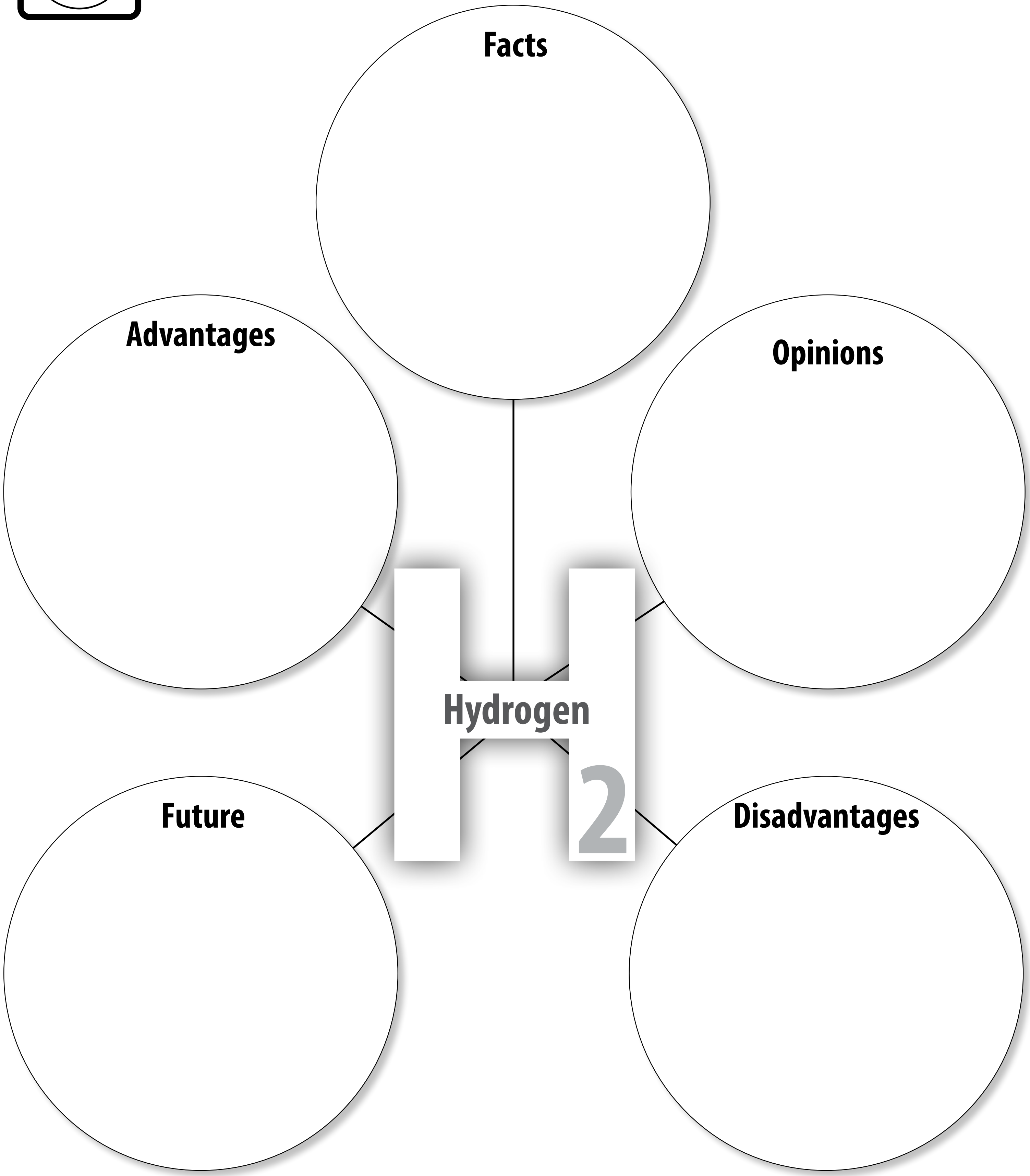
Hydrogen in Society

Role Group: ____________________

Question 1	Question 2	Question 3	Question 4
Essential Details	**Essential Details**	**Essential Details**	**Essential Details**

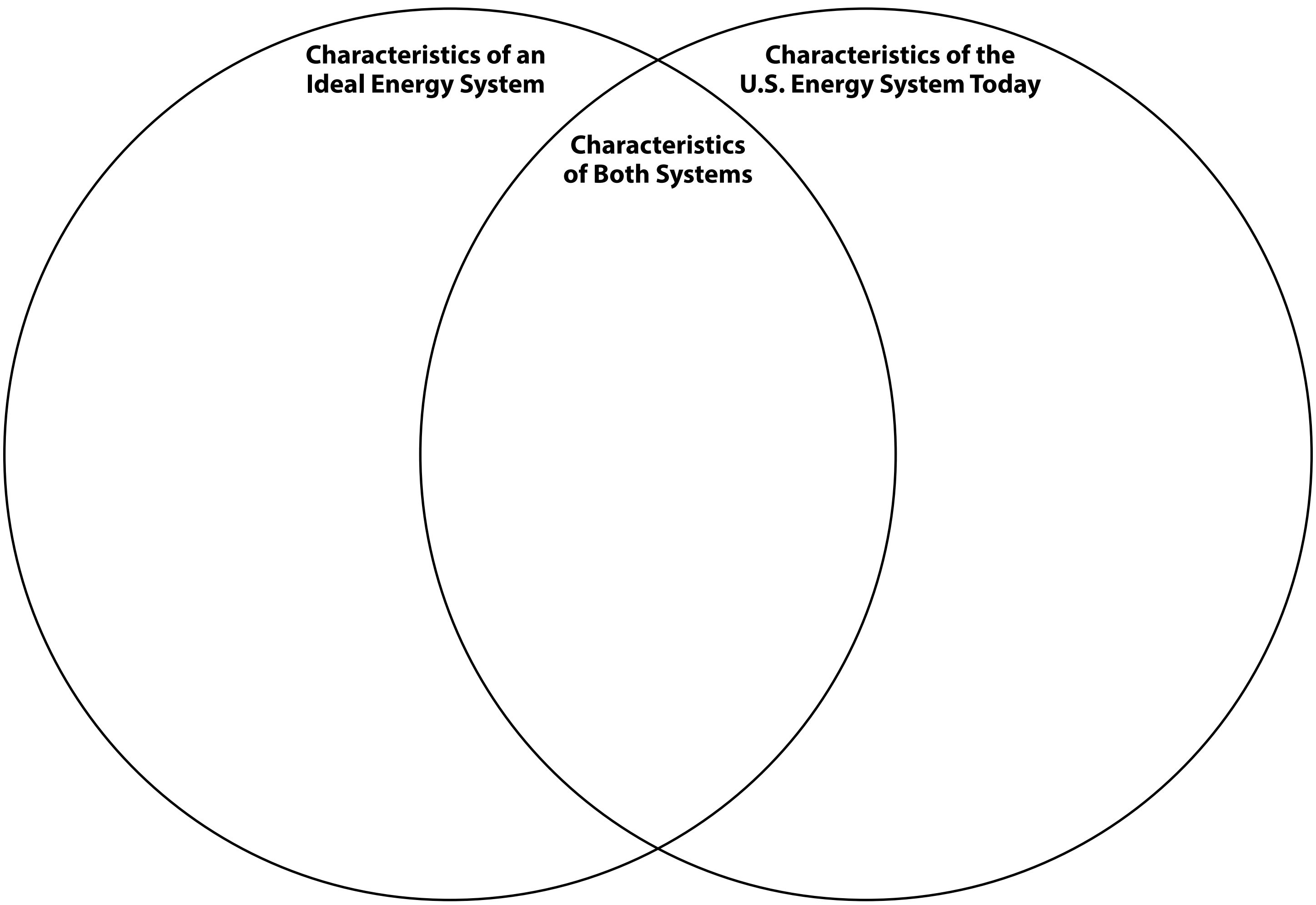
So What? What's important to understand about this?

Hydrogen in Society Presentation Organizer



Comparing Energy Systems

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



The Science of Hydrogen

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

What is Hydrogen?

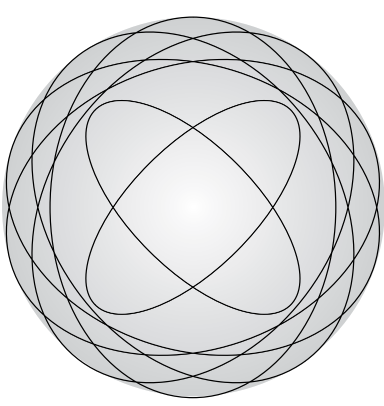
Fusion

Hydrogen

Radiant Energy

Hydrogen Compounds

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



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

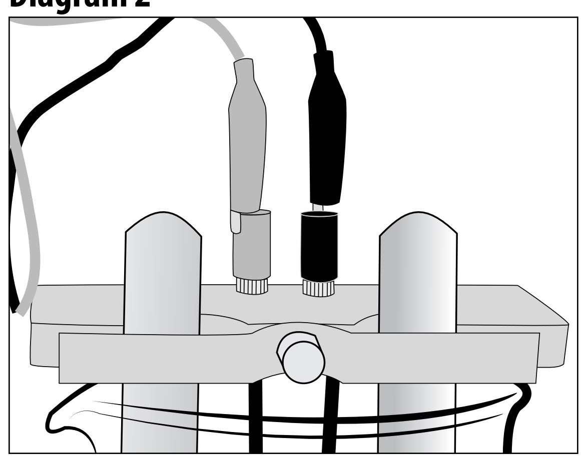
Brownlee Apparatus Setup and Instructions

Preparation of Apparatus

1. Fill a 1,000 mL beaker about 2/3 full with electrolyte solution.
2. Submerge one test tube below the surface of the electrolyte in the beaker and allow the test tube to fill. Do not let go of the test tube.
3. While the test tube is submerged, use tongs to place the rubber stopper in the test tube to seal it, and remove the test tube from the electrolyte solution.
4. Remove the test tube and invert. If any air bubbles rise to the top, repeat steps 2 and 3.
5. Place the inverted test tube into the beaker so the bottom of the test tube is up and the mouth of the test tube and the stopper are down below the surface of the electrolyte. (Diagram 1)
6. Repeat steps 2-6 for the other test tube.
7. Place the apparatus in the beaker so it is resting on the lip of the beaker. Loosen the thumb screw at the front and rotate the plastic piece used to secure the test tubes until it is vertical.
8. Attach the alligator clips to the connections at the top of the apparatus (Diagram 2).
9. While keeping the mouth of each test tube submerged, use test tubes to carefully remove the stopper from the test tube and place the test tube over one electrode. See Diagram 3 on page 38.
10. Rotate the plastic bar so it is horizontal and in front of the test tubes, and tighten the thumb screw to secure.
11. Make sure the mouth of the test tubes are over the electrode, but that each electrode is just barely inside each test tube. Slightly loosen the thumb screw and move the test tubes if necessary, then retighten the thumb screw.

Diagram 1

Diagram 2



CONTINUED ON NEXT PAGE

Brownlee Apparatus Setup and Instructions

✔ Procedure for Electrolysis Demo

1. Connect the alligator clips to the terminals of the 9V battery (Diagram 3).
2. You should immediately observe bubbles rising into both tubes. If you do not observe them, check your connections.
3. Note which electrode is connected to the positive and negative terminals of the battery, using Tube 1 and Tube 2 designations.
4. Observe and record the relative gas volumes in each tube at least 3 times over the course of the student activity.
5. Disconnect the battery from the apparatus.
6. Record the color of the gases in the test tubes.
7. Ask students which test tube contains hydrogen gas and which contains oxygen gas based on what they read.
8. These procedures must be conducted quickly or the gas will escape! Have a student helper light a splint. Using tongs, lift the oxygen tube straight up, keeping it inverted. Quickly shake the tube to remove excess liquid and have your partner blow out the flame on the splint. Insert the glowing splint straight up into the tube without touching the sides. Record your observations. (Diagram 4).
9. Remove the hydrogen tube and keep it inverted. Have your helper re-light the splint. Turn the tube to a 45° angle tilted down, and immediately bring the splint close to the mouth of the tube. Record your observations.

Diagram 3

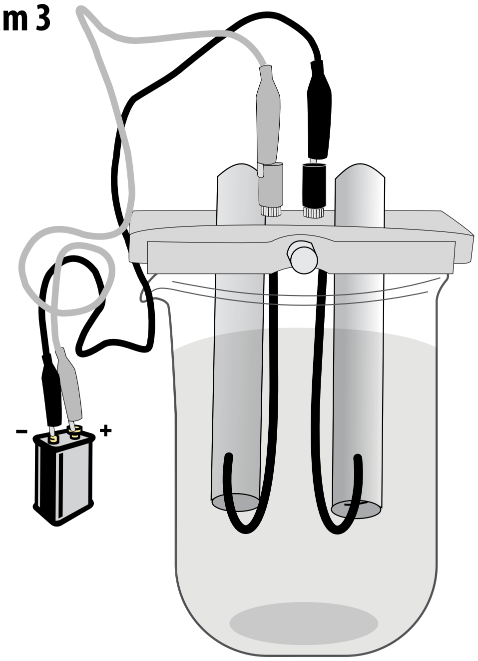
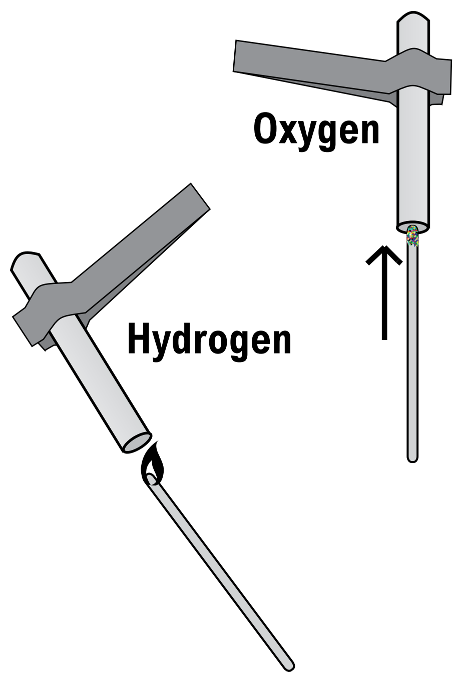
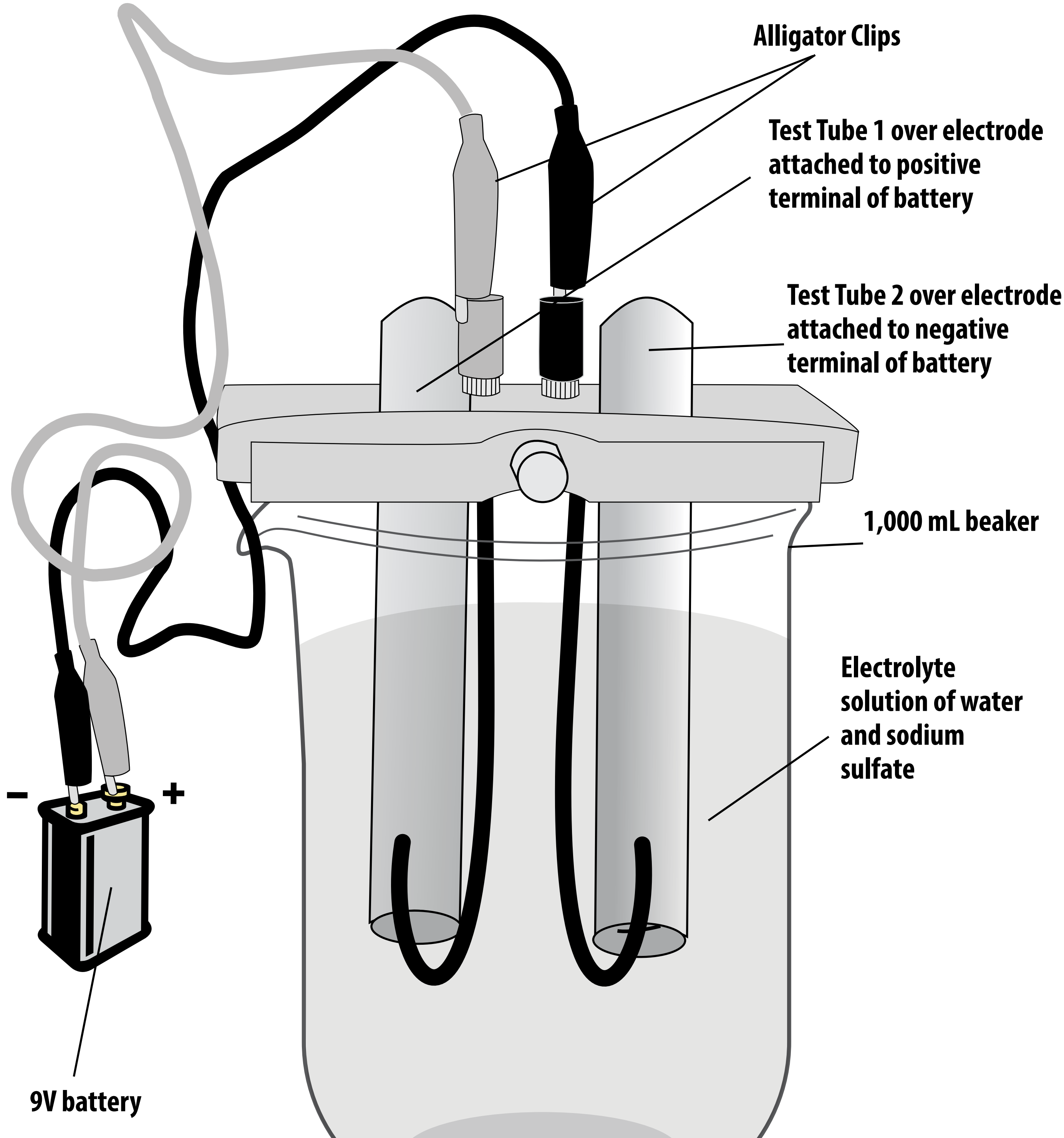


Diagram 4

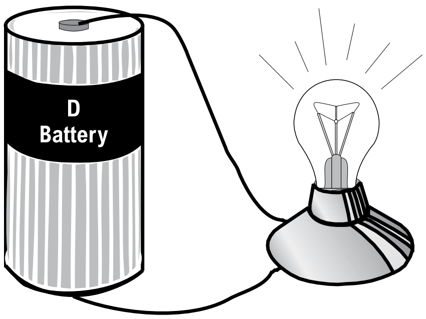


Brownlee Apparatus



Electrochemistry and Electrolysis

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



Voltaic cells, such as batteries or fuel cells, convert chemical energy into electrical energy. The primary part of a voltaic cell are electrodes and an electrolyte. An **electrode** is a **conductor** that can carry electrons to or from a substance. When electrons are exchanged, a chemical reaction called oxidation-reduction occurs. Oxidation cannot occur without reduction, and reduction cannot occur without oxidation. This takes place on the surface of the electrode in a voltaic cell.

The negative electrode, the site of oxidation, is called the **anode**. This is where free electrons are released. Oxidation is known as a half-reaction because it is only one half of the oxidation-reduction process. The electrode on which electrons are acquired is called the **cathode** and is where reduction occurs. The cathode is labeled as the positive electrode on a battery.

Attaching a battery to a **circuit** provides a pathway for electrons to flow from the anode to the cathode. These moving electrons are what we call **electricity** and can be used to do work such as lighting an LED flashlight or powering a cell phone.

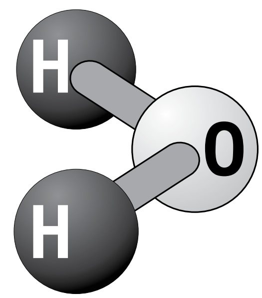
The electrodes are separated by an **electrolyte** which carries ions between the electrodes. An ion is an atom or group of atoms with an **electric charge**. Electric charges occur when there is an excess or deficiency of electrons as compared to the number of protons present. If a neutral atom gains electrons, it has a negative charge. If it loses electrons, it has a positive charge.

Many different ions can be used in voltaic cells. The batteries used in cell phones, laptop computers, and other rechargeable electronic devices often contain lithium ions. Polymer electrolyte membrane (PEM) fuel cells have hydrogen ions, which are just protons.

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

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

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



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

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

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

Small-Scale Electrolysis of Water

Background

Electrolysis of water is relatively simple to accomplish. Industrial production facilities use specially designed electrolysis chambers, but you can use just about any container, a battery, and a couple of electrodes to do the same thing. Because pure water will not conduct electricity, an electrolyte must be added. The energy provided by the battery breaks the bonds in the water and it decomposes into hydrogen and oxygen. The oxidation state of each element also changes. Hydrogen is reduced from a 1+ charge to 0, and oxygen is oxidized from 2- to 0.

Question

- When water decomposes via electrolysis, which element collects at the anode? At the cathode?

Hypothesis

- Based on what you have read, write a hypothesis explaining which element you think forms at each electrode.

Materials

- Petri dish
- 2 Graphite (pencil lead) electrodes
- 2 Alligator clips
- 9-volt Battery
- Approximately 100 mL 0.25 M Na_2SO_4 in distilled water
- Safety glasses

Safety Warning

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

Procedure

1. Pour the sodium sulfate solution into the petri dish.
2. Attach one end of an alligator clip to each pencil lead or electrode. Attach the other end of the wires to the terminals on the battery.
3. Submerse the electrodes as far as you can in the electrolyte but do not allow them to touch each other. If you can, keep the alligator clips out of the solution, too.
4. Make a sketch of your set-up. Note which electrode is connected to the positive end and which is connected to the negative end of the battery.
5. Allow the electrolysis to continue for up to ten minutes. Record your observations.
6. Disconnect the battery from the alligator clips.
7. From your reading, determine which electrode produced hydrogen gas and which one produced oxygen gas.

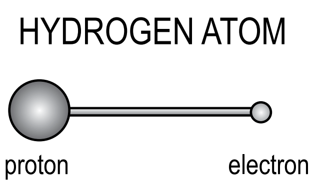
Data and Observations

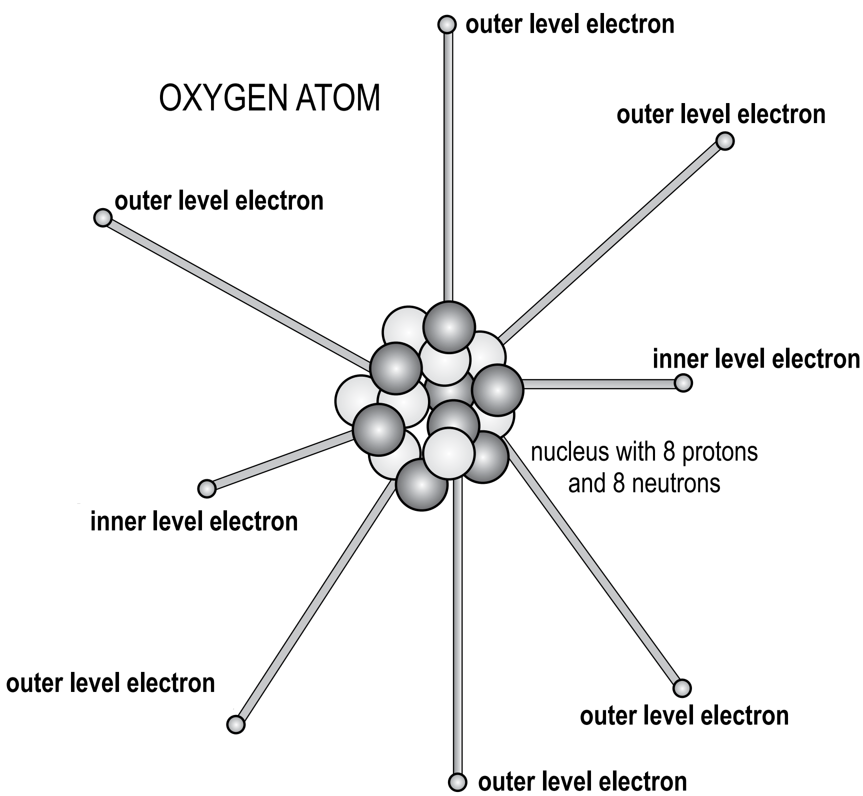
- Make a diagram of your set-up. Be sure to label everything and identify which electrode is connected to each end of the battery. Can you identify the anode and cathode?
- Record observations. What is happening in the dish?

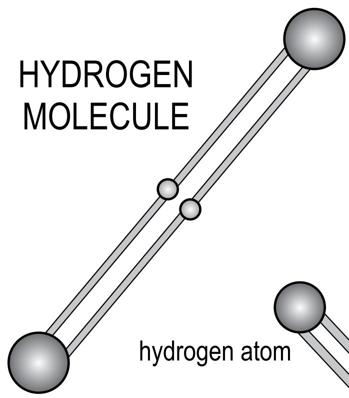
Conclusion

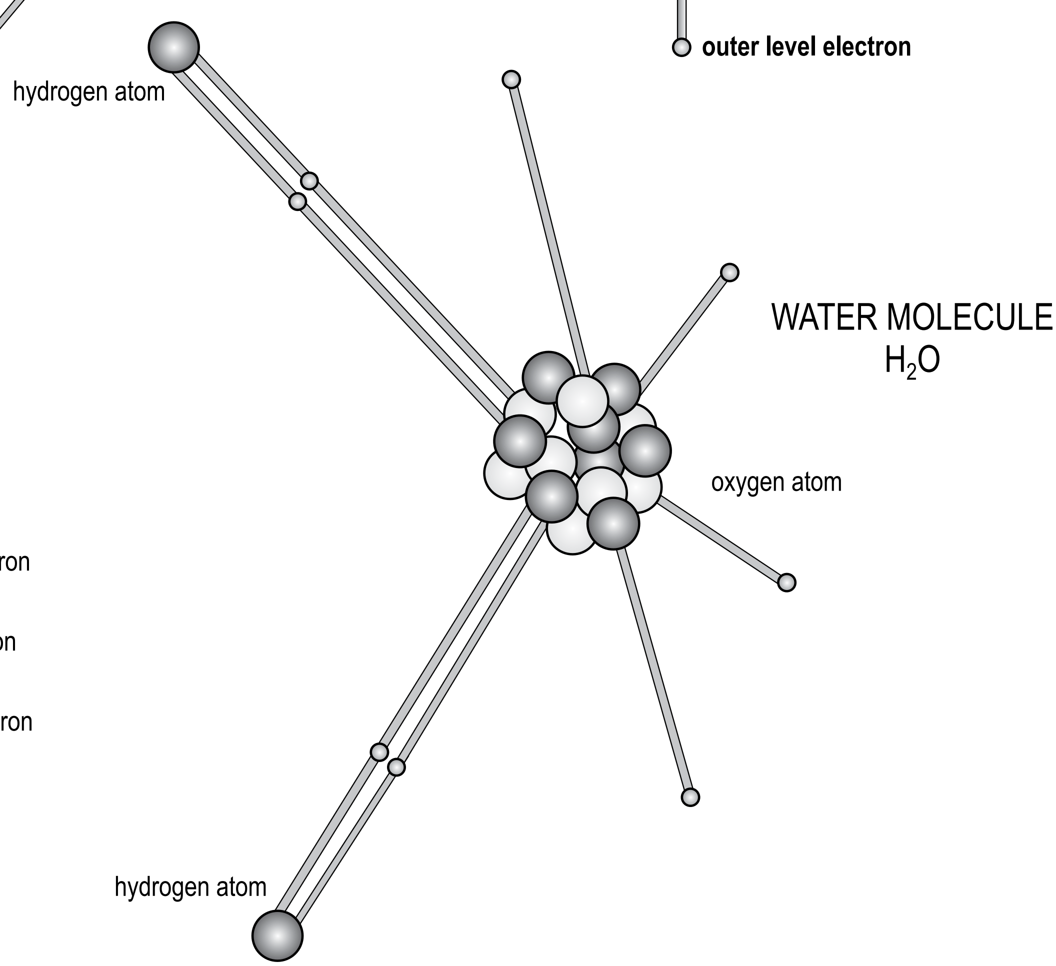
1. What did you notice in terms of the amount of each gas being produced? Which electrode was producing hydrogen gas? Use the evidence you gathered to justify your answer.
2. At which site (anode, cathode) did oxidation occur? How do you know? Use experimental evidence to support your answer.

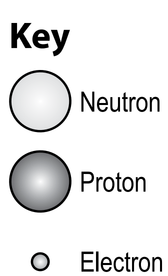
Element Models











Element Models

Background

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

Key Terms

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

Overview

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

Materials

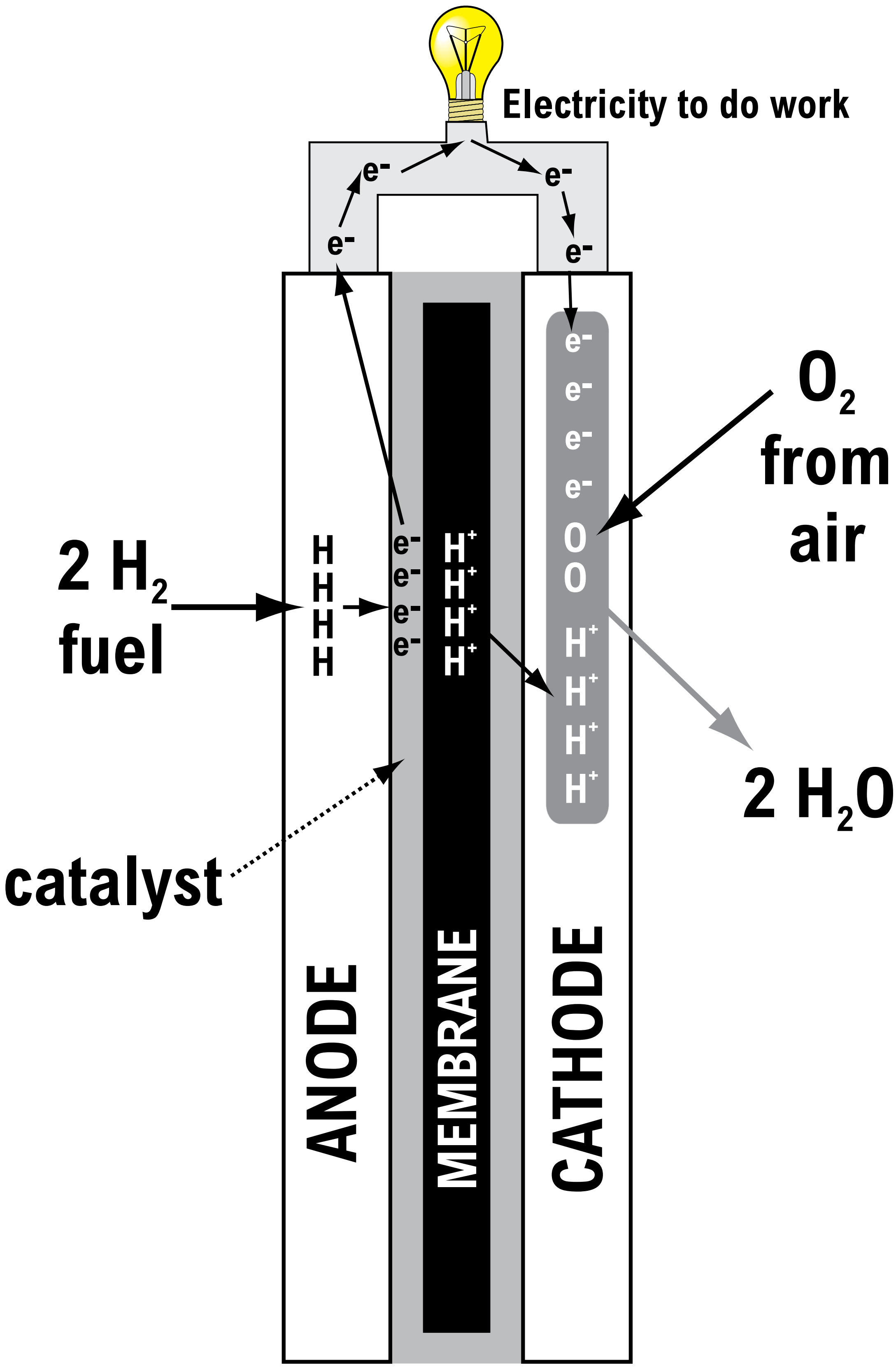
- 3 Colors of modeling clay
- Plastic straws
- Scissors

Procedure

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

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

Fuel Cell


Electricity to do work
e-
e-
e-
e-
2 H_2 fuel
H H H H
e- e- e- e-
H+ H+ H+ H+
e- e- e- e-
O O
H+ H+ H+ H+
O_2 from air
2 H_2O
catalyst
ANODE
MEMBRANE
CATHODE

What Is a Fuel Cell?

Background

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

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

Overview

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

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

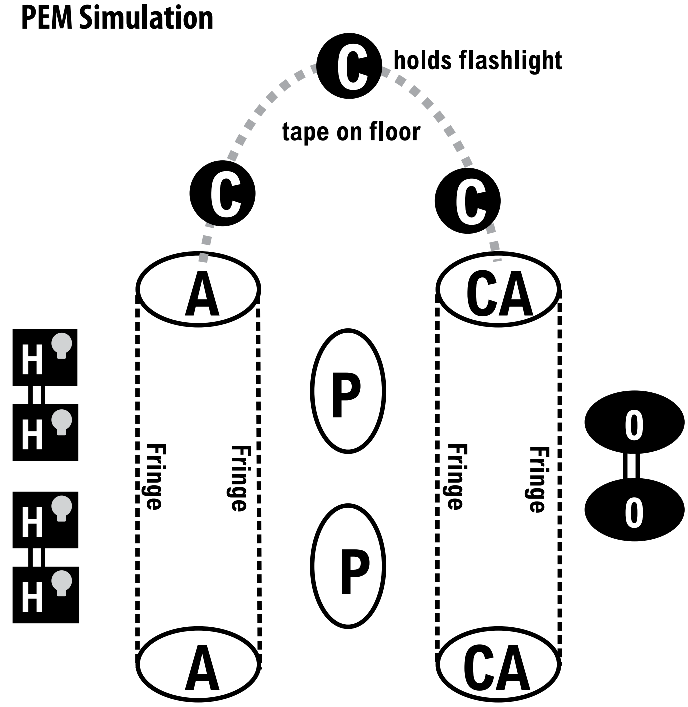
Materials

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

Procedure

1. Choose roles or wait for your role to be identified by your teacher. Put on hang tags, hold the equipment you need, and use the diagram to get in place for the activity.
2. Simulate the fuel cell system several times, switching roles with a classmate after each simulation.
3. Draw a diagram of a fuel cell and explain how it works using all of the roles in the simulation.

PEM Simulation



Fuel Cell Simulation

Students (15) Representing The Following Roles

- 4 Hydrogen atoms (H)
- 2 Oxygen atoms (O)
- 2 Anodes (A)
- 2 Cathodes (CA)
- 2 PEMs (P)
- 3 Circuit Members (C)

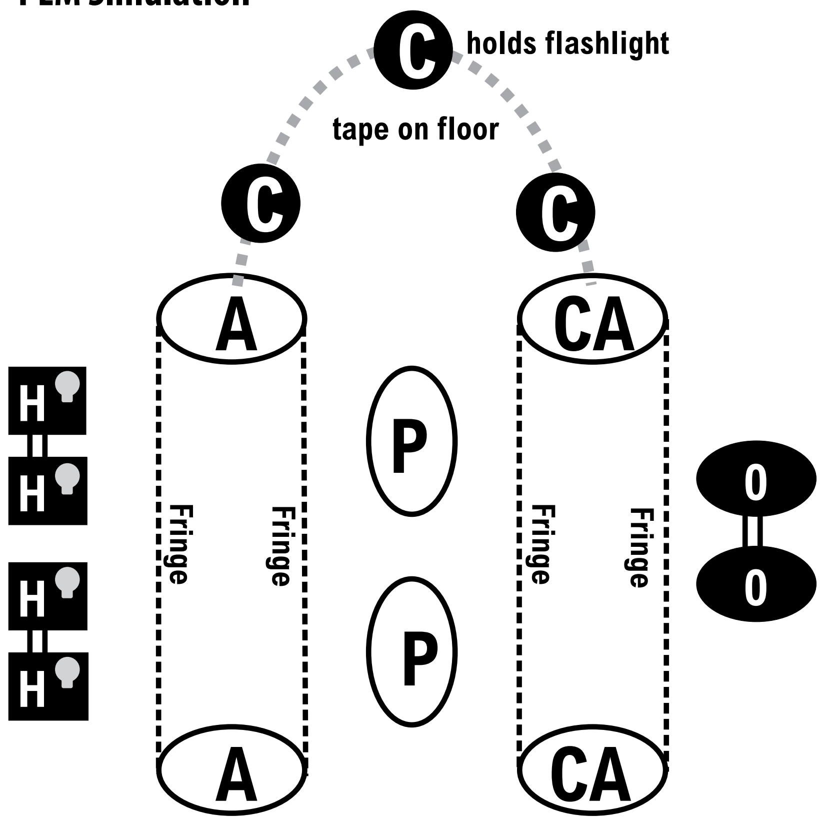
Materials

- 4 Pieces of fringe (each six feet long)
- 4 Flashing bulbs
- 1 Flashlight
- 1 Piece of colored tape to make circuit on floor
- 1 Hang tag for each student

✔ Procedure

1. All students wear hang tags representing their roles. The Hydrogen hang tags have H on one side and H+ on the other. The Oxygen hang tags have O on one side and O^{--} on the other.
2. The two Anodes hold up two pieces of six-foot fringe forming a rectangle. The two Cathodes hold up two pieces of six-foot fringe forming a rectangle.
3. The two PEMs stand between the Anode and Cathode.
4. Two sets of two Hydrogens link arms to create two Hydrogen molecules on the outside of the Anode. Each Hydrogen carries a flashing bulb (turned off) that represents its electron.
5. Two Oxygens link arms to create an Oxygen molecule on the outside of the Cathode.
6. The Hydrogens pass through the fringe into the Anode and each separate into two Hydrogen atoms.
7. The Oxygens pass through the fringe into the Cathode and separate into two Oxygen atoms.
8. The Hydrogen atoms pass through the inner fringe.
9. The PEMs stop the Hydrogen atoms from moving.
10. The Hydrogen atoms hand their electrons to the first Circuit Member and turn their hang tags to H^+ ions.
11. The PEMs allow the H^+ ions to pass through to the Cathode.
12. The Circuit Member turns on the flashing bulbs and hands them to the middle Circuit Member, who turns on a flashlight as he/she receives the electrons and turns the flashlight off as he/she passes the electrons to the last Circuit Member. The last Circuit Member hands two electrons to each Oxygen atom in the Cathode, who switches his/her hang tag to Oxygen ion (O^{--}).
13. Two Hydrogen ions link arms with an Oxygen ion (with the Oxygen in the middle), turning their hang tags and forming a water molecule. The water molecules then exit the outside of the Cathode.

PEM Simulation



H

H^+

O

O^{--}

A

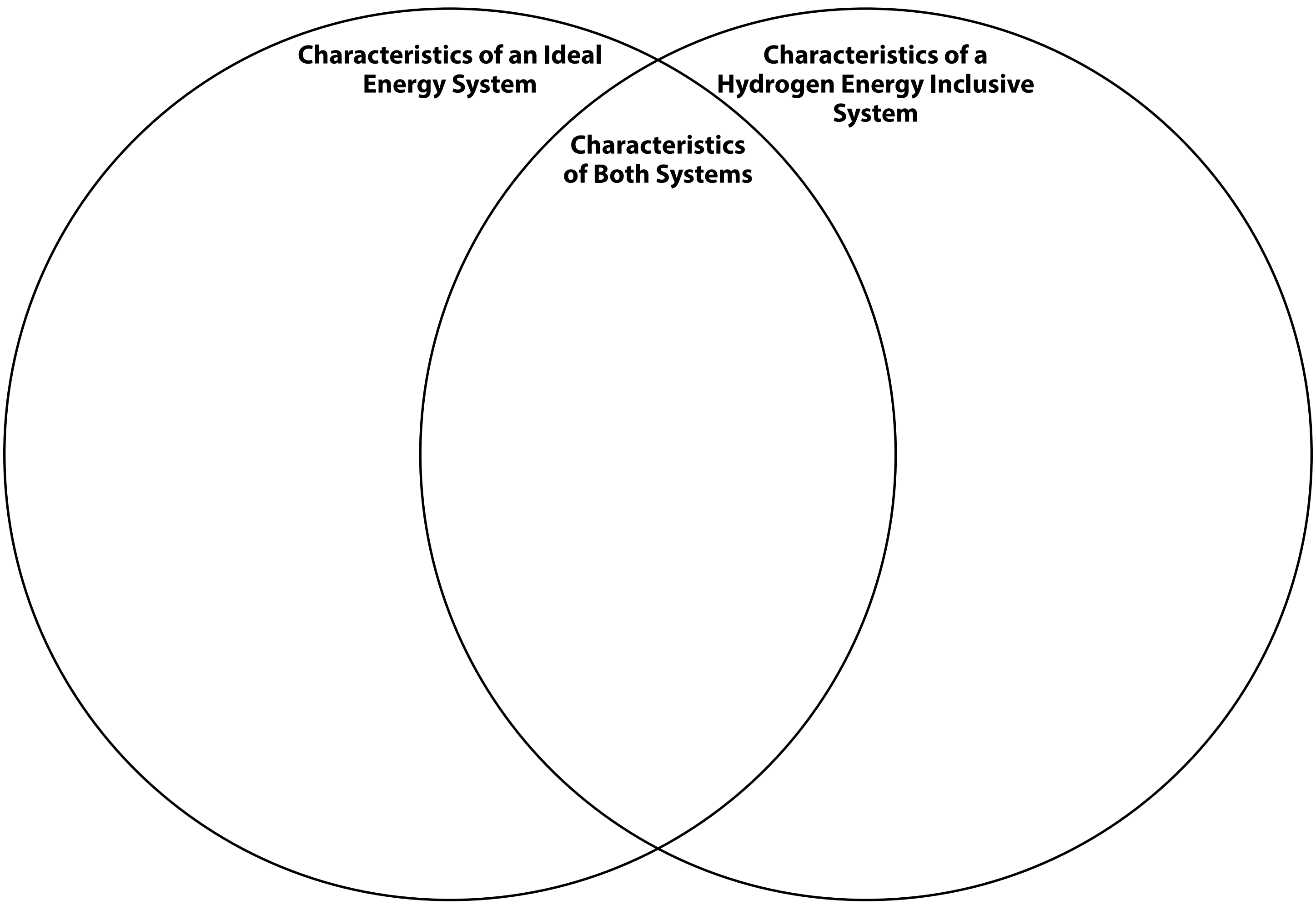
CA

C

P

Hydrogen in Our Energy System

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



Hydrogen in the Round

I have Hydrogen.

1. Who has a name for a substance in which all of the atoms are identical?
2. Who has an experimental method of producing hydrogen using a semiconductor to absorb sunlight?

I have Electron.

1. Who has the name of an area around the nucleus of an atom where an electron is most likely to be found?
2. Who has a device like a battery that uses an external source of fuel to produce electricity, and releases water and thermal energy?

I have Element.

1. Who has the positively charged subatomic particle in the nucleus of an atom?
2. Who has a method of producing hydrogen gas from biomass?

I have Energy Level.

1. Who has the form of energy that travels in electromagnetic waves?
2. Who has a battery or fuel cell that generates electricity through a chemical reaction?

I have Proton.

1. Who has the neutral subatomic particle in the nucleus of an atom?
2. Who has an experimental process to produce hydrogen using bacteria and algae?

I have Radiant Energy.

1. Who has the process that releases energy in the core of the sun?
2. Who has a closed loop that carries electrical energy?

I have Neutron.

1. Who has the subatomic particle that moves outside the nucleus of an atom?
2. Who has the term for a substance that moves energy and sometimes requires another energy source to create it?

I have Nuclear Fusion.

1. Who has the process that uses steam to split methane molecules to produce hydrogen and oxygen?
2. Who has a membrane that allows hydrogen ions to pass through, but not electrons?

Hydrogen in the Round

I have Steam Reforming. 1. Who has the process that uses moving electrons to split water into hydrogen and oxygen? 2. Who has the side of a PEM fuel cell through which hydrogen fuel enters?	**I have Photobiological Microbial Production.** 1. Who has a substance or system that moves energy in a usable form from one place to another? 2. Who has the chemical bond usually found between metals and nonmetals?
I have Electrolysis. 1. Who has the method of using sunlight to split water into hydrogen and oxygen? 2. Who has the special material that splits hydrogen gas into hydrogen ions and electrons?	**I have Energy Carrier.** 1. Who has a device that uses hydrogen fuel to produce electricity, water, and heat? 2. Who has the chemical bond that occurs between nonmetals such as hydrogen and oxygen?
I have Photoelectrolysis. 1. Who has the method of producing hydrogen by superheating wood and agricultural waste? 2. Who has the side of a fuel cell with the channels to distribute oxygen to the catalyst?	**I have Fuel Cell.** 1. Who has a device that produces electricity through a chemical reaction? 2. Who has the ability to make a change in temperature, position, size, or state of matter?
I have Biomass Gasification. 1. Who has the process by which algae and bacteria use sunlight to produce hydrogen? 2. Who has the name of the particle formed when an atom loses or gains electrons?	**I have Electrochemical Energy Conversion Device.** 1. Who has a path through which electricity travels? 2. Who has coal, natural gas, petroleum, propane, and uranium?

Hydrogen in the Round

I have Circuit.

1. Who has a short name for Polymer Electrolyte Membrane?
2. Who has wind, solar, geothermal, hydropower, and biomass?

I have Cathode.

1. Who has an atom or group of atoms that have an electrical charge?
2. Who has the substances organized in the Periodic Table?

I have PEM.

1. Who has the negative side of a fuel cell?
2. Who has a chemical reaction that draws energy in from its surroundings?

I have Ion.

1. Who has the attraction or bond between two oppositely charged ions?
2. Who has the subatomic particle in the nucleus that determines atomic number?

I have Anode.

1. Who has a substance that speeds up a reaction, without being consumed in the reaction, such as in a fuel cell?
2. Who has a method for reducing greenhouse gases produced by fossil fuel combustion and steam reformation?

I have Ionic Bond.

1. Who has the chemical bond in which two atoms share electrons?
2. Who has the subatomic particle with which the strong nuclear force is associated, and which helps hold the nucleus together?

I have Catalyst.

1. Who has the positive side of a fuel cell?
2. Who has the system of organizing all of the known elements?

I have Covalent Bond.

1. Who has the ability to do work?
2. Who has the subatomic particle that carries a negative charge?

Hydrogen in the Round

I have Energy. 1. Who has energy sources that are limited and cannot be replenished in a short time? 2. Who has the name of the area at a precise distance where the electrons are held in an atom?	**I have Endothermic.** 1. Who has the name for the trapping, storage, and use of carbon gases? 2. Who has the most cost effective method of producing hydrogen fuel today?
I have Nonrenewable. 1. Who has energy sources that are unlimited or can be replenished in a short period of time? 2. Who has the form of energy that comes from the sun and powers photosynthesis?	**I have Carbon Capture, Utilization, and Storage.** 1. Who has the arrangement of elements by their physical and chemical properties? 2. Who has a simple method of using electricity to produce very pure hydrogen?
I have Renewable. 1. Who has a chemical reaction that absorbs energy? 2. Who has the process that combines very small atoms into larger atoms, releasing vast amounts of radiant energy?	**I have Periodic Table.** 1. Who has an abundant, clean, domestically available, flexible fuel? 2. Who has a clean fuel that can be produced by steam reforming and electrolysis?

HYDROGEN BINGO

A. Knows the atomic number of hydrogen

B. Knows the percentage of U.S. energy consumption supplied by renewables

C. Knows the process that produces energy in the sun's core

D. Can define energy carrier

E. Knows what a fuel cell is

F. Can define distributed generation

G. Knows a process that separates water into hydrogen and oxygen

H. Knows the number of neutrons in a hydrogen atom

I. Knows in what form energy from the sun travels to the Earth

J. Can name four renewable energy sources

K. Knows the percentage of U.S. energy consumption supplied by fossil fuels

L. Knows the top energy carrier used in the U.S.

M. Knows the U.S. percentage of world population

N. Can name four nonrenewable energy sources

O. Knows the U.S. percentage of world energy consumption

P. Can name two ways hydrogen is used today

A NAME	**B** NAME	**C** NAME	**D** NAME
E NAME	**F** NAME	**G** NAME	**H** NAME
I NAME	**J** NAME	**K** NAME	**L** NAME
M NAME	**N** NAME	**O** NAME	**P** NAME

Pre/Post Hydrogen Assessment

1. The average American uses how much energy compared to the average world citizen?
- **a.** half as much
- **b.** twice as much
- **c.** about four times as much
- **d.** ten times as much

2. What percentage of U.S. energy consumption is from renewable energy sources?
- **a**. 3-5%
- **b.** 10-15%
- **c.** 21-40%
- **d.** more than 40%

3. About how much of total crude oil supply does the United States import from foreign countries?
- **a.** 5-10%
- **b.** 30-35%
- **c.** 40-50%
- **d.** 75-80%

4. How much of total U.S. energy consumption is used by the transportation sector of the economy?
- **a.** 9%
- **b.** 29%
- **c.** 39%
- **d.** 49%

5. An ideal energy system would ____________
- **a.** include domestic and imported energy sources.
- **b.** use only nonrenewable energy sources.
- **c.** use a variety of energy sources.
- **d.** All of the above.

6. Hydrogen is one of the most abundant elements in the universe. **True** **False**

7. Hydrogen gas is abundant in underground reservoirs on Earth. **True** **False**

8. Hydrogen fuel can be produced from __________
- **a.** water.
- **b.** natural gas.
- **c.** biomass.
- **d.** All three.

9. Hydrogen can be used ____________
- **a.** as a vehicle fuel.
- **b.** to produce electricity.
- **c.** Both a and b.
- **d.** Neither a nor b.

10. Electrolysis is a process in which electricity is used to ____________
- **a.** turn water into steam.
- **b.** combine hydrogen and oxygen molecules to make water.
- **c.** split water molecules into hydrogen and oxygen gases.
- **d.** produce light and heat.

11. A fuel cell ____________
- **a.** produces electricity.
- **b.** uses hydrogen as fuel.
- **c.** emits only water and heat.
- **d.** All of the above.

12. A fuel cell must be replaced often, like a non-rechargeable battery. **True** **False**

13. Hydrogen can be transported as a liquid or a gas. **True** **False**

14. Hydrogen is as safe as gasoline or diesel fuel when handled properly. **True** **False**

15. Hydrogen could meet many of our energy needs in the future. **True** **False**

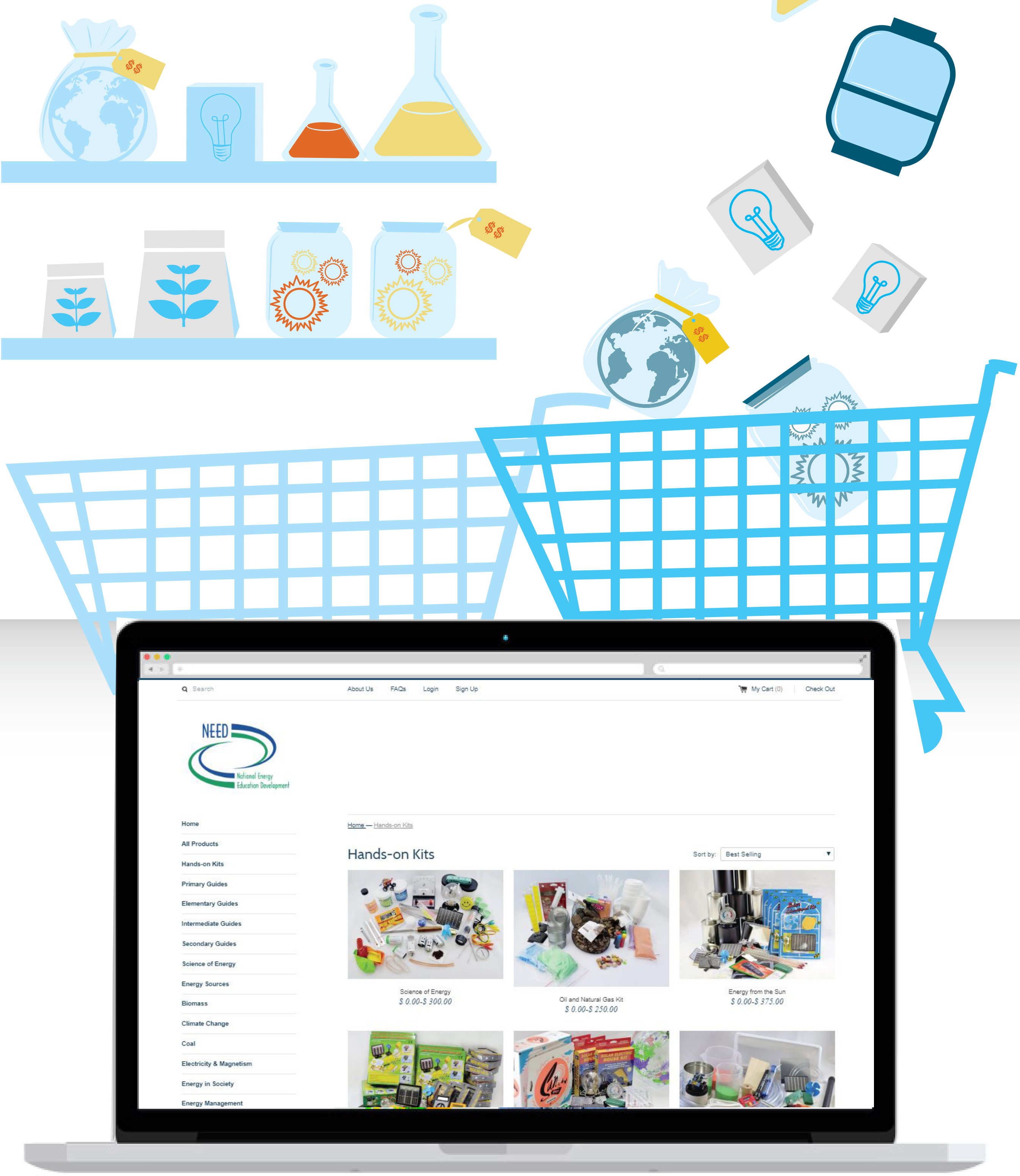
Glossary

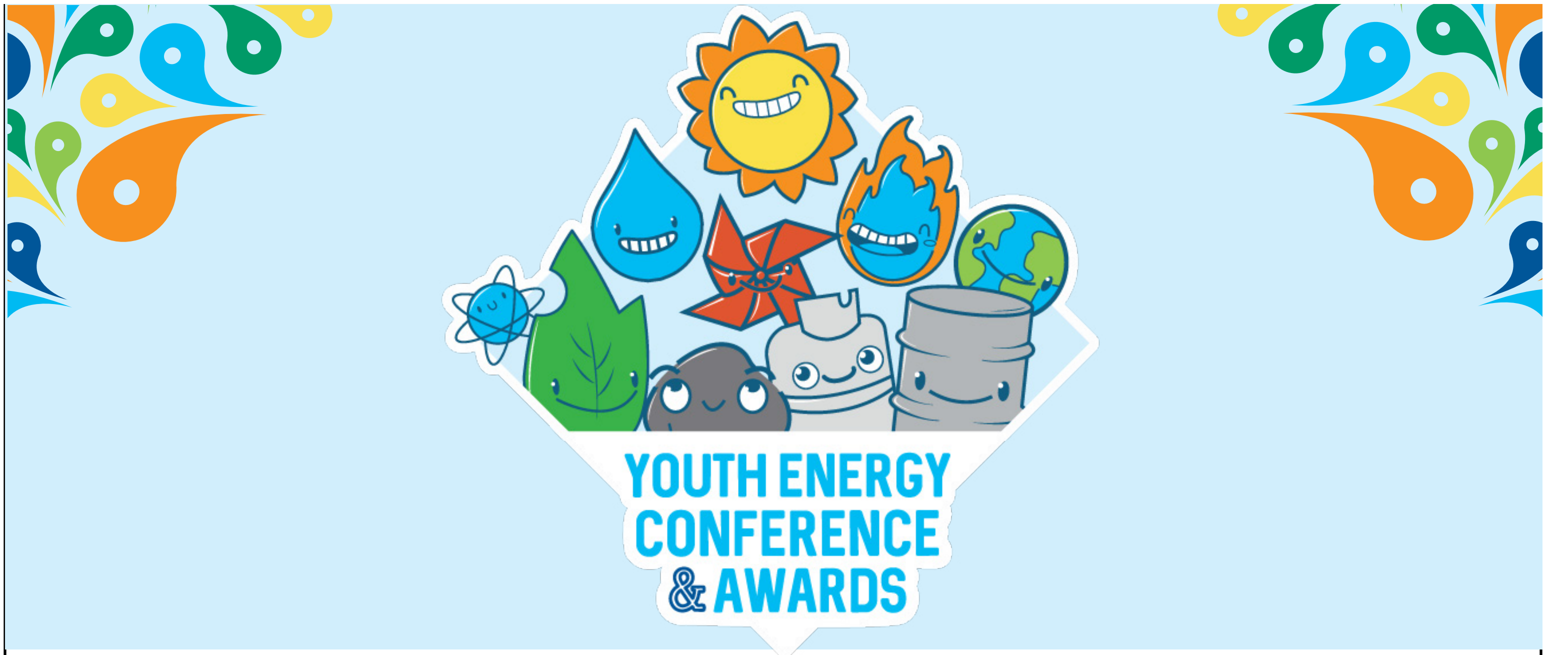
absorption	a process in which one substance permeates another
adsorption	the attachment of molecules of gases, liquids, or dissolved substances to a solid surface
ammonia	chemical combination of nitrogen and hydrogen, NH_3
anode	the electrode of a fuel cell or battery that produces electrons
atom	the smallest unit of an element that can exist alone or in combination
atomic mass	the average mass of one atom of an element
atomic number	the number of protons in an atom's nucleus
biomass	organic materials used as fuel
biomass gasification	process in which wood chips and agricultural wastes are superheated until they turn into hydrogen and other gases
carbon dioxide (CO_2)	a colorless, odorless, incombustible gas formed during respiration, combustion, and organic decomposition; an important greenhouse gas
carbon monoxide (CO)	a colorless, odorless, poisonous gas, produced by incomplete burning of carbon-based fuels, including gasoline, oil, and wood
catalyst	a substance that increases the rate of a chemical reaction without being produced or consumed in the reaction
cathode	the electrode of a fuel cell or battery that consumes electrons
centralized generation	generation of electricity that is produced in large quantities off-site and then distributed to the consumers
chemical energy	the potential energy that is stored in the bonds of molecules
circuit	the path through which an electric current flows
coal gasification	process of turning coal into gases using high temperature and pressure, then mixing the gases with steam to produce hydrogen
combustion	rapid chemical reaction of oxygen with a substance, producing light and heat
compound	two or more elements chemically bonded together
conductor	a substance that conducts heat or electricity
covalent bonding	bonds that occur when atoms are held together with shared electrons
decompose	broken down into basic elements
decomposition reaction	a reaction that separates a substance into two or more different substances
diatomic molecule	a molecule with two atoms
dissociate	the breaking of a compound into its components
distributed generation	generation of electricity at or near the location of consumption
distribution system	the network of wires and other equipment that delivers electricity
dry cell	a voltaic cell in which the electrolyte is a paste
electric charge	property of a particle that describes how the particle behaves in an electric field
electricity	a form of energy that is created by the flow of electrons
electrochemical energy conversion device	a device such as a battery or fuel cell that uses a chemical reaction to produce electricity
electrochemistry	branch of chemistry studying production of electricity by chemical reactions and chemical changes
electrode	a conductor that can carry electrons to or from a substance
electrolysis	a process that uses an electric current to break a molecule apart
electrolyte	a substance whose water solution conducts an electric current due to the presence of ions
electrolytic cell	a device that converts electrical energy into chemical energy through electrolysis
electron	a subatomic particle that has a negative charge found in an orbital around the nucleus

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

ORDER MATERIALS AND CURRICULUM ONLINE!

Anemometers and solar cells and light meters — oh my! Getting your guides and kits (or refills) has never been easier! Check out NEED's official online store at NEED.org/shop.

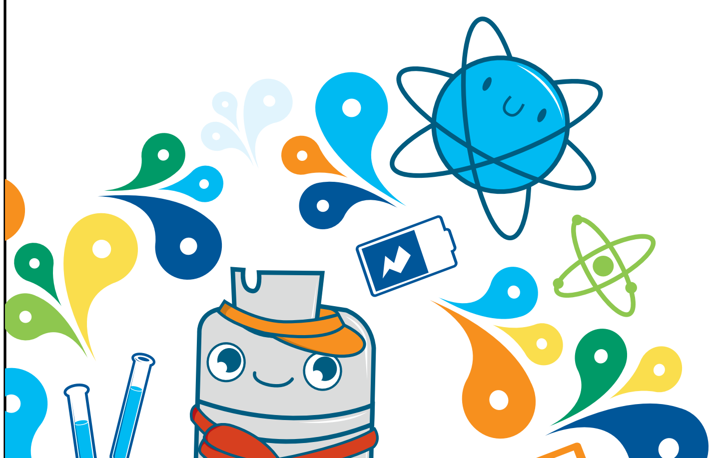




YOUTH ENERGY CONFERENCE AND AWARDS

The NEED Youth Energy Conference and Awards gives students more opportunities to learn about energy and to explore energy in STEM (science, technology, engineering, and math). The annual June conference has students from across the country working in groups on an Energy Challenge designed to stretch their minds and energy knowledge. The conference culminates with the Youth Awards Ceremony recognizing student work throughout the year and during the conference.

For More Info: www.youthenergyconference.org



YOUTH AWARDS PROGRAM FOR ENERGY ACHIEVEMENT

All NEED schools have outstanding classroom-based programs in which students learn about energy. Does your school have student leaders who extend these activities into their communities? To recognize outstanding achievement and reward student leadership, The NEED Project conducts the National Youth Awards Program for Energy Achievement.

Share Your Energy Outreach with The NEED Network!
This program combines academic competition with recognition to acknowledge everyone involved in NEED during the year—and to recognize those who achieve excellence in energy education in their schools and communities.

What's involved?

Students and teachers set goals and objectives and keep a record of their activities. Students create a digital project to submit for judging. In April, digital projects are uploaded to the online submission site.

Want more info? Check out **www.NEED.org/Youth-Awards** for more application and program information, previous winners, and photos of past events.

H_2 Educate Evaluation Form

State: ____________ **Grade Level:** ____________ **Number of Students:** ___________

1. Did you conduct the entire unit?	❑ Yes	❑ No
2. Were the instructions clear and easy to follow?	❑ Yes	❑ No
3. Did the activities meet your academic objectives?	❑ Yes	❑ No
4. Were the activities age appropriate?	❑ Yes	❑ No
5. Were the allotted times sufficient to conduct the activities?	❑ Yes	❑ No
6. Were the activities easy to use?	❑ Yes	❑ No
7. Was the preparation required acceptable for the activities?	❑ Yes	❑ No
8. Were the students interested and motivated?	❑ Yes	❑ No
9. Was the energy knowledge content age appropriate?	❑ Yes	❑ No
10. Would you teach this unit again?	❑ Yes	❑ No

Please explain any 'no' statement below.

How would you rate the unit overall?	❑ excellent	❑ good	❑ fair	❑ poor
How would your students rate the unit overall?	❑ excellent	❑ good	❑ fair	❑ poor

What would make the unit more useful to you?

____

____

____

____

Other Comments:

____

____

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Please fax or mail to:
The NEED Project
8408 Kao Circle
Manassas, VA 20110
FAX: 1-800-847-1820

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